Development and Investigation of a Virtual Physical Assessment for Workplace Concussions

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A thesis submitted to the University of Ottawa in partial fulfillment of the requirements for the Doctorate in Philosophy degree in Rehabilitation Sciences

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To my parents who believed in me more than I could ever believe in myself. To my husband, William, my rock, my biggest supporter, and my motivation.

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Authorization

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Abstract

Background: Workplace concussions can have a significant impact on workers. Many workers live far from concussion assessment centers, making it challenging to receive specialized assessment post-injury. The COVID-19 pandemic heightened challenges as in-person assessments for non-urgent cases was significantly reduced. However, the pandemic did create an opportunity for researchers and clinicians to explore the use of virtual assessment in practice. This shift exposed an area that requires further investigation as there is limited information regarding how virtual assessments should be done and which measures should be used. Further, there is limited information on the barriers and facilitators associated with the virtual approach to assessment. Finally, information regarding the specific feasibility of administering concussion measures virtually and the properties associated with administering these measures virtually is minimal. To understand these virtual properties in relation to the in-person assessment, there is also a gap in knowledge in that the synthesis of psychometric properties associated with certain measures administered in-person is not well articulated in the literature.
Objectives: The aim of this dissertation was to: 1) develop a virtual physical concussion assessment toolkit for use by clinicians who are treating workers injured on the job and presenting with persistent symptoms; 2) investigate the feasibility of the developed assessment and associated study procedures and document preliminary information regarding the reliability and sensitivity of the virtual physical assessment when compared to a corresponding in-person assessment; and 3) document the psychometric properties associated with in-person administration of a subset of measures included in the virtual physical assessment toolkit for purposes of comparison of the properties when administered in the two different contexts (explored in a project that goes beyond this dissertation).
Methodology: This dissertation consists of four projects. The first two projects together address aim 1 and follow a sequential mixed methods study design. This consisted of survey administration guided by the Delphi approach, working group completion with expert clinicians (Chapter 3), and focus group completion with clinicians and people living with workplace concussions (Chapter 4). A feasibility study design to answer aim 2 was then followed and consisted of patient-participants attending in-person and virtual assessments at the Ottawa Hospital (Chapter 5). The measures identified in Chapters 3 and 4 were used to complete these feasibility study assessments. Finally, a scoping review was then completed to address aim 3 to identify and document the psychometric properties associated with a subset of the measures included in the feasibility study virtual assessment (vestibular and ocular measures) (Chapter 6).
Results: The clinician-prioritized measures to include in a virtual physical assessment toolkit are documented and include the finger-to-nose test, Vestibular/Ocular Motor Screening (VOMS), cervical spine range of motion, balance testing (single leg stance test, tandem stance test, feet together), evaluation of saccades, and evaluation of effort. The barriers and facilitators associated with administering each of these measures are highlighted and include, respectively, factors such as questionable accuracy of administering the measures in a remote context and having adequate supports in place when completing a virtual assessment. The feasibility of administering these clinician-identified and prioritized measures in a virtual environment was investigated, which confirmed the acceptability of the environmental set-up and moderate to high levels of confidence in findings on the assessment by both clinicians and people with brain injuries. Preliminary information on psychometric properties associated with the virtual assessment indicate poor (0.0) to excellent (1.0) sensitivity and poor (Kappa=0.38-0.49) to excellent

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(Kappa=1.0) levels of inter-rater and intra-rater reliability. The psychometric properties of administering a subset of these measures (VOMS, saccades, balance testing) in-person was documented, and appear to vary significantly in the literature.
Conclusion: This dissertation contributes to the advancement of knowledge in the field of concussion rehabilitation. Specifically, this work led to an initial understanding of the feasibility of the virtual concussion assessment (using specific measures related to the physical domains of a concussion examination), along with a preliminary understanding of possible properties associated with the measures. This work has provided important information regarding what is needed to further drive the understanding of virtual concussion assessment, and the barriers and facilitators associated with such virtual assessments.

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Résumé

Contexte: Les commotions cérébrales sur le lieu de travail peuvent avoir un impact important sur les travailleurs. De nombreux travailleurs vivent loin des centres d'évaluation des commotions cérébrales, ce qui rend difficile l'obtention d'une évaluation spécialisée après la blessure. La pandémie de COVID-19 a accentué les difficultés, car les évaluations en personne pour les cas non urgents ont été considérablement réduites. Cependant, la pandémie a donné l'occasion aux chercheurs et aux cliniciens d'explorer l'utilisation de l'évaluation virtuelle dans la pratique. Cette évolution a mis en évidence un domaine qui nécessite des recherches plus approfondies, car il existe peu d'informations sur la manière dont les évaluations virtuelles doivent être effectuées et sur les mesures à utiliser. En outre, on dispose de peu d'informations sur les obstacles et les facilitateurs associés à l'approche virtuelle de l'évaluation. Enfin, les informations concernant la faisabilité spécifique de l'administration virtuelle des mesures de commotion cérébrale et les propriétés associées à l'administration virtuelle de ces mesures sont minimes. Pour comprendre ces propriétés virtuelles par rapport à l'évaluation en personne, il existe également une lacune dans les connaissances en ce sens que la synthèse des propriétés psychométriques associées à certaines mesures administrées en personne n'est pas bien articulée dans la littérature.

Objectifs: L'objectif de cette thèse était de : 1) développer une trousse d'évaluation physique virtuelle des commotions cérébrales à l'usage des cliniciens qui traitent les travailleurs blessés au travail et présentant des symptômes persistants ; 2) étudier la faisabilité de l'évaluation développée et des procédures d'étude associées et documenter les informations préliminaires concernant la fiabilité et la sensibilité de l'évaluation physique virtuelle par rapport à une évaluation en personne correspondante ; et 3) documenter les propriétés psychométriques associées à l'administration en personne d'un sous-ensemble de mesures incluses dans la trousse d'évaluation physique virtuelle à des fins de comparaison des propriétés lorsqu'elles sont administrées dans les deux contextes différents (explorées dans un projet qui va au-delà de cette thèse).

Méthodologie: Cette thèse se compose de quatre projets. Les deux premiers projets répondent à l'objectif 1 et suivent un modèle d'étude séquentiel à méthodes mixtes. Il s'agit de l'administration d'une enquête guidée par l'approche Delphi, de la réalisation d'un groupe de travail avec des cliniciens experts (chapitre 3) et de la réalisation d'un groupe de discussion avec des cliniciens et des personnes vivant avec des commotions cérébrales (chapitre 4). Une étude de faisabilité a ensuite été réalisée pour répondre à l'objectif 2. Elle a consisté à faire participer des patients à des évaluations en personne et virtuelles à l'Hôpital d'Ottawa (chapitre 5). Les mesures identifiées aux chapitres 3 et 4 ont été utilisées pour réaliser les évaluations de l'étude de faisabilité. Enfin, une revue de la portée a été réalisée pour répondre à l'objectif 3, afin d'identifier et de documenter les propriétés psychométriques associées à un sous-ensemble de mesures incluses dans l'évaluation virtuelle de l'étude de faisabilité (mesures vestibulaires et oculaires) (chapitre 6).

Résultats: Les mesures priorisées par les cliniciens à inclure dans une boîte à outils d'évaluation physique virtuelle sont documentées et comprennent le test du doigt au nez, le dépistage de la motricité vestibulaire/oculaire (VOMS), l'amplitude de mouvement de la colonne cervicale, le test d'équilibre (test d'équilibre sur une jambe, test d'équilibre en tandem, pieds joints), l'évaluation des saccades, et l'évaluation de l'effort. Les obstacles et les facilitateurs associés à l'administration de chacune de ces mesures sont mis en évidence et comprennent, respectivement, des facteurs tels que la précision douteuse de l'administration des mesures dans

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un contexte distant et la mise en place de soutiens adéquats lors de la réalisation d'une évaluation virtuelle. La faisabilité de l'administration de ces mesures identifiées et hiérarchisées par les cliniciens dans un environnement virtuel a été étudiée, ce qui a confirmé l'acceptabilité de la configuration de l'environnement et des niveaux modérés à élevés de confiance dans les résultats de l'évaluation à la fois par les cliniciens et les personnes souffrant de lésions cérébrales. Les informations préliminaires sur les propriétés psychométriques associées à l'évaluation virtuelle indiquent une sensibilité faible (0,0) à excellente (1,0) et des niveaux de fiabilité inter-évaluateurs et intra-évaluateurs faibles (Kappa=0,38-0,49) à excellents (Kappa=1,0). Les propriétés psychométriques de l'administration d'un sous-ensemble de ces mesures (VOMS, saccades, test d'équilibre) en personne ont été documentées et semblent varier de manière significative dans la littérature.

Conclusion: Cette thèse contribue à l'avancement des connaissances dans le domaine de la réadaptation des commotions cérébrales. Plus précisément, ce travail a permis une première compréhension de la faisabilité de l'évaluation virtuelle des commotions cérébrales (en utilisant des mesures spécifiques liées aux domaines physiques d'un examen de commotion cérébrale), ainsi qu'une compréhension préliminaire des propriétés possibles associées aux mesures. Ce travail a fourni des informations importantes sur ce qui est nécessaire pour approfondir la compréhension de l'évaluation virtuelle des commotions cérébrales et sur les obstacles et les facilitateurs associés à ces évaluations virtuelles.

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Publications

Peer-Reviewed Publications and Presentations Related to Thesis

Published

Barnes, K., Sveistrup, H., Bayley, M., Egan, M., Rathbone, M., Taljaard, M., & Marshall, S. Identification of Clinical Measures to Use in a Virtual Concussion Assessment: Protocol for a Mixed-Methods Study. (2022). *Journal of Medical Internet Research Research Protocols*, *11*(12):e40446. doi: 10.2196/40446

Barnes, K., Sveistrup, H., Bayley, M., Egan, M., Rathbone, M., Taljaard, M., & Marshall, S. (2024). Clinician-Prioritized Measures to Use in a Virtual Concussion Assessment: a Delphi Study. *Journal of Medical Internet Research Formative Research*, 8:e47246. doi: 10.2196/47246

In Press

Barnes, K., Sveistrup, H., Karimijashni, M., Bayley, M., & Marshall, S. Psychometric Properties of Vestibular and Ocular Measures Used for Concussion Assessments: a Scoping Review. Submitted to Journal of Head Trauma Rehabilitation (February 2024).

Under Review

Barnes, K., Sveistrup, H., Karimijashni, M., Bayley, M., Egan, M., Bilodeau, M., Rathbone, M., Taljaard, M., & Marshall, S. Barriers and facilitators associated with the virtual concussion physical assessments from the perspectives of clinicians and people living with workplace concussions: a qualitative study. Submitted to the Journal of Medical Internet Research (January 2024).

Barnes, K., Sveistrup, H., Karimijashni, M., Bayley, M., Egan, M., Bilodeau, M., Rathbone, M., Taljaard, M.,& Marshall, S. Investigation of the Feasibility of Study Procedures to Estimate Sensitivity and Reliability of a Virtual Assessment Developed for Workplace Concussions. Submitted to the Journal of Medical Internet Research Formative Research (June 2024).

Presentations

Barnes K, Sveistrup H, Marshall S. (2023). Identification of Clinical Measures to Use in a Virtual Concussion Assessment: Preliminary Results of a Mixed-Methods Study. UHN Brain Injury Conference. Toronto, Canada. Poster Presentation.

Barnes K, Marshall S. (2023). Development of a Virtual Assessment for Workplace Concussions. OWN Symposium Innovation and Opportunities in Healthcare. Toronto, Canada. Podium Presentation.

Barnes K, Sveistrup H, Marshall S. (2023). Barriers and facilitators associated with the virtual concussion physical assessments from the perspectives of clinicians and people living with workplace concussions. Canadian Concussion Network Annual Meeting. Calgary, Canada. Poster Presentation.

Barnes K, Sveistrup H, Marshall S. (2023). Investigation of Feasibility of a Virtual Concussion Assessment. Ottawa Hospital Research Day. Ottawa, Canada. Poster Presentation.

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Barnes, K., Sveistrup, H., Karimijashni, M., Bayley, M., Egan, M., Bilodeau, M., Rathbone, M., Taljaard, M., & Marshall, S. (2024). Investigation of a Virtual Concussion Assessment: a Feasibility Study. Canadian Concussion Centre Concussion Symposium. Toronto, Canada. Rapid Podium Presentation.

Barnes, K., Sveistrup, H., Karimijashni, M., Bayley, M., Egan, M., Bilodeau, M., Rathbone, M., Taljaard, M., & Marshall, S. (2024). Investigation of a Virtual Concussion Assessment: a Feasibility Study. Canadian Concussion Centre Concussion Symposium. Toronto, Canada. Poster Presentation.

Barnes, K., Sveistrup, H., Karimijashni, M., Bayley, M., Egan, M., Bilodeau, M., Rathbone, M., Taljaard, M., & Marshall, S. (2024). Investigation of a Virtual Concussion Assessment: a Feasibility Study. Canadian Concussion Network Annual Meeting. Ottawa, Canada. Poster Presentation.

Published Abstracts

Barnes, K., Sveistrup, H., Karimijashni, M., & Marshall, S. Barriers and Facilitators Associated With Virtual Concussion Assessments From the Perspectives of Clinicians and People Living With Concussions: A Qualitative Study. (2023). *Journal of Head Trauma Rehabilitation*, *38*(4):E328-E370. doi: 10.1097/HTR.0000000000000884

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Other Peer-Reviewed Publications and Presentations

Published

O'Neil, J., **Barnes, K**., Morgan Donnelly, E., Sheehy, L., & Sveistrup, H. Identification and Description of Balance, Mobility, and Gait Assessments Conducted via Telerehabilitation for Individuals With Neurological Conditions: Protocol for a Scoping Review. (2021). *Journal of*

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McIsaac DI, Fergusson DA, Khadaroo R, Meliambro A, Muscedere J, Gillis C, Hladkowicz E, Taljaard M; **Group Authorship the Prepare Investigators**. PREPARE trial: a protocol for a multicentre randomised trial of frailty-focused preoperative exercise to decrease postoperative complication rates and disability scores. (2022). *British Medical Journal Open*, *12*(8):e064165. doi: 10.1136/bmjopen-2022-064165

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In Press

Gu, Y., McIsaac, DI., Hladkowicz, E., **Barnes, K**., Boet, S., McCartney, C., Ramlogan, R. Using the Theoretical Domains Framework to Identify Barriers and Facilitators for Using Peripheral Nerve Blocks in Older Adult Hip Fracture Patients: A National Survey. Submitted to the Canadian Journal of Anesthesia (March 2024).

Under Review

Karimijashni M, Yoo S, **Barnes K**, Lessard-Dostie H, Dabbagh A, Ramsay T, Poitras S. Postoperative rehabilitation interventions in patients at risk of poorer outcomes following knee: A Systematic Review. Submitted to the Journal of Injury, Function and Rehabilitation (March 2024).

Karimijashni M, Yoo S, **Barnes K**, Lessard-Dostie H, Dabbagh A, Ramsay T, Poitras S. Pre-rehabilitation interventions in patients at risk of poor outcomes following knee: A Systematic Review. Submitted to the Journal of Arthroplasty (June 2024).

Presentations

Barnes K, Hladkowicz E, McIsaac DI. (2021). Barriers and facilitators to frailty-focused exercise prehabilitation before cancer surgery. Patient Safety Conference, Ottawa, Canada. Poster Presentation.

Barnes K, Hladkowicz E, McIsaac DI. (2021). Barriers and facilitators to frailty-focused exercise prehabilitation before cancer surgery. The Ottawa Hospital Research Day, Ottawa, Canada. Poster Presentation.

Karimijashni M, Yoo S, **Barnes K**, Poitras S. (2022). Postoperative rehabilitation interventions in patients undergoing knee or hip arthroplasty at risk of poor outcomes: A protocol for two systematic reviews. Ottawa Musculoskeletal Research Symposium, Ottawa, Canada. Oral Presentation.

Karimijashni M, Yoo S, **Barnes K**, Lessard-Dostie H, Dabbagh A, Ramsay T, Poitras S. (2023). Post-operative rehabilitation interventions in patients at risk of poor outcomes following knee or hip arthroplasty: A Systematic Review. Ottawa Musculoskeletal Research Symposium, Ottawa, Canada. Oral Presentation.

Karimijashni, M., Yoo, S., **Barnes, K**., Lessard-Dostie, H., Dabbagh, A., Ramsay, T., Poitras, S. (2024). Post-operative rehabilitation interventions in patients at risk of poor outcomes following knee or hip arthroplasty: A Systematic Review. Canadian Orthopedic Association Annual Meeting, Halifax, Canada. Poster Presentation.

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Contribution of Co-Authors to Publications

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Bayley M, Egan M, Rathbone M, Taljaard M: provided expertise regarding methodology and soundness of study, revision and approval of manuscript
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Karimijashni M: aided with screening and recruitment, data management and analysis, revision and approval of manuscript
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Sveistrup H, Marshall S: provided expertise regarding methodology and soundness of study and made significant revisions to manuscript leading to publication

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Legend

ABI: acquired brain injury

AP: anterior-posterior

AUC: Area Under the Curve

BBT: BTrackS Balance Test

BESS: balance error scoring system

C: clinician-participant

CB&M: community balance and mobility scale

CBIAS: Computerized Brain Injury Assessment System

CI: confidence interval

cm: centimeters

COBALT: concussion balance test

COSMIN: The Consensus based Standards for the selection of health Measurement INstruments

COVS: computerized oculomotor vision screening

CT: computerized tomography

CTSIB: clinical test of sensory interaction in balance

CTT: classical test theory

DGI: dynamic gait index

DHI: dizziness handicap inventory

DNF: deep neck flexor

DVA/DVAT: dynamic visual acuity test

ECFIS: eyes closed while standing on a firm surface

ECFOS: eyes closed while standing on an unstable (foam) surface

ED: emergency department

EEG: electroencephalography

EOFIS: eyes open while standing on a firm surface

EOFOS: eyes open while standing on an unstable (foam) surface

FGA: functional gait assessment

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Freq: frequency

GED: General Education Development

GST: gaze stabilization test

HIA-1: Head Injury Assessment

HiMAT: High Level Mobility Assessment Tool

ICC: intraclass correlation coefficient

JPET: joint position error test

KD: King-Devick

LASSO: least absolute shrinkage and selection operator

MACE: military acute concussion evaluation

mBESS: modified balance error scoring system

mCTSIB: modified clinical test of sensory interaction and balance

ML: medio-lateral

MMT: manual muscle testing

MRC: medical research council

mTBI: mild traumatic brain injury

N/n: number

NA: Not applicable

NPC: near point convergence

NR: Not reported

NZ: New Zealand

OA: overall

OKAN: Optokinetic after-nystagmus

OKS: optokinetic stimulation

P: patient-participant

PRISMA: Preferred Reporting Items for Systematic reviews and Meta-Analyses

PRISMA-ScR: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews

Q: quote

RCI: reliable change indices

RMS: Root Mean Square

ROC: Receiver Operating Characteristic

ROM: range of motion

r_s: Spearman correlation

S/S: signs and symptoms

SCAT: Sport Concussion Assessment Tool

SCAT3: Sport Concussion Assessment Tool- 3rd edition

SD: standard deviation

SPNTT: smooth-pursuit neck-torsion test

SOT: sensory organization test

SSVEP: stead-state visual evoked potentials

TBI: traumatic brain injury

TOHRC: The Ottawa Hospital Rehabilitation Centre

VMS: visual motion sensitivity

VOMS: Vestibular Ocular Motor Screening

VOR: vestibulo-ocular reflex

WBB: Wii Balance Board

WSIB: Workplace safety and Insurance Board

y: year

Chapter 1. Introduction and Review of Literature

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1.1 Introduction

Traumatic brain injuries (TBIs) are complex injuries (Matthews et al., 2020) which are categorized as mild, moderate, or severe in nature and are differentiated by duration of unconsciousness and posttraumatic amnesia as well as differences in level of responsiveness (motor, verbal, and eye-opening responses to cues) (Matthews et al., 2020). It is estimated, however, that the majority of TBIs are mild in nature, with an occurrence of 80-90% (Kontos & Collins, 2018). According to the American Congress of Rehabilitation Medicine, mild TBIs (mTBIs) are diagnosed when a plausible mechanism of injury occurs and when one or more of the following criteria are met: presence of clinical signs, acute symptoms, and neuroimaging evidence (Silverberg et al., 2023). Workplace injuries account for a meaningful portion of mTBIs or concussions (Matthews et al., 2020), with approximately 25% of adult concussions occurring in the workplace (Terry et al., 2018). Comprehensive assessments post-workplace concussion can be challenging for the patient, as symptoms can be aggravated while being exposed to clinical environments that have bright lights and loud noises (Ryan & Warden, 2003). Environmental control represents one potential advantage of a telehealth (where clinical care services are delivered remotely) or virtual assessment in the concussion population.

Telehealth is considered an umbrella term encompassing all internet-based or electronic-based health-related activities (Montes et al., 2022). Telehealth requires the use of telecommunication technology to deliver services without having the clinician and patient attend a face-to-face meeting. Telemedicine (where medical services are delivered remotely) and telerehabilitation (where rehabilitation services are provided through information and communication technologies) are types of telehealth that have become increasingly used tools over the past 10 years (Goyal et al., 2020; Mani et al., 2019).

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Individuals living in rural communities, remote from assessment centers, experience multiple barriers to accessing needed care in a timely manner (Ownsworth et al., 2020). Mani et al. (2019) reported that over 45% of individuals live in rural settings globally, however, there are minimal physiotherapists in these areas, which limits access to such services. In these cases, the need to travel to clinics to receive care from specialized clinicians is a challenge (Montes et al., 2022). To reduce the burden associated with attending in-person assessments, remote approaches have proven to be a viable method to assess people, while in their home environment. Virtual approaches to care have many documented benefits, including improved access, improved efficiency, reduced travel time, reduced time away from work, and reduced expenses associated with attending in-person appointments (Montes et al., 2022; Tenforde et al., 2017; Zhao et al., 2020).

While virtual approaches to care have been used for many years, restrictions placed on access to care, in efforts to protect the safety of people from COVID-19, led to an increase in the use of virtual approaches (Toresdahl et al., 2021; Womble et al., 2022). Remote assessments were pushed to the forefront of care, which in turn, encouraged clinicians and researchers to explore the use and feasibility of telehealth in various health populations (Goyal et al., 2020; Toresdahl et al., 2021). With this rapid acceleration and increased use of virtual care, governments demonstrated interest in the availability of telehealth as evidenced by new billing structures and new programs (Fu et al., 2022).

1.2 Overarching Aims of Dissertation

It is within this context that the overall goal of this dissertation was to contribute to the development of a virtual physical concussion examination toolkit with preliminary data on the reliability and sensitivity of the virtual assessment compared to the in-person assessment. This

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work was intended to provide preliminary information for virtual physical concussion assessments in the Workplace Safety and Insurance Board (WSIB) context. While it is apparent in the literature that in-person concussion physical measures have minimal or variable psychometric properties documented, there was a strong rationale to explore the administration of existing measures in virtual environments due to the abrupt shift to virtual care brought on by COVID-19 that forced clinicians to complete virtual assessments using measures that contained no information on their virtual properties. There are four projects included in this dissertation, each targeting a highlighted gap, outlined below.

1.2.1 Projects 1 and 2

The aims of Projects 1 and 2 were to identify which measures expert clinicians currently use in-person and identify as most relevant to document patient status in the physical domains (neurological examination, cervical spine, vestibular, oculomotor), along with evaluation of effort, assessed during the concussion examination. A secondary aim was to determine the expert-clinician perceived feasibility of the measures when administered in a virtual context and document feedback about perceived and real barriers and facilitators to completing or engaging in virtual physical concussion assessments. Survey administration guided by the Delphi approach, working group completion with expert clinicians (Project 1), and focus group completion with experienced clinicians and with people living with workplace concussion (Project 2) were the methods used to address these aims.

1.2.2 Project 3

The aim of Project 3, a feasibility study, was to determine the rate of recruitment, length of time required to complete study assessments, and obtain feedback from both clinician-assessors and patient-participants regarding the virtual physical assessment. The aim was to

investigate if preliminary data suggests that specific measures (relating to: the neurological examination, cervical spine, vestibular, oculomotor, and effort assessment) are reliable and sensitive to deficits when compared to in-person administration of the same measures.

1.2.3 Project 4

Project 4, a scoping review, aimed to address a gap that was identified in Project 1 in which the synthesis of psychometric properties of in-person concussion measures is lacking in the literature. Further, we need an understanding of in-person psychometric properties when interpreting data regarding psychometric properties of virtually administered measures, which was initially explored in the feasibility study in this dissertation (Project 3) and is being further explored in a larger evaluative study that goes beyond this dissertation (Appendix D). The scoping review focused on the vestibular and ocular domains solely as the first point of exploration. There is significant overlap in the existing concussion measures that aim to evaluate vestibular and ocular deficits and the current literature commonly combines these two domains, so a decision was made to focus on the vestibular and ocular domains first and explore the remaining physical domains in future work.

1.3 Review of the Literature

The focus of the review of literature, guided by the overarching aims of this work, targeted: the importance of assessments; the concussion examination, with a focus on the physical domains (neurological examination, vestibular, ocular, cervical spine), and on key measures identified by the clinicians in Project 1. Evaluation of effort (measure of validity of performance or evaluating if optimal effort was employed on the assessment) was also examined due to the relevance in relation to its role in WSIB worker's compensation. Other elements of the literature review included focus on the in-person psychometric properties associated with the

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identified physical measures and comparisons of in-person and virtual administration of clinical measures.

1.3.1 Assessment

Clinical assessment involves the selection and use of multiple tools and information sources to inform clinical decisions such as diagnosis and determination of need for therapeutic intervention (Fawcett, 2007). The information gained or collected in assessments is interpreted to make these decisions. The assessment is a critical component of the therapeutic process and is central to disability, illness, and injury management (Fawcett, 2007). It acts as the foundation of management and is therefore essential for effective, targeted intervention. A standardized assessment is of particular interest and is defined as a '*published measurement tool, designed for a specific purpose in a given population, with detailed instructions provided as to when and how it is to be administered and scored, interpretation of the scores, results of investigations or reliability and validity*' (Fawcett, 2007, p. 22).

1.3.2 Concussion Assessment

Various clinicians may assess, manage, and treat people post-concussion, including physiatrists, neurologists, sports medicine physicians, physiotherapists, athletic therapists, among others. In turn, the approaches to assessment post-concussion may vary by setting and clinician (Zasler et al., 2019). Further, the overall goals of evaluation may be different depending on when the assessment is conducted post-injury. In the acute setting (<48 hours post-injury) the aim is to rule out serious injury, which may require ongoing observation or even surgical intervention as seen with moderate to severe TBI, and to provide diagnosis and education for those with mTBI/concussion. The aim of an outpatient assessment, in people experiencing persisting symptoms post-injury, is to confirm the concussion diagnosis and identify signs contributing to

symptom presentation, which will in turn inform the treatment plan. According to Leddy et al. (2021), a comprehensive evaluation upon initial presentation in the outpatient setting is warranted as symptoms related to the traumatic event may arise following the initial assessment that was completed in the acute phase post-injury. A comprehensive assessment is required to address all symptoms (cognitive, psychological, physical), which are commonly experienced by people with concussion (Pieroth, 2022).

Various approaches to the assessment of concussion have been outlined in the literature. According to Zollman (2016), subtle neurological deficits may be observed in people presenting for a clinical assessment of persistent concussion symptoms. Findings could include hearing loss, visual deficits, vestibular dysfunction including gross balance impairment, impairments with reaction time, and tremor. Leddy et al. (2021) provides an outline of a brief assessment that includes recommended tests and evaluations that should be included in a physical concussion examination in an outpatient setting. The examination includes autonomic assessment, cervical assessment, neurological examination (includes dynamic balance and gait, oculomotor, motor, reflexes, sensory, and cranial nerves evaluation) (Leddy et al., 2021). Matuszak et al. (2016) presented a toolbox of concussion measures for in-person use in people with persisting symptoms, however, underdeveloped psychometric property data associated with the measures was expressed as a concern. The neurological examination (evaluation of cranial nerves, reflexes, and manual muscle testing), balance/coordination assessment, vestibulo-ocular evaluation, and head and cervicothoracic evaluation were some of the measures included in the described toolkit.

The identified areas of physical assessment described by Leddy et al. (2021), Matuszak et al. (2016), and Zollman (2016), guided the selection of domains of focus for this dissertation

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work. Effort-based measures were of additional focus for the review of literature due to the relevance to eligibility for WSIB compensation in this project (people with workplace injuries were of focus). Availability of compensation has been shown to potentially impact levels of effort employed on assessments (Donders et al., 2021). For the purposes of this work, including the remainder of the literature review and dissertation articles, I am, therefore, focusing on the physical domains associated with a concussion examination, along with the evaluation of effort.

1.3.2.1 In-Person Concussion Measures. This following section focuses on physical measures used to assess people with concussion, in-person, along with the psychometric properties associated with the measures, when available.

1.3.2.1.1 Neurological Examination. The purpose of the neurological examination is to identify the presence of a neurologic deficit (abnormal functioning because of an injury to the brain, spinal cord, nerves, or musculature). The neurological examination, however, is typically normal in the mTBI population (Greenberg et al., 2015; Masanic & Bayley, 1998). A battery of tests used to evaluate neurological deficits could, however, prove to be clinically useful to screen for abnormalities or more significant pathology and therefore could be of use in the concussion population (Greenberg et al., 2015; Masanic & Bayley, 1998). Furthermore, the neurological examination could be used to identify subtle deficits in coordination, balance, and cranial nerves, which could persist beyond resolution of other mTBI symptoms (Zollman, 2016).

The physical assessment components of the neurological examination include cranial nerve (evaluation of cranial nerves to identify lesions at different levels), motor (evaluation of the motor system, such as assessment of strength to identify patterns of weakness), sensation (evaluation of the sensory system, such as ability to sense touch), and coordination (evaluation of motor actions to confirm ability to integrate sensory feedback with motor output) assessment

(Fuller, 2020). The composite score on the neurological examination has a reported moderate sensitivity, with a value of 0.61 and excellent specificity with a value close to 1.0, when completed in-person (Matuszak et al., 2016).

Coordination assessment, such as the finger-to-nose evaluation (examinee touches examiner with index finger then touches tip of nose with index finger), is important to include in the motor performance evaluation in the concussion neurological examination (Vartiainen et al., 2006). The finger-to-nose test (time to complete five repetitions) has established normative values in healthy people ranging from 15 to 40 years old, totaling 2.9 ± 1.1 seconds for the dominant hand and 3.0 ± 1.2 seconds for the non-dominant hand (Schneiders et al., 2010). The intra-rater reliability of the timed finger-to-nose test has an intraclass correlation coefficient (ICC) value of 0.86 for both the dominant and non-dominant hands (in healthy participants). While the sensitivity and specificity metrics have not yet been reported for people with concussion, Rodrigues et al. (2017) reported that the time to perform the finger-to-nose test has a sensitivity of 0.714 and specificity of 0.692 in people with stroke.

Cranial nerve evaluation is an important component of the neurological examination in concussion assessments as it has been reported that injury to either a single or multiple cranial nerves could occur following a mTBI (Matuszak et al., 2016). Most common cranial nerves affected in the concussion population include the olfactory, oculomotor, trochlear, and facial nerves. The composite score (all cranial nerves combined) associated with the cranial nerve examination has been reported to have a high specificity valuing 0.95, yet poor sensitivity valuing 0.22 (Matuszak et al., 2016).

The motor examination could include manual muscle testing (involves the evaluation of strength through observing movement against gravity or against applied resistance) and

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evaluation of reflexes (involves application of a stimulus, which induces an involuntary response) have also been recommended to be assessed following a concussion to detect more significant pathology. There lacks evidence to support that these areas are impacted following a concussion (Matuszak et al., 2016), but would be relevant in identifying focal neurologic deficit associated with more severe TBI.

Abnormal findings on a sensory examination could include numbness or other abnormal sensations including position, pain or vibration. While evaluation of sensation is a recommended component of the neurological examination, there is limited information on its use in the concussion context and can often be subjective when tested (Scorza & Cole, 2019). Specifically, there is a reliance on subjective reports to establish objective evidence on the function of the sensory system.

1.3.2.1.2 Oculomotor. Ocular symptoms experienced by people with concussion could include blurred or double vision, impairments in eye movements, difficulty with tasks requiring eye movements such as reading, and ocular pain (Mucha et al., 2014). Assessment of ocular symptoms is an important component of the concussion examination due to the high incidence (~65%) of visual disturbance following the injury (Goodrich et al., 2013). Commonly used ocular measures include the King-Devick test, smooth pursuits, saccades, and near point convergence.

Tests such as the King-Devick test could be useful to assess saccadic eye movements, which could be impacted following a concussion. The King-Devick test requires the person with concussion to rapidly read numbers out loud and is a time-based test (Clugston et al., 2019). The test-retest reliability of the total time on the King-Devick is excellent (ICC = 0.91) (Worts et al., 2018). The King-Devick has a documented sensitivity of 86% and specificity of 90% (Yorke et

al., 2017). While the King-Devick test is frequently used in the acute phase post-sport concussion, Subotic et al. (2017) explored its use in individuals experiencing persistent concussion symptoms (three or more months post-injury). This study found that those experiencing persistent symptoms performed significantly worse (achieved slower times) than healthy individuals on the King-Devick test and moderately worse than individuals who were in the acute phase post-injury (median five days post-injury) (Subotic et al., 2017). The King-Devick test specifically evaluates saccadic eye movements and does not assess other eye movements, such as near point convergence or smooth pursuits, which is a limitation of its use (Mucha et al., 2014).

Murray et al. (2020) noted that both saccadic (involves moving eyes horizontally and vertically) and smooth pursuit (involves following a moving target with the eyes) ocular ability could be impaired post-concussion. Hunfalvay et al. (2019) evaluated the use of saccadic eye tests as diagnostic markers of TBIs (mild to severe). Horizontal saccades have a documented sensitivity and specificity of 0.78 and 0.77, respectively, in people with TBIs. Vertical saccades have a documented sensitivity and specificity of 0.65 and 0.64, respectively, in people with TBIs. A similar study by Hunfalvay et al. (2020) evaluated the use of smooth pursuit tests as a diagnostic marker of TBIs (mild to severe) where the vertical smooth pursuit test had a documented sensitivity and specificity of 0.73 and 0.68, respectively (Hunfalvay et al., 2020). These studies appear to support that eye tracking has a potential role in identifying deficits associated with concussion.

A study by Pearce et al. (2015) assessed the near point convergence test (involves determination of the point closest to the eyes where double vision onsets) in athletes post-sport related concussion. According to this study, near point convergence values at or below five

centimeters is considered normal convergence and values above five centimeters are considered presence of convergence insufficiency. Three trial administrations of the near point convergence test yielded ICCs ranging from 0.95 to 0.98. When the authors evaluated reliability by group (normal versus convergence insufficiency), ICCs for the normal group ranged from 0.92 to 0.97 and ranged from 0.78 to 0.89 for the convergence insufficiency group, suggesting greater variability in the convergence insufficiency group, which is potentially attributed to participant fatigue. According to Mucha et al. (2014), the near point convergence component of the Vestibular/Ocular Motor Screening (VOMS), a measure that requires self-reports of symptoms following completion of various vestibular and ocular tests, demonstrated a significant relationship between convergence distance and likelihood of concussion and demonstrated the ability to accurately identify people with concussion (area under the curve = 0.64).

1.3.2.1.3 Vestibular. The vestibular system provides information regarding body and head positioning and has a role in maintaining balance and visual control (Mucha et al., 2014). Both the vestiubolo-spinal (responsible for motor responses involved in maintaining balance) and vestibulo-ocular (responsible for maintaining a clear visual field during head movements) systems are important areas of focus in a comprehensive concussion assessment (Mucha et al., 2014). Postural control measures frequently used to evaluate vestibulo-spinal deficits post-concussion include the Balance Error Scoring System (BESS), the sensory organization test (SOT), the concussion balance test (COBALT), the single leg stance test, tandem stance test, the Romberg, and the modified clinical test of sensory interaction in balance (CTSIB) (Baracks et al., 2018; Guskiewicz, 2011; Murray et al., 2014; Quintana et al., 2021). Most of these identified measures are used in the acute phase post-injury and their use in detecting deficits beyond the acute phase has not yet been deeply explored or established. Certain gait tests may also be useful

to evaluate vestibular deficits in people with concussion including the dynamic gait index (DGI) and functional gait assessment (FGA).

The BESS test involves the evaluation of postural control in three different stances (single leg stance, double leg stance, and tandem stance), all with eyes closed. These stances are evaluated both on flat ground and while standing on a foam surface. The test-retest reliability for the total error score on the BESS is good (ICC values range from 0.70-0.78) (Amin et al., 2014; Yorke et al., 2017). It has a reported sensitivity ranging from 34-60% (low to moderate) and specificity ranging from 91-93% (excellent), however this was measured at the acute phase post-injury when balance deficits are more significant (Buckley et al., 2018; Haran et al., 2016). Sweeny et al. (2020) explored the use of the BESS and force plate measures to evaluate postural control in concussion-injured community-dwelling adults, longitudinally, from within the first seven days post-injury to 12 weeks post-concussion. No changes in BESS scores were observed up to three months post-injury. It was noted that these findings potentially indicate that the adults had already recovered at the time of initial evaluation (seven days post-injury), or that subtle deficits are not captured by the BESS (Sweeny et al., 2020). Although the BESS has reported practice effects, these effects were not observed in this longitudinal study, which may be due to the population being community-dwelling adults, rather than athletes who are characteristically different (different motor learning and postural control abilities) (Sweeny et al., 2020). While the BESS has support for its use in the acute phases post-injury, its use beyond this phase is less studied and less understood. Cushman et al. (2018) explored the reliability of the BESS in people experiencing persisting symptoms post-concussion and reported an ICC reliability value of 0.83 in the adult population.

The SOT involves postural control evaluation using specialized equipment (force plate and visual surround equipment). The test-retest reliability of the SOT is very good with a reported value of 0.83 (Cripps et al., 2016). The SOT has a reported sensitivity of 34-38% and specificity of 88-95% (Haran et al., 2016).

The modified CTSIB involves evaluation of postural control in different conditions, including standing on flat ground, standing on a foam surface, standing with eyes open, and standing with eyes closed. The test-retest reliability of the modified CTSIB is excellent with reported ICC values ranging from 0.91-0.97 (Murray et al., 2014). The reported sensitivity and specificity metrics of the modified CTSIB when compared to the SOT, in people with unilateral vestibulopathy, is 68% and 44%, respectively (Park et al., 2013). The use of the SOT and modified CTSIB in the post-acute phase after a concussion is less explored.

A study by Vartiainen et al. (2006) evaluated the test-retest reliability of motor performance measures (balance and gait measures) following TBI (varying severities). Measures evaluated in this study included standing on one leg (single leg stance test) and tandem walking forwards. The test-retest reliability of the single leg stance has a documented Kappa value (reliability statistic) of 0.63 (good) on the right leg and Kappa values ranging from 0.43 to 0.49 (moderate) on the left leg. The test-retest reliability of the tandem walking forward has documented ICC values ranging from 0.57 to 0.84 (moderate to very good) (Vartiainen et al., 2006). The single leg stance test administered in the sport-related concussion context using an inertial balance sensor has moderate to good properties, with a documented sensitivity of 0.42 and specificity of 0.76 (Baracks et al., 2018). Schneiders et al. (2010) documented the normative values of completing the single leg stance test eyes closed in healthy participants aged 15 to 40 years old. Values for

single leg stance on a firm surface, on the dominant and non-dominant leg were 20.4 ± 3.0 and 21.0 ± 2.9 seconds, respectively.

The DGI and FGA are tests that involve the evaluation of gait under different conditions such as with changes in pace, stepping over obstacles, and with head turns. The test-retest reliability of the FGA is excellent (ICC = 0.91) (Leddy et al., 2018). Its' sensitivity and specificity metrics in people with TBI is unknown (Lei-Rivera et al., 2013). The test-retest reliability of the DGI is also excellent (ICC = 0.98) (Medley et al., 2006). It has a reported sensitivity of 85% and specificity of 69% in people with moderate to severe TBI (Lei-Rivera et al., 2013).

The above-described measures all evaluate static balance or gait. Based on the literature reviewed, there are limited dynamic balance measures currently available to evaluate balance post-injury. One proposed test, the COBALT, is a dynamic balance measure, which involves evaluation of balance in six different conditions including standing with head turns and trunk rotations (Massingale et al., 2018), however, it lacks information on reliability, sensitivity and specificity.

1.3.2.1.4 Vestibular and Oculomotor. Disruption of the vestibular and ocular systems could lead to symptoms such as dizziness, blurred vision, nausea, and discomfort in busy environments (Quintana et al., 2021). Various measures have been developed and used in the concussion population to evaluate both the vestibular and ocular symptoms including the VOMS and the dynamic visual acuity test (DVAT) (Quintana et al., 2021).

The VOMS was developed with the purpose of briefly assessing vestibular and ocular impairments following a concussion in the sport context. The VOMS consists of evaluation of near point convergence, vestibulo-ocular reflex (VOR) (involves rotation of the head horizontally and vertically while maintaining focus on a central target), visual motion sensitivity

(involves maintaining focus on thumbs of outstretched arms while rotating the trunk, head, and eyes right and left), smooth pursuits, and saccadic eye movements. Verbal ratings of baseline symptoms (for headache, dizziness, nausea, fogginess) and changes in these symptoms following completion of each component of the VOMS are self-reported. According to Pieroth (2022), the VOMS tool provides one of the best approaches to vestibulo-ocular assessment post-concussion, however, it is important to note that false positives may occur. The VOMS has demonstrated moderate to very good test-retest reliability with a documented ICC value ranging from 0.6-0.81 (Kontos et al., 2021). It has a documented sensitivity of 96% and specificity of 74% (Buttner et al., 2021; Elbin et al., 2021). The VOMS has demonstrated the ability to detect deficits in the post-acute phase post-concussion (Sinnott et al., 2019).

The DVAT requires hands-on approaches to evaluation. The clinician places their hands on the patient's head and rotates the head while the patient reads letters on the Snellen chart (chart with varying sized letters). The test-retest reliability of the DVAT is good (ICC = 0.77) (Kaufman et al., 2014). The sensitivity and specificity of the DVAT in people with vestibular hypofunction is 55% and 90%, respectively (Schubert et al., 2002).

1.3.2.1.5 Cervical Spine. Cheever et al. (2016) reported that cervical spine injuries and concussions could overlap in terms of mechanism of injury as well symptom presentation, and therefore cervical spine evaluation should be included in a comprehensive concussion assessment (Leddy et al., 2018). According to Pieroth (2022), over a third of patients report neck pain at 72 hours post-concussion. An examination of the cervical spine is recommended, including an evaluation of the musculature and alignment, and range of motion evaluation. Cervical spine deficits may lead to neck pain, headaches, dizziness, fogginess, nausea, or tenderness in the cervical area. Specific cervical measures have been identified which can be

used to evaluate the cervical spine post-concussion. These tests include cervical spine range of motion evaluation, the joint position error test (JPET), smooth-pursuit neck-torsion test (SPNTT), physical palpation of the cervical spine, among others (Cheever et al., 2016).

Cervical range of motion is recommended to be evaluated following a concussion (Matuszak et al., 2016). Active range of motion, which involves independent rotation of the head right and left, extension and flexion of the neck by looking up and down, and lateral bending of the head to the right and left, is frequently assessed using a goniometer when conducted in-person. The test-retest reliability of cervical spine range of motion evaluation using a goniometer is excellent (ICC = 0.83-0.98) (Farooq et al., 2016). A study by Dall'Alba et al. (2001) explored the diagnostic accuracy of computerized cervical spine range of motion evaluation in adults with whiplash and reported a sensitivity and specificity of 86% and 95%, respectively.

Cervical spine proprioception evaluations, such as the JPET, aim to detect abnormalities in one's ability to control where the head is in space, which could contribute to concussion symptomatology, such as vestibular issues (Hammerle et al., 2019; Reddy et al., 2019). The JPET measures cervical spine proprioception through one's ability to reposition the head to a neutral position after completing a full rotation of the head to the right or left with eyes closed. The JPET is particularly useful to identify people with cervical spine injury (sensitivity value of 82% and specificity value of 92%) (Cheever et al., 2016). The test-retest reliability ranges from moderate to excellent (ICC = 0.42-0.90) (Lee et al., 2006).

The SPNTT is a test that can detect cervical injury. It involves maintaining the head in a neutral position while the trunk rotates left and right. The test is particularly sensitive to individuals with cervicogenic dizziness, supported by high reported levels of sensitivity (90%) and specificity (91%) (Cheever et al., 2016).

1.3.2.1.6 Evaluation of Effort. Effort-based tests (involves demonstration of performance at optimal ability) or symptom validity (accuracy of subjective issues expressed by the individual) or performance validity (the extent to which results obtained on an objective measure are truly reflective of actual capabilities) tests can provide insight into levels of effort employed on an assessment and could potentially detect malingering (exaggeration of symptoms for some personal gain) (Donders et al., 2021; Kontos & Collins, 2018). Symptom exaggeration in which the individual amplifies a symptom or sign of mTBI is most commonly apparent in worker's compensation claims (Zollman, 2016). Donders et al. (2021) indicated that people with mTBI who failed an effort-based test were twice as likely than the individuals who did not fail either of the symptom or performance validity test to be participating in a compensation-seeking dispute at the time of the assessment (Donders et al., 2021). Further, persons involved in litigation are more likely to experience worse outcomes post-injury. Methods to assess effort and validity of overall assessment is important in neurological examinations (Zasler, 2015). Physical measures have been developed for the sole purpose of determining effort levels, symptom/performance validity, or exaggeration of symptom presentation, including the Waddell signs (Davis, 2021) and the honest palm sign (Zasler, 2015).

Waddell signs are grouped into five categories including distraction (improvement in examination observed when the patient is distracted), tenderness (such as pain reported in response to light touch), overreaction (response is out of proportion to stimulus), simulation (reported pain in response to simulated maneuvers), and regional disturbance (such as decreased sensation that is not in line with dermatomes) (Davis, 2021). These signs are commonly used in people with back pain and have yet to be explored in people with concussion. The honest palm sign (looking for nail marks in the palms during tests such as manual muscle testing) is an

example of an approach used to evaluate effort in a physical examination (Zasler, 2015), however its use has yet to be explored in the concussion population. Therefore, due to the limited available physical measures, typically, on examination, physical effort would be identified by give way weakness, unusual balance testing such as astasia-abasia or test abandonment (Zasler, 2015).

1.3.3 Comparison of Virtual and In-Person Neurological Assessments

Al Hussona et al. (2020) outlined the components of the neurological examination that can be conducted in a virtual context, which includes mental status; cranial nerves (pupils, eye movements, facial strength); motor examination (pronator drift, forearm rolling); sensory assessment (light tough, cold); coordination (finger-to-nose, heel-to-shin); and balance/gait assessment (observe two-feet stance, observe tandem gait). According to Awadallah et al. (2018), fair to very good agreement (Kappa = 0.32-0.82) was found in most items of the neurological examination when comparing bedside versus telemedicine examination in people in the acute emergency department. Craig et al. (1999) further described a telemedicine-based neurological examination in people on the neurological ward. The neurological examination was performed through both telemedicine and face-to-face methods and consisted of assessments such as reflexes, coordination, sensation, eye movements, balance, and gait. According to Craig et al. (1999), a telemedicine neurological examination was less reliable (Kappa = 0.21-0.44) in identifying abnormalities when compared to the in-person examination (Kappa = 0.41-0.49) for the evaluation of eye movements and coordination, when completed by a junior doctor. However, with the advancement of technology, findings may vary in current times. Durfee et al. (2007) reported on the technical feasibility of tele-assessments in healthy participants. The study found no difference in findings between remote and in-person assessments, which consisted of

various evaluations such as range of motion evaluation of the shoulder and knee and manual muscle testing.

A review by O'Neil et al. (2023) identified the telerehabilitation assessments available for people with neurological conditions along with the psychometric properties associated with the assessments, if available. Only roughly one-third of the studies identified in this review documented psychometric properties associated with the telerehabilitation assessments. In a small number of studies, moderate to excellent correlations were documented when remote and in-person administration of certain neurological measures was compared. A lack of congruence between in-person and virtual administrations was more commonly reported for measures such as the Nine Hole Peg Insertion Test (place pegs from a container into holes on a board) (Pearson's correlation coefficient (ρ)=0.31 for time; ρ=0.21 for number of dropped pegs), Box & Block Test (move blocks from one component to another in a container as quick as possible) (ρ=-0.23 for number of transported blocks; ρ=-0.21 for number of dropped blocks), and a reaching test (reach for moving and stationary targets in a virtual reality environment) (lower peak velocities observed) (O'Neil et al., 2023). Toledano-Shubi et al. (2024) compared in-person and virtual administration of various functional and balance tests (Berg Balance Scale, 30-Second Sit-to-Stand, Timed Up and Go, MniBESTest, and the 4-Meter Walk) in home-dwelling older adults. Low to moderate agreement (95% limits of agreement = -4.93 to -0.35) between in-person and virtual administration was reported for these measures, except for the 30-Second Sit-to-Stand, in which excellent agreement (95% limits of agreement = -1.13) was reported. Only a single feasibility study, by Vargas et al. (2017) compared the in-person and remote completion of components of the concussion examination, including the Standardized Assessment of Concussion (brief cognitive test), modified BESS, and the King-Devick test. This study

documented an excellent level of agreement between the in-person and remote approaches, with the King-Devick times within three seconds of each other 100% of the time, modified BESS within three points of each other 100% of the time, and 100% agreement on the Standardized Assessment of Concussion.

Based on this summary of the review of literature, it is apparent that there are multiple gaps in the concussion assessment. While there appears to be a need to further explore and expand on the understanding of the measures used to assess people experiencing persistent symptoms post-concussion, in-person, there is also now a need to explore the use of these measures in a virtual context. While the COVID-19 pandemic drove the increased use of telehealth approaches globally, clinicians had minimal experience or training to assess using virtual methods. Clinical measures typically used in-person were used in virtual environments despite the lack of validation and evidence to support their use in that setting. While in-person care has resumed post-pandemic, there remains a need to develop and establish important psychometric properties of measures used virtually, based on the pandemic experiences (Montes et al., 2022). To develop a virtual assessment that could be used in practice, a systematic approach to development of the assessment is recommended (Montes et al., 2022). This dissertation work addresses this highlighted gap by first identifying clinical measures selected by clinicians that are commonly used in-person to evaluate deficits associated with the neurological examination, vestibular, ocular, and cervical spine, along with the evaluation of effort in the concussion examination that may be feasibly administered in a virtual environment, followed by investigating the real feasibility, and preliminary reliability and sensitivity properties associated with virtual administration of the identified measures.

1.4 Philosophical, Theoretical, and Methodological Overview of Dissertation

Figure 1.1 presents an overview of the philosophical and theoretical lenses, and methodological approaches that guided this dissertation.

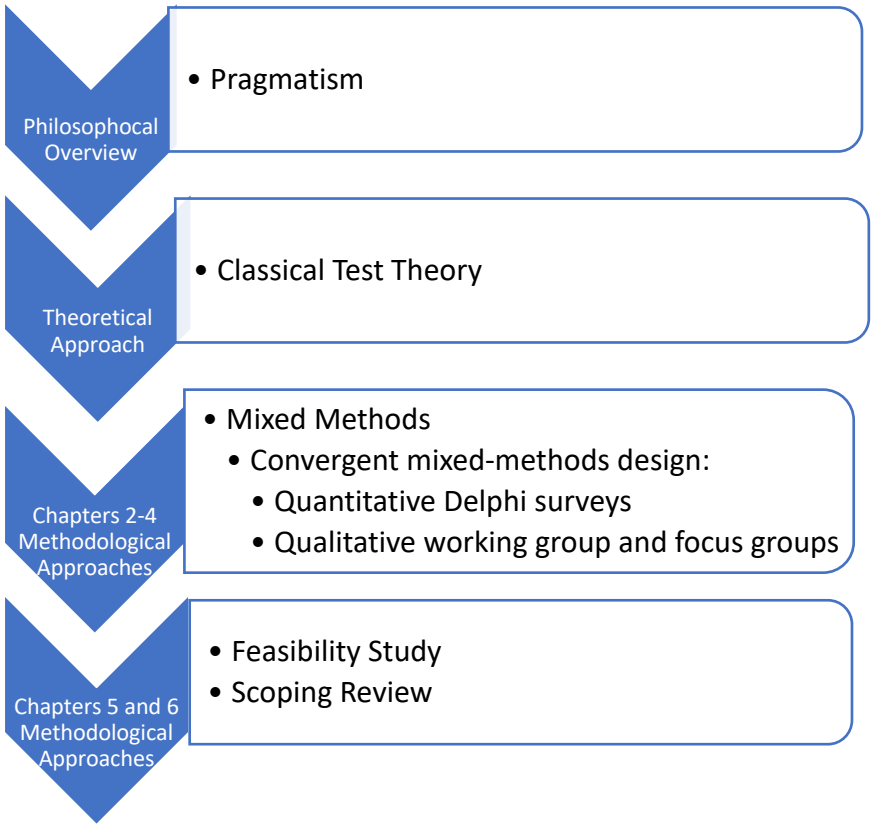


Figure 1.1. Overview of Philosophical, Theoretical, and Methodological Approaches that Guided this Dissertation

1.4.1 Philosophical Views, Researcher's Position, and Theoretical Lens

A paradigm could be defined as a 'system of beliefs' that influences researchers' decisions regarding research questions and methods (Shannon-Baker, 2016). The different paradigms describe structures and approaches for the way research is conducted (Mackenzie & Knipe, 2006).

This dissertation is grounded within the pragmatic paradigm (Mackenzie & Knipe, 2006). My clinical experience as a registered kinesiologist drove the pursuit of my research. I worked as a kinesiologist at a complex care clinic where I treated people who sustained concussions while at work. When the COVID-19 pandemic pushed leaders to enforce stay at home orders, I was

one of the many clinicians that had to shift my practice to virtual care. With little to no direction, we had to transition how we assessed, treated, and interacted with patients. As I was working with people with workplace injuries, there were expectations to continue to report findings on assessments, however these assessments were conducted virtually and the approach to using clinical measures virtually had not been standardized or validated. This led me to question the effectiveness of the virtual approach to assessment in the concussion context and motivated me to attempt to explore this issue through research. I identified a real-world clinical issue and aimed to begin to address this issue through my work.

This dissertation is grounded within the pragmatic paradigm since I decided to develop a virtual concussion assessment through mixed methods approaches and to implement and obtain real world clinical data on the assessment. Pragmatism is often associated with mixed methods approaches (Mackenzie & Knipe, 2006). There is a focus on the consequences of the work and an emphasized importance on the research questions and the use of multiple data collection methods to inform the problem of interest (Creswell & Clark, 2018). The virtual assessment was developed through Delphi surveys and provided quantitative data, which was further explored and expanded on in a working group and focus groups (qualitative data). Further, the feasibility study consisted of patient-participants attending in-person and virtual assessments (quantitative data) and providing feedback (qualitative data) on the approaches. Guided by pragmatism, I decided to follow a mixed methods approach to this dissertation work, as it can provide a more complex understanding of the problem of focus (Shannon-Baker, 2016). This work is problem-centered, in that the main goal is to address the issue of there being limited information and evidence regarding the virtual concussion assessment available, which is in line with the pragmatic paradigm.

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The pragmatic paradigm is based on the belief that theories can be both contextual and generalizable by analyzing them for transferability to another situation (Shannon-Baker, 2016). This is related to this dissertation, as in-person concussion assessments could demonstrate feasibility and acceptability in a transferable virtual context. Pragmatism has a focus on practicality, meaning that the researcher collects data by 'what works' and real-world implications (Creswell & Clark, 2018). This relates to the aim of using survey, working group, and focus group data from clinician and patient-participants to inform the selection of clinical measures to include in a virtual assessment toolkit, which was further tested in a clinical environment in a feasibility study to ensure the measures were clinically relevant and patient-centered. This work is anticipated to have an impact on real-world clinical rehabilitation and may inform future care practices.

1.4.2 Theoretical Framework

The theoretical framework that guided this dissertation is the Classical Test Theory (CTT), which is a theory of measurement. It defines the conceptual foundation of reliability (Furr, 2022) and acts as a reference point for psychometric approaches to measurement tool development and evaluation (DeVellis, 2006; Kean & Reilly, 2014; Wang & Osterlind, 2013). CTT is widely used in health outcomes research and is the dominant theoretical approach in clinical outcome assessments (McClimans et al., 2017).

The framework is based on three key ideas: measurement consists of error, this error can be explained as a random variable, and the concept of correlation. Beginning from works of Charles Spearman in 1904 and expanded on by Melvin Novick in 1968, CTT outlines how correlation values can be corrected to include acknowledgement of error (McClimans et al., 2017). There is an equation (presented in Figure 1.2) that is associated with CTT and is based on

the understanding that the score achieved on a test consists of two different components, random error of the measurement ('e') and the true score, which is the actual score, or true ability of the person being assessed ('T') (Furr, 2022; Raykov & Marcoulides, 2011). 'X' in the equation, refers to the observed score (Furr, 2022) and reflects the score obtained on the measure administered (Furr, 2022).

$$X = T + e$$

Figure 1.2. The CTT equation. Observed score (X) is the sum of the true score (T) + error (e)

Reliability is an important feature of CTT and relates to the consistency of a measure when repeatedly administered or when repeatedly scored/rated by two different raters or the same rater. Validity is an additional feature of CTT and refers to the extent to which similar scores are obtained when an alternate form of the measure is administered (Erguven, 2013), which could be interpreted as the similarity of the ability of one approach to identify deficits compared to the other approach (virtual approach when compared to the in-person reference standard, as an example of concurrent validity). In accordance with CTT, if measures contain high reliability, then the observed score can be considered closely reflective of the true score (true ability) (Erguven, 2013). The development and use of standardized tests has the capacity to reduce the presence of errors, strengthening the reliability properties (Fawcett, 2007).

An example of the equation interpretation in relation to comparing the in-person and virtual approaches and investigating reliability of the virtual assessment, associated with this dissertation work, relates to the measurement of balance ability of people with concussion. If this balance test was administered in a noisy environment in-person and quiet environment virtually, scores are expected to be worse in-person compared to if the balance test was administered in the

quiet virtual environment. The true score on the virtual and in-person assessment is the same (balance ability is the same) but the difference on the observed score could be explained as an error score (the error added by the measurement approach). When considering reliability of the virtual assessment, the true score is the same when the measures are repeatedly administered by two different clinicians, however the observed score may differ if error exists. According to Furr (2022), psychometric properties associated with a measure may be different for different respondents. Further, a measure completed in-person may have different properties than a measure administered online or virtually (Furr, 2022). CTT provides a strong framework and rationale for beginning to explore the reliability and sensitivity properties of concussion measures when administered virtually compared to in-person administration of the same measures.

1.4.3 Methodological Approaches

There are four projects included in this dissertation. Project 1 consisted of Delphi surveys and a working group. Project 2 consisted of focus group completion with experienced clinicians and with people living with workplace concussion. Projects 1 and 2 together follow an explanatory sequential mixed methods design. The quantitative data (clinical measures identified in surveys) were further explored in a working group and focus groups and informed the questions for the qualitative data collection. The results were analyzed and interpreted to determine how the qualitative results expanded on the quantitative results (Creswell & Clark, 2018). The information from Projects 1 and 2 informed the decision regarding which measures to use in Project 3, a feasibility study and informed which domains to explore in Project 4, a scoping review. Project 3 consisted of patient-participants attending in-person and virtual assessments using the measures identified in Projects 1 and 2, and clinicians observing and rating

recordings of the assessments. Project 4 consisted of a scoping review where two physical domains (vestibular and ocular) associated with the concussion examination tested in the feasibility study were of focus. Figure 1.3, below, presents a methodology flow diagram for this dissertation.

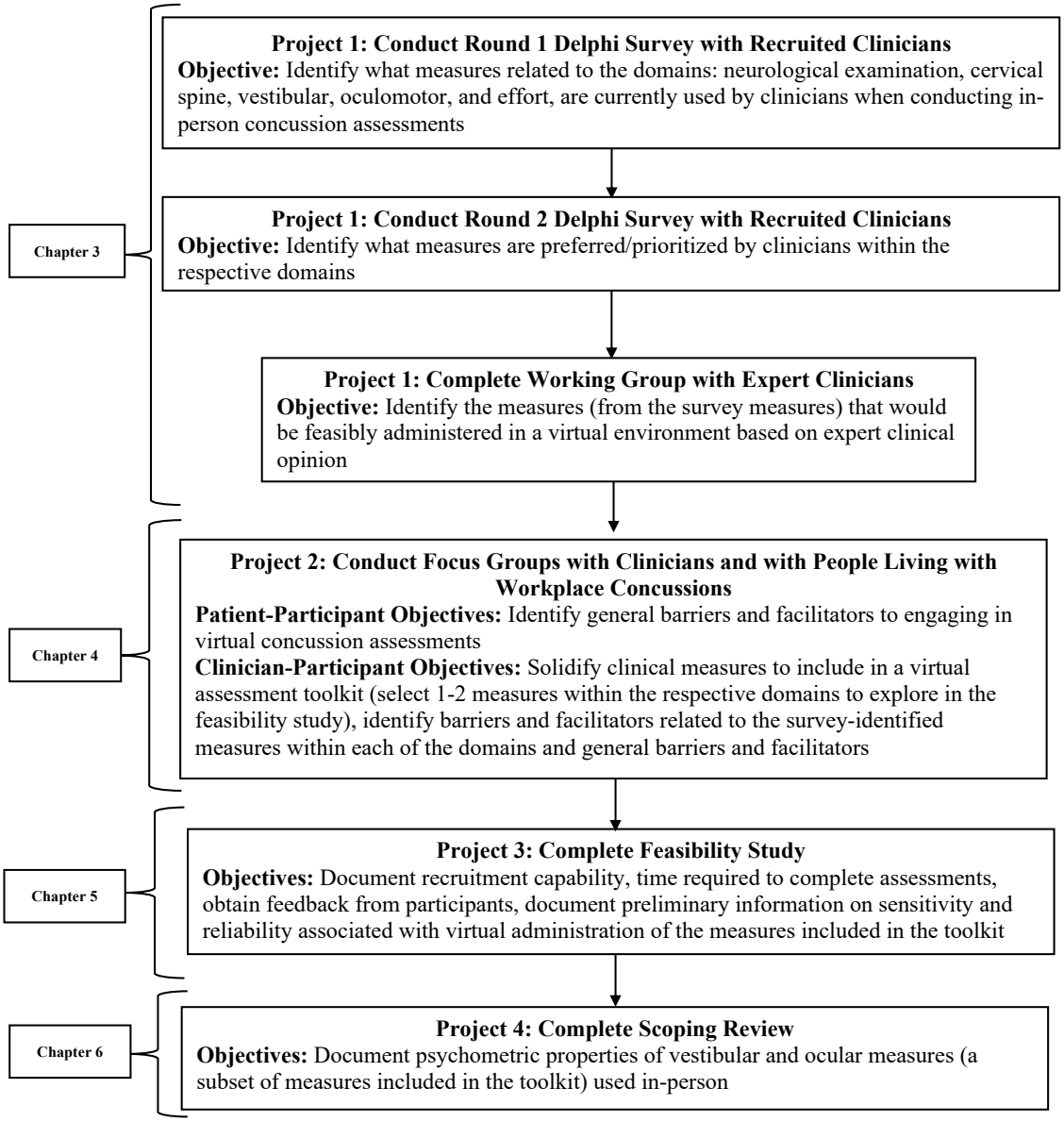


Figure 1.3. Dissertation Methodological Flow Diagram.

1.4.3.1 Methods of Data Collection and Research Questions

This dissertation process and study procedures are further guided by work completed by Montes et al. (2022) who outlines a roadmap to the development of a virtual assessment. Adaptation of measures to virtual contexts should take a phased approach, starting with those that are safe and feasible (Montes et al., 2022). According to this work, expert consensus is sought to determine feasibility of administering measures in a virtual environment.

Guided by the approach outlined by Montes et al. (2022), to identify clinical measures to include in the virtual assessment toolkit that were both clinically relevant and patient-centered, I conducted two rounds of Delphi surveys with clinicians and focus groups with both clinicians and people living with workplace concussion. The perceived feasibility of administering the measures in a virtual environment was determined through the working group where expert clinicians expressed the perceived current feasibility of administering the measures virtually, based on their opinion and expertise. Expert consensus was sought through the Delphi surveys, working group, and focus groups to solidify the measures to be the first point of exploration in the feasibility study. Figure 1.4 outlines the roadmap components that were targeted through the Delphi surveys, working group, and focus groups.

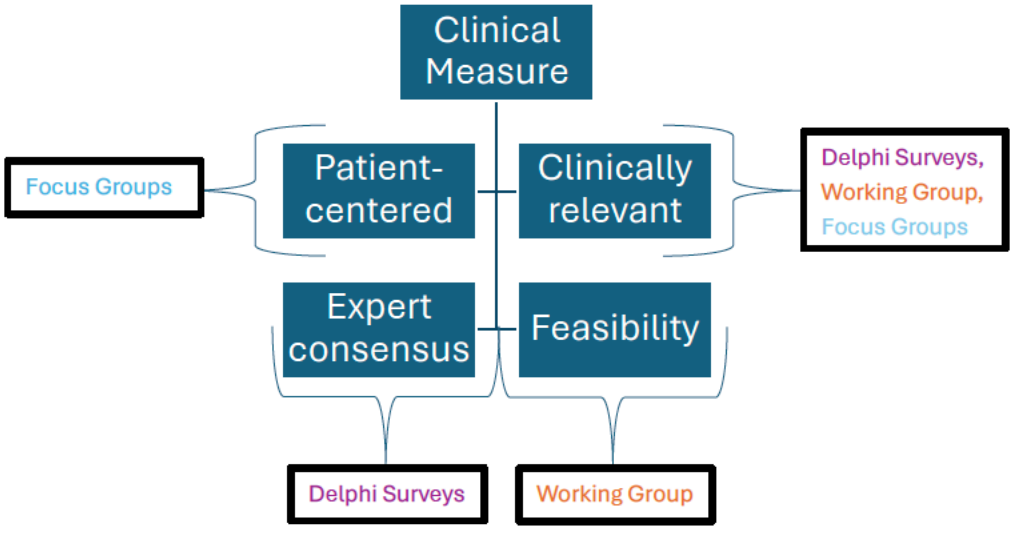


Figure 1.4 Components of the roadmap outlined by Montes et al. (2022) relevant to Delphi surveys, a working group, and focus groups

The feasibility of administering the measures in a virtual context was further tested in the feasibility study, where I documented information regarding the safety, obtained feedback regarding the environmental and technology set-up, and obtained preliminary data (pilot data) on the sensitivity and reliability of the measures included in the toolkit. Figure 1.5 outlines the roadmap components that were targeted through the feasibility study.

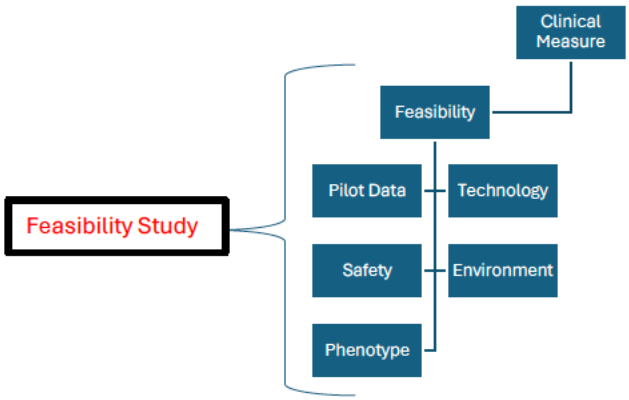


Figure 1.5 Components of the roadmap outlined by Montes et al. (2022) relevant to a feasibility study

Information about in-person administration of a subset of measures included in the virtual assessment, for the purposes of comparing to the psychometric properties associated with virtual administration (preliminarily investigated in the feasibility study and is being further explored in a larger study that goes beyond this dissertation), was obtained through completion of a scoping review. The relevant components of the roadmap related to this work in its totality is outlined in Figure 1.6.

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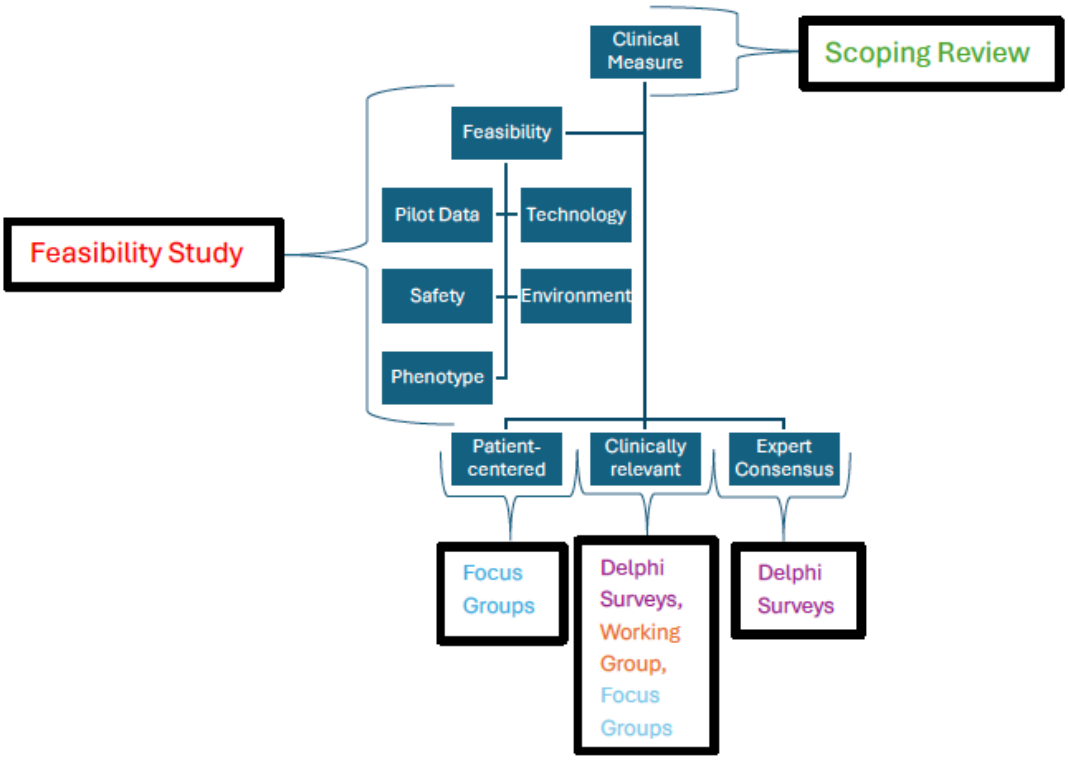


Figure 1.6 Components of the roadmap outlined by Montes et al. (2022) relevant to this dissertation

Information regarding the methodological approaches used in each chapter is further outlined in the section below.

1.4.3.1.1 Project 1: Delphi Surveys. The Delphi survey method is a consensus approach frequently employed to improve healthcare decision-making. It involves multiple stages and is an iterative process which aims to consolidate participant-opinion into consensus (Hasson et al., 2000). The Delphi approach frequently consists of multiple rounds of questionnaire administration to participants, who are experts on the topic of interest. There is no clear definition of 'expert' in the Delphi approach (Taylor et al., 2016). Responses from the first round are usually communicated to the participants through controlled feedback (Hasson et al., 2000). In this approach, there is a tendency for the opinions and judgments of the experts participating to converge or align as the questionnaire administration goes on (Fink-Hafner et al., 2019). There

is not a universally accepted or standard number of participants that are required to participate in the Delphi approach, however, a range of 10 to 100 participants has been documented (Fink-Hafner et al., 2019). Questionnaires administered in the Delphi approach frequently commence with qualitative questions with the aim of identifying possible elements relevant to the topic of interest. The structure of the second round of questionnaires is more in line with quantitative data collection (Fink-Hafner et al., 2019).

The following research questions were addressed in Project 1 using the Delphi survey and working group methods of data collection:

a. Which concussion measures (related to the neurological examination, cervical spine, vestibular, oculomotor, and effort assessment) are currently being used by expert clinicians in-person?
b. What are the most relevant concussion measures for each domain as perceived by the clinicians?
c. Which of the identified measures are perceived to be feasible in a virtual context?

1.4.3.1.2 Project 2: Focus Groups. Focus groups are frequently guided by a researcher and consist of several participants who discuss a certain topic of interest related to the research questions (Breen, 2006). When participants are located at a distance from one another, focus groups are a useful approach to data collection (Breen, 2006). Focus groups is a method of qualitative data collection that is supportive of studies exploring a new domain. They are supportive of dynamic dialogue (allows researcher to gain an understanding of various participant perspectives), and participants have control over the discussion (allows participants to discuss areas based on their perceptions of importance) (Breen, 2006).

The following research questions were addressed in Project 2 using focus groups as the method of data collection:

a. Which measures (from the surveys) do clinicians perceive would work best in virtual practice?

b. In order to explore feedback related to virtual concussion assessments, the following questions were discussed with the clinician-participants for each measure from the surveys:

- What are the clinician-perceived barriers related to using the identified measure in a virtual context?
    - What are the clinician-perceived practical issues (space in clinic, safety, access to equipment, need for hands-on approaches, etc.) related to using the identified measure in a virtual context?
    - What are the clinician-perceived technical issues (connectivity, availability of internet, comfort with technology, etc.) related to virtual assessments?
- What are the clinician-perceived facilitators related to using the identified measure in a virtual context?
    - What are the clinician-perceived practical facilitators related to using the identified measure in a virtual context?
    - What are the clinician-perceived technical facilitators related to virtual assessments?

b. In order to explore feedback related to virtual concussion assessments from the perspectives of people living with workplace concussion, the following research questions were discussed with the patient-participants:

- What are the challenges or barriers associated with virtual concussion assessments?

- What are the practical and technical barriers related to virtual concussion assessments?

- What are the benefits or facilitators associated with virtual concussion assessments?

- What are the practical and technical facilitators related to virtual concussion assessments?

1.4.3.1.3 Project 3: Feasibility Study. A feasibility study is a useful methodological approach to determine if study procedures are appropriate and acceptable, to evaluate recruitment, and to obtain preliminary information on a phenomenon of interest (Arain et al., 2010). Feasibility studies are typically completed prior to a larger, main study and are commonly used to inform certain parameters of the main study, such as willingness of participants to participate, eligibility numbers, and characteristics of measures used in the study (Arain et al., 2010). While feasibility studies do not evaluate the outcomes that will be evaluated in the main study, they can provide some insight into the outcomes and identify changes needed for the main study (Arain et al., 2010).

Flexible methodology is often used with feasibility studies allowing them to be more adaptive and formative when compared to pilot studies (Orsmond & Cohn, 2015). This is an important distinction and led to the selection of doing a feasibility study. The aim here was to test out our methodology so that we can make necessary changes for the main study (which goes beyond this dissertation- see Appendix D).

The following research questions were addressed in Project 3 using a feasibility study design:

a. Can we recruit appropriate participants?

b. How long do study procedures take?

c. Are the procedures and set-up acceptable to participants?

d. Are participants confident in the findings on the assessments?

e. Does the preliminary data suggest that the virtual assessment is reliable and sensitive to deficits when compared to the in-person assessment?

1.4.3.1.4 Project 4: Scoping Review. A scoping review is a useful approach to synthesize evidence and identify knowledge gaps (Munn et al., 2018). Scoping reviews are useful to understand the scope of current literature on a given topic. The aim here is not to determine and/or evaluate the effectiveness of a certain measure but rather to report on the characteristics of the measures. The purpose is to map the evidence associated with certain measures (Munn et al., 2018).

The following research questions were addressed in Project 4 using a scoping review study design:

1) Which vestibular and ocular measures are used to evaluate people with concussion in-person?
2) What are the documented psychometric properties associated with the identified vestibular and ocular measures?

1.5 Thesis synopsis

This dissertation consists of five manuscripts (Chapters 2-6) related to the overarching objective of developing and exploring the preliminary reliability and sensitivity metrics of a virtual assessment developed for workplace concussions (see Figure 1.7). Chapter 7 presents an integrative discussion, summarizing the key findings of this dissertation and the clinical, policy, and research-related implications the findings may have. The long-term goal of this work, which goes beyond this dissertation, is the development of the virtual assessment with sufficient

support for use in practice. The goal of this dissertation is to contribute to this development with preliminary data regarding the reliability and sensitivity of components of the virtual assessments compared to in-person assessments. We are currently completing a larger-scale study sufficiently powered to establish some of these important properties, including reliability and sensitivity (protocol presented in Appendix D). Once further research has been conducted on the use of the virtual assessment, it is intended to support WSIB clinicians with a feasible virtual assessment approach for people living with concussion, with data supporting its reliability and sensitivity.

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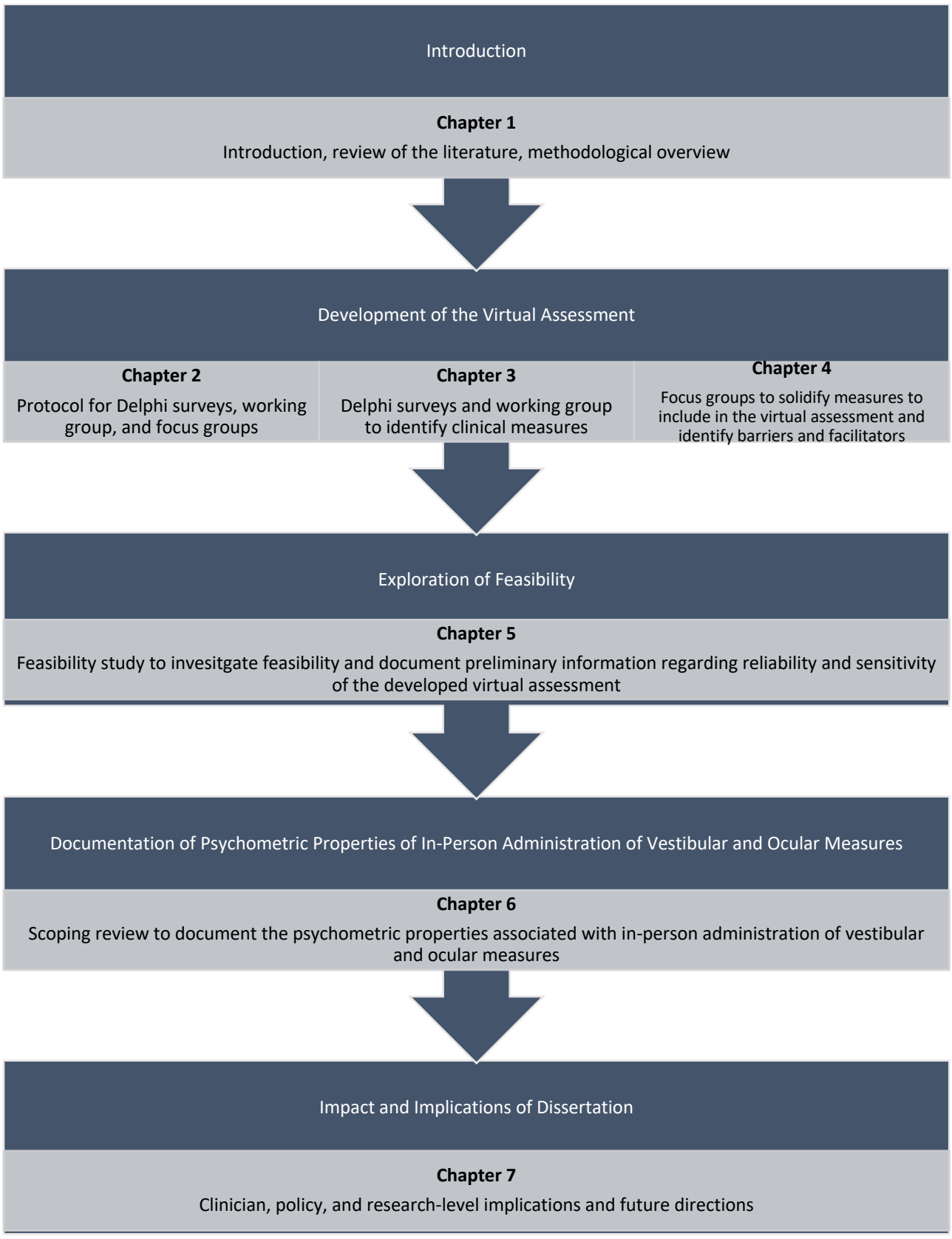


Figure 1.7. Outline of chapters included in dissertation.

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Chapter 2. Identification of Clinical Measures to Use in a Virtual Concussion Assessment: Protocol for a Mixed-Methods Study

Chapter 2 has been formatted based on the requirements of the peer-reviewed journal in which it was submitted.

The published protocol used for clinician surveys, a working group, and focus groups is presented in Chapter 2. The protocol was published in the Journal of Medical Internet Research-Research Protocols (International Registered Report Identifier (IRRID): DERR1-10.2196/40446). Ethics approval was obtained by the Ottawa Health Sciences Network Research Ethics Board (20210575-01H), the Bruyère Research Ethics Board (M16-22-006) and the University of Ottawa Board of Ethics (H-02-22-7611).

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Identification of Clinical Measures to Use in a Virtual Concussion Assessment: Protocol for a Mixed-Methods Study

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Abstract

Background: Workplace concussions can have a significant impact on workers. The impact of concussion symptoms combined with challenges associated with clinical environments that are loud, bright and busy, create barriers to conducting effective in-person assessments. While the opportunity for remote care in rural communities has long been recognized, the COVID-19 pandemic has catalyzed the transition to virtual assessments and care into the mainstream. With this rapid shift, many clinicians have been completing remote assessments. However, the approaches and measures used in these assessments have not yet been standardized. Furthermore, the psychometric properties of the assessments when completed remotely using videoconference have not yet been documented.

Objectives: Through this mixed-methods study, we aim: 1) To identify which concussion assessment measures clinicians are currently using in-person and are most relevant to five physical domains: neurological examination (cranial nerve, coordination, motor, sensory), cervical spine, vestibular, oculomotor, and effort assessment; 2) To document the psychometric properties of the measures identified; 3) To identify measures that appear feasible in a virtual context; and 4) To identify practical and technical barriers/challenges, facilitators and benefits to conducting or engaging in virtual concussion assessments.

Methods: This study will follow a sequential mixed methods design using a survey and Delphi approach, working groups with expert clinicians, and focus groups with experienced clinicians and people living with concussions. Our target sample sizes are 50 clinicians for the Delphi surveys, 4 clinician-participants for the working group, and 5-7 participants for each focus group (roughly 6-10 total groups being planned with at least two groups consisting of people living with concussions). The results from this study will inform the decision regarding which measures to include in a virtual assessment toolkit, to be tested in a future planned prospective evaluation study.

Results: The study is expected to be completed by January 2023.

Conclusion: This mixed-methods study will document the clinical measures that are currently used in-person and identify those that are most relevant to assessing the physical domains impacted by concussions. Potential feasibility of using these measures in a virtual context will be explored.

Keywords: telehealth; virtual care; concussion; mTBI; assessment; examination

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Introduction

Background

Concussions or mild traumatic brain injuries (mTBIs) affect thousands of Canadians every year [1]. Workplace injuries account for a notable portion of non-sport concussions [2]. Indeed Terry et al. [3] reported that approximately 25% of adult concussions occur at work. Workplace injuries resulting in concussions pose a significant challenge for employers and insurers while disrupting the lives of the workers due to greater recovery times compared to non-work-related concussion [4]. In general, roughly 10-20% of individuals who sustain a concussion, experience symptoms lasting beyond the one to two-week typical recovery timeframe [5,6]. In the workplace context specifically, prolonged symptoms lead to reduction in productivity at work or even disability, which in turn has an economic impact on people, companies, and government agencies [3]. While it is apparent that there is a need for further support and research in the workplace concussion rehabilitation field, a focus on the evaluation of concussion will be an important starting point to individualizing care.

Assessing symptoms and function after concussion presents clinicians with challenges due to the complex and diverse symptom presentation and a lack of sensitive and reliable clinical assessment measures [7]. Symptoms may be physical (such as dizziness, balance issues, headaches, neck pain, and vision difficulties), emotional (such as irritability and disinhibition) and/or cognitive (such as memory and concentration difficulties) [7-11]. All the domains of concussion symptoms must be considered [8]. Currently, however, there does not exist a gold standard test to evaluate all concussion symptoms. Commonly, a battery of tests and symptom self-reports are relied upon [7,12,13]. For example, the Balance Error Scoring System (BESS) and the Sensory Organization Test (SOT) are used to assess balance deficits following a concussion injury [14]. The King-Devick test and the Vestibular Ocular Motor Screen (VOMS)

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may be used to evaluate oculomotor deficits [14,15]. Furthermore, the psychometric properties of the tools involved are often underdeveloped, and clinical utility varies. There is an additional challenge with all assessments of injured workers because of access to compensation that may interfere with the validity of effort provided during the assessment [3]. Measures that allow the examiner to ensure that a valid effort was made to complete the assessment should be considered.

With the shift in clinical service delivery to virtual healthcare driven by the COVID-19 pandemic, the need for valid and reliable approaches to virtual concussion assessments has become more pressing. As well, people living in remote areas or for whom travel is difficult due to comorbidities continue to have great need for assessment that can be carried out at distance [16,17]. Such assessment would also be helpful for people whose symptoms are aggravated by travel and environmental factors, such as noise and light [18].

Clinicians are currently completing virtual concussion assessments using a variety of clinical assessment measures; however, as with in-person assessments, there is no standardized approach to assessing adult concussions virtually. Resources have been developed to support completion of the virtual concussion examination, including a training manual for the examination and a living guideline which outlines considerations for the pediatric examination [19,20]. Comparison of the measures identified in these resources when administered in an in-person and virtual context has not yet occurred.

The psychometric properties of many of the assessment measures being used have not been established for use in-person or virtually. Accelerated adoption of information and communication technology has been occurring globally to enhance service delivery during the COVID-19 pandemic, however, it is unclear whether the outcomes of assessments completed

virtually are consistent with assessments performed in-person [21,22]. It is therefore important to understand if the measures used to assess concussions in-person could provide equivalent results when used virtually [23].

Overall, there are multiple clinical assessment measures being used by clinicians to assess the physical domains impacted by a concussion injury. There is no standardized toolkit of measures available, with established psychometric properties, that are relevant and feasible in a virtual context nor are there guidelines outlining specific measures to use in the adult population [12-14].

Objective

The objective of this mixed-methods study is to produce a toolkit of measures that can be used in virtual assessments of concussion physical symptoms.

Methods

This study will follow a sequential mixed methods design [24] that will include a Delphi survey, a working group consultation, and focus groups. The methodological approach is outlined in Figure 1.

Participants

Delphi Survey

Expert clinicians (physiatrists, neurologists, sports medicine physicians, and physiotherapists) from across Canada will be identified through both regional and national professional and brain injury/concussion organizations and networks. Members of these networks represent an accessible and meaningful sample that will include many practicing clinicians with concussion assessment experience. The survey will be sent through these networks and associations by including the survey link in a newsletter or by sending the survey link through email to all members of the networks/associations. To ensure ‘experts’ are

completing the survey, respondents will be asked to rate their concussion expertise using a 5-point Likert scale (Strongly Not Competent to Strongly Competent). Any responses from participants self-reporting their competency as below 3 or 'Neutral' will be excluded. When needed, targeted emails will be sent to expert clinicians with publicly available contact information to ensure representation (minimum of two responses) of each profession.

Sample Size for Delphi Survey

Our target sample size is 50 clinicians, which we consider adequate to reach saturation on the types of clinical measures used in practice. This sample size is feasible based on an anticipated 25% response rate and assuming that approximately 200 clinicians will view the survey [25,26]. Clinicians who complete the first-round survey will be sent the second-round survey. It is expected that the second round of surveys will elicit a response rate of approximately 60% (~30 clinicians) [27].

Working Group Membership

A working group consisting of expert clinicians, including at least one neurologist, physiatrist, sports medicine physician, and physiotherapist, will meet to discuss the feasibility of virtual use of each measure identified in the survey. Members of the research team will be offered the opportunity to participate. Targeted emails to Canadian-practicing clinicians will also be employed to ensure representation from each clinical field. A final list of potentially feasible outcome measures will be identified in the working group, which will then be further explored in the focus groups.

Focus Group Membership

Focus groups consisting of 5 to 7 participants [28,29] will be conducted following the methodological framework outlined by Breen [30]. It is hypothesized that between 6 to 10 focus groups will be adequate to reach saturation (2-3 groups consisting of people living with concussions who have experience with virtual assessment and 4-8 focus groups consisting of

clinician-experts) [28,29]. Patient-participants who have attended a virtual concussion assessment will be identified and recruited from the Ottawa Hospital Rehabilitation Centre. The remaining focus groups will contain mixes of neurologists, physiatrists, sports medicine physicians and physiotherapists. Participants who complete the Delphi surveys will have the option to express interest in participating in a focus group. Additional recruitment strategies include face-to-face recruitment at the Rehabilitation Centre at the Ottawa Hospital and through Ontario Workers Network clinics. Targeted emails to Canadian-practicing clinicians will also be employed.

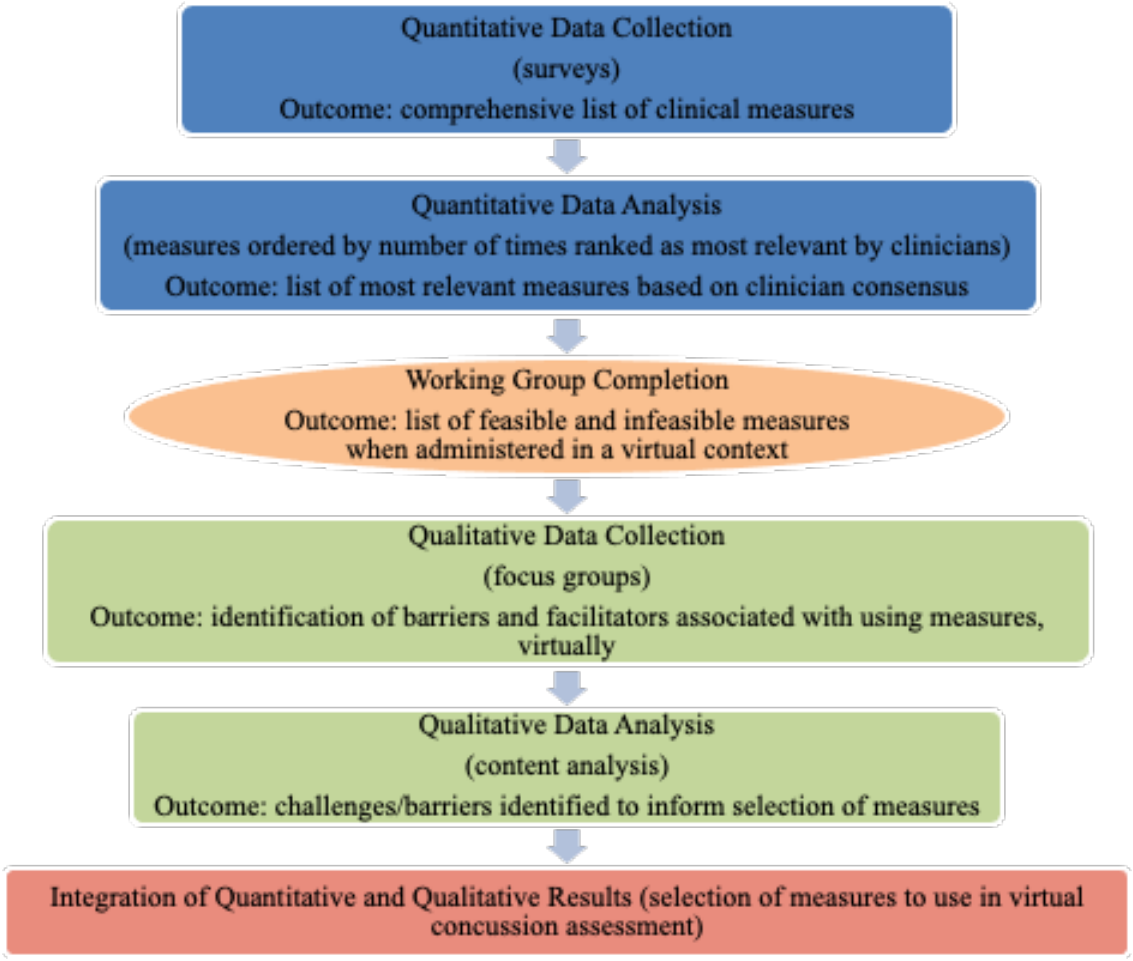


Figure 1. *Sequential explanatory approach commencing with survey administration guided by the Delphi methods and working group completion (quantitative) followed by focus group completion (qualitative) to expand on and explain survey and working group results.*

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Procedures

Quantitative Delphi Survey Data Collection

The survey process will follow a Delphi method, which aims to seek consensus among the participants [31]. In round one, clinicians will receive a link for participation which includes the implied consent form, demographic questionnaire and open-ended questions with free text boxes asking participants to identify multiple outcome measures they currently use to assess each five domains of interest (see *Figure 2)*. The invitation to participate in the surveys will be undersigned by a physiatrist (SM), including the affiliation, to secure buy-in and encourage responses. Measures identified by at least 15% of all participants (e.g., 8/50 participants) or least 60% of participants from one profession will be retained for the survey in round two.

In round two, all participants from round one will be asked to rank-order, according to perceived usefulness for their practice, the concussion assessment measures from each domain (neurological exam, cervical spine, oculomotor, vestibular, and effort) retained from the first round (see *Figure 2)*. Prior to completing the second-round survey, participants will be invited to review reading materials with information on the retained measures, including information on sensitivity, specificity, and feasibility from the literature, when available.

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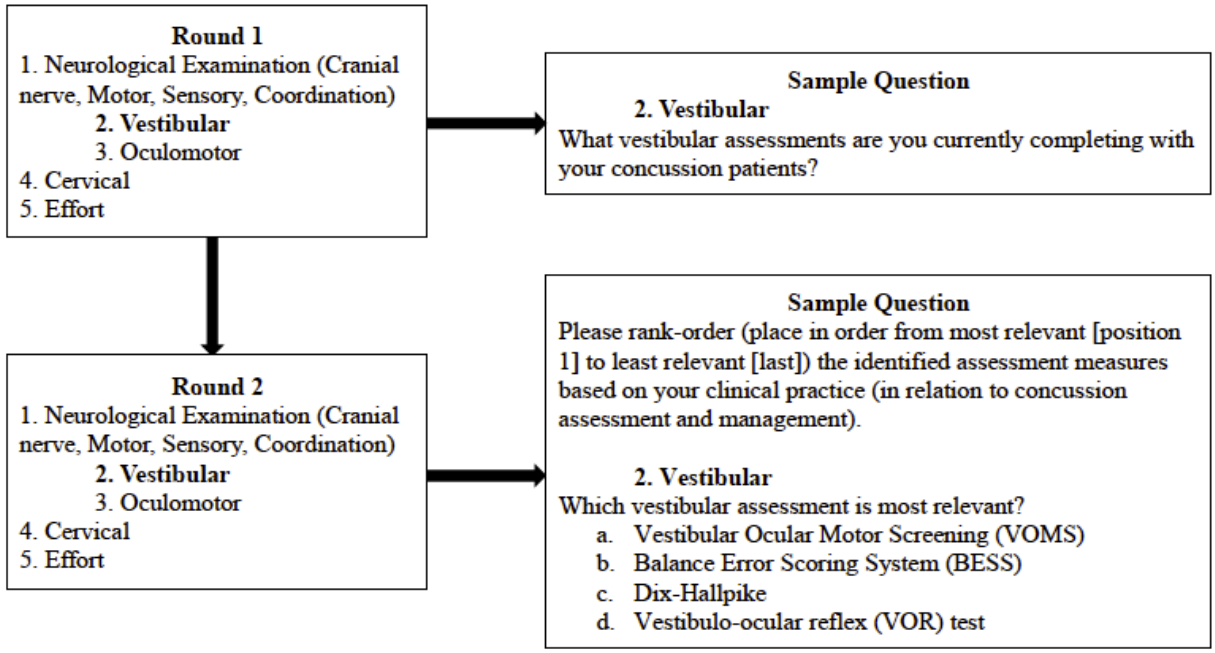


Figure 2. *Clinical domains of interest for identification of assessment measures and sample questions for the vestibular domain for Round one and two surveys. Similar questions were provided for each domain.*

Delphi Survey Questionnaire Administration

To increase response rates, reminder emails will be sent at 7-day and 14-day time points following the initial emails in the first and second rounds [25,30]. A universal level of consensus does not yet exist for the Delphi survey approach; however, various works have suggested a range of 51-80% agreement [27]. For the purposes of this study, an above 51% agreement level for rankings of assessments has been set for the second round. Assessments which reach 15% in round one will be considered for clinical feasibility by the expert clinician working group.

Working Group to Derive Consensus as to List of Feasible Measures

A working group consisting of expert clinicians will meet over a videoconferencing platform (which involves bidirectional visual and audio communication technology), to discuss the current feasibility of the identified measures in a virtual context. Any measures deemed not feasible in the working group will be eliminated from further discussion in the focus groups. The final list of measures will be further explored in the clinician focus groups.

Qualitative Focus Group Data Collection

Focus groups with both clinician and patient-participants will be conducted. An interview guide with broad open-ended questions will be used as a prompt for the conduct of the focus groups. All focus groups will occur over a videoconferencing platform and will be audio-video recorded for later transcription. See Appendix A for the semi-structured interview guide for both patient and clinician-participants.

Clinician-Participant Focus Groups

Prior to the focus group, clinician-participants will be provided with available psychometric properties documented in the literature of the in-person measures that were identified from the second round of the surveys as well as descriptions of the assessments/instructions on how to complete the assessments. Clinician-participants in the focus groups will be prompted about the practical and technical issues associated with using each of the final measures. Barriers and facilitators associated with the assessments, including adverse events experienced or observed, will also be explored.

Patient-Participant Focus Groups

Patient-participants will be prompted to discuss the benefits and challenges associated with virtual concussion assessments based on their experiences.

Data Analysis

Quantitative Analysis of Delphi Surveys

Clinical measures identified in round one of the Delphi surveys will be categorized into the pre-established domains (neurological examination, cervical spine, vestibular, oculomotor, effort assessment). Frequency counts of the measures will be used to identify most commonly identified measures [32] and consistency of wording for the description of measures will be documented. For example, some clinicians may describe the measure rather than providing the name of the measure.

The quantitative data obtained in the second round of surveys (rank-order of measures) will be analyzed descriptively (summary statistics to demonstrate patterns in the data). Measures of frequency and agreement percentages will be calculated.

Qualitative Analysis of Focus Groups

NVivo will be used to organize the qualitative data analysis. Recordings from the focus groups will be transcribed verbatim. Content analysis will be used to analyze the focus group data [33]. Two research assistants will independently identify codes related to barriers/challenges, benefits and facilitators associated with using each of the identified measures. Codes will be sorted into two levels of categories: categories related to assessment of specific symptoms/domains and categories related to virtual assessment in general.

Ethics

Ethics approval was obtained by the Ottawa Health Sciences Network Research Ethics Board in September 2021 followed by the Bruyère Research Institute Research Ethics Board and the University of Ottawa Board of Ethics in February 2022.

Results

Survey administration and the working group have been completed. Focus group recruitment is underway. The final results of the surveys, working group and focus groups will lead to the identification of clinical measures to use in a virtual assessment toolkit, which will be tested in a future planned evaluation study.

Discussion

We presented a protocol for a mixed methods study to identify the most appropriate clinical measures to include in a virtual assessment. We hypothesize that the measures identified in the surveys will vary based on clinical profession. We anticipate reliability properties of the identified measures to range from moderate to strong (intraclass correlation coefficients = 0.41 to above 0.81). It is anticipated that the working group and focus group discussions will lead to an

understanding of some of the real and perceived barriers and facilitators related to participating in or completing a virtual concussion assessment. We expect patient-perceived challenges to relate to the technical issues with technology and clinician-perceived challenges to relate to the challenges associated with engaging in hands-on approaches in virtual care.

A toolbox of concussion physical assessments has been proposed by Matuszak et al. [14], which includes measures to assess domains that are frequently impacted by a concussion injury; however, many of the physical assessment measures used in the concussion population have limited psychometric data. The proposed toolbox includes evaluation of vital signs, mental status, neurological examination (cranial nerves, manual muscle testing, reflexes), head and cervicothoracic evaluation, balance/coordination assessment and vestibulo-ocular evaluation [14]. This toolbox is proposed for the in-person examination. However, many of the virtual resources and guidelines include similar evaluations [19, 20].

While telehealth has long-existed, the COVID-19 global pandemic has increased both its need and its use in delivering healthcare services [34]. The COVID-19 pandemic has accelerated the need for telemedicine-supported remote assessment and has pushed both clinicians and researchers to determine what aspects of medical care could be feasible in a telehealth context [34, 35]. A scoping review by O'Neil et al. [36], noted that videoconferencing could be a valid means to remotely assess patients with moderate to severe TBI. In addition, according to Fjeldstad-Pardo et al. [37], no adverse events have been identified during participation in telerehabilitation, indicating that it is a safe approach to deliver services. Specifically, telerehabilitation has been reported to be feasible and effective for the intervention and management of neurological patients [38]. There has been a significant increase in the use of virtual assessments, with a rapid transition due to the pandemic. This transition limited the ability

to implement virtual care using a planned and organized approach. The transition was a reaction to the pandemic rather than a planned response [39]. Due to this reactionary response, clinicians have been forced to complete remote assessments with limited information on the accuracy and reliability of the measures used in these assessments.

It is, therefore, important to understand which assessments clinicians are completing both in-person and virtually in the context of the concussion examination. A study by Tobler-Amman et al. [40] found that correlation values were low when measures assessing similar constructs in people living with stroke were administered in-person and virtually. While clinicians thought the measures were assessing the same construct, the low correlation values indicate that administering the measures in the two different contexts may not provide the same information. Similarly, a study by Wang et al. [41] found that participants elicited a weaker reach when an assessment was completed virtually compared to in-person in people living with Parkinson's disease. In the context of the concussion examination, understanding which assessments are being conducted and how the assessments are being conducted both in-person and virtually is necessary to determine the equivalence of the assessments when administered in both contexts. Psychometric properties should be established in both in-person and virtual contexts of use to ensure accurate and reliable implementation in both contexts [42]. If the outcome measures used in-person have poor documented psychometric properties or no documented psychometric properties there may be additional challenges to validity and reliability when using the measure in a virtual context. It is important to gain an understanding of the properties of the clinical measures and their ability to produce equivalent results to the in-person assessment to inform decision-making in terms of their use in practice and their potential use in the virtual context [43].

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With the increase in need for the uptake of telehealth in rural and remote areas, and now globally due to the COVID-19 pandemic, standardization of a feasible virtual concussion assessment is needed. The identification of the clinical measures that are most relevant and contribute the most reliable information in an adult concussion examination and the identification of the barriers and facilitators associated with using these specific measures in a telehealth context is an important first step to lead to this standardization. The results of this study and the future planned prospective evaluation study will be published and disseminated to targeted end-users and networks.

Strengths and Limitations of Methodological Approaches

Some important strengths of the Delphi method include that it is a useful approach when lack of clarity exists, which is likely the case in the concussion assessment field [44]. It is apparent that although the Delphi approach has many strengths, it also has some limitations. Generally, the Delphi approach lacks agreed-upon standards or consensus [44].

Focus groups have been reported to be beneficial when participants are located in different geographical locations [30], which will occur in this project due to the need to gain input from various clinicians and from people living with concussions in order to inform the follow-up studies. Some important limitations of focus groups include: the group setting nature of the focus groups may discourage participants from sharing their input and similarly one single participant may dominate the focus group discussion (overpower other participants) [30].

Conclusion

This mixed-methods study will identify the assessment measures that are currently being used in-person to evaluate people living with concussions. This study will further identify the barriers and facilitators, challenges and benefits associated with using the identified measures,

virtually. Psychometric properties documented in the literature when available of the in-person measures that will be discussed in the focus groups will be described. Results from this study will inform the selection of measures to include in a virtual assessment toolkit, which will be tested in follow-up studies. It is apparent that there are multiple gaps in the clinical assessment of concussion. While there appears to be a need to further explore and expand on the understanding of the measures used to assess individuals experiencing prolonged symptoms in-person, there is also now a need to explore the use of these measures in a virtual context. The limitations of the COVID-19 pandemic have highlighted the need for a rapid change in service delivery to virtual means, and while limited information exists regarding concussion assessment in a virtual context, remote assessments are currently being conducted in clinical practice and therefore need to be better understood.

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Data Availability

Data sharing is not applicable to this article as no data sets were analyzed during the current study.

Authors' Contributions

All authors have made substantial contribution to the work presented in this paper.

Conflicts of Interest

None declared.

Abbreviations

BESS: balance error scoring system

mTBI: mild traumatic brain injury

SOT: sensory organization test

VOMS: vestibular/ocular motor screening

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Appendix A

Clinician-Participant Focus Group Interview Guide

1. General conversation about what clinicians experience as barriers and facilitators to virtual assessment of concussion symptoms.
2. Have you experienced any adverse events while completing a virtual assessment? (If so, could you discuss it?)
3. For each of the identified measures from the second Delphi round and working group, the following questions will be asked:
    a. Of the identified [vestibular] assessments, which of these do you think would work best in your practice?
    a. What are some barriers to using the measure in a virtual concussion assessment?
        i. What are some practical issues associated with using the measure in a virtual context?
        ii. What are some technical issues associated with using the measure in a virtual context?
    b. What are some facilitators to using the measure in a virtual context?
        i. What are some practical facilitators associated with using the measure in a virtual context?
        ii. What are some technical facilitators associated with using the measure in a virtual context?

Patient-Participant Focus Group Interview Guide

1. Please tell me about the virtual assessments you've participated in.
2. Based on your experience, what are some challenges/barriers you faced when completing a virtual assessment?
    a. Practical barriers?
    b. Technical facilitators?
3. What are some benefits/facilitators you experienced?
    a. Practical facilitators?
    b. Technical facilitators?
4. Do you have any recommendations that could improve virtual assessments?
5. Do you have any other feedback based on your experiences with virtual assessment?

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Chapter 3. Clinician-Prioritized Measures to Use in a Virtual Concussion Assessment: A Delphi Study

Chapter 3 has been formatted based on the requirements of the peer-reviewed journal in which it was submitted.

Chapter 3 contains the results of the Delphi surveys and working group, documenting the clinical measures clinicians are currently using in their in-person practice and the perceived feasibility of administering those measures virtually, based on expert opinion. The manuscript associated with Chapter 3 was submitted to the Journal of Internet Medical Research on May 11, 2023. Transfer to the sister journal, the Journal of Medical Internet Research Rehabilitation and Assistive Technologies was recommended on September 8, 2023. The transfer was accepted and submitted to the journal on November 28, 2023. Notification of revisions was received on May 20, 2024. The revisions were addressed and submitted on June 27, 2024. Transfer to the sister journal, the Journal of Medical Internet Research Formative Research was recommended on July 6, 2024. Acceptance was obtained on July 14, 2024.

Ethics approval was obtained by the Ottawa Health Sciences Network Research Ethics Board (20210575-01H), the Bruyère Research Ethics Board (M16-22-006) and the University of Ottawa Board of Ethics (H-02-22-7611).

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Clinician-Prioritized Measures to Use in a Virtual Concussion Assessment: A Delphi Study

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Abstract

Background: There is little guidance available, and no uniform assessment battery used in either in-person and remote evaluations of people who are experiencing persistent physical symptoms post-concussion. Selecting the most appropriate measures for both in-person and virtual physical assessments is challenging because of the lack of expert consensus and guidance.
Objective: This study used expert consensus processes to: i) identify clinical measures currently used to assess five physical domains affected by concussion (neurological examination, cervical spine, vestibular, oculomotor, effort) and ii) determine the feasibility of applying the identified measures virtually.
Methods: The Delphi approach was used. In the first round, experienced clinicians were surveyed regarding their use of measures in concussion assessment. In the second round, clinicians reviewed information regarding the psychometric properties for all measures that were identified in the first round by at least 15% of participants. In the second round, experts rank-ordered the measures from most relevant to least relevant based on their clinical experience and the documented psychometric properties. A working group of 4 expert clinicians then determined feasibility to virtually administer the final set of measures.
Results: Fifty-nine clinicians completed survey Round 1 listing all measures they used to assess the physical domains affected by a concussion. The frequency counts of the 146 different measures identified were determined. Thirty-three clinicians then completed the second-round survey and rank-ordered 22 measures that met the 15% cut-off criterion retained from Round 1. Measures ranked first were coordination, range of motion, Vestibular Ocular Motor Screening (VOMS), and smooth pursuits. These measures were feasible to administer virtually by the working group members, however modifications for virtual administration were recommended, such as adjusting the method of measurement.
Conclusions: Clinicians ranked assessment of coordination (finger to nose test and rapid alternating movement test), cervical spine range of motion, VOMS, and smooth pursuits as most relevant measures under their respective domains. Based on expert opinion, these clinical measures are considered feasible to administer for concussion physical examinations in the virtual context, with modifications, however the psychometric properties have yet to be explored.

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Introduction

Concussions also known as mild traumatic brain injuries can occur in a variety of different settings such as within sport, in the workplace and from falls that occur during activities of daily living [1]. A diverse group of clinicians including sports medicine physicians, neurologists, physiatrists, and physiotherapists may complete physical assessments post-concussion. Approaches to completing the concussion physical examination appear to be variable amongst clinicians. While the available guidelines provide an overview of the important components of a vocational assessment following a concussion [2], there are no widely agreed upon guidelines outlining specific measures to use in the concussion assessment. This is particularly important in the context of work-related injuries where benefits and treatment are related to clinical findings. Roughly 1 in 5 adults are unable to return to work at 6 months post-injury following their concussion [1], many of whom require specialized assessment at this time point post-injury.

A number of domains, each with a variety of potential measures, should be assessed in the concussion examination [2]. Furthermore, different measures may be used when the injured person is evaluated immediately following a concussion injury, a few days following the injury, and a few months following the injury. Leddy et al. [3] outlined an evidence-based physical examination for neurologists assessing adults presenting with persistent symptoms post-concussion, however, specific measures for certain domains remains undefined.

Identification of appropriate measures for remote concussion assessment is an important challenge that moved to the forefront of healthcare with the COVID-19 driven shift in clinical practice to virtual care. Remote concussion assessments are increasingly common, yet the measures used to complete these assessments continue to vary due to the lack of standardization and consistency regarding best practices amongst clinicians. In response to this shift, virtual

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examination resources targeting family medicine physicians have been developed to support the diagnosis and acute evaluation of concussion through remote assessment [4]. These resources outline approaches that can be transferred from the typical in-person concussion examination to a virtual context. Specific limitations include orthostatic vitals, dynamic gait, and cardiovascular/respiratory evaluation that are very difficult to complete in a virtual context without special equipment sent to the patient. Also, in response to the shift to virtual care, McPherson et al. [5] published adaptations to the evaluation of cranial nerves, oculomotor, vestibular, and cervical spine deficits along with assessment of orthostatic intolerance from the Buffalo Concussion Physical Examination for use in remote assessment of sport outpatients (in both acute and persistent symptom contexts). Finally, a living guideline for the acute assessment and management of pediatric concussion presents approaches to completing the virtual concussion examination in the pediatric population [6]. These resources are based on expert opinion and support the feasibility of completing components of the concussion examination remotely. Variations in the approaches to remote assessment presented in the above-noted resources highlights the lack of standardized approaches to the virtual assessments currently used in clinical practice. Furthermore, most of these resources were developed in the context of the sport setting or the pediatric patient population. Information is lacking on the measures recommended for use in remote concussion examination of community-dwelling adults who may have sustained a concussion injury in the workplace and are experiencing persistent symptoms.

In the absence of evidence or sufficient information to support clinical decisions, such as decisions on clinical measures to use in practice, expert consensus is often sought [7,8]. One approach to finding consensus on possible clinical measures is to use the Delphi method and typically involves at least two rounds of survey administration to expert clinicians. Commonly,

exploratory questions are asked in the first round followed by more targeted, specific questions in a subsequent round. The Delphi method is a useful approach to obtain anonymous opinions from several individuals across disciplines and wide-spread locations [7]. Expert opinions on the topic of interest transform into consensus in this approach [9]. Importantly, consensus does not indicate that the measures selected are the correct measures to use in a concussion assessment. Rather, the results from the consensus act to structure follow-up discussions (in working groups) and inform subsequent decisions [10].

Previous work has used the Delphi approach to identify clinical measures in various populations. Reneker et al. [11] aimed to document the cervical spine measures used in concussion to distinguish between cervicogenic and other factors contributing to dizziness post-sport related concussion. Consensus on clinical utility of the identified measures was determined by the clinicians who participated in the study. Similarly, while not specific to concussion, Winser et al. [12] used a Delphi approach to identify balance measures used by clinicians to evaluate people with cerebellar ataxia. Clinicians were first asked to list the measures that they use in practice and then select the most appropriate measure for the assessment of balance. This study identified three balance measures (Berg Balance Scale, the Scale for the assessment and rating of ataxia, and the Timed Up and Go) as most appropriate, however, noted that evaluation of test psychometric properties is needed. While these studies identify balance and cervical spine measures for specific purposes, there remains limited information on the identification of clinical measures to use in the evaluation of physical domains impacted by a concussion.

The purpose of this work was to: i) identify clinical measures currently used to assess five pre-defined domains following a concussion injury (neurological examination, vestibular, oculomotor, cervical spine, and effort); and ii) determine the feasibility of administering the

measures remotely. Findings from this study will inform the selection of measures for use in a virtual concussion assessment that will be tested in a planned evaluative study. We focused on the physical domains of a concussion examination since they appear to be more challenging and require more adaptations to administer virtually when compared to measures of cognitive or emotional health. Further, while there is overlap in concussion symptom domains, classification systems typically segregate physical symptoms from cognitive and emotional symptoms. For example, Ellis et al. [15] presented a classification system in which signs and symptoms post-concussion are grouped into physiologic, vestibulo-ocular, cervicogenic, and cognitive/mood-related domains.

Methods

The complete methodology is presented in Barnes et al. [13]. The published protocol presents a flow diagram of the methodological process, which includes a Round 1 survey to identify clinical measures used to evaluate physical domains impacted by a concussion, a Round 2 survey to rank-order the identified measures from Round 1, and a working group to document the perceived feasibility of administering the identified measures from the surveys in a virtual environment. This study was approved by the Ottawa Health Sciences Network Research Ethics Board (20210575-01H), the Bruyère Research Institute Research Ethics Board (M16-22-006) and the University of Ottawa Board of Ethics (H-02-22-7611).

Delphi Survey Approach

Round 1

An open invitation was sent to clinician-members of 8 regional and 4 national brain injury/concussion and professional associations/networks through email and monthly newsletters over a span of 3 months (February to May 2022). Wherever possible, targeted emails to clinicians with publicly available contact information were employed to ensure there was a

representative sample of at least 2 participants from each clinical profession of interest (physiatry, sports medicine, neurology, and physiotherapy). Purposive sampling techniques were employed to recruit at least 50 expert Canadian-practicing clinicians with experience completing in-person concussion assessments in any setting (sport contexts, emergency departments, rehabilitation centers, family medicine offices, etc.). Justification of the sample size is presented in the published protocol [13]. As reported by Hasson [10], inclusion of participants who have an interest in the topic and knowledge about the topic may aid with increasing content validity of the findings of the Delphi approach. Through the open invitation and self-reports of competency, we were able to recruit participants who had an interest in concussion assessment and management and who had sufficient experience completing concussion assessments, potentially strengthening the content validity of the survey findings.

A comprehensive list of clinical measures used to assess five domains of concussion (neurological examination, vestibular, oculomotor, cervical spine, and effort assessment) at all time points post-injury (acute, subacute, persistent) was compiled. An 'other' domain was also included in Round 1 of the survey due to the anticipated classification variations between clinicians for certain clinical measures. For example, balance or gait tests were included in the vestibular as well as in the 'other' domain by clinicians. An adjusted list of measures was created to group all clinical measures under the pre-determined domains. The adjusted list of measures was rank ordered by frequency. Only measures that reached at least 15% agreement ((number of participants that identified measure ÷ total number of participants) × 100) were included in Round 2. Due to the number of measures anticipated to be identified in the survey, we previously set the 15% criteria so that we could narrow down the most relevant measures in the subsequent round, with relatively good level of agreement amongst clinicians. Further, to ensure

representation from each clinical profession, we planned to include any measures reaching at least 60% agreement with a professional group in Round 2. All participants who completed Round 1 were invited to complete Round 2. To ensure the survey responses were anonymous, in line with the Delphi approach, a separate form was created for email input so that we could send the Round 1 participants the Round 2 survey.

Development of Reading Materials (Review of the Literature)

As we were particularly interested in the accuracy with which the tools identified pathology, a literature review of the sensitivity and specificity of retained measures was carried out following Round 1 using the following databases: Pubmed (Ovid), Medline (Ovid), CINAHL, and Google Scholar. Search terms used related to the population of interest (all brain injuries due to limited information in the literature on psychometric properties in concussion), psychometric properties of interest (sensitivity and specificity) and clinical measures of interest (measures presented in Table 2). No date limitations were set. The findings from the review of the literature were used to develop descriptions of the identified measures and their psychometric properties; this information was provided in written form to all Round 2 participants. The measures' sensitivity and specificity metrics identified from the review of the literature that were used to develop the reading materials provided to Round 2 participants is presented in Multimedia Appendix 1.

Round 2

The expert-clinicians were provided with the results of Round 1 and reading materials prior to completing the second-round surveys and were given a month to complete the second survey. Round 1 results were summarized in tables outlining all measures that were at or above the 15% level of agreement and all additional measures that did not meet the cut-off. The sensitivity, specificity and additional considerations for the administration of each measure (e.g.

equipment needed, time for administration) identified in the review of literature were presented. The clinicians were then asked to re-rank the identified measures from most to least relevant to their in-person clinical practice. Mean rankings were calculated by summing the product of the weight and frequency count for each measure and dividing by the total number of responses. The weight was determined by the number of measures within each domain.

Working Group

A working group, consisting of a physiatrist, neurologist, physiotherapist-researcher, and sports medicine physician, met in June 2022 to determine feasibility of administering the measures virtually. The working group members were recruited through targeted emails. A moderator (KB) facilitated the working group. The group was audio and video recorded, transcribed into written format and analyzed using content analysis. A physiatrist (MB) (member of the working group but did not attend working group discussion) reviewed the measures independently and commented on feasibility of virtual application of the measures based on personal experience and expertise.

Results

Round 1

Figure 1 presents a flow diagram of the survey process. Fifty-nine clinicians participated in Round 1 of the Delphi survey. The demographic information of the included participants is presented in Table 1. The majority of participants were physiotherapists followed by sports medicine physicians, physiatrists, and neurologists. The 'other' category of clinical professions included five occupational therapists, three kinesiologists/athletic therapists, two speech language pathologists, two trainees (medical and physiotherapy), a physician's assistant, an orthopaedic surgeon, and a family medicine physician. The majority of participants had over 10 years of experience in clinical practice and assessed over 50 people with concussions annually.

One participant self-reported 'strongly incompetent' for their competency of completing the in-person concussion assessment and therefore their responses were excluded from data analysis as the aim was to survey experts leaving n=58 in Round 1.

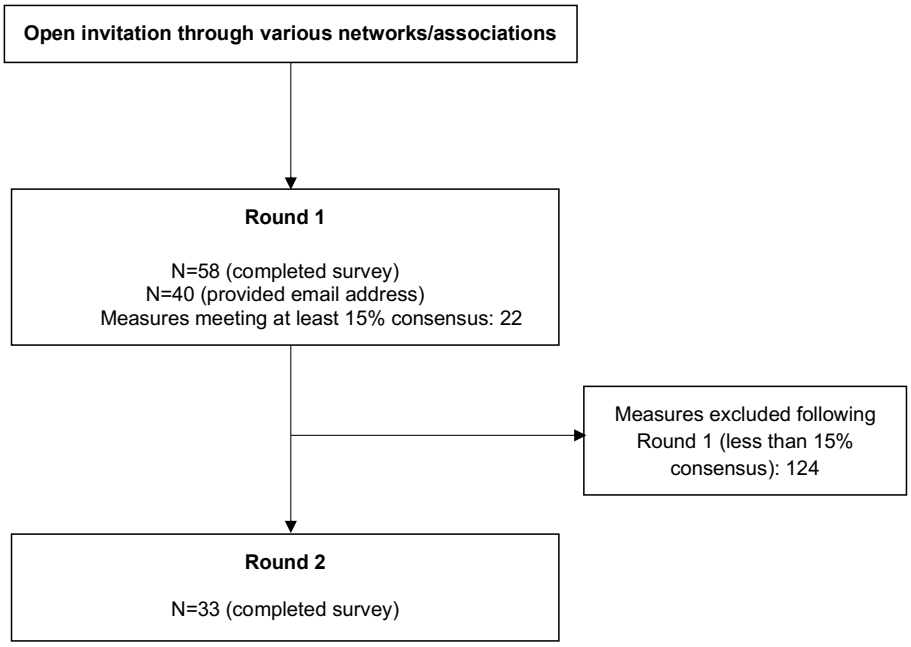


Figure 1. Delphi survey flow diagram.

Table 1: Demographic information of clinicians that completed round 1 survey. N=58

		Frequency	Percentage (%)
Age	20-29	10	17.2
	30-39	25	43.1
	40-49	8	13.8
	50-59	10	17.2
	60+	5	8.6
	Prefer Not to Respond	0	0.0
Clinical Profession	Physiatrist	5	8.6
	Neurologist	2	3.4
	Sports Medicine Physician	10	17.2
	Physiotherapist	26	44.8
	Other	15	25.9
Years in Clinical Practice	1-5	17	29.3
	5-10	13	22.4

	10+	27	46.6
	Did not respond	1	1.7
Volume of Practice (concussion patients assessed per year)	0-25	20	34.5
	25-50	16	27.6
	50+	22	37.9
Self-Report Competency In-Person	Strongly Incompetent	0	0.0
	Incompetent	0	0.0
	Neutral	10	17.2
	Competent	31	53.4
	Strongly Competent	17	29.3
Self-Report Competency Virtual	Strongly Incompetent	2	3.4
	Incompetent	6	10.3
	Neutral	24	41.4
	Competent	23	39.7
	Strongly Competent	3	5.2

After categorizing the measures identified in Round 1 based on the definitions of the domains, 146 different measures were identified (31 measures were identified in the neurological examination domain, 41 were identified in the vestibular domain, 26 in the oculomotor domain, 37 in the cervical spine domain, and 11 in the effort domain). The measures that reached the pre-defined cut-off level of agreement (at least 15%) are presented in Table 2. The list of clinical measures that did not meet the 15% cut-off is presented in Multimedia Appendix 2. The majority of clinicians reported not using any measures to evaluate effort/malingering/symptom validity in their clinical practice. No relevant measures met the cut-off criteria for the effort domain, and it was, therefore, not included in the second survey. Further, when responses were grouped and analyzed based on the clinical profession (physiotherapist, neurologist, physiatrist, sports medicine physician) of the respondents, no additional measures met the criteria of at least 60%.

Table 2: Round 1: List of measures that reached at least 15% agreement. (N=58)

Domain	Measures	Frequency	Agreement (N/58*100)
Neurological Examination	Coordination: finger-to-nose, heel-to-shin; Rapid alternating movements	37	64%

	Cranial nerve	34	59%
	Sensation	20	34%
	Reflexes	19	33%
	Motor (tone, pronator drift, strength/power using MRC grading/MMT)	16	28%
	Myotomes	13	22%
Vestibular	VOMS	25	43%
	Balance (feet together, single leg stance, tandem stance)	23	39%
	VOR assessment	21	36%
	BESS/mBESS	21	36%
	Dix-Hallpike	20	34%
	Head thrust/Head impulse test	14	24%
	Gait/Tandem gait	13	22%
	Romberg	12	20%
	Dynamic Visual Acuity	10	17%
Oculomotor	Saccades	21	36%
	Convergence	20	34%
	Smooth pursuits	15	26%
Cervical	Range of motion	49	84%
	Palpation	26	44%
	Strength (MMT, DNF endurance)	21	36%
	Joint position error test	9	16%

BESS = balance error scoring system; DNF = deep neck flexor; mBESS = modified balance error scoring system; MMT=manual muscle testing; MRC = medical research council; TBI = traumatic brain injury; VOMS = vestibular ocular motor screening; VOR = vestibulo-ocular reflex

Round 2

Thirty-three of the 40 clinicians who agreed to be contacted for Round 2 completed this survey. Table 3 presents the mean rankings for each of the measures and presents the final rank-orders for each of the domains. Multimedia Appendix 3 includes all ranking values, weights and frequency counts.

Table 3: Round 2: Mean rankings of measures.

Domain	Measures	Mean Ranking
Neurological Examination (Mean ranking /6)	Coordination: finger-to-nose, heel-to-shin; Rapid alternating movements	4.67
	Cranial nerve (evaluation of 12 cranial nerves)	4.52
	Motor (tone, pronator drift, strength/power using MRC grading/MMT)	4.09
	Reflexes	2.85
	Myotomes	2.45
	Sensation	2.42
Vestibular	VOMS	7.52

(Mean ranking /9)	Balance (feet together, single leg stance, tandem stance)	6.45
	VOR test	6.18
	BESS/mBESS	5.61
	Dix-Hallpike	4.58
	Gait/Tandem gait	4.36
	Head thrust/Head impulse test	3.91
	Dynamic Visual Acuity	3.52
	Romberg	2.88
Oculomotor (Mean ranking /3)	Smooth pursuits	2.24
	Saccades	1.91
	Convergence	1.85
Cervical (Mean ranking /4)	Range of motion	3.67
	Palpation	2.94
	Strength (MMT, DNF endurance)	1.88
	Joint position error test	1.52

BESS = balance error scoring system; DNF = deep neck flexor; MMT=manual muscle testing; MRC = medical research council; VOMS = vestibula ocular motor screening; VOR = vestibulo-ocular reflex

Working Group

All participants in the working group had over 10 years of experience in clinical practice and self-reported as "competent" or "strongly competent" in completing in-person concussion assessments. Only one working group participant self-reported a neutral competency in completing the virtual assessment, however, all participants had sufficient experience with conducting virtual concussion assessments. All others self-reporting as "competent" or "strongly competent". Reports of competency were subjective and based on self-perception.

When asked what technologies were used to complete remote assessments, participants reported using either a laptop, desktop, or laptop with large external monitor. Three participants reported not always being able to see the whole body of the patients and only one participant reported being able to see the whole body of patients when completing assessments when requested. The physiatrist who reviewed the measures independently identified similar concerns to those of the members of the working group.

Sixteen measures were deemed feasible to complete virtually but of these, the majority would require modifications (see Table 4). Six measures were deemed infeasible to complete virtually.

Table 4: Working group: Feasibility of completing identified measures virtually as reported by the working group members.

Domain	Measures	Considerations of administering measure virtually as identified by experts	Feasible when administered virtually?
Neurological Examination	Coordination: finger-to-nose, heel-to-shin; Rapid alternating movements	Need to see end point (stable end point) for finger-to-nose: touch camera on screen Heel-to-shin is much more challenging due to positioning of camera: possible if someone is holding the camera Rapid alternating movements is feasible	Y
	Cranial nerve	Taste and smell are a challenge (would see object before smelling) Use of Snellen chart is a challenge Consistency of instructions for administration is a barrier	Y (for majority)
	Motor (tone, pronator drift, strength/power using MRC grading/MMT)	Tone is not feasible Pronator drift is feasible Manual muscle testing is feasible up to 3/5 Cannot complete traditional power testing of muscles Feasible if incorporate a functional test (squat) to provide insight into strength	Y (for majority)
	Reflexes	Only feasible if a trained clinician is with the person in-person	N
	Myotomes	Feasible up to 3/5 grading	Y, but not recommended
	Sensation	Could self-assess but may not be useful information Risk of false negative is high: not recommended virtually	Y with modifications, but not recommended
Vestibular	VOMS	Smooth pursuits, saccades, VOR: feasible (most clinicians only complete these 3 components); need well placed camera VOR: feasible, however keeping at right speed is a challenge; could use metronome smartphone application Convergence: feasible, measurement is the barrier (unless have person helping in-person) Visual motion sensitivity: feasible, however safety concern if standing, need to have enough range (cannot do this in seated position unless have a swivel chair) If solely using VOMS to capture subjective changes in symptoms, then would be feasible	Y with modifications
	Balance (feet together, single leg stance, tandem stance)	Challenge is getting full view of person completing the test Concerns regarding safety, especially with single leg stance Modify environment: have table in front to grab on to, couch nearby to fall into, another person in-person	Y
	VOR test	Challenge is seeing eye movements Feasible if evaluating subjective response	Y
	BESS/mBESS	Full BESS would not be feasible due to safety concerns when standing on foam surface mBESS may be feasible, however safety is still a concern Seeing errors may be a challenge depending on camera angle	Y (mBESS only)

	Dix-Hallpike	Not feasible unless someone trained is with the person in-person	N
	Head thrust/Head impulse test	Not feasible as movement must be unexpected Neck pain is a barrier even in-person	N
	Gait/Tandem gait	Feasible, however safety is a concern Modify environment (couch or wall nearby) or have another person in-person Camera angle is a challenge: prefer profile view when observing gait	Y
	Dynamic Visual Acuity	The computerized dynamic visual acuity test may be feasible, however, need specialized equipment on head, likely making it infeasible Clinical dynamic visual acuity requires a specific set-up (Snellen chart, specific distance from chart), identifying objective difference would be a challenge and therefore likely not feasible Requires a person in-person	N
	Romberg	Feasible, however, safety is a concern and may not be sensitive to balance deficits, especially if administered virtually	Y
Oculomotor	Smooth pursuits	Feasible, person follows finger on screen, could use YouTube videos with object moving to standardize	Y
	Convergence	Feasible, however, measurement is a challenge	Y with modifications
	Saccades	Feasible, look at top corner of one side of screen to top corner of other side	Y
Cervical	Range of motion	Only feasible for active range of motion Feasible, side view for neck flexion and extension, anterior view for lateral flexion, rotation is a challenge (could use smartphone application to detect angle for rotation) Challenge is not being able to complete passive evaluation	Y with modifications
	Palpation	Feasible if self-palpate Subjective but useful information	Y with modifications
	Strength (MMT, DNF endurance)	DNF endurance: not feasible (camera angle would be a challenge, person needs a specific positioning of the neck which would be a challenge to obtain virtually, usually need a hard surface) MMT: Can get an idea of up to 3/5 grading, could complete self-resistance May not be useful for concussion	N
	Joint position error test	Not feasible, specialized equipment and specific positioning needed Could use a modified version where the person looks at the light on the computer and clinician monitors for re-positioning of head May not be generalizable or useful as a screening assessment	N

BESS = balance error scoring system; DNF = deep neck flexor; MMT=manual muscle testing; MRC = medical research council; N = no, measure is not feasible when administered virtually; VOMS = vestibula ocular motor screening; VOR = vestibulo-ocular reflex; Y = yes, measure is feasible when administered virtually

A discussion regarding the sensitivity and specificity of the balance measures occurred during the working group deliberations. Specifically, some clinicians reported that based on their experience with in-person administration, virtual administration of certain measures, such as coordination assessments, provided less reliable information. The Balance Error Scoring System

(BESS)/modified BESS (mBESS) was judged by them to have poor ability to distinguish between healthy individuals and individuals with concussion. The working group participants, however, reported that the mBESS and Romberg may be useful tools to screen for gross motor balance deficits in a virtual examination. These measures were, therefore, deemed feasible and potentially useful to include in the virtual concussion assessment for people presenting with persistent symptoms. Based on the Round 2 survey results, balance testing (single leg stance, tandem stance, feet together) and VOMS may be more relevant to clinical practice and therefore more suitable to include in the virtual assessment toolkit. Similarly, the clinicians reported that the objective measurement of convergence in the convergence oculomotor measure and the near point convergence component of the VOMS are extremely challenging to assess in a virtual context, however it could be a useful tool if solely using the test as a screening tool to document subjective changes in symptoms. Some clinicians reported that the amount of reliable information that they receive with virtual administration of the VOMS is minimal, however, components of the test may be useful.

Discussion

In this study we used a Delphi survey methodology to identify all clinical measures clinicians are using to evaluate the physical domains impacted by a concussion injury at all time points post-injury. This was followed by an expert-clinician working group that documented the current perceived feasibility and use of the measures for virtual assessments.

This study confirmed that clinicians use varied approaches when completing in-person evaluations of the physical domains impacted by a concussion injury with almost 150 different concussion evaluation measures identified by the survey clinician-participants. Based on the findings, it appears that there is no widely accepted, standardized approach to assessing concussions, however the use of coordination testing, the VOMS, smooth pursuits, and cervical

spine range of motion may be the most relevant measures. This is therefore an area prime for some standardization work. Matuszak et al. [16] documented that the concussion examination in still-symptomatic individuals has not yet been standardized or supported by evidence, and the variation in measures identified in the study may reflect this lack of standardization. According to the Living Concussion Guidelines, valid, standardized tools are needed to assess and monitor symptoms [17], however specific measures containing these characteristics have not yet been outlined. Concussions are a unique condition in which assessments are conducted in a variety of different locations and by a heterogenous group of clinicians [18]. This, therefore, may have contributed to the variety of measures identified by the clinicians that participated in the survey. Further, many factors may have contributed to the selection of measures by the clinician-participants such as time since injury, clinician practice type, cost of clinical measures, equipment needed, ease of use, time needed to administer a measure, accessibility and familiarity, among others [19, 20].

It is possible that the reading material provided to the participants outlining the psychometric properties of the tools based on the review of the literature, did not influence the responses and rankings in the second-round survey resulting in a maintenance in ranking of measures from Round 1 to Round 2. Presenting the reading material, which included information about the measure properties, may have reinforced the participants' original opinions about the clinical measures, leading clinicians to rank the most common measures from Round 1 as first in Round 2. Reasoning for this may be due to the psychometric properties associated with the measures. As demonstrated in Multimedia Appendix 1, the documented psychometric properties are commonly weak to moderate or undefined for many of the measures used in a concussion assessment whether done virtually or in person. Clinician rankings for coordination testing,

VOMS and cervical range of motion in Round 1 and Round 2 (within their respective domains) did not change, where all three measures were found to have acceptable sensitivity properties (above 70%), however, the properties available for coordination testing and cervical range of motion are not specific to concussion. Stokes and O'Neill [21] documented that physiotherapists are aware of how to administer clinical measures and track progress using the measures; however, their confidence is lower in terms of their knowledge regarding the properties of the measures. Wedge et al. [22] similarly reported that physiotherapists need more information on the psychometric properties of clinical measures. Most physiotherapists included in the study by Wedge et al. [22] indicated that they did not critically assess the properties of the clinical measures they use in their practice, however there is a desire to have this information more readily available. Many of the physiotherapists further reported that they were unaware of publications providing relevant psychometric property information [22]. Awareness and knowledge of the relevant psychometric properties may therefore inform selection of clinical measures. In practice, clinicians are encouraged to adopt an approach to assessment that is evidence-based, which includes consideration of the current research, clinical expertise, and client or patient preference [23]. There are, however, challenges and barriers to implementing evidence-based practice in clinical settings, such as time limitations, and lack of access to up-to-date research [23]. These factors may have further influenced clinician-selection of measures in the surveys in this study. Clinicians selecting measures without the information provided in this study may have come to different, less evidence-based ranking decisions.

The measures identified in the surveys and discussed in the working group are in line with the recommendations presented in concussion assessment and management guidelines and remote concussion resources [2-4, 6]. Guidance for the virtual general neurologic examination

was presented by Al Hussona et al. [24] and aligns with the findings of the working group in this study. According to this guidance, the majority of the cranial nerve examination can be feasibly completed virtually, including: the motor (muscle bulk, pronator drift, antigravity power, squat), sensory (compare light touch or cold on both index fingers and tops of both of the big toes), coordination (including finger-to-nose, heel-to-shin, and rapid alternating movements), and gait (that includes double leg stance, normal gait and tandem gait) examinations. Similarly, according to Ellis et al. [6], a modified cranial nerve examination (in the concussion context) can be completed virtually and includes evaluation of extraocular movements, smooth pursuits, facial symmetry, facial sensation, and movement of palate and tongue. Motor and coordination evaluation according to this guideline includes pronator drift assessment and rapid alternating hand movements. Some limitations identified by Al Hussona et al. [24] for the virtual examination include the inability to perform a fundoscopy examination, detailed power examination, and neuro-otology manoeuvres such as the Dix-Hallpike. While the guidance by Al Hussona et al. [24] is not specific to the concussion examination, it does support the findings of the working group in this study in relation to the concussion assessment as the concerns and considerations that were brought up by the working group members are similar to those presented in the guidance.

Montes et al. [25] developed a roadmap for remote assessment in neuromuscular disorders, and this roadmap could be used across various conditions, including concussion. According to Montes et al. [25], effective adoption of measures in virtual practice should include identifying measures that are clinically relevant and patient-centered. Further, expert opinion and consensus is needed to identify the feasibility of virtual assessments in various populations and conditions. Measures that could be safely and feasibly administered in virtual environments

should be the first point of consideration for adaption to virtual environments. Guided by this work by Montes et al. [25], the findings from this study provide an informed foundation on which to base the virtual concussion assessment. It is important to note that this study identifies the clinician-perceived measures that are most relevant to assessing certain physical domains affected by concussion [3]. By identifying the most relevant measures (and some of their associated psychometric properties) used to evaluate the physical domains impacted by a concussion injury that are feasible virtually, we now have an understanding of the clinician-perceived measures that should be initially explored when commencing to determine measures that should be administered in the different contexts, both in-person and virtually.

Limitations

The majority of participants in the Delphi survey were physiotherapists and there was an uneven distribution of participants based on clinical profession. Physiotherapists' opinion may, therefore, be relatively over-represented in this survey compared to the other clinical professions. To address this, we included a cut-off of consensus amongst each clinical profession as well as amongst all participants, however, with only two neurologist, two speech language pathologist, and three kinesiologist/athletic therapist responses, reaching that cut-off would be a challenge for those professions. Similarly, while the working group included representation from clinical professions that typically complete a concussion examination, input may be missing from other clinical professions such as athletic therapists/trainers or kinesiologists, nurses and neurosurgeons. Furthermore, concussion injuries may occur in different contexts and may be assessed by different clinician professionals and at different time points; these factors may contribute to the low level of consensus and broad range of measures identified in both rounds of surveys in our study. There may have been greater consensus if the questions were specific to

assessments conducted on people experiencing persistent symptoms post-injury, however, based on the lack of guidance available on the specific measures to use in the assessment of people experiencing persistent symptoms, variation would be expected.

Conclusion

The Delphi approach resulted in low to moderate agreement amongst the clinician-participants regarding the most relevant measures used to evaluate certain physical domains impacted by a concussion injury. This work highlights the broad range of measures being used in practice, however points to the use of coordination testing, the VOMS, smooth pursuits, and cervical spine range of motion as measures that may be most relevant in a concussion examination, within their respective domains. These measures ranked first amongst the survey clinician-participants were determined to be feasible with modifications in a virtual context as decided upon by expert clinicians in the working group. While these measures have been included in most of the remote concussion assessment guidelines and resources, the psychometric properties are underdeveloped for all in the concussion context. These measures, therefore, present a clear starting point for investigation of psychometric properties associated with virtual administration given their rankings and perceived feasibility in the virtual environment.

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Data Availability

All data generated or analyzed during this study are included in this published article.

Authors' Contributions
All authors have made substantial contribution to the work presented in this paper.

Conflicts of Interest
None declared.

Abbreviations
BESS: balance error scoring system

DNF: deep neck flexor

mBESS: modified balance error scoring system

MMT: manual muscle testing

MRC: medical research council

mTBI: mild traumatic brain injury

TBI: traumatic brain injury

VOMS: vestibular/ocular motor screening

VOR: vestibular ocular reflex

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Multimedia Appendix 1

Table S1. List of measures with identified psychometrics that reached at least 15% agreement in round 1. (N=58)

Domain	Measures	Diagnostic Accuracy
Neurological Examination	Coordination: finger-to-nose, heel-to-shin; Rapid alternating movements	Adults with stroke: Timed Finger to nose: **Sensitivity:** 71% **Specificity:** 69% [1]
	Cranial nerve	Adults with focal cerebral hemisphere lesions: Visual field defect: **Sensitivity**: 22% **Specificity**: 95% [2]
	Sensation	Not reported
	Reflexes	Adults with focal cerebral hemisphere lesions: Hyperreflexia: **Sensitivity**: 11% **Specificity**: 100% [2]
	Motor (tone, pronator drift, strength/power using MRC grading/MMT)	Adults with focal cerebral hemisphere lesions: Pronator drift: **Sensitivity:** 22% **Specificity:** 100% Focal muscle weakness: **Sensitivity**: 20-30% **Specificity:** 100% [2]
	Myotomes	Not reported
Vestibular	VOMS	Adults with acute/subacute concussion: **Sensitivity:** 96% **Specificity:** 46% [3]
	Balance (feet together, single leg stance, tandem stance)	Community-dwelling older adults with recurrent falls: Single leg stance: **Sensitivity:** 33% **Specificity:** 71% [4]
	VOR assessment	Not reported
	BESS/mBESS	Adults with acute concussion: **Sensitivity:** 10-60% **Specificity:** 40-93% [5, 6]
	Dix-Hallpike	Adults with benign paroxysmal positional vertigo: **Sensitivity:** 82% **Specificity:** 71% [7]
	Head thrust/Head impulse test	Adults with vestibular hypofunction: **Sensitivity:** 63-72% **Specificity:** 64-78% [8]
	Gait/Tandem gait	Youth with acute/subacute concussion: Tandem gait: **Sensitivity:** 41% **Specificity**: 90% [9]

	Romberg	Young adults with vestibular dysfunction: **Sensitivity:** 55% **Specificity:** 64% [10]
	Dynamic Visual Acuity	Not reported
Oculomotor	Saccades	Youth and adults with TBI: Computerized only: Horizontal: **Sensitivity:** 77% **Specificity:** 78% Vertical: **Sensitivity:** 64% **Specificity:** 65% [11]
	Convergence	Not reported
	Smooth pursuits	Youth and adults with TBI: Computerized only: **Sensitivity**: 68% **Specificity:** 73% [12]
Cervical	Range of motion	Adults with whiplash: Computerized: **Sensitivity:** 86%, **Specificity:** 95% [13]
	Palpation	Not reported
	Strength (MMT, DNF endurance)	Not reported
	Joint position error test	Adults with cervical spine injury: **Sensitivity:** 82% **Specificity:** 90% [14]

BESS = balance error scoring system; DNF = deep neck flexor; mBESS = modified balance error scoring system; MMT=manual muscle testing; MRC = medical research council; TBI = traumatic brain injury; VOMS = vestibular ocular motor screening; VOR = vestibulo-ocular reflex

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Multimedia Appendix 2
Delphi survey round one: measures that did not meet the 15% cut-off criteria

Table S2: Clinician-identified measures that did not meet the 15% cut-off criteria in Delphi survey round one. N=58

Domain	Measures	Frequency	Agreement (N/58*100)
Neurological Examination	Functional testing/capacity	5	9%
	Babinski, Hoffman's	4	7%
	Infrared Goggle Testing	3	5%
	Observation, Auditory screen, Dysmetria, Dysdiaokokinesia, Clonus, Upper limb tension tests, Mental capacity/status	2	3%
	Adiadokokinesis, Calibrated stick drop reaction time, Fukuda step test, Upper motor neuron testing, Hyperventilation, Verbal screen, Plantar reflex, Optic nerve/disc assessment, Cognition, Temporomandibular joint range of motion, Mini-mental state examination, Higher cortical functions, Tremor, Bradykinesia	1	2%
Vestibular	Dynamic gait index	7	12%
	Dizziness handicap inventory	6	10%
	Benign paroxysmal positional vertigo assessment, Head roll test	5	9%
	Functional gait assessment	4	7%
	Motion sensitivity testing, Motion sensitivity quotient, Modified clinical test of sensory interaction in balance (mCTSIB)	3	5%
	Head shake, Mini balance evaluation systems test (MiniBest), Berg, Dynamic balance, Walking on heels, Walking on toes	2	3%
	Otoscopy, Community balance and mobility scale (CB&M), Head impulse nystagmus test of skew examination (HINTS), Gait backwards, Gait sideways, Tandem backwards, Grapevine, Computerized dynamic foot plate, Effects of noise, Pressure (Valsalava, tragal pressure) on symptoms, 10m walk test, modified COBALT, Positional testing (with goggles), Narrow base of support with eyes closed, Epleys, Peripheral vestibular assessment, Visual vertigo analogue score, Provoked vertigo (supine to sit/sit to supine, bend to floor)	1	2%
Oculomotor	Cover eye test/cover/uncover test, Visual fields	8	14%
	Pupil reactivity, Accommodation, Tracking, Nystagmus check	7	12%
	Gaze stabilization	6	10%
	Visual motion sensitivity, Extraocular muscles (EOM)	5	9%
	King-Devick, Visual midline shift	4	7%
	Visual acuity, Fixation	2	3%
	Pupils equal round reactive to light (PERL), Single and 2-point gaze, Optic discs, Diplopia, Focus, Skew deviation, Eyeball movement, Light and accommodations reflex, Subjective visual vertical test, University of Pennsylvania hand out	1	2%
	Vertebral artery assessment	8	14%

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Cervical	Spurlings	7	12%
	Proprioception, Flexion rotation test	6	10%
	Alar & transverse ligament tests, Passive intervertebral movements/Passive accessory intervertebral movement (PIVM/PAIVMs), Posture	4	7%
	Tenderness, Deep neck extensor, Joint mobility	3	5%
	Dynamic stability, Smooth pursuit neck torsion test, Cranio-cervical stability	2	3%
	Neck muscle length/tension, Localized pain, Cervical axial compression muscle flexibility, Trigger point assessment, Times testing for neck endurance, Muscle tone and control, Head neck dissociation, Upper limb scan, Dynamic mobility, Head lift endurance, Neck extension rotation test, Joint glides, L'hermitte, RIMS, Upper extremity tests, Muscle bulk activity, Upper extremity strength, Provocative maneuvers for cervicogenic headache, Craniovertebral ligament stability, X-ray cervical spine	1	2%
Effort	None	31	53%
	Buffalo Concussion Treadmill Test	10	17%
	Buffalo Concussion Bike Test, Functional lifting	4	7%
	Observation, Immediate post-concussion assessment and cognitive test (ImPACT), Consistency of presentation/Abnormal responses, Treadmill test	3	5%
	Waddel sign	2	3%
	Rey's 15 item test, Attentional test, RPE, Symptom scales	1	2%

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Multimedia Appendix 3
Round Two Mean Rankings

Table S3: Delphi survey round two mean rankings for each measure.

		Mean Rankings		Response Count and Weight																										
				Rank 1			Rank 2			Rank 3			Rank 4			Rank 5			Rank 6			Rank 7			Rank 8			Rank 9		
Domain	Measures	Mean Ranking	Sum of all (weight*response count)	Frequency (#)	Weight	Weight*Response Count	Frequency (#)	Weight	Weight*Response Count	Frequency (#)	Weight	Weight*Response Count	Frequency (#)	Weight	Weight*Response Count	Frequency (#)	Weight	Weight*Response Count	Frequency (#)	Weight	Weight*Response Count	Frequency (#)	Weight	Weight*Response Count	Frequency (#)	Weight	Weight*Response Count	Frequency (#)	Weight	Weight*Response Count
Neurological Examination	Cerebellar testing (Coordination: finger-to-nose, heel-to-shin; Rapid alternating movements)	4.666666667	154	10	6	60	16	5	80	0	4	0	2	3	6	4	2	8	0	1	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Cranial nerve	4.515151515	149	17	6	102	4	5	20	3	4	12	1	3	3	4	2	8	4	1	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Sensation	2.424242424	80	0	6	0	1	5	5	6	4	24	7	3	21	11	2	22	8	1	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Reflexes	2.848484848	94	2	6	12	1	5	5	6	4	24	10	3	30	9	2	18	5	1	5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Motor (tone, pronator drift, strength/power using MRC grading/MMT)	4.090909091	135	4	6	24	8	5	40	14	4	56	3	3	9	1	2	2	4	1	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Myotomes	2.454545455	81	0	6	0	3	5	15	4	4	16	10	3	30	4	2	8	12	1	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Vestibular	VOMS	7.515151515	248	17	9	153	3	8	24	3	7	21	5	6	30	2	5	10	1	4	4	2	3	6	0	2	0	0	1	0
	Balance (feet together, single leg stance, tandem stance)	6.454545455	213	5	9	45	11	8	88	4	7	28	6	6	36	1	5	5	0	4	0	1	3	3	3	2	6	2	1	2
	VOR test	6.181818182	204	1	9	9	9	8	72	6	7	42	5	6	30	7	5	35	3	4	12	1	3	3	0	2	0	1	1	1
	BESS/mBESS	5.606060606	185	2	9	18	4	8	32	6	7	42	7	6	42	3	5	15	5	4	20	4	3	12	2	2	4	0	1	0
	Dix-Hallpike	4.575757576	151	3	9	27	1	8	8	2	7	14	5	6	30	8	5	40	2	4	8	5	3	15	2	2	4	5	1	5
	Head thrust/Head impulse test	3.909090909	129	2	9	18	1	8	8	5	7	35	1	6	6	3	5	15	4	4	16	5	3	15	4	2	8	8	1	8
	Gait/Tandem gait	4.363636364	144	3	9	27	1	8	8	5	7	35	3	6	18	1	5	5	7	4	28	3	3	9	4	2	8	6	1	6
	Romberg	2.878787879	95	0	9	0	0	8	0	1	7	7	1	6	6	6	5	30	1	4	4	9	3	27	6	2	12	9	1	9
	Dynamic Visual Acuity	3.515151515	116	0	9	0	3	8	24	1	7	7	0	6	0	2	5	10	10	4	40	3	3	9	12	2	24	2	1	2
Oculomotor	Saccades	1.909090909	63	7	3	21	16	2	32	10	1	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Convergence	1.848484848	61	11	3	33	6	2	12	16	1	16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Smooth pursuits	2.242424242	74	15	3	45	11	2	22	7	1	7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cervical	Range of motion	3.666666667	121	25	4	100	6	3	18	1	2	2	1	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Palpation	2.939393939	97	7	4	28	20	3	60	3	2	6	3	1	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Strength (MMT, DNF endurance)	1.878787879	62	0	4	0	2	3	6	25	2	50	6	1	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Joint position error test	1.515151515	50	1	4	4	5	3	15	4	2	8	23	1	23	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

BESS = balance error scoring system; DNF = deep neck flexor; mBESS = modified balance error scoring system; MMT=manual muscle testing; MRC = medical research council; VOMS = vestibular/ocular motor screening

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Multimedia Appendix 4
Round Two Consensus Values

While the aim of the study was to identify the most relevant measures using rank-orders of measures, consensus values for rankings of each measure were also calculated. Frequency counts and consensus values (calculated by dividing frequency counts by number of responses for each ranking) for measures that reached or exceeded 50% consensus are shown in table S4. The consensus target, greater than 50%, was reached on the first-ranked measure for three of the five domains. For the neurological examination and vestibular domains, consensus at 51.52% was reached for the first ranked outcome measures of cranial nerve evaluation and VOMS, respectively. The cervical spine assessment was the only domain where consensus was reached for all measures (range of motion, followed by palpation, followed by strength, followed by the joint position error test) with range of motion ranked as most relevant at 75.76%. There was no consensus on the oculomotor domain measures.

Table S4: Frequency counts and consensus values for measures reaching at least 50% consensus within each rank.

		Frequency (#) and Consensus (%)							
		Rank 1		Rank 2		Rank 3		Rank 4	
Domain	Measures	#	%	#	%	#	%	#	%
Neurological Examination	Coordination: finger-to-nose, heel-to-shin; Rapid alternating movements	-	-	-	-	-	-	-	-
	Cranial nerve	17	51.52	-	-	-	-	-	-
	Motor (tone, pronator drift, strength/power using MRC grading/MMT)	-	-	-	-	-	-	-	-
Vestibular	VOMS	17	51.52	-	-	-	-	-	-
Cervical	Range of motion	25	75.76	-	-	-	-	-	-
	Palpation	-	-	20	60.61	-	-	-	-
	Strength (MMT, DNF endurance)	-	-	-	-	25	75.76	-	-
	Joint position error test	-	-	-	-	-	-	23	69.70

DNF = deep neck flexor; MMT=manual muscle testing; MRC = medical research council; VOMS = vestibular/ocular motor screening

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Frequency counts and consensus values for all measures that met the previously set criteria (15% of clinicians identifying a measure) are presented in table S5.

Table S5: Delphi survey round two frequency counts and consensus values for all measures that met the previously set criteria

		Frequency (#) and Consensus (%)																	
		Rank 1		Rank 2		Rank 3		Rank 4		Rank 5		Rank 6		Rank 7		Rank 8		Rank 9	
Domain	Measures	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Neurological Examination	Cerebellar testing (Coordination: finger-to-nose, heel-to-shin; Rapid alternating movements)	10	30.30	16	48.48	0	0.00	2	6.06	4	12.12	0	0.00	N/A	N/A	N/A	N/A	N/A	N/A
	Cranial nerve	17	51.52	4	12.12	3	9.09	1	3.03	4	12.12	4	12.12	N/A	N/A	N/A	N/A	N/A	N/A
	Sensation	0	0.00	1	3.03	6	18.18	7	21.21	11	33.33	8	24.24	N/A	N/A	N/A	N/A	N/A	N/A
	Reflexes	2	6.06	1	3.03	6	18.18	10	30.30	9	27.27	5	15.15	N/A	N/A	N/A	N/A	N/A	N/A
	Motor (tone, pronator drift, strength/power using MRC grading/MMT)	4	12.12	8	24.24	14	42.42	3	9.09	1	3.03	4	12.12	N/A	N/A	N/A	N/A	N/A	N/A
	Myotomes	0	0.00	3	9.09	4	12.12	10	30.30	4	12.12	12	36.36	N/A	N/A	N/A	N/A	N/A	N/A
Vestibular	VOMS	17	51.52	3	9.09	3	9.09	5	15.15	2	6.06	1	3.03	2	6.06	0	0.00	0	0.00
	Balance (feet together, single leg stance, tandem stance)	5	15.15	11	33.33	4	12.12	6	18.18	1	3.03	0	0.00	1	3.03	3	9.09	2	6.06
	VOR test	1	3.03	9	27.27	6	18.18	5	15.15	7	21.21	3	9.09	1	3.03	0	0.00	1	3.03
	BESS/mBESS	2	6.06	4	12.12	6	18.18	7	21.21	3	9.09	5	15.15	4	12.12	2	6.06	0	0.00
	Dix-Hallpike	3	9.09	1	3.03	2	6.06	5	15.15	8	24.24	2	6.06	5	15.15	2	6.06	5	15.15
	Head thrust/Head impulse test	2	6.06	1	3.03	5	15.15	1	3.03	3	9.09	4	12.12	5	15.15	4	12.12	8	24.24
	Gait/Tandem gait	3	9.09	1	3.03	5	15.15	3	9.09	1	3.03	7	21.21	3	9.09	4	12.12	6	18.18
	Romberg	0	0.00	0	0.00	1	3.03	1	3.03	6	18.18	1	3.03	9	27.27	6	18.18	9	27.27
	Dynamic Visual Acuity	0	0.00	3	9.09	1	3.03	0	0.00	2	6.06	10	30.30	3	9.09	12	36.36	2	6.06
Oculomotor	Saccades	7	21.21	16	48.48	10	30.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Convergence	11	33.33	6	18.18	16	48.48	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Smooth pursuits	15	45.45	11	33.33	7	21.21	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cervical	Range of motion	25	75.76	6	18.18	1	3.03	1	3.03	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Palpation	7	21.21	20	60.61	3	9.09	3	9.09	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Strength (MMT, DNF endurance)	0	0.00	2	6.06	25	75.76	6	18.18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Joint position error test	1	3.03	5	15.15	4	12.12	23	69.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

BESS = balance error scoring system; DNF = deep neck flexor; mBESS = modified balance error scoring system; MMT=manual muscle testing; MRC = medical research council; VOMS = vestibular/ocular motor screening

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Chapter 4. Barriers and facilitators associated with virtual concussion physical assessments from the perspectives of clinicians and people living with workplace concussions

Chapter 4 has been formatted based on the requirements of the peer-reviewed journal in which it was submitted.

Chapter 4 contains the results of the focus groups, documenting the barriers and facilitators associated with virtual concussion assessments and the clinical measures the clinicians perceived would work best in virtual practice based on their experience (out of the measures identified in the surveys and working group). The manuscript associated with Chapter 4 was submitted to the Journal of Internet Medical Research on January 9, 2024. We received major revisions on July 1, 2024. The revisions were addressed and submitted on August 22, 2024. It was accepted for publication on September 25, 2024. It is currently In Press.

Ethics approval was obtained by the Ottawa Health Sciences Network Research Ethics Board (20210575-01H), the Bruyère Research Ethics Board (M16-22-006) and the University of Ottawa Board of Ethics (H-02-22-7611).

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Barriers and facilitators associated with virtual concussion physical assessments from the perspectives of clinicians and people living with workplace concussions

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Abstract

Background: Evaluating concussion clinical status using virtual platforms has become increasingly common. While virtual approaches to care are useful, there is limited information regarding the barriers and facilitators associated with the virtual concussion assessment. The objectives of this study were to: i) identify the barriers and facilitators associated with engaging in virtual concussion assessments from the perspective of people living with workplace concussions, ii) identify the barriers and facilitators to completing virtual assessments of concussion from the perspectives of clinicians, and iii) identify the clinical measures related to four clinical domains that would be most appropriate in virtual practice: general neurological examination, vestibular, oculomotor, and cervical spine, along with evaluation of effort.
Methods: Separate online focus groups were conducted with expert concussion clinicians and people living with workplace concussions. A moderator led the focus group using a semi-structured interview guide that targeted discussion of participants' experiences with virtual assessments. The discussions were recorded, transcribed and analyzed by two reviewers using content analysis. Barriers and facilitators associated with completing the physical concussion examination were categorized based on domain of the concussion examination and more general barriers and facilitators. Clinician selected measures believed to work best in virtual practice were described using frequency counts.
Results: Four focus groups with 15 people living with workplace concussions and three with 14 clinicians were completed using Microsoft Teams. Barriers were identified such as triggering of symptoms associated with completing an assessment over video (mentioned 8% and 4% of the time for patient- and clinician-participants, respectively), challenges with location and set-up (mentioned 10% of the time for patient-participants), communication (mentioned 21% and 4% of the time for patient- and clinician-participants, respectively), and safety concerns (mentioned 7% for both patient- and clinician-participants). Facilitators were identified such as having access to support (mentioned 27% and 14% of the time for patient- and clinician-participants, respectively), implementing symptom management strategies throughout the assessment (mentioned 7% of the time for patient-participants), and having access to resources (mentioned 17% of the time for clinician-participants). From the perspective of the clinician-participants included in this study, the clinical measures recommended most for virtual practice were finger to nose testing, balance testing, Vestibular Ocular Motor Screening, saccades, and cervical spine range of motion within their respective domains (neurological examination, vestibular, oculomotor, cervical spine assessment).
Conclusions: Virtual assessments appear to be useful for both people living with workplace concussions and clinicians. While barriers were identified, such as challenges associated with exposure to screens, virtual assessments have benefits including improved access to care. The clinician-selected measures that were considered best in virtual practice will be investigated in an upcoming evaluative study.

Key words: remote, mild traumatic brain injury, telehealth, assessment, workplace injury

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Introduction

Concussions result from indirect or direct impacts to the head, and usually lead to neurological symptoms [1] . While the majority of individuals who sustain a concussion recover within days of the injury, an estimated 10 to 20% experience persistent symptoms post-injury requiring intervention [2] . Following a concussion sustained in the workplace, there is an increased likelihood of reporting persistent symptoms [3,4] . This may be attributed to several factors, including access to worker's compensation, fear of returning to the site of the injury, [3] and the demands of work that can exacerbate symptoms. Timely access to care can be challenging for workers in remote and rural communities due to poor accessibility to specialized clinicians [5–8] . The COVID-19 pandemic further presented challenges to accessing in-person care for workplace injuries [9,10] .

Virtual care, the remote delivery of healthcare services that may address some of these challenges, often uses visual and audio communication or videoconferencing technology [11,12] . For patients with concussion, virtual care could improve access to care [7,13–16] and has been shown to be beneficial from the perspective of clinicians, although not without limitations [17] . A recent study by van Ierssel et al. [17] explored the perspectives of 25 clinicians on assessing and managing concussions through virtual care approaches. They reported that clinicians believed that virtual care could be beneficial for monitoring functional status at follow-up, for screening patients, and for identifying those who may require further in-person assessment. Moreover, participants did not believe care to be jeopardized by virtual follow-up assessments. In general, the literature supports that clinicians recognize advantages to using virtual care approaches for concussion assessment and management, but there is a need to further explore the effectiveness of virtual assessment in the context of concussion care.

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There is limited information on the barriers and facilitators associated with virtual care from the perspectives of people with a concussion. One study [18] explored virtual care experiences from the perspectives of patients, caregivers, and healthcare providers in the geriatric medicine setting. Uncertainty about accuracy (ability to validly identify deficits) was reported as a concern, with patients and caregivers, who questioned whether a comprehensive understanding of patient status was captured [18] . Patient- and caregiver-participants in this study, however, highlighted the benefits, such as improved access to care and engagement with caregivers in appointments, emphasizing that a hybrid approach to care may be superior to virtual-only approaches [18] . However, with regards to post-concussion care, experiences may differ from those in the geriatric medicine setting. People with concussion may experience greater fatigue when compared to other populations due to screen exposure [19] . Further, most concussions occur in younger people (< 30 years) when compared to the geriatric population [20] , who are potentially more comfortable and less intimidated by the technology involved [21] . Both the clinician and patient perspectives are important for a comprehensive understanding of its potential usefulness [11] , and therefore a detailed exploration of experiences associated with virtual assessments from the perspectives of people living with workplace concussion is needed.

There is a critical need to identify the barriers and facilitators associated with the main domains of the physical examination (neurological examination, vestibular, oculomotor, and cervical spine), when completing a hands-on comprehensive assessment is not possible [22–24] . There is an additional need to evaluate the effort employed during an assessment, which is particularly the case in the context of injured workers, as the presence of and access to compensation following a work-related injury could influence performance (if low effort is

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employed) and subsequent findings on an examination [25] . While the evaluation of effort is not a clinical domain, it is considered a component of the examination used to interpret the clinical results, and therefore, is presented as a separate 'domain' throughout this paper.

The objectives of the present study were to: a) explore the barriers and facilitators related to engaging in virtual concussion assessments from the perspective of people living with workplace concussions; b) document the barriers and facilitators associated with completing a virtual concussion examination (neurological examination, vestibular, oculomotor, cervical spine domains, and effort) as identified by concussion-expert clinicians with experience completing virtual assessments; and c) document concussion-expert clinicians' opinions regarding which clinical measures from the above domains work best in virtual practice. This study focused on the assessment of physical domains due to significant adaptations required to administer these measures virtually and due to individual interpretations of how best to administer these when compared with measurements of emotional or cognitive health.

Methods

In this paper, we report on part of a mixed methods study. The full protocol [26] as well as initial findings from surveys and a working group to identify targeted clinical measures [27] have been recently published. The present paper reports on focus group discussions related to the previously identified clinical measures. Research ethics approval was obtained from the Ottawa Health Sciences Network Research Ethics Board (20210575-01H), the University of Ottawa Board of Ethics (H-02-22-7611) and the Bruyère Research Ethics Board (M16-22-006).

Participants and recruitment

Patient-participants were recruited through the Ontario Workers Network clinic at the Ottawa Hospital. Eligible patient-participants were adults (≥ 18 years old) who had attended at

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least one initial or follow-up virtual assessment following a workplace concussion injury, through a videoconferencing platform. Purposive sampling was used to identify these eligible patient-participants [28] . The sampling strategy was designed to ensure adequate distribution of specific characteristics, such as patient age and sex. Eligible participants were approached by telephone and were provided with a description of the aims of the study before consenting. We attempted to recruit at least five participants per group [29,30] , however, some participants did not attend the scheduled group or had to cancel, so the groups ranged from 2-5 participants. We attempted to include a diverse group of participants in terms of age, date since injury, and sex.

Eligible clinician-participants were Canadian-practicing clinicians (neurologists, physiatrists, family medicine physicians, sports medicine physicians, physiotherapists, athletic therapists, and kinesiologists) with expertise in concussion (not specifically workplace concussion) and with experience completing virtual concussion assessments. Eligible clinician-participants were recruited through targeted emails and outreach to rehabilitation clinics across Canada. Purposive sampling was used [28] to ensure distribution of certain characteristics, such as clinician profession. Similar to the patient-participant groups, we attempted to recruit 5-7 clinicians per group, however, due to scheduling challenges, the groups ranged from 4-5 participants. We attempted to include a diverse group of clinicians in terms of clinical profession.

Data Collection

In a previous paper, we surveyed clinicians concerning their use of clinical measures in their in-person practice [27]. The clinicians rank-ordered the measures based on relevant measures to their in-person practice within the following domains: neurological examination, vestibular, oculomotor, cervical spine, and effort assessment. We then documented the perceived feasibility of administering these measures virtually, based on expert clinician

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opinion [27] . The measures identified in this work were further discussed in this focus group study.

Focus groups were completed over a videoconferencing platform (Microsoft Teams) from August 2022 to January 2023. Consenting participants attended one focus group (either a clinician group or a patient group). Semi-structured guides (see Barnes et al. [26]) were used to direct the discussion for both clinician- and patient-focus groups. The guides were reviewed and revised by the study team prior to the commencement of the focus groups to confirm the appropriate wording of the questions and ensure the questions captured the aspects that the team was aiming to explore. The patient interview guide consisted of nine questions regarding practical and technical barriers and facilitators to undergoing virtual assessment and sought feedback and recommendations for virtual assessments. The clinician interview guide included 12 questions related to i) practical and technical barriers and facilitators to virtual assessment and ii) domain-specific questions related to the neurological examination, vestibular, oculomotor, cervical spine domains, and effort assessment, as well as those prompting the participants to discuss and select the outcome measures (from [26,27]) within each clinical domain that they felt would work best in virtual practice.

Focus groups were moderated by KB. A note-taker (MK) was present to prevent loss of data, record non-verbal expressions and key discussion points to add further context to the recording, and aid with technical issues. The focus groups were audio-video recorded and transcribed verbatim by KB.

All participants completed a demographic form following completion of the focus group. Questions related to age, sex, work status, virtual assessments completed post-concussion, and symptoms were completed for patient-participants. Questions related to age, sex, clinical

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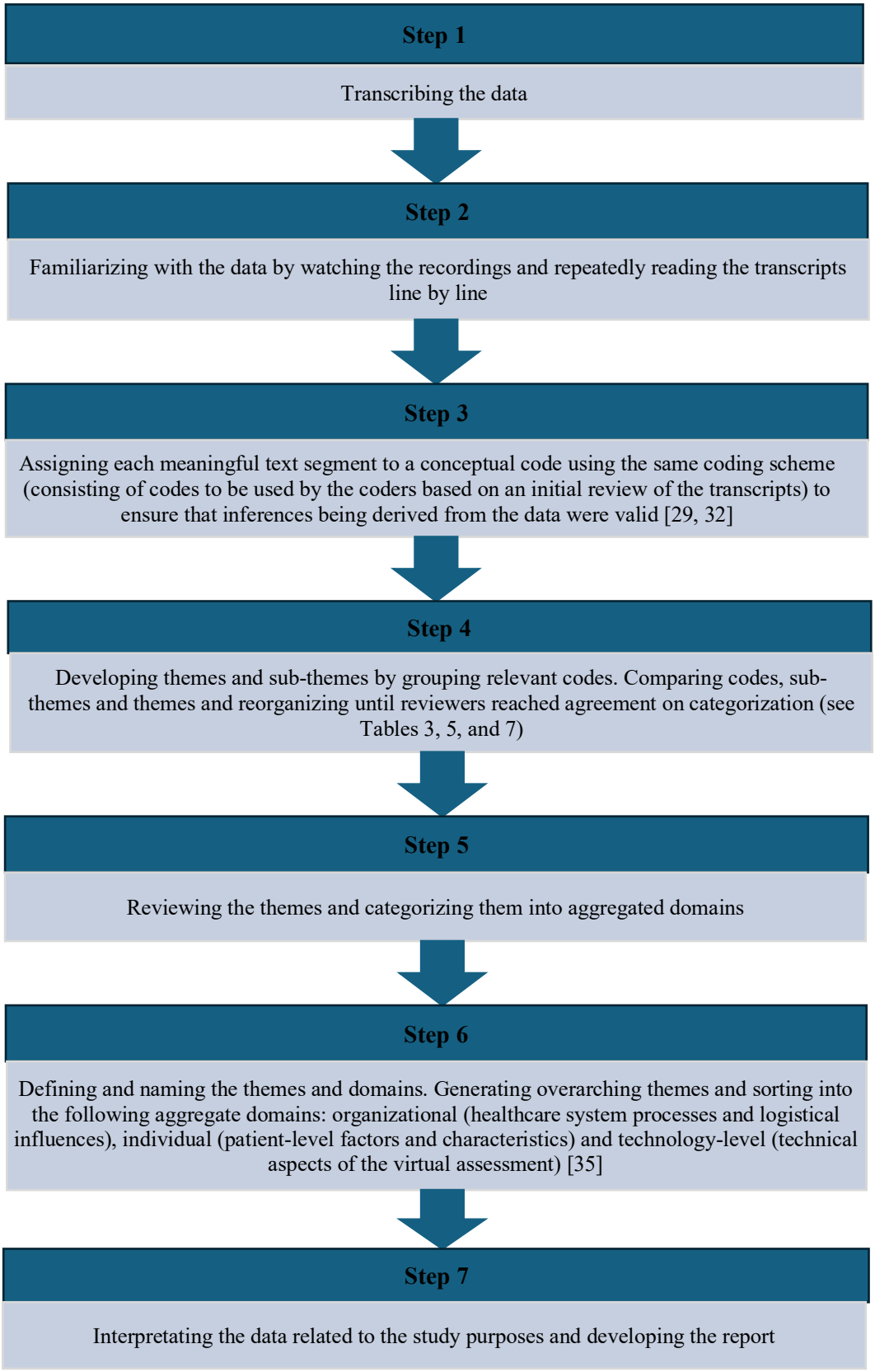
profession, clinical experience, volume of practice of concussion patients, virtual assessments completed in the last year, and self-perceived competency associated with completing the in-person and virtual assessment were completed for clinician-participants.

Data Analysis

Clinician- and Patient-Participant Identification of Barriers and Facilitators

Two reviewers (KB, MK) used inductive qualitative content analysis [31] in NVivo 12 qualitative data analysis software (QSR International Inc., Burlington, MA, USA). Analysis started simultaneously with data collection so that data saturation (point at which no new themes were identified) could be monitored. The analytic process consisted of 7 steps (see Figure 1) [32–34] .

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Figure 1. Analytic process flow diagram.

To ensure that inferences being derived from the data were valid, the coders analyzed the data using the same coding scheme (consisting of codes to be used by the reviewers based on an initial review of the transcripts) [29, 32]. They met weekly to peer review data analyses and discuss interpretations until reaching consensus. Frequency counts were generated for each theme by tabulating the number of times each theme was identified in the transcripts, and percentage of times each theme was reported by the participants was presented (see Tables 3,5, and 7).

The clinician sub-themes were further categorized into the pre-defined categories (domain-specific and general categories). Domain-specific was defined as any barrier or facilitator that was discussed in relation to specific measures under the following domains: neurological examination, vestibular, oculomotor, cervical spine, and effort. General was defined as any barrier or facilitator that relates to the virtual assessment not specific to the domains. The patient-participant sub-themes were all categorized as general barriers and facilitators. NVivo 12 was used to calculate Cohen's Kappa coefficients, to determine agreement between the two coders for all of the codes.

Clinician-Participant Selection of Clinical Measures

Pre-reading materials were provided, to the clinician-participants only, before the focus group. These materials contained descriptions of the clinical measures identified by clinicians in an earlier study [27] to be discussed in the focus groups, Youtube links with video demonstrations of the measures and a summary of select psychometric properties of each measure. Details of these materials are described elsewhere [27] . From this list, the clinicians selected the one(s) that they perceived would provide the most information when administered

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virtually. The two reviewers independently documented the frequency of the clinician selection of each clinical measure.

Results

Focus Group Structure

Seven focus groups (four with people living with workplace concussions and three with clinicians) were completed. Saturation was reached after 3 groups for both the patient and clinician-groups, however, as we experienced challenges recruiting males, we conducted one additional male-only focus group. This allowed us to have two mixed-sex focus groups, a female-only focus group and a male-only focus group. Focus groups were made up of 2 to 5 participants. A total of 15 people with workplace concussions and 14 clinicians participated in the focus groups. The focus group discussion lasted between 30 to 90 minutes each as some groups contained only 2 participants and some groups contained up to 5. Cohen's kappa was calculated as 0.80 across all groups (considered substantial agreement) for all codes for both the clinician and patient-participant focus groups.

Participants

Patient-participants

Table 1 presents the demographic information of the patient-participants. The age range of the patient-participants was between 20 to 59 years (mean age = 40.9 ± 13.1 years). The majority of participants were female (73%). All participants were experiencing persistent symptoms post-workplace concussion injury at the time of their virtual assessment. Injury dates upon participation in the focus group ranged from 9 months to almost 4 years post-concussion. All participants reported physical symptoms as most common (100% of participants), followed by cognitive (40% of participants), and then emotional symptoms (13.3% of participants).

Clinician-participants

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Table 2 presents the demographic information for the clinician-participants. Each focus group consisted of a mix of clinicians. A total of 8 physicians (sports medicine physicians, physiatrists, and a family medicine physician) and 6 other clinicians (athletic therapists and physiotherapists) participated. The clinicians' virtual assessment experience ranged from less than 10 virtual assessments completed in the last year to over 20 completed. The majority of clinicians self-reported their competency of completing the in-person and virtual assessment as 'strongly competent' and 'competent', respectively.

Table 1. Patient-participant demographic characteristics (N=15)

Age range (freq. %)	
20-29y	3 (20.0%)
30-39y	4 (26.7%)
40-49y	5 (33.3%)
50-59y	3 (20.0%)
60+y	0 (0.0%)
Sex (freq. %)	
Female	11 (73.3%)
Male	4 (26.7%)
Current work status (freq. %)	
Off work	2 (13.3%)
Full return to work	5 (33.3%)
Modified return to work, same occupation	6 (40.0%)
Modified return to work, different occupation	2 (13.3%)
Virtual assessments completed post-concussion (freq. %)	
1-5	7 (46.7%)
6-10	4 (26.7%)
>10	4 (26.7%)
Currently experienced symptoms (freq. %)	
Somatic symptoms (headaches, tinnitus vision blurriness, fatigue, nausea, migraines dizziness)	15 (100.0%)
Emotional symptoms (over stimulation, anxiety, anger, frustration)	2 (13.3%)
Cognitive symptoms (slow thinking and expression of thoughts, memory, issues processing information, unable to concentrate)	6 (40.0%)

Freq: frequency; N: number; y: years

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Table 2. Clinician-participant demographic characteristics (N=14)

Age range (freq. %)	
20-29y	1 (7.1%)
30-39y	5 (35.7%)
40-49y	2 (14.3%)
50-59y	3 (21.4%)
60+y	3 (21.4%)
Sex (freq. %)	
Female	6 (42.9%)
Male	8 (57.1%)
Clinical profession	
Physiotherapist	4 (28.6%)
Physiatrist	5 (35.7%)
Athletic Therapist	2 (14.3%)
Sports Medicine Physician	2 (14.3%)
Family Medicine Physician	1 (7.1%)
Clinical experience, y	
1-5	3 (21.4%)
5-10	4 (28.6%)
>10	7 (50.0%)
Current volume of practice of concussion patients	
0-25	5 (35.7%)
25-50	2 (14.3%)
>50	6 (42.9%)
Did not respond	1 (7.1%)
Virtual assessments completed in the last y	
0-10	3 (21.4%)
10-20	1 (7.1%)
>20	7 (50.0%)
Unsure	3 (21.4%)
Competency of in-person neurological assessment	
Strongly Incompetent	0 (0.0%)
Incompetent	0 (0.0%)
Neutral	1 (7.1%)
Competent	4 (28.6%)
Strongly Competent	9 (64.3%)
Competency of virtual neurological assessment	
Strongly Incompetent	0 (0.0%)
Incompetent	1 (7.1%)
Neutral	3 (21.4%)
Competent	8 (57.1%)
Strongly Competent	2 (14.3%)

Freq: frequency; N:Number; y:years

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Themes

Barriers

Table 3 presents the barriers for both the patient- and clinician-participants. Quotes are represented as numbers in the text within each aggregate category. For example, “P12- Q1”, refers to quote #1 from patient-participant #12 or “C2- Q7”, meaning quote #7 from clinician-participant #2. For the clinicians only, categorization of the sub-themes (domain-specific or general) are presented. Percentage of times each theme was reported by the participants is presented. This was calculated by dividing the frequency of times a specific theme was mentioned by participants by the total number of times all themes were mentioned by participants. For example, location and set-up at home was identified as a barrier by patient-participants (due to limited space, noise at home, being in a different province, etc.) 9.88% (16/162) of the time. Clinical process-related factors were identified as a barrier by clinician-participants 10.45% (21/201) of the time. Rankings associated with the barriers reported by the patient- and clinician-participants are presented in Table 4. The darker shades reflect barriers reported more frequently and lighter shades reflect barriers identified less frequently. White indicates that the barrier was not reported by patient- or clinician-participants.

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Table 3. Patient- and clinician-participant barriers

Aggregated domains	Overarching Themes	Sub-themes	Patient		Clinicians			Quote Examples
			Identified by Patient-participant	Frequency (Percentage) of Times Patients Reported (out of a total of 162 themes mentioned)	Identified by Clinician-participant	Frequency (Percentage) of Times Clinicians Reported (out of a total of 201 themes mentioned)	Clinician Categories	
Organizational level	Environmental set-up	Location and set-up at home	✓	16 (9.88%)	-	-	-	*"a lot of the times they couldn't do my assessment virtually because I lived in a different province" (P12 - Q1)*
	Clinical process-related factors	Lack administration support	-	-	✓	21 (10.45%)	General	*"But think about the time that it takes to explain to somebody, try to see what it is that you're doing. You know it's, it takes far more time than than seeing them in person." (C2 – Q7)*
		Time	-		✓		Domain-specific *Cervical Neurological*	
Individual level	Communication and engagement	Challenges with communication	✓	34 (20.99%)	✓	9 (4.48%)	Domain-specific *Neurological*	*"harder to explain um what was going on. I also have speech issues so trying to express sometimes over virtual is difficult." (P6 - Q4)*
		Challenges building rapport and connecting with clinician	✓		✓		General	*"I found the virtual assessment created a bit of a barrier on creating relationships, though, and you weren't able to as easily connect or especially if it is your first time seeing them, athlete or patient"* (C3 - *Q11)*
	Triggering physical and emotional symptoms	Screens trigger physical symptoms	✓	13 (8.02%)	✓	9 (4.48%)	General	*"My big, bothersome side effects was ah like technology. Just the audio like the kind of the sound that comes out of the audio really irritated me. And with the visual like the screen that would really drive my eyes and my head crazy, so it wasn't really convenient for, to be in front of a screen trying to recover from a concussion" (P14 - Q3)*
		Emotional	✓		-		-	*"depending on how symptomatic they are, screen time isn't great for them. So, um you know, decreased tolerance to screen time is one of the things and you might not be able to make it through a full assessment." (C6 - Q10)*
	Safety	Unease working to limit of ability	✓	11 (6.79%)	-	15 (7.46%)	-	"*Once COVID hit, we were all like on video with the clinic and it was a little bit harder because I've fallen a lot. Umm.*

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		Feelings of tests being safer in-person	✓		-		-	*I'm in a walker now. A walker. Um. And sometimes there aren't people here at the house, so if I do fall I, it's it's a little scarier in a way.*" *(P1 - Q2)*
		Safety	-		✓		Domain-specific *Vestibular* *Neurological*	*"If they had really poor balance, you're not there to guard them as a physio. We're always kind of told to guard when you're doing that kind of stuff and they have nobody else there to help guard then that's a problem." (C9 – Q8)*
	Comfort	Patient comfort and preference	-	-	✓	9 (4.48%)	Domain-specific *Effort*	*"When you think about effort, it's like, well, part of it is that the individual has to be comfortable, right, in the virtual assessment…I wouldn't draw any conclusions around effort from a virtual assessment." (C4 - Q12)*
		Psychological impact	-		✓		General	
	Environmental set-up	Environmental and patient set-up	-	-	✓	16 (7.96%)	Domain-specific *Vestibular* *Oculomotor* *Neurological* *Effort*	*"A barrier for gait and tandem gait is kind of having enough space where you can see them walking on on the screen too. So probably back to that camera umm set up and everything and then making sure there's enough space in their house so they can actually do a a long enough walk that you can see any abnormalities too." (C6 – Q9)*
Technology level	Technology and internet	Healthcare system barriers	✓	32 (19.75%)	-	41 (20.40%)	-	*"the Internet stuff because I I have a hard time doing computers right now and due to vision loss and stuff and I just forget how to do it. So, um that's something that's, if I didn't have somebody here, I wouldn't have been, I wouldn't have been able to do it." (P3 - Q6)* *"I find the eye tests are the the most challenging and mainly it's you know, it's whose finger to follow is 1 but also the resolution especially if depending on on the quality of their camera it's the hardest and the closer they get to the screen of course the more blurry it becomes to them also, so it's really hard." (C10 – Q15)*
		Issues/lack comfort with technology and internet	✓		-		-	
		Format of required documents	✓		-		-	
		Technical and internet issues	-		✓		Domain-specific *Oculomotor* *Neurological*	
		Camera and device limitations	-		✓		Domain-specific *Vestibular* *Oculomotor* *Neurological*	
	Accuracy/ completeness of physical exam	Incomplete evaluation/lack accuracy	✓	56 (34.57%)	-	53 (26.37%)	-	*"I have only had one in person um assessment with both OT and the doctor. And it was like like very hands on compared to any of the other assessments before. The other assessments like that were online kind of just felt like we were going through a checklist to make sure like you know, nothing's like terrible condition, but the one in person, for sure, that felt longer and more in depth." (P8 - Q5)*
		Lacking physical contact	✓		-		-	
		Unable to complete assessment in entirety	-		✓		Domain-specific *Vestibular* *Oculomotor* *Cervical*	

							Neurological	*"If you're gonna do this, you're gonna have them walk by the camera and and you sort of say, ok, now aim the camera down at your feet as you're walking or that, go back far enough there just really isn't enough space for that, camera is not wide enough and whatnot or or goes low enough to really get a good assessment. You can get a generally gestalt of it, but I don't think it's an accurate assessment." (C1 - Q13)*
		Lack accuracy	-		✓		Domain-specific *Vestibular* *Oculomotor* *Cervical* *Neurological*	
		Unable to assess certain conditions and subtleties	-		✓		Domain-specific *Vestibular* *Oculomotor* *Cervical* *Neurological*	
	Visibility	Visibility	-	-	✓	28 (13.93%)	Domain-specific *Vestibular* *Oculomotor* *Cervical* *Neurological*	*"It's the visibility of of, you know, trying to count errors on on camera." (C2 – Q14)*

- : not identified/not applicable; **C:** Clinician-participant; **P:** Patient-participant; **Q:** Quote

Table 4. Ranking of barriers reported by patient- and clinician-participants

Barrier	**Patient-Participant Rank**	**Clinician-Participant Rank**
Accuracy/ completeness of physical exam		
Communication and engagement		
Technology and internet		
Environmental set-up- Organizational Level		
Triggering physical and emotional symptoms		
Safety		
Clinical process-related factors		
Comfort		
Environmental set-up- Individual Level		
Visibility		

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Patient-Participant Barriers

Organizational Level

Patient-participants reported some issues with being in a province different from that of the assessing clinician. For example, some professional associations require clinicians to be licensed to practice in the province in which the patient is located for the virtual assessment (patient may be located in Quebec and the clinician located in Ontario). Participants further voiced concerns regarding privacy associated with using a videoconferencing platform including fear of people overhearing conversations and concerns regarding the security of the videoconferencing platform (Q1).

Individual Level

Patients-participants expressed safety concerns (Q2). Participants believed that certain components of the assessment would feel safer when done in-person, specifically the balance tests. They believed this would have an impact on the results; participants felt that they could "*perform better*" and "*push out of their comfort zone*" with the in-person assessments when compared to the virtual assessments.

Patient-participants felt that virtual assessments could activate physical and emotional symptoms. Use of screens was commonly reported to trigger physical concussion symptoms (headaches, dizziness, vision issues, etc.) (Q3). Feelings of isolation and depression could be increased during virtual assessment: "*you do feel very isolated*" and "*you are all alone and it gets very depressing*".

Patient-participants also reported challenges communicating issues related to their condition and challenges building rapport with their clinicians through videoconferencing platforms (Q4).

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Technology Level

A barrier identified included the perspective that less accurate information is obtained with the virtual assessment and the perspective that the virtual assessment is incomplete. The participants perceived that clinicians were unable to see subtle issues associated with their condition, such as "*eye twitches*" or "*tremors*". Participants perceived the in-person examination to feel more in-depth and hands-on whereas the virtual assessment felt unfinished (Q5). Furthermore, participants expressed a lack of physical contact with the virtual assessment, which seemed to be particularly noticeable for the cervical spine examination.

Participants reported issues with internet connection and with the videoconferencing platforms used for the virtual assessment. Different clinicians using different platforms, videoconferencing platforms that are difficult to use, and the format of the required documents, such as needing to complete online questionnaires, were identified challenges to completing the virtual assessment (Q6).

Clinician-Participant Barriers

Organization Level

Lack of time (due to the additional time required to set the patient up correctly on the screen in a virtual appointment) and lengthy clinical measures were identified as domain-specific barriers (Q7). Challenges due to lack of administrative support to aid with the virtual assessment process was identified as a barrier, which also relates to the processes in the clinical setting.

Individual Level

Safety concerns were expressed with all balance measures and components of the neurological examination (e.g., pronator drift due to a need for the patient to close their eyes during the test, functional squat) by clinician-participants (Q8).

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Environmental and patient-set-up was identified as a domain-specific barrier. Specifically, clinicians reported challenges with the patients' environment, such as lacking space, and challenges getting patients in appropriate positions to complete clinical measures (Q9).

Clinicians reported that computer screens can trigger physical concussion symptoms, which makes it challenging to complete a comprehensive assessment virtually, representing a general barrier. Clinicians expressed that patients have minimal tolerance to screens, which leads to a need to take frequent breaks (Q10).

Clinicians identified challenges with communicating with patients through screens, including challenges with explaining how to complete a measure virtually and challenges associated with building rapport and forming connections with patients, reflecting a general barrier (Q11).

Lack of patient comfort with the virtual assessment and clinician stress/frustration associated with completing the virtual assessment due to technical challenges were identified as barriers. The importance of patient comfort was particularly relevant to the discussion regarding the evaluation of effort (observing if the patient is performing at optimal capacity) in a virtual assessment. Clinicians reported that due to the lack of comfort and confounding factors (i.e., fatigue, symptom aggravation associated with the screen, unclear picture), it would be very challenging to draw conclusions regarding effort employed in a virtual assessment (Q12).

Technology Level

A domain-specific barrier identified by clinician-participants included an inability to complete the physical examination in its entirety. For example, clinicians reported an inability to complete a full cranial nerve examination (part of the neurological examination) virtually and an inability to touch a patient's neck when completing cervical spine palpation. Clinicians also

questioned accuracy for certain measures (such as the modified Balance Error Scoring System and oculomotor tests) when administered virtually (Q13). Furthermore, clinicians expressed challenges associated with identifying subtle deficits experienced by patients and an inability to assess comorbid conditions. Most of these were limitations identified due to the quality of current technology (clarity of the image on the screen).

Clinicians identified an inability to get an understanding of the full picture, such as missing body language cues due to only being able to see a patient's upper body. Camera limitations were discussed (Q14).

Camera, device, and internet issues were identified as general barriers to completion of the virtual assessment. Unstable internet, use of different devices (particularly mobile phones), and positioning of the camera were all barriers identified that could influence the quality of the virtual assessment (Q15).

Facilitators

Table 5 presents the facilitators for both the patient- and clinician-participants. Rankings associated with the facilitators reported by the patient- and clinician-participants are presented in Table 6. The information is presented in the same format as it is for barriers, as described above. A figure presentation of the overarching themes, sub-themes, and codes are presented in Appendix A (patient-participants) and B (clinician-participants). Definitions of the sub-themes associated with tables 3 and 5 are presented in Appendices C and D, respectively.

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Table 5. Patient- and clinician-participant facilitators

Aggregated domains	Overarching Themes	Sub-themes	Patient		Clinicians			Quote Examples
			Identified by Patient-participant	Frequency (Percentage) of Times Patients Reported (out of a total of 154 themes mentioned)	Identified by Clinician-participant	Frequency (Percentage) of Times Clinicians Reported (out of a total of 151 themes mentioned)	Clinician Categories	
Organizational level	Format of delivered care and material	Use of functions available on the virtual platform	✓	23 (14.94%)	-	29 (19.21%)	-	*"One thing I would suggest is, for things like the neurology appointment, I know I think it would be good if someone could just go um be comfortable just for your appointment, be comfortable. We might need to do this, this, because then, for me, it sounds like for you know, we wanna appreciate the person's time and also like I'm setting up and making sure things are like, you know, whatever, like, please if I need to do this so having knowing kind of what your spatial requirements are gonna be might be a good idea. Just so that it can help us" (P2 – Q17)* *"I find that a lot of times the patient gets on to the appointments virtually and they have this sense of anxiety because they don't know what they're going to go through in the assessment. They don't know how long it's going to last. They don't know how taxing is going to be for those who are severely concussed it can be incredibly taxing. So, I find just having a basic outline that we'll be doing some some history taking some brief history taking some some measurements range of motion and that sort of thing, Balance testing, whatever it is we're going to be testing just to give them an advance." (C5 - Q22)*
		Introduction to technology and resources	✓		✓		Domain-specific *Vestibular* *Oculomotor* *Cervical* *Neurological*	
		Integration and patient-selection of virtual	✓		✓		General	
	Support	Opportunity to involve more care team members	✓	42 (27.27%)	-	21 (13.91%)	-	*"But I do find that when you are having technical difficulties, that calling them and they'll send you a new link or whatever, or they'll even call you on the phone umm to do your appointments just by voice, which helps me a lot as well" (P3 – Q16)* *"I've done this where an occupational therapist helped me with the eye exam. It it was so much. I felt so much more confident. In what we were testing" (C11 - Q24)*
		Easy contact with clinician/technical support	✓		-		-	
		Support	-		✓		Domain-specific *Vestibular* *Oculomotor* *Neurological*	
		Cost saving	✓		-		-	

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		Travel	✓		-		-	
	Use of resources	Use of resources to complete assessment	-	-	✓	25 (16.56%)	Domain-specific *Vestibular* *Oculomotor* *Cervical* *Neurological*	*"The only way you could do this would be with some sort of app, that sort of, uh, can detect that that, that, that pupil or whatnot and then track it for you on the screen as you're, they're doing it." (C1 - Q23)*
Individual level	Symptom management	Offering symptom management strategies	✓	11 (7.14%)	-	-	-	*"During our appointments, we were taught about the blue light ah and certain glasses we can wear during virtual, and then we made-up a rule cause I was always very stubborn at first with my injury and I really like to make eye contact through virtual. I thought it made it look more professional and how it should be. And they told me you don't need to do that because you are a patient. And so, we did 20 seconds looking at the, looking at the person speaking to you and then nobody will be offended if you look 2 minutes at your wall. So, 20 seconds, 2 minutes. Whenever you start feeling symptoms." (P7 - Q19)*
	Support	Home support	✓	42 (27.27%)	-	21 (13.91%)	-	*"I still have to do the balancing stuff, but I always make sure that somebody is here with me um that my partner is here with me so he can, if something happens." (P3 – Q20)* *"For some patients, if they have like a, you know, a partner or family member or somebody that you know, you can just ask to come for the physical exam, right? You ask them to just, you know, bring them along. And that helps with some of the safety aspects of it." (C4 - Q26)*
		Support	-		✓		Domain-specific *Vestibular* *Oculomotor* *Neurological*	
	Environmental set-up	Environmental and patient set-up	-	-	✓	16 (10.60%)	Domain-specific *Vestibular* *Oculomotor* *Neurological* *Effort*	*"I think sometimes actually just having like a shoe box and a laptop is pretty helpful cause the shoebox lets the laptop be up at more eye height." (C5 - Q27)*
Technology level	Use of measure to identify gross deficits	Use of measure as global screen and rely on subjective information	-	-	✓	24 (15.89%)	Domain-specific *Vestibular* *Oculomotor* *Cervical* *Neurological*	*"I would say I would say that like eye movements was is really like in my practice a a screen to make sure that they have eye movement, didn't have some kind of odd, you know like palsy, right. But beyond that, it just really you can't really interpret much more. Virtual." (C4 - Q29)*

- : not identified/not applicable; **C:** Clinician-participant; **P**: Patient-participant; **Q**: Quote

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Table 6. Ranking of facilitators reported by patient- and clinician-participants

Facilitator	Patient-Participant Rank	Clinician-Participant Rank
Support- Individual Level		
Support- Organizational Level		
Format of delivered care and material		
Symptom management		
Use of resources		
Environmental set-up		
Use of measure to identify gross deficits		

Table 7 presents the clinician- and patient-participant identified benefits associated with the virtual concussion assessment. While not necessarily facilitators to the use of virtual assessments, the participants identified some benefits to this approach. The information is presented in the same format as it is for the barriers and facilitators, as described above.

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Table 7. Patient- and clinician-participant virtual care benefits

Aggregated domains	Overarching Themes	Sub-themes	Patient		Clinician			Quote Examples
			Identified by Patient-participant	Frequency (Percentage) of Times Patients Reported (out of a total of 80 themes mentioned)	Identified by Clinician-participant	Frequency (Percentage) of Times Clinicians Reported (out of a total of 22 themes mentioned)	Clinician Categories	
Organizational level	Access	Improved access	-	36 (45.00%)	✓	15 (68.18%)	General	*"I also had difficult to, traveling the distance because I live a far ways away. So it was, you know, it was nicer to have the virtual just because I didn't have to travel" (P6 - Q9).* *"I found that virtual assessments also allowed for patients who couldn't necessarily drive due to symptoms it facilitates having quicker access as well as, you know, being at least able to check in on them." (C3 - Q25)*
		Cost saving	✓		-		-	
		Travel	✓		-		-	
Technology level	Convenience, comfort and ease	Sense of it being easier and more convenient at home	✓	44 (55.00%)	✓	7 (31.81%)	General	*"it's convenient. It was very convenient to take it in the house and not have to go anywhere and they like again, it was a negative partly, but also a positive was the comfort I felt in my own home. I did feel better, my symptoms were I'd say better than they would have been in the hospital. And. Yeah. So, I think that it was like I, yeah, yeah, I I felt I feel safer and more comfortable in my home." (P11 – Q21)* *"It could be easier to reach out to them a little bit earlier in the process because there aren't those barriers are of, you know, having to book an in-person appointment, them having to find transportation or having to find support to be brought in. So, they're in the comfort of their own homes and it's better for them in terms of their recovery because for a lot of these patients coming in is like a 1/2 day or a full day process." (C11 - Q28)*

- : not identified/not applicable; **C:** Clinician-participant; **P**: Patient-participant; **Q**: Quote

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Patient-Participant Facilitators and Benefits

Organizational Level

A facilitator identified by the participants included having another healthcare professional in-person with them (if in clinic), such as an occupational therapist, while the physician completed the virtual examination. Participants expressed that having easy access to technical support, when needed, would be helpful in troubleshooting technical difficulties and easing feelings of anxiety (Q16).

Having a choice of device used in the virtual assessment, being prepared in advance of the assessment and using the features that videoconferencing offers (such as the record function) were facilitators identified by the patient-participants that all relate to the process and format in which the assessment is delivered. Specifically, participants reported that having the ability to choose the device and screen size used for the virtual assessment would encourage use of the virtual assessment. Participants felt that having at least one in-person assessment, reflecting a hybrid approach, was helpful to enhance their feelings of comfort with the virtual assessment. Advanced preparation was another key facilitator identified. Participants felt that being contacted prior to the assessment and being provided with information regarding what to expect would be helpful (Q17).

Having easy access to care was a benefit of virtual assessment use. Participants valued having access to care especially when they were unable to attend in-person assessments due to various reasons (COVID-19 restrictions, comorbidities, unable to drive, etc.) (Q18).

Individual Level

Implementing symptom management strategies throughout the virtual assessment was identified as a facilitator. When clinicians offered screen breaks or recommended symptom

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management strategies to use during the assessment, such as using blue light glasses, the virtual assessments were more manageable for participants (Q19).

Having equipment such as a chair or another person (partner, family member) at home were facilitators related to both the individual and organization level aggregate domains identified by patient-participants. Participants reported feeling safe completing their assessments at home with these safety measures in place (Q20).

Technology Level

A sense of ease, comfort and control with virtual assessments was expressed as a benefit. Specifically, feeling as though care was not jeopardized when assessed virtually, and a sense of virtual assessments being more convenient, comfortable, and requiring less energy were all facilitators identified (Q21). Furthermore, the participants felt that they could be more independent with the virtual approach (e.g., not rely on others to drive to be able to attend an assessment) and could control their environments better at home when compared to a hospital or clinic setting.

Clinician-Participant Facilitators and Benefits

Organization Level

Adequate preparation and integration of the virtual assessment with the in-person assessment (hybrid approach to care where the virtual option is available, if needed) were identified domain-specific facilitators. Clinicians expressed that sending information in advance of the assessment and informing patients of what to expect improved ease of completing a virtual assessment (Q22). Additionally, having a back-up in case the primary connection for the virtual assessment failed would help with the flow of the virtual assessment. These facilitators relate to the format in which the assessment and material needed for the assessment are delivered.

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Using resources to support administration of certain measures virtually, such as mobile applications that can measure cervical spine angles or eye movements or systems that could analyze vestibular deficits, were identified as domain-specific facilitators by clinicians (Q23). For example, there are applications (such as HeadCheck) that clinicians reported using in their virtual practice that provide objective information on eye movements.

A domain-specific facilitator identified by the clinician-participants included having access to clinical support in-person. Clinicians reported that this would be particularly helpful due to safety concerns and due to challenges seeing subtleties over camera (Q24).

Clinicians reported the benefit of improved access to care that virtual care provides. Clinicians perceived that virtual assessment approaches could eliminate the need for patients to drive to assessment centers (or rely on a family member to drive) and perceived that this could facilitate easier and quicker access to care for the patient (Q25).

Individual Level

Similar to patient-participants, clinicians expressed that holding onto a physical support (e.g., chair, wall, another person) facilitated administration of certain measures virtually and was expressed as useful for most domains of the physical examination. Further, access to emotional and technical support (family member, partner) at home could help with virtual assessment process. This also allows clinicians to gain the family member perspective, which could aid in getting collateral information and obtaining a more comprehensive understanding of clinical status (Q26).

Having an appropriate space to complete the virtual assessment at home and appropriately setting up the patient on the screen were identified as domain-specific facilitators. Clinician-participants identified strategies, such as placing the computer on a shoebox and asking

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the patient to stand in a corner to complete certain measures, such as balance tests, virtually, would facilitate completion of the physical examination (Q27).

Technology Level

Clinicians reported a sense of ease, comfort and convenience with virtual assessments. Particularly, they expressed that the virtual assessment allows patients to be in the comfort of their homes and eliminates some of the obstacles that need to be overcome to get to assessment centers (time, driving, costs), which relates to a general benefit (Q28).

Clinician-participants reported that using most of the measures to identify gross deficits (rather than specific deficits) or that using some of the measures for subjective information rather than objective information was a facilitator to its use in a virtual context (Q29). For example, when using the modified Balance Error Scoring System, clinicians reported that counting errors is a challenge over camera, so the measure is administered to identify gross balance deficits rather than identify subtle issues. Similarly, when administering the Vestibular/Ocular Motor Screening tool, clinicians rely on subjective reports of symptom changes and do not use this measure to identify specific ocular or vestibular issues.

Clinician-Selection of Measures that Would Work Best in Virtual Assessments

The frequency of selection of each clinical measure is presented in Table 8. Within their respective domains, clinicians identified the finger-to-nose test, balance testing, the Vestibular/Ocular Motor Screening, saccades, and cervical spine range of motion as the measures that would work best and give the most relevant information in their virtual practice out of the list of measures provided.

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Table 8. Clinician-selection of measures that would work best in virtual practice within the respective domains

Domain	Measures	Description of Measures	Frequency of Selection
Neurological Examination	Coordination: finger-to-nose; Rapid alternating movements	Finger-to-nose: patient extends arm, and touches examiner's outstretched finger then touches patient's nose Rapid alternating movements: patient alternately taps the back and palm surface of one hand onto the other hand; Toe tapping: patient repeatedly taps foot on floor [36]	9
	Motor (pronator drift, functional squat)	Pronator Drift: stretch both arms forward, with palms facing upward, and eyes closed [36] Functional squat: Observe perform 10 body-weight squats [37]	3
	Cranial nerve	I: Smell object II: Read Snellen chart (chart with varying sized letters; cover one eye), Ask patient to look at your eyes, place hands on both sides of patient's head with index fingers extended, ask patient to indicate which finger you move (left or right) Fundoscopy exam: Clinician views eye using ophthalmoscope III, IV, VI: Eye movements: pursuit (follow moving target), convergence (eyes move at same time, such as observing an object nearing the patient's nose), saccades (alternate gaze between right and left, and up and down targets) V: Facial sensation: light touch, pinprick both sides; clench teeth, open jaw against resistance VII: Facial movements (show teeth, whistle, close eyes tightly) VIII: Hearing test (tuning fork), test balance, gait test for nystagmus (beating/twitching of eyes) IX, X: Voice (say 'ah' with tongue depressor), swallowing, cough, gag reflex XI: Shrug shoulders, turning head left and right (against resistance) XII: Open mouth, stick out tongue [36]	1
Vestibular	Balance (feet together, single leg stance, tandem stance)	Feet together: Standing with feet together. Time-based tests. Single leg stance: Standing on one leg, eyes open and eyes closed. Time-based tests. Tandem stance: Stand in heel to toe stance, eyes closed. Time-based test [38]	9
	VOMS	Smooth pursuits: Patient maintains focus on the target as the examiner moves the target smoothly in the horizontal and vertical direction. Saccades: The examiner holds two single points horizontally. Instruct the patient to move their eyes as quickly as possible from point to point. Repeat the test with 2 points held vertically. Convergence: The patient focuses on a target and slowly brings it toward the tip of their nose. Vestibular-Ocular Reflex: The patient is asked to rotate their head horizontally while maintaining focus on the target. The test is repeated vertically. Visual Motion Sensitivity: The patient holds arm outstretched and focuses on their thumbs. Patient rotates, together as a unit, their head, eyes and trunk to the right and left [39]	9
	Romberg	Stand with feet together on a flat, hard surface. The examinee asked to stand still and keep their eyes open for about 30 seconds. Next, the examinee asked to close their eyes and stand for 30 seconds. Time-based test [36]	3
	VOR test	Move head quickly side to side; repeat up & down [36]	3
	Gait/Tandem gait	Observe patient walk. Observe heel-to-toe walk [36]	1
	mBESS	Single leg stance (stand on one leg), tandem (stand in heel to toe position), and double leg stance (stand feet together) on flat ground and foam surfaces, with eyes closed. Examiner records errors during each condition (open eyes, lift hands off hips, etc.) [40]	0
Oculomotor	Saccades	Rapid movement of eyes between fixed points. Instruct the patient to look from one target to the other as quickly as possible – vertical and horizontal [41]	7
	Smooth pursuits	Pursuits are performed in H pattern. Participants track object [42]	5
	Convergence	Use a pencil, placed just above the nose between the eyes. Move the target toward the patient at a rate of about 1-2cm/s, encouraging them to keep the target single. Measure the patient's reported subjective break (target becomes double) in centimeters. Measure in centimeters [43]	2
Cervical	Range of motion	Active range of motion: head turn left, right, up, down, side flexion left and right [38]	13
	Self-Palpation	Patient feels with fingers and hands during physical examination of neck [38]	2

mBESS: modified Balance Error Scoring System; **VOMS**: Vestibular Ocular Motor Screening; **VOR**: Vestibular Ocular Reflex

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Discussion

This study used focus groups to identify barriers and facilitators associated with virtual concussion assessments. To our knowledge, this work is the first to explore the barriers and facilitators associated with virtual concussion assessments from the perspectives of people living with workplace concussions. The findings of this study support that a hybrid approach (first assessment completed in-person then follow-ups completed virtually) to concussion assessment is preferred by both people living with workplace concussions and clinicians. It appears that the virtual approach to concussion assessment is of value, highlighting a need to further explore and consolidate information on the effectiveness of the clinical measures used in concussion assessments when administered virtually. People living with workplace concussions seem to prefer having the initial assessment with the care team in-person, followed by virtual assessments as needed. Virtual assessments were perceived as most appropriate for follow-ups and for a global screen of deficits rather than for identifying specific deficits.

In this study, overlapping themes were identified for both clinician and patient-participants. Interestingly, both clinicians and patients commented on difficulties associated with completing the required documents (questionnaires) virtually. Both expressed a need to verbally complete the required documents with the patients over the phone or have support in place so that they have help to complete them prior to the virtual assessment. This is in line with Beaton et al. [44] , who documented that the preferred method of information delivery for people living with concussion is in auditory format.

Both clinicians and people living with workplace concussions highlighted that inaccurate values may be obtained with the virtual assessment, which was the most common barrier identified (identified by patient- and clinician-participants ~35% and 26% of the time).

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Objectivity in assessments conducted using virtual care is a challenge, especially with the lack of clarity when observing certain movements through videoconferencing, which in turn influences clinicians' abilities to adequately assess patients [24] . Virtual care has been used for the management of concussions; however, an identified limitation is the challenge associated with the remote physical examination [24] . Subtle abnormalities such as those observed during objective oculomotor assessments could be difficult to capture through videoconferencing [7] . Furthermore, a neurological examination in its entirety is not currently feasible through videoconferencing [45,46] . Particularly, a complete evaluation of the cranial nerves (fundoscopy) cannot be completed along with motor and sensory function, cervical spine palpation, strength testing, muscle reflexes, and neuro-otology maneuvers such as those for vertigo [7,15,37,47] . Both clinicians and patients expressed challenges associated with using technology, including the virtual approach to assessment can be symptom-triggering, safety concerns with the virtual assessment in relation to potential for falling, challenges with the set-up at home, and barriers associated with communicating and establishing a clinician-patient rapport through a screen.

This study identified technical, individual and organizational-level barriers that are in line with some of the current literature on virtual care in people living with neurological conditions. Ownsworth et al. [48] reported limitations associated with videoconferencing specifically, which include issues with technology and incompatibility for the patient (inability to use technology). Technical issues such as poor video or audio quality due to either varying quality of devices used or WIFI signal strength, and difficulty placing the camera are identified barriers specific to videoconferencing [11] . Logistical challenges when a caregiver is not present at home to aid with the virtual session contributes to the non-feasibility of virtual care approaches

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[13] . Concerns of lack of security and concerns regarding privacy in terms of family members overhearing sessions are described barriers [11] , which was an expressed concern by patient-participants in this study. Consistent with the findings of this study, the literature documented that lack of resources including lack of access to needed administrative or skilled personnel support, and lack of time, as virtual assessments are perceived to take more time to appropriately set up the patient, influence the feasibility and use of videoconferencing approaches [49] . A limitation associated with virtual assessments identified by the participants in this study includes lack of physical presence [48] . Lack of physical presence has been documented to be associated with challenges in terms of building rapport when not face-to-face as well as an inability to gain a full understanding of the patient's status [48] . The patient-clinician relationship may be jeopardized if technologies are used due to the difficulties associated with building trust through screens and the challenges of clear communication [15,45,47] .

From a facilitation standpoint, both the clinicians and people living with workplace concussions in this study highlighted the convenience and improved access that virtual assessments provide. Both groups emphasized the need to have appropriate supports and preparation in place, however, only the patient-participants identified this as the most common facilitator (identified ~27% of the time). The patient-participants in this study identified the importance of having easy access to technical support. This is in line with Hale-Gallardo at al. [13] who reported that virtual care coordinators and technical clinicians are viewed as resources that could facilitate the adoption of technology-based care in clinical practice. Having assistants help setup the system is a necessary facilitator to videoconferencing [16] . Family support is additionally viewed as a facilitator due to the help they provided with the technical and clinical aspects of the videoconferencing, [11] . The increased likelihood of family members being

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present during videoconferencing is an advantage, which could aid with gathering information [50] . This is also helpful to aid with remembering recommendations and next steps of care. Clinician-participants identified the format of the assessment and materials (adequate preparation, integration of the virtual with the in-person assessment) as the most common facilitator (identified ~19% of the time). Development of clear instructions and advanced planning to prepare for issues, are all necessary facilitators to videoconferencing [16] . The importance of having an initial in-person touchpoint and preference for the hybrid approach was highlighted in the literature. This approach enhances the comfort of the patient with the clinician [11] . Clinician and patient understanding of the benefits of virtual approaches to care, which includes cost-savings, autonomy for the user, and reduced travel and wait times act as a facilitators for use of technology-based approaches to assessment [11,16,47] .

Several unique findings of this study are specific to virtual assessment after concussion. Specifically, the challenges with completing the virtual assessment due to screen intolerance and resulting symptom aggravation were a notable barrier to engaging in a virtual assessment. Depending on the timepoint in recovery, exposure to screens could be a very challenging barrier to overcome to complete a safe and effective assessment virtually. One strategy to address this issue, which was identified as a facilitator by participants, was implementing symptom management strategies (screen breaks, blue light glasses) so that the virtual assessment could be more tolerable. Additionally, due to subtle deficits that are commonly experienced by people living with workplace concussions, virtual care approaches may not be currently adequate to capture these subtleties and therefore in-person care may be needed to identify issues that go beyond gross deficits. Further, there are potential contradictions with the focus group data. For example, balance and the VOMS were selected as the vestibular measures that would work best

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in virtual practice by the clinicians. However, several issues were identified with these measures such as the challenges with visualizing subtle deficits associated with eye movements and balance when assessing virtually. Even with these challenges, the clinicians still believed that out of the measures identified in the surveys and discussed in the focus groups, these measures would be most appropriate for virtual assessments.

This work expands on some of the previous work on the clinician-perspectives of virtual concussion care to outline barriers and facilitators to completing components of the physical examination [17] . Finally, this work reports on clinician-identified measures that will work best in a virtual context and identifies the barriers and facilitators associated with using these measures virtually so that the most appropriate measure for virtual administration can be selected. This work supports the identification of clinical measures to include in a virtual version of a concussion assessment, which will be further explored in a future planned evaluation study with the aim of documenting the psychometric properties of the measures. These measures will be included in a virtual assessment toolkit, which will be tested in the future study.

Limitations

There are some important limitations to acknowledge with this work. The context of this work is within workplace injury and all the patient-participants who participated in the focus groups were experiencing persistent symptoms post-injury at the time of their virtual assessment. Their experiences may be unique to those experiencing injuries occurring in the workplace and therefore the results may not be generalizable to people with concussions from other causes. Furthermore, only 27% of the patient-participants were male, which indicates that the results of this study may be more reflective of female experiences. However, Merritt et al. [51] reported that prevalence of concussions is higher in females, so the distribution of males and females in

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this study may be a close reflection of concussion occurrence in the working population. Additionally, while attempts were made to include clinicians from various clinical fields (while focusing on professions that typically complete the physical examination), certain professions were not represented in the focus groups such as neurology and occupational therapy. Finally, the selection of measures as most appropriate to use in a virtual assessment may be biased based on clinician experiences and practices. Clinician level of comfort with each clinical measure may have influenced their decisions.

Conclusion

It is important to note that patients and clinicians identify limitations and challenges associated with virtual care. A hybrid approach to concussion assessment seems to be the most accepted model to assessment from the perspectives of both clinicians and people living with workplace concussions. This study demonstrates the acceptance and perceived value of virtual approaches in concussion assessment and therefore supports the rationale for further exploration of the psychometric properties of the virtual concussion assessment. There is an identified need to establish reliability and validity properties of the virtual concussion examination.

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Declaration of Interest

The authors report there are no competing interests to declare.

Authors' contributions

KB, HS, and SM contributed to the development of the protocol, with supporting guidance from MB, ME, MB, MR, and MT. KB, HS, SM, MB, ME, MB, MR, MT reviewed and approved the protocol. KB moderated the focus group. MK participated as a note-taker in the focus groups. KB transcribed the focus groups. KB and MK coded the transcripts and generated the themes. KB drafted the manuscript. All authors reviewed and approved the final version of the manuscript.

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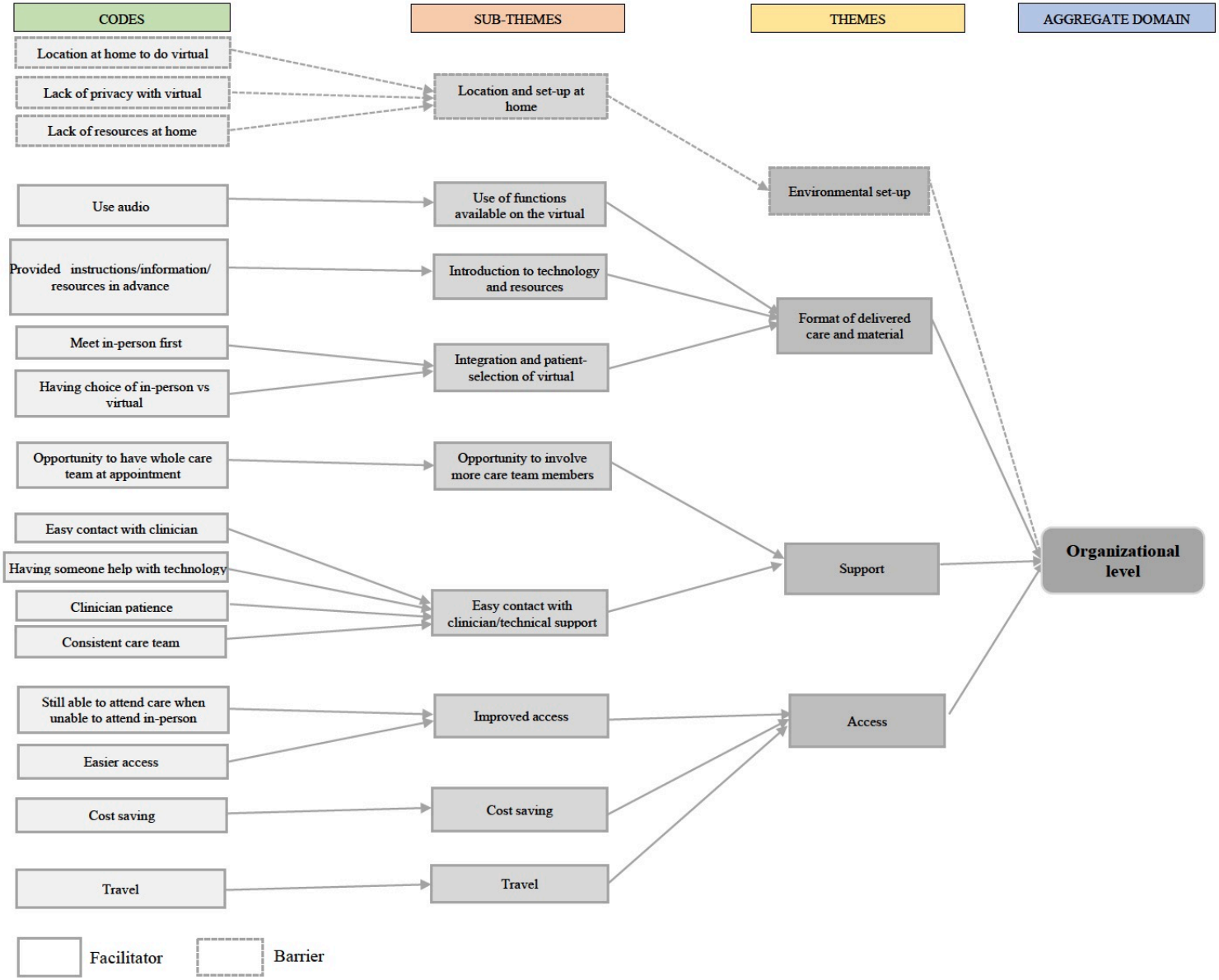
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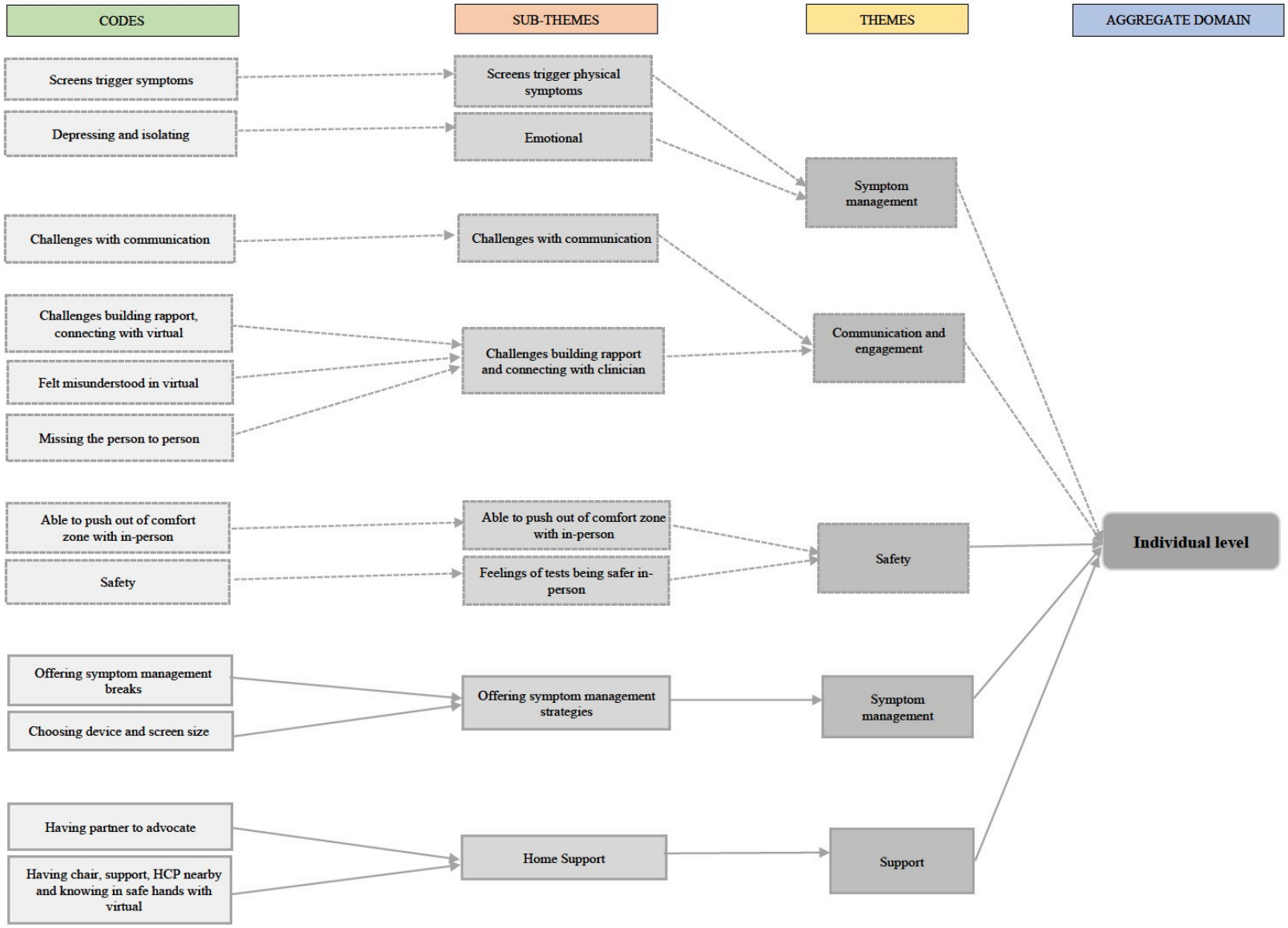
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Appendix A
Patient-Participant Overarching Themes, Sub-Themes and Codes

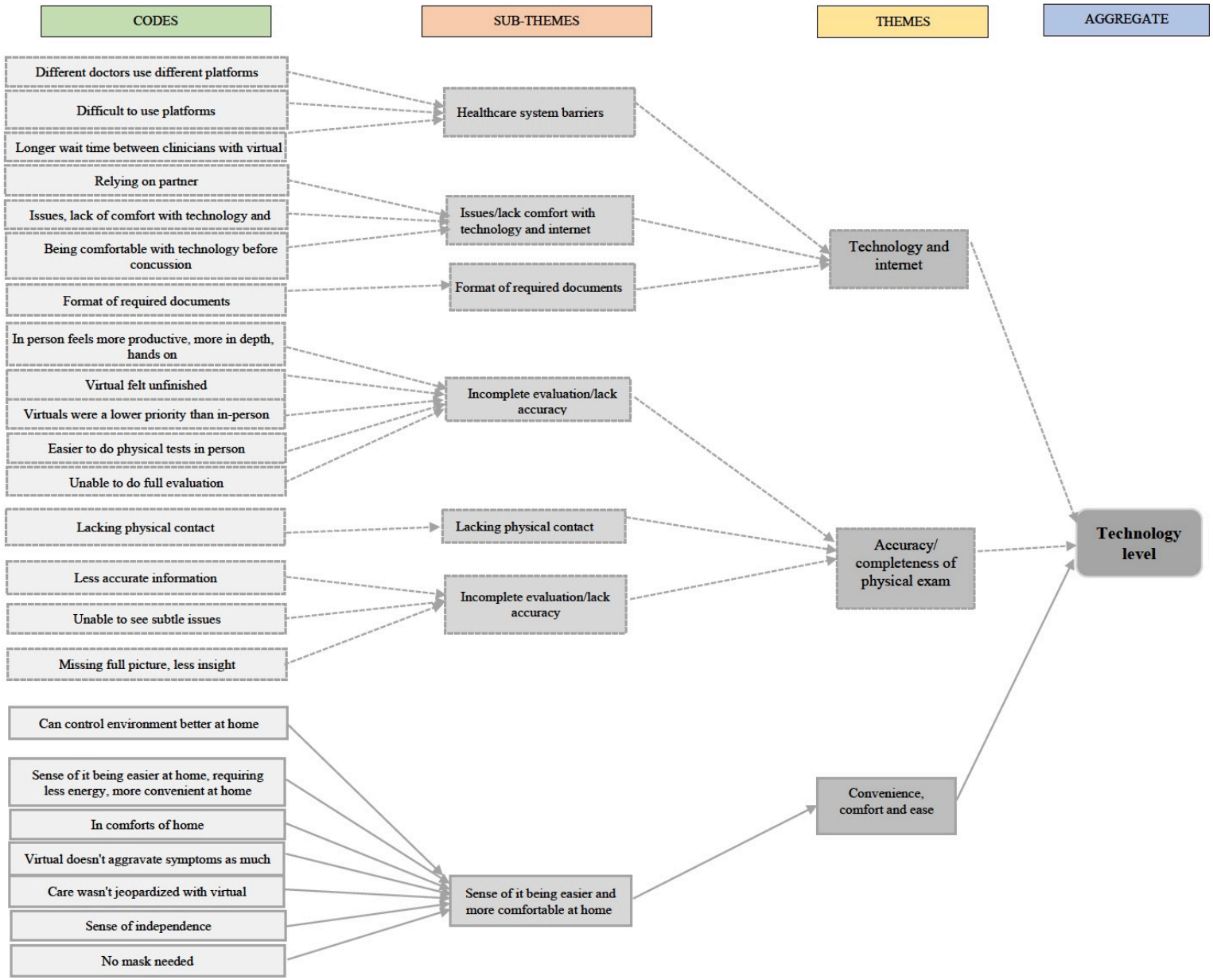
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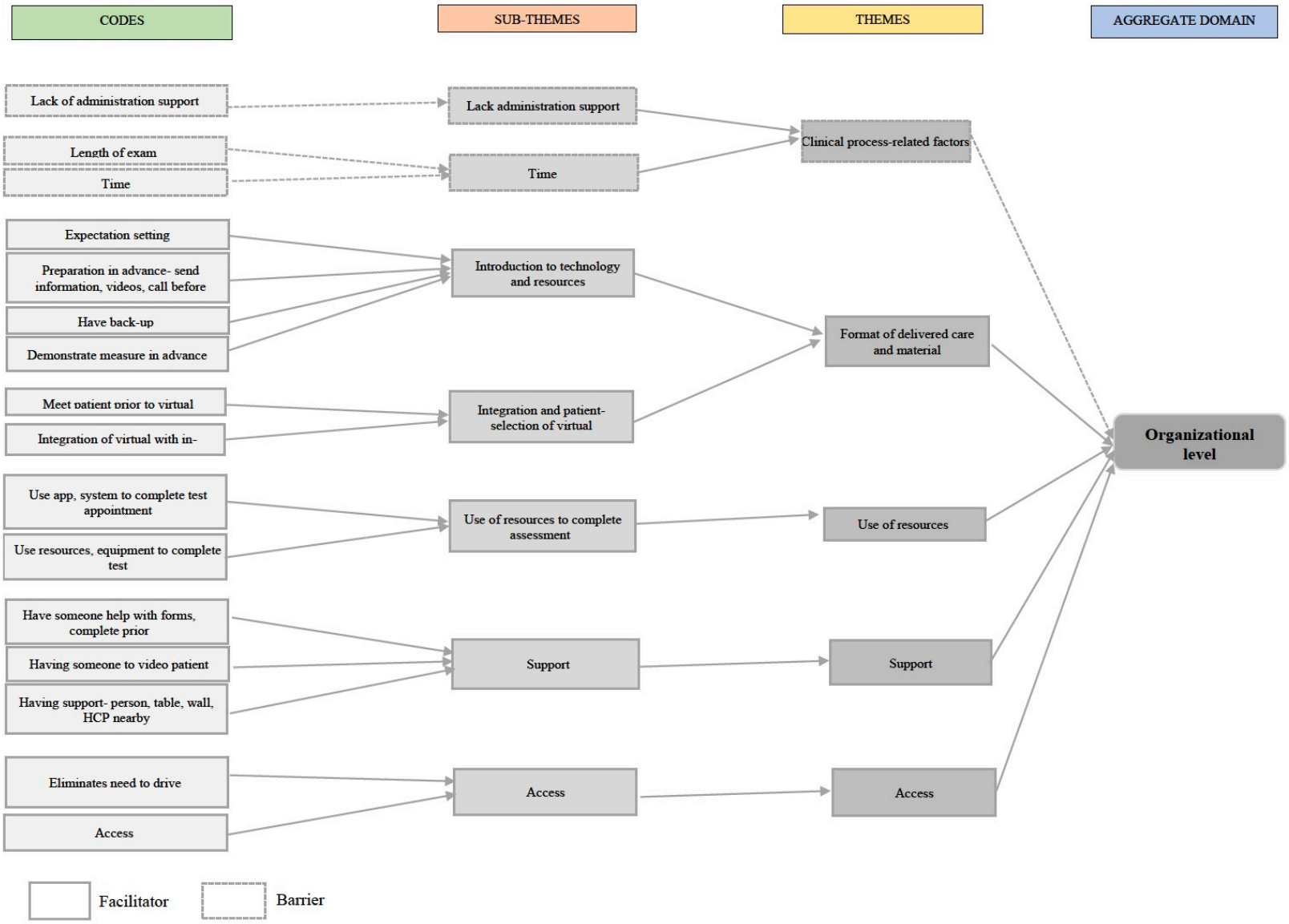
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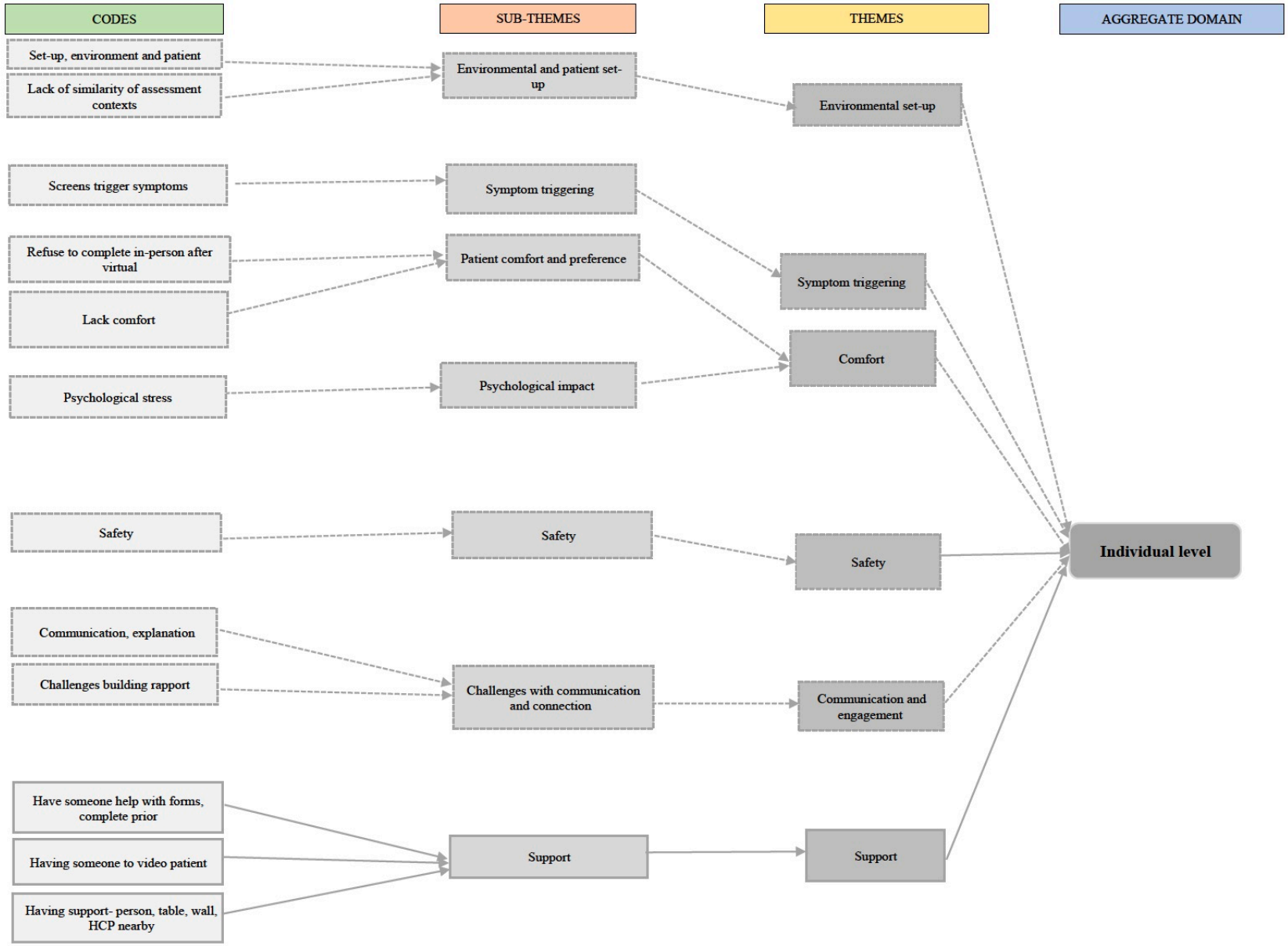
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Appendix B
Clinician Overarching Themes, Sub-Themes and Codes

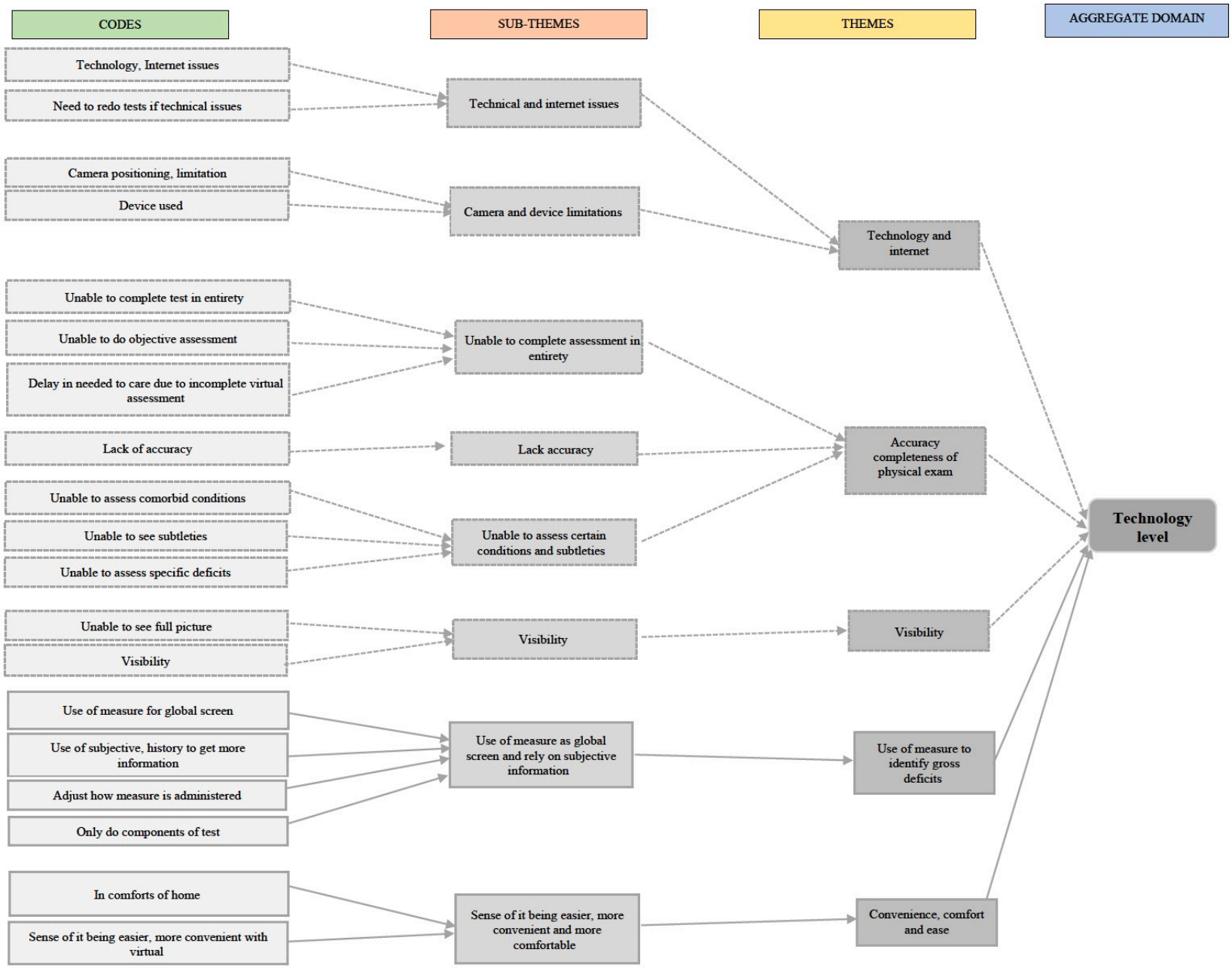
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Appendix C
Patient Sub-Theme Definitions

Sub-theme	Definition
Location and set-up at home	Having adequate space and an optimal set-up in the home environment
Use of functions available on the virtual platform	Use of recording function for later access to information
Introduction to technology and resources	Send information regarding what to expect with the virtual assessment and information about the assessment in advance
Integration and patient-selection of virtual	Having an in-person touchpoint prior to completing a virtual assessment and allowing the patient to use the device that will work best for them
Opportunity to involve more care team members	Patients are able to include more members involved in care at same appointment so that everyone is on the same page
Easy contact with clinician/technical support	Having someone that is available and easy to contact if needed for technical issues
Improved access	Improved access and easy access to care
Cost saving	Reduced cost associated with virtual assessment
Travel	No need to travel when attending virtual appointment
Screens trigger physical symptoms	Exposure to screens triggers concussive symptoms
Emotional	Feelings of isolation/depression when only attending virtual appointments
Challenges with communication	Difficulties communicating with clinicians through a screen
Challenges building rapport and connecting with clinician	Difficulties building rapport and connecting with clinicians through a screen
Able to push out of comfort zone with in-person	Feeling as though can push harder in terms of treatment and performance on tests in-person
Feelings of tests being safer in-person	Safety concerns (fall risk) while completing certain measures
Offering symptom management strategies	Being offered breaks and other symptom management strategies such as blue light glasses to aid with symptoms
Home support	Having a person at home or chair nearby for support
Healthcare system barriers	Longer wait times between clinicians with virtual care and different care teams use different virtual platforms
Issues/lack comfort with technology and internet	Challenges with connection due to internet issues
Format of required documents	Completing mandatory questionnaires online is more challenging than paper copies in-person

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Incomplete evaluation/lack accuracy	Ability to complete a full evaluation and accurately assess and identify deficits is lacking
Lacking physical contact	Unable to complete hands on evaluation such as touching the neck
Sense of it being easier and more convenient at home	Convenience and ease associated with the virtual assessment, along with improved comfort at home

Appendix D
Clinician Sub-Theme Definitions

Sub-Theme	Definition
Lack administrative support	Administrators are not always present to aid with technical difficulties
Time	Limited time to complete an assessment
Symptom triggering	Exposure to screens triggers concussive symptoms
Patient comfort and preference	Lack of patient comfort with a virtual assessment and preference for in-person for certain aspects of care
Psychological impact	Clinician-stress associated with dealing with technical issues in a virtual assessment
Challenges with communication and connection	Difficulties communicating with patients and building rapport through a screen
Lack accuracy	Ability to accurately assess and identify deficits is lacking
Environmental and patient set-up	Home environment of the patient (space, ability to position oneself on camera)
Visibility	Challenges seeing a patient on camera
Safety	Safety concerns (fall risk) while completing certain measures
Unable to assess certain conditions and subtleties	Difficulties assessing certain conditions such as vertigo and difficulties assessing subtleties such as nystagmus
Unable to complete assessment in entirety	Unable to complete hands on evaluation such as palpating the neck or completing a fundoscopy exam
Camera and device limitations	Limitations associated with the device the patient is using (phone) and camera quality issues
Technical and Internet issues	Challenges with connection due to internet issues
Support	Having a person at home or chair nearby for support
Use of resources to complete assessment	Use of mobile applications or videos to support the virtual assessment
Introduction to technology and resources	Send information regarding what to expect with the virtual assessment and information about the assessment in advance
Environmental and patient set-up	Having adequate space and an optimal set-up in the home environment
Use of measure as global screen and rely on subjective information	Using clinical measures as a screen of global deficits rather than as a measure of specific deficits and relying on subjective information provided by the patient rather than objective information

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Integration and patient-selection of virtual	Having an in-person touchpoint prior to completing a virtual assessment and allowing the patient to use the device that will work best for them
Access	Improved access and easy access to care
Sense of it being easier, more convenient and more comfortable	Convenience and ease associated with the virtual assessment, along with improved patient comfort at home

Chapter 5. Investigation of the Feasibility of Study Procedures to Estimate Sensitivity and Reliability of a Virtual Physical Assessment Developed for Workplace Concussions

Chapter 5 has been formatted based on the requirements of the peer-reviewed journal in which it was submitted.

Chapter 5 contains the results of the feasibility study, documenting feedback from clinician-assessors and patient-participants regarding the virtual assessment and documenting preliminary information regarding the sensitivity and reliability of the virtual assessment. The manuscript associated with Chapter 5 was submitted to the Journal of Medical Internet Research Formative Research on June 20, 2024. Minor revisions were requested on September 4, 2024. Revisions were submitted on September 18, 2024. It was accepted for publication on September 25, 2024. It is currently In Press.

Ethics approval was obtained from the Ottawa Health Sciences Network Research Ethics Board (20230311-01H) followed by the Bruyère Research Ethics Board (M16-22-006) and the University of Ottawa Board of Ethics (H-06-23-9348).

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Investigation of the Feasibility of Study Procedures to Estimate Sensitivity and Reliability of a Virtual Physical Assessment Developed for Workplace Concussions

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Abstract

Background: Virtual approaches to workplace concussion assessment have demonstrated value to end users. The feasibility of administering physical concussion assessment measures in a virtual context has been minimally explored and there is limited information on important psychometric properties of physical assessment measures used in virtual contexts.
Objectives: The objectives of this feasibility study were to: determine recruitment capability for a future larger-scale study aimed at determining sensitivity and reliability of the virtual assessment, time required to complete study assessments, acceptability of virtual assessment to people with brain injuries and clinicians, and to document preliminary results of sensitivity of the virtual assessment when compared to the in-person assessment and to estimate the preliminary inter-rater and intra-rater reliability of the virtual assessments to inform a future larger-scale study that is adequately powered to reliably estimate these parameters of interest.
Methods: People living with acquired brain injury attended two assessments (one in-person and one virtual) in a randomized order. The measures administered in these assessments included: the finger-to-nose test, balance testing, the Vestibular/Ocular Motor Screening (VOMS) tool including documentation of change in symptoms and distance for near point convergence (NPC), saccades, cervical spine range of motion, and evaluation of effort. Both assessments occurred at the Ottawa Hospital Rehabilitation Centre. After the assessments, a clinician different from the person who completed the original assessments then viewed and documented findings independently on the recordings of the virtual assessment. The same second clinician viewed the recording again approximately one month following initial observation.
Results: Rate of recruitment was 61% of people approached, with a total of 20 patient-participants included in the feasibility study. Three clinicians participated as assessors. Length of time required to complete the in-person and virtual assessment procedures averaged nine and 13 minutes, respectively. The majority of clinician and patient-participants agreed or strongly agreed that they were confident in the findings on both in-person and virtual assessments. Feedback obtained revolved around technology (e.g. screen size), lighting, and fatigue of participants in the second assessment. Preliminary estimates of sensitivity of the virtual assessment ranged from poor (finger-to-nose testing: 0.0) to excellent (NPC: 1.0). Preliminary estimates of reliability of the virtual assessment ranged from poor (balance testing, saccades, and range of motion: Kappa=0.38-0.49) to excellent (VOMS change in symptoms: Kappa=1.0).
Conclusion: The results of this feasibility study indicate that our study procedures are feasible and acceptable to participants. Certain measures show promising psychometric properties (reliability and sensitivity); however, wide confidence intervals limit the ability to draw definitive conclusions. A planned follow-up study will expand on this work and include a sufficiently large sample to estimate these important properties with acceptable precision.

Keywords: brain injury, virtual, assessment, remote, evaluation

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Introduction

Workplace concussions impose a significant burden on the healthcare system, insurance providers, employers, and injured workers [1]. Conducting effective assessments after a workplace concussion are important for guiding intervention and facilitating recovery [2]. In this context, it is crucial to use measures that accurately capture deficits experienced by workers who are reporting persisting symptoms post-concussion [3–5]. Ideally, an assessment should be comprehensive, consisting of measures that evaluate all domains including physical (i.e., cervical musculoskeletal and vestibulo-oculomotor function), cognitive, and socio-emotional that can be impaired by a concussion [6–8]. Furthermore, measures included in an assessment should be reliable, valid, sensitive, and possess clinical utility characteristics (practical, timely, low cost, minimal equipment, etc.) [3,9,10]. However, clinical concussion measures that excel in all these characteristics are limited.

Workplace concussions occur in both rural (1,400 per 100,000 people [11]) and urban populations. Virtual care offers an alternate approach to assessment that could be particularly beneficial for individuals living in rural areas who may experience challenges with attending in-person assessments allowing them to connect to experts that they may not have been able to access previously [12]. Virtual approaches to concussion assessment have demonstrated value to end-users (clinicians and patients), however, the feasibility of administering certain measures virtually and the accuracy of the findings from remote assessments has yet to be explored [13,14]. The lack of documented reliability and sensitivity properties associated with measures administered in virtual assessments of people with concussions poses a barrier to ongoing use and availability of these virtual assessments in practice. Further barriers to completing remote assessments include concerns regarding safety, environmental set-up, and the need for support at

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home [14–17]. While there are clear challenges to completing assessments, particularly physical assessments, at a distance, there are also many identified benefits [13,14].

A scoping review by O'Neil et al. [18] reported a notable gap in the documentation of psychometric properties of measures administered in a virtual context in people living with neurological conditions, including concussion. Agreement between in-person and virtual assessments has been explored for musculoskeletal measures [19,20] and minimally explored in people living with neurological conditions [21]. Palacin-Marin et al. [19] provides preliminary support for use of virtual means to administer certain measures related to low back pain such as evaluation of mobility and the visual analogue scale for pain. Specifically, intraclass correlation coefficient (ICC) values for inter-rater and intra-rater reliability ranged between 0.92 and 0.96 and the alpha reliability statistic was greater than 0.8 for the majority of measures when the virtual approach was compared to the in-person approach [19]. Similarly, Cabana et al. [20] examined the reliability of measures used for total knee arthroplasty. Measures, including knee range of motion, scar condition, knee joint swelling, lower limb muscle strength, Timed Up and Go test, Tinetti gait test, and Berg balance test, evaluated using a videoconferencing platform, demonstrated good reliability (>0.80), however levels of agreement ranged between -33% to 29% for measures of function and -20% to 8% for measures of knee range of motion [20]. Russell et al. [21] compared in-person and virtual physical measures for people living with Parkinson's Disease and reported that the physical assessment could be feasibly, reliably, and accurately completed using a telerehabilitation system. This previous work highlights a need and a value to further explore the feasibility associated with virtual administration of physical measures and to investigate the psychometric properties of the clinical measures administered remotely for individuals with concussion.

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With the COVID-19 pandemic, many clinicians have integrated virtual physical assessments into their practice. Yet, there there is limited research evaluating the feasibility, sensitivity, and reliability of the virtual concussion assessment. Using a systematic approach including focus groups [14], working group and expert consensus [22,23], we developed a clinical assessment for individuals with concussion. The assessment includes measures of balance, cervical spine mobility, coordination, and vestibular/ocular movements [14,22,23]. As an essential first step, prior to embarking on a full-scale study, we conducted a feasibility study. The primary feasibility objectives were to inform the methodology for a large-scale study. The feasibility measures include rate of recruitment of both patient and clinician-participants (willingness to participate to ensure capability of recruiting enough participants in a 1.5-year timeframe available for the larger-scale study), feedback regarding the assessment approaches in the study, and preliminary information on three psychometric properties of the measures included in the virtual assessment (inter-rater and intra-rater reliability [24], and sensitivity [25] when administered virtually compared to in-person). While this study was not designed to estimate the psychometric properties of the measures with sufficient precision, it will provide some preliminary information to inform a sample size calculation for the future large study [26]. The study design and analysis considerations for this study were informed by Russell et al. [27].

Methods

Ethics

Ethics approval was obtained from the Ottawa Health Sciences Network Research Ethics Board (20230311-01H) in June 2023 followed by the Bruyère Research Ethics Board (M16-22-006) and the University of Ottawa Board of Ethics (H-06-23-9348) in June and July 2023, respectively.

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Participants and Recruitment

Patient-Participants

People living with acquired brain injuries (ABIs) or concussions, were recruited from ABI outpatient clinics publicly funded or Worker Safety and Insurance Board (WSIB) clinics based out of the Ottawa Hospital Rehabilitation Centre (TOHRC). Inpatients from TOHRC ABI inpatient rehabilitation service were also recruited.

Eligible participants were adults aged 18 years or older, who were attending a scheduled outpatient assessment or who were admitted to the ward and were under the care of one of our study clinicians. In addition to people living with concussion, people living with other forms of ABIs (e.g. moderate to severe traumatic brain injury, hypoxia, etc. [28]) were recruited for this study. Given that normal findings are frequently observed on the neurological examination in people with concussion [29,30], the broader inclusion ensured that participants with identifiable positive findings on the neurological examination were represented in the sample. Participants unable to speak English or French and unable to complete both the in-person and virtual assessment procedures were excluded.

The electronic medical records of patients attending in-person appointments and the list of patients admitted to the ward were screened to identify eligible individuals who were then approached via telephone (outpatients) or face-to-face (inpatients) to discuss possible participation in the study. Patient-participants verbally consented over the telephone or provided informed consent in-person.

No sample size calculation was conducted for the feasibility study. Instead, we planned to recruit participants for a period of five months based on logistical considerations. The results from this feasibility study, including information regarding the number of participants who were

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abnormal on the measures included in the virtual assessment and preliminary estimates of sensitivity and reliability, were used to inform the sample size calculation for the larger-scale study. We plan to include the data from the feasibility study in the future larger-scale study, assuming the protocol does not need to be modified between the feasibility and definitive study.

Clinician-Participants

Clinicians employed at TOHRC, and actively completing ABI assessments were recruited to participate. Assessors were responsible for completing the study assessments and observing and rating recordings of completed assessments. Eligible clinicians were approached via telephone and consented over the telephone.

Training

The Virtual Concussion Exam Manual [31] was adapted and reviewed by all clinicians prior to their participation in the study. The manual contains clear instructions on administering clinical measures virtually. Clinicians were encouraged to consult the adapted manual for guidance while conducting study assessments.

In-Person and Virtual Assessments

Each patient-participant completed both the in-person and virtual assessment at TOHRC on the same day. The assessments were conducted during a scheduled in-person appointment for outpatients, or a specific appointment set up for inpatients. The two assessments were separated by a brief rest period [32] with additional rest time provided until the participant could complete the remainder of the measures.

The order of the assessments (in-person and virtual) was randomized and counter-balanced to ensure an equal number of participants completed the in-person and virtual assessments first. Randomization occurred through REDCap using a random numbers table. The

rationale was to equalize the influence of fatigue and learning effects on the subsequent assessment. The assessments consisted of the same clinical measures (Table 1).

Table 1: Outline of measures included in the virtual assessment, clinical decision for each measure, and guideline for clinical decision

Measure	Clinical Decision	Guideline for Decision	Reference
Finger-to-nose test	Normal or Abnormal	Abnormality considered hesitation, tremor, under or overshooting	[33]
Balance testing (feet together, single leg stance, tandem stance) for 20 seconds with eyes open and closed	Normal or Abnormal	Abnormality considered inability to hold the position for 20 seconds	[31]
Saccades	Normal or Abnormal	Abnormality determined by saccade speed, accuracy, initiation, intrusions or oscillations, range of motion and conjugacy	[34]
VOMS- Change in symptoms	Changes in symptoms documented following completion of each component	Change greater than or equal to two points out of 10 was considered abnormal	[35]
VOMS - Near point convergence	Distance documented	A distance greater than or equal to five centimeters was considered abnormal	[35]
Cervical spine range of motion	Estimated angles for cervical flexion, extension, lateral flexion, and rotation recorded	Values were compared to pooled norms for healthy individuals aged 20 to 59 years old documented in a recent systematic review to identify abnormality: flexion = 50-72°; extension = 58-77°; lateral flexion = 37-47°; rotation = 67-81°	[36]

VOMS: Vestibular/Ocular Motor Screening

For the virtual assessment, the patient-participant was in a separate room from the assessor. All patient-participants used the same computer and received technical support from a research team member, if needed. Safety precautions during the virtual assessment included: i) presence of a research team member in the room throughout the virtual assessments; and ii) positioning patient-participants in front of a wall, chair, or bed during balance testing. All virtual assessments used a Dell Vostro 3520 Laptop (with a 15.6-inch display) running the Microsoft Teams (Microsoft Inc, Seattle, USA) platform (for the patient-participants). Assessors used desktop computers. The virtual assessments were audio-video recorded for later review and evaluation by a different clinician. For the in-person assessment, a research team member was present in the room to record the assessment using the same laptop as the virtual assessment. Safety precautions were provided by the assessing clinician.

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Observation of Recordings of Assessments

Two assessors (Rater A and Rater B) documented clinical findings for each patient-participant. Rater A completed the in-person and synchronous virtual assessments. Rater B documented findings asynchronously from audio-video recordings of the virtual assessment at two time points separated by approximately one month. Figure 1 outlines the study assessment procedures.

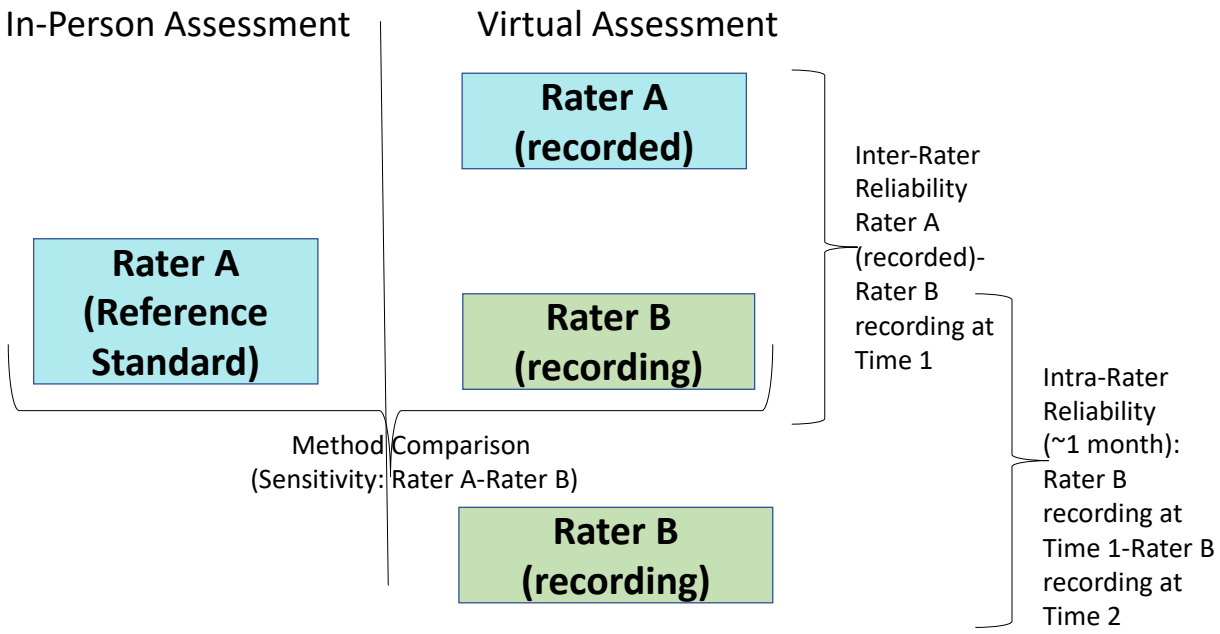


Figure 1. Assessment procedures modified from Russell et al. [27]

Feedback

Feedback was obtained from both clinician and patient-participants using a feedback form, following completion of the assessments. Participants answered questions related to the environmental set-up of the virtual assessment, confidence in the assessment findings, perceived similarity between the two approaches, and provided any additional feedback on the form.

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Analysis

Rate of Recruitment and Time Required to Complete Study Procedures

Descriptive data are provided for average number of participants recruited per month, rate of recruitment, and average and range of time required for in-person and virtual assessments separately.

Participant Characteristics, Feedback and Confidence Ratings

Participant characteristics (sex, age, injury information, etc.) were analyzed descriptively. Feedback obtained following completion of study assessments and perceived confidence ratings in findings on study assessments for both clinician and patient-participants were summarized narratively.

Reliability and Sensitivity

Quantitative data analyses were completed using IBM SPSS (version 28). Inter-rater reliability was determined by comparing the results documented by Rater A (virtual assessment) with those documented by Rater B (virtual assessment at Time 1). Intra-rater reliability was determined by comparing the results from Rater B at Time 1 versus Time 2. All measures were coded into binary categories (abnormal versus normal; see Table 1). Some measures had single items (VOMS change in symptoms, VOMS NPC, saccades), whereas some measures (balance testing, cervical spine range of motion, finger-to-nose testing) included multiple items where each was rated as 0 or 1 and results were summed. For both inter- and intra-rater reliability, unweighted kappa statistics were calculated. Kappa is calculated by dividing the difference between the observed agreement (proportion of times raters agreed) and expected agreement by chance (agreement that would occur by random chance) by one minus the expected agreement by chance. Kappa values between 0 and 1.0 were documented where values closer to 0 indicate poor

reliability and values closer to 1.0 indicate perfect agreement [37]. 95% confidence intervals were calculated manually by multiplying the standard errors obtained from SPSS by the z statistic 1.96 and adding and subtracting that value to/from the Kappa values to obtain the upper and lower bounds [38].

Sensitivity of the virtual assessment was determined by comparing the results documented by the clinician who observed and rated the recording of the virtual assessment (Rater B at Time 1) with the results documented by the clinician conducting the in-person assessment (Rater A, Reference Standard) [27]. The value reflects the proportion of people identified as impaired on the in-person measure who were identified as impaired on the virtual measure [25]. Sensitivity is calculated by dividing the true positives (identified correctly as impaired on the in-person and virtual assessments) by the sum of the true positives and false negatives (virtual assessment failed to identify as impaired, but the in-person correctly identified as impaired). 95% confidence intervals were calculated using the online VassarStats Clinical Calculator [39] .

Adverse Events

Adverse events, including the severity and type were monitored. Significant worsening of symptoms requiring medical attention, such as an emergency department visit or a new injury was considered an adverse event [41].

Results

Participant Characteristics

Twenty patient-participants completed both the in-person and virtual assessments (see Table 2). Fifteen (75%) of the participants were female. Most participants were working at the time of their assessment. Most participants reported limitations in functional abilities and

perceived their mental health as fair to poor. When considering the criteria outlined above regarding identification of abnormality on each measure, 18 out of the 20 participants were abnormal on at least one of the measures in the in-person assessment.

Table 1. Demographic characteristics (N=20)

Age range, y		21-58
Sex (freq. %)	Female	15 (75%)
	Male	5 (25%)
Gender (freq. %)	Woman	15 (75%)
	Man	5 (25%)
Ethnicity (freq. %)	White	15 (75%)
	Black	1 (5%)
	Arab	1 (5%)
	Southeast Asian (e.g., Vietnamese, Cambodian, Malaysian, Laotian)	1 (5%)
	West Asian (e.g., Iranian, Afghan)	1 (5%)
	First Nation/Indigenous	1 (5%)
Highest Educational Attainment (freq. %)	Secondary (high) school diploma or equivalent	8 (40%)
	Postsecondary certificate, diploma or degree	12 (60%)
Current Work Status (freq. %)	Off work	7 (35%)
	Modified return to work, same pre-injury occupation	6 (30%)
	Full return to work, same pre-injury occupation	4 (20%)
	Full return to work, different occupation	2 (10%)
	First time working	1 (5%)
Functional limitations		
Moderate activities (freq. %)	Yes, limited a lot	3 (15%)
	Yes, limited a little	10 (50%)
	No, not limited at all	7 (35%)
Climbing stairs (freq. %)	Yes, limited a lot	3 (15%)
	Yes, limited a little	8 (40%)
	No, not limited at all	9 (45%)
Perceived mental health (freq. %)	Excellent or very good	2 (20%)
	Good	6 (30%)
	Fair or poor	12 (60%)

Freq.: frequency; **N**: number; **y**: year

Injury characteristics of the 20 patient-participants is presented in Table 3. Fourteen (70%) participants sustained a concussion, and the remainder sustained a moderate to severe traumatic brain injury or other form of ABI, with most injuries occurring outside of the workplace context.

Table 3. Injury information (N=20)

Diagnosis (freq. %)	Other acquired brain injury	6 (30%)
	Mild traumatic brain injury/concussion	14 (70%)
Mechanism of Injury (freq. %)	Work	6 (30%)
	Motor vehicle accident	4 (20%)
	Assault	2 (10%)
	Fall/Hit head at home	4 (20%)
	Sport	2 (10%)
	Poisoning	1 (5%)
	Encephalitis	1 (5%)

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Date of Injury (freq. %)	< 6 months ago	3 (15%)
	6 months to < 1 year ago	3 (15%)
	1 to < 2 years ago	7 (35%)
	2 to < 3 years ago	3 (15%)
	>3 years ago	4 (20%)

freq.: frequency; **N**: number

Most participants used technology daily and the majority rarely needed assistance when using technology (Table 4).

Table 4. Virtual assessment and technology experience (N=20)

Previously attended virtual assessment (freq. %)	Yes	11 (55%)
	No	9 (45%)
If yes, number attended (freq. %)	< 5	8 (40%)
	5-10	1 (5%)
	>10	1 (5%)
	Unsure	1 (5%)
Distance located from the rehabilitation centre (freq. %)	< 30 minutes	9 (45%)
	30-60 minutes	8 (40%)
	>60 minutes	2 (10%)
	NA- no home	1 (5%)
Technology available for virtual assessment (freq. %)	Computer	2 (10%)
	Laptop	8 (40%)
	Smartphone	2 (10%)
	Multiple devices (iPad, smartphone, computer)	7 (35%)
	None	1 (5%)
Use of technology (freq. %)	Weekly	3 (15%)
	Daily	17 (85%)
Assistance needed during use of technology (freq. %)	Never	7 (35%)
	Rarely	9 (45%)
	Monthly	2 (10%)
	Weekly	1 (5%)
	Daily	1 (5%)

Freq.: frequency; **N**: number

Three clinicians participated as assessors. Two assessors (a male and female), acting as Rater A, were a physiatrist and a physician assistant. The third clinician (a male), acting as Rater B, was a physiatrist, and observed the recordings of the assessments. These clinicians typically assess more than 50 ABI patients annually and reported feeling confident in their ability to complete the in-person and virtual assessments.

Rate of Recruitment

We experienced challenges recruiting clinicians willing to conduct the study assessments and clinicians' scheduling conflicts posed difficulties with patient-participant recruitment, and therefore, involvement of additional professions, such as physiotherapists, will be needed to support the larger-scale study. We recruited, on average, one patient-participant per week at

TOHRC. Thirty-three potential participants were identified. Seven could not be reached. Of potential participants reached, 6 (23%) declined, primarily due to concerns that the multiple assessments would make their symptoms worse. Our rate of recruitment was, therefore, 61% of people approached and 77% of people reached.

Length of Time Required to Complete Study Assessments

The time required to complete the in-person assessment ranged from five to 13 minutes and averaged nine minutes. The time required to complete the virtual assessment ranged from seven to 26 minutes and averaged 13 minutes.

Feedback

Clinician-Participants

Perceived Similarity of Virtual and In-Person Assessments

The two assessors (Raters A) believed that they obtained similar information from both the in-person and virtual assessment in a majority (80%) of cases. On four occasions, the assessors reported that the patient-participant fatigued and/or experienced heightened symptoms during the second assessment, however, on two of these four occasions the assessor still believed that comparable findings were obtained even with the exacerbation. For example, one clinician reported that the findings were "*comparable, but patient fatigued and became more symptomatic"* and another reported an *"increase in symptoms during the second assessment."* On two occasions, the assessor reported that they did not believe similar information was obtained as one of the patient-participants felt more comfortable in-person and the other patient-participant was able to follow directions better in-person, reporting that the participant "*had an easier time with directions in-person*".

Challenges

One assessor expressed some issues with virtual tests due to dark lighting in the assessment rooms when blinds were open, and patient-participants were positioned in front of windows, reporting "*lighting in background, lost sight of pen*". Another assessor noted audio issues ("*sound delay*") during the virtual assessment with sound going in and out, forcing the assessor and patient-participant to repeat statements. Technical challenges related to internet connectivity were experienced on two occasions, with reports of "*internet freezing in exam room*" and "*initial connection slow*".

Patient-Participants

Perceived Similarity of Virtual and In-Person Assessment Findings

Most (60%) of the patient-participants believed that similar findings were obtained in both the in-person and virtual assessments. One patient-participant was unsure about the similarity of findings, reporting "*measurement wise, I can't say*". Three patient-participants mentioned that ocular tests may have been easier for the clinician to observe in-person. For example, one participant reported that "*there might have been a difference in visual tests*" and another reported that "*I think eye movements are more easy to observe in-person*." One patient-participant reported that more relevant clinical data was obtained in-person, one reported that their concussion symptoms were worse virtually due to screen exposure, one expressed doubt that the virtual assessment would have been sufficient for their initial assessment, and one perceived that similar information was not obtained as conversation was easier in-person.

Challenges

Patient-participants expressed minimal concerns regarding the environmental set-up of the virtual assessment. One patient-participant reported that it would be helpful to see the whole

body of the clinician for demonstrations of measures or to observe a photo of the measure on the screen beforehand. Another noted that while the set-up was adequate, space was limited for one of the measures that required her to rotate her body. Technical support was required for all participants to manage camera angles during virtual completion of balance testing. One participant highlighted the value of having someone physically present to troubleshoot any camera angle challenges. Two participants suggested that a larger screen size would be beneficial, with one reporting that "*the screen was a bit small and needed to be adjusted to capture all my movements*" and another reported that "*a bit larger screen might be better for evaluation to see eye movements*". Finally, four patient-participants reported that the lighting was an issue for both the in-person and virtual assessment due to light sensitivity associated with the concussion, whereas assessors commented on lighting in relation to visibility of the patient-participant during the virtual assessment. For example, one patient-participant reported that "*lighting would be great on a dimmer*" and another reported that the assessments were "*a bit bright with the lights on*".

Confidence Ratings

The assessors expressed high confidence in their findings on the in-person (100%) and virtual (95%) assessments. Only on one occasion was an assessor 'neutral' in terms of their confidence in their findings on the virtual assessment.

Most patient-participants agreed or strongly agreed that they felt confident in their assessors' findings on the in-person (95%) and virtual (75%) assessments. Two patient-participants did not feel confident and two were 'neutral' in their confidence levels on the virtual assessment. One participant did not feel confident on both the in-person and virtual assessment.

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Preliminary Information on Sensitivity of the Virtual Assessment Compared to the In-Person Assessment

The preliminary sensitivity of the virtual compared to in-person administration of the measures ranged from 0.0 to 1.0 (Table 5). This suggests poor (finger-to-nose testing) to excellent (NPC) ability to detect deficits in the virtual assessment when deficits are truly present (based on the reference standard, which is the in-person assessment). On two occasions, evaluation of saccades was not documented by the assessor in error. On one occasion, the VOMS was not completed due to patient inability to complete the measure because of aggravation of symptoms. No abnormality was documented for effort on both the in-person and virtual assessment and therefore sensitivity could not be computed.

Table 5: Sensitivity of the virtual assessment compared to the in- person assessment

Measure	N.	Sensitivity	95% CI
Cervical Spine			
ROM	20	0.33	0.09 to 0.69
Vestibular			
Balance- Eyes open and closed: feet together, single leg stance, tandem stance	20	0.94	0.69 to 1.0
VOMS- Change in symptoms	19	0.92	0.60 to 0.99
VOMS- NPC	19	1.0	0.70 to 1.0
Neurological Examination			
Finger-to-nose	20	0.0	0.0 to 0.60
Oculomotor			
Saccades	18	0.50	0.09 to 0.91
Effort			
Optimal effort	20	*	-

***Statistic could not be computed as the values documented by both assessors are constant for this measure (all normal findings reported)**
CI, confidence interval; **NPC**, near point convergence; **ROM**, range of motion; **VOMS**, Vestibular/Ocular Motor Screening

Preliminary Information on Inter-Rater and Intra-Rater Reliability

Table 6 presents the preliminary information on the inter-rater and intra-rater reliability of the measures when administered virtually. Cohen's Kappa values for inter-rater reliability ranged from poor for balance testing (0.38), range of motion (0.47) and saccades (0.49) to

excellent (1.0) for VOMS change in symptoms. The intra-rater reliability ranged from poor (0.44) for evaluation of saccades to very good (0.89) for VOMS change in symptoms.

Table : Inter-rater and intra-rater reliability of the measures when administered virtually

	Intra-rater reliability			Inter-rater reliability		
Measure	**N.**	**Cohens Kappa**	**95% CI**	**N.**	**Cohens Kappa**	**95% CI**
Cervical Spine						
ROM	20	0.69	0.29 to 1.0	20	0.47	0.04 to 0.90
Vestibular						
Balance testing- Eyes open and closed: feet together, single leg stance, tandem stance	20	0.61	0.11 to 1.0	20	0.38	-0.09 to 0.86
VOMS - Change in symptoms	20	0.89	0.67 to 1.0	20	1.0	1.0 to 1.0
VOMS - NPC	20	0.76	0.47 to 1.0	20	0.67	0.34 to 0.99
Neurological Examination						
Finger-to-nose	20	*	-	20	*	-
Oculomotor						
Saccades	20	0.44	-0.2 to 1.0	18	0.49	0.04 to 0.94
Effort						
Optimal effort	20	*	-	20	*	-

***Statistic could not be computed as the values documented by the second assessor are constant for these measures (all normal findings reported)**
CI, confidence interval; **N**, number; **NPC**, near point convergence; **ROM**, range of motion; **VOMS**, Vestibular/Ocular Motor Screening

Given the recruitment rate and preliminary psychometric property information, for the larger-scale study, a total of 60 participants will be needed, of which approximately 51 participants are expected to have an abnormal finding. At one center, we anticipate being able to approach ~6 participants per month. With the anticipated recruitment rate of 61% over 5 months, we can feasibly recruit 20 participants, which would mean the future large study with a target sample size of 60 would require 15 months to complete recruitment.

Adverse Events

Most (17/20) participants reported an increase in pre-existing brain injury symptoms, such as increased headaches, dizziness, and nausea, during the VOMS measure, however, this was true for both the in-person and virtual assessments.

Discussion

This is one of the first studies to examine the feasibility and preliminary psychometric property information of concussion assessment using virtual approaches. According to Montes et al. [42], a systematic approach to virtual assessment development is essential, with established in-person measures serving as a basis for comparison/as a reference standard. Taking this into consideration, we first carried out reviews of the psychometric properties of potential measures to help select the measures to be included in our virtual assessment [14,22,23]. In this study we report on the feasibility and preliminary psychometric properties of these assessments to provide initial evidence of the virtual assessment and inform a larger study of virtual assessment for concussions.

Rate of recruitment is a critical indicator of the success of a future larger-scale study. Our moderate rate of recruitment indicates that there is sufficient interest among people with ABI to participate in a virtual assessment-based study, however additional strategies may be needed in order to increase our ability to reach potential participants. Although, patient-participants showed moderate to high willingness to participate, we did experience more difficulties recruiting males and recruiting people with other forms of ABI when compared to recruitment of people with concussions. This was mainly because the practice of one of our assessors only included people with concussions (and not other forms of ABI). We experienced some difficulty recruiting people with known abnormality on specific tests, particularly those with abnormal coordination, as people with concussion typically have normal coordination and recruitment of people with concussion was easier due to the nature of the practice of our recruited assessors. Rate of patient recruitment appeared to be influenced by clinical status (concerns regarding aggravation of symptoms due to the nature of the measures and the need to complete the measures twice). Hunt

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et al. [43] reported that stakeholder engagement in concussion research may be inhibited by injury-related factors, personal deterrents (vulnerability and fear), and environmental barriers. Concussion symptoms, including physical, cognitive, and emotional, were identified as a barrier to involvement by patient-participants [43].

The length of time required to complete our study procedures is another essential aspect of evaluating feasibility and participant burden. Factors influencing the time required to complete the study assessments included participant ability to follow instructions, participant symptom aggravation, and technology issues (internet speed). The average time required to complete our virtual assessment was longer than the in-person assessment, which is contrary to findings reported by Tran et al. [44] who noted that virtual visits tend be similar in length when compared to in-person visits. However, adaptation of certain measures to virtual environments, such as the VOMS, has been previously reported to take time and practice [45], which may have contributed to the additional time required to complete the virtual assessment. While the duration of the virtual assessment was longer than the in-person, the reduced travel time required to attend an in-person visit highlights the convenience associated with virtual assessments from the patient-perspective [46,47], although increased clinician-time required may be a concern [14].

Additionally, having technical support with camera angles may have positively impacted the experience of the participants with the virtual assessment in this feasibility study. A research team member was present to aid with moving the laptop to improve visibility of the patient for the clinician, close blinds, and to troubleshoot internet issues. Ownsworth et al. [48] reported that ongoing access to support could improve user-friendliness and facilitate use of virtual care. Further, there is a need for reliable and high-quality videoconferencing technology, which could present as a challenge in practice due to variable accessibility and cost [49]. To improve the issue

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associated with lighting, expressed by participants, it is recommended that blinds are closed when completing virtual assessments and lights are bright enough for clinicians to observe the individual on screen, however, are manageable for the individual in terms of limiting symptoms aggravation. To improve visibility, a blank backdrop is recommended along with appropriate positioning of the camera at eye level [50].

Participants perceived the environmental set-up of the virtual assessment to be adequate. The feedback obtained highlighted the advantages of virtual assessments over the traditional in-person assessments, which is consistent with the literature, including eliminating the need to drive to the assessment centre, and the ability to control the environment better at home, such as having the capacity to dim lights [46,51,52]. However, home can present challenges as well [53]. The virtual assessments for this study were all conducted using the same laptop and within the same setting, which may have positively impacted the experiences of the participants. The home environment may present with unique challenges, such as distractions and variable screen sizes, which in turn may impact outcomes on the assessment [54] It is recommended that to develop a plan and schedule for these assessments to minimize such distractions in the home setting [54]. Further, one participant in our study was homeless and was admitted as an inpatient, and therefore would not have access to needed technology in a home environment.

When virtual assessments are implemented in practice, it is important to ensure that findings obtained through the virtual assessment are comparable to those obtained through in-person approaches [27]. For the most part, the clinician and patient-participants in this feasibility study perceived as though findings were similar on the in-person and virtual assessment. This perception of congruence is supported by objective data obtained by Vargas et al. [55] who examined the feasibility of virtual assessment of concussion using a telemedicine robot in which

a neurologist remotely assessed injured athletes simultaneously to sideline provider in-person assessments. Vargas et al. [55] provides preliminary information on the strong level of agreement (within three seconds or points 100% of the time) between findings documented by the in-person sideline provider and the remote neurologist on specific concussion measures (Standardized Assessment of Concussion (a cognitive test), modified Balance Error Scoring System (a balance test), and King-Devick test (a saccadic eye movement test)) [55]. While the perception of congruence was high, participants, both assessors and patients, were more often more confident in the findings on the in-person assessment when compared to the virtual assessment. These findings are in line with Gilbert et al. [56] who noted that clinicians and patients were satisfied with virtual consultations, however in-person consultations are still preferred (outside the COVID-19 pandemic).

In-person measures should have acceptable reliability properties for method comparison studies to have meaningful results [27]. It is therefore recommended to determine the reliability properties of the virtual assessment as part of the method comparison study. Sensitivity metrics of the measures included in the virtual assessment are also of interest, as clinical assessment findings are relied upon to detect deficits and guide intervention [2]. The preliminary investigation of reliability and sensitivity in this study appear to vary when compared to previously reported in-person values. Reliability values for in-person administration of the measures ranges from moderate (test-retest reliability of the single leg stance, with a Kappa of 0.43 [57]), to excellent (within-tester reliability of cervical spine range of motion with an intraclass correlation coefficient of 0.90 [58]). The sensitivity metrics associated with in-person administration of the measures ranges from moderate (0.45 for balance testing in people with traumatic brain injury [59]) to excellent (96% for the VOMS assessed in people with

concussion58). The findings of this feasibility study indicate that the evaluation of finger-to-nose testing, saccades and cervical spine range of motion appear to have poorer properties associated with virtual administration when compared to in-person metrics, which have documented sensitivities of 71% [59], 64-77% [62] and 86-95% [63], respectively.

Consistent with the literature, the lack of physical presence in the virtual assessment may have been associated with an inability to gain a full understanding of the patient's status in these measures and subtle abnormalities such as those observed during oculomotor assessments may have been more difficult to capture through videoconferencing [64, 65], which was also subjectively acknowledged by patient-participants in this feasibility study. Documentation of psychometric properties of measures administered in both in-person and virtual contexts is required to support the hybrid approach to care, which integrates both in-person and virtual interactions with clinicians. This approach is desired by both clinicians and people living with concussions [13,14].

The data obtained in this study suggest that there are specific measures, such as the evaluation of saccades, cervical spine range of motion, and finger-to-nose testing that are more difficult to administer virtually and therefore a high level of care in delivery should be considered to increase reliability and sensitivity. Further development and research are, therefore, needed in this area to determine how best to administer these measures virtually. This could include using advanced technologies, improving training of clinicians, or improving administration instructions [50], all of which will be considered for the large-scale study. Best practices for administering these measures need to be identified and strategies to overcome limitations posed by the virtual environment should be explored.

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Strengths and Limitations

A strength of this study includes the use of technology and software that are commonly used to complete virtual assessments at TOHRC. This decision was made to mimic as best as possible the current clinical approach to virtual assessments. Further, the expanded criteria to include participants with various forms of ABI, ensured the inclusion of the individuals with identifiable positive findings. This approach not only facilitated recruitment but also enhanced the generalizability of our findings.

Our study also has several limitations. First, this study was carried out in a controlled environment to standardize as many aspects of the virtual assessment as possible. Thus, we did not test the virtual assessment in real-world settings such as with people present in remote or rural regions, where factors such as home environments, technology used, internet, etc., may have influenced reliability. Second, due to an inability to complete the assessments more than twice, we were unable to establish reliability properties of the in-person assessment and relied on the literature for the in-person properties needed for comparisons, which will also be required for the larger-scale study. Third, it was not feasible for two different clinicians to conduct the initial in-person and virtual assessments in our clinical environment due to scheduling constraints, so the same clinician completed both initial study assessments. In an attempt to mitigate potential bias and in line with best practices for method-comparison studies comparing in-person and virtual approaches [27], we randomized the order of the study assessments and compared the in-person assessment conducted by Rater A with the findings of the observed recording completed by Rater B, however, this approach is limited in that rater differences may have impacted the findings. Finally, the widths of the confidence intervals reported in this feasibility study are extremely wide (due to the small sample size) and therefore there is little conclusion one can

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draw from the psychometric property estimates. The small sample size further limits the generalizability of the study findings. More data and extensive study are needed to definitively establish the reliability and sensitivity properties associated with the virtual concussion assessment.

Conclusion

For clinical measures to be confidently used by clinicians in virtual care practice, comparisons need to be made to their in-person counterparts. Given the width of the confidence intervals, little can be concluded regarding the sensitivity of the concussion measures administered virtually when compared to in-person administration and the reliability of those measures. However, this feasibility study documents the time needed to complete components of a concussion assessment virtually and confirms probable safety of the assessment, with no adverse events specific to the virtual assessment documented. The findings of this feasibility study provide a foundation and will inform processes for a planned follow-up study that contains an adequate sample size to estimate the psychometric properties with adequate precision. Future work should expand on this foundation through the exploration of the impacts of home environments on virtual concussion assessment outcomes and through the investigation of additional relevant psychometric properties, such as responsiveness.

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Authors' Contributions

All authors have made substantial contribution to the work presented in this paper.

Conflicts of Interest

None declared.

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Chapter 6. Psychometric Properties of Vestibular and Ocular Measures Used for Concussion: A Scoping Review

Chapter 6 has been formatted based on the requirements of the peer-reviewed journal in which it was submitted.

Chapter 6 contains the results of a scoping review, documenting the psychometric properties of certain vestibular and ocular concussion measures administered in-person. The manuscript associated with Chapter 5 was submitted to the Journal of Head Trauma Rehabilitation on February 8, 2024. Revisions were requested on April 1, 2024. The revised version was returned to the journal on April 30, 2024. The manuscript was accepted with minor revisions on May 20, 2024. The revised manuscript was returned on May 29,2024. Acceptance was obtained on May 29, 2024. It is currently In Press.

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Psychometric Properties of Vestibular and Ocular Measures Used for Concussion Assessments: A Scoping Review

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Competing Interests
The authors have no conflicts of interest to declare.

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Abstract

Background: Concussions most commonly affect the vestibular and ocular systems. Clinical measures used in the assessment of vestibular and ocular deficits should contain strong psychometric properties so that clinicians can accurately detect abnormality to guide treatment interventions.
Objectives: The aim of this scoping review was: 1) to identify the measures used to evaluate the vestibular and ocular domains post-concussion 2) to document the psychometric properties of the measures.
Methods: Two databases (Medline (Ovid) and Embase) were searched from inception to May 2023. An updated search was completed in January 2024 using the same databases and search terms. Studies were screened and data were extracted independently by two reviewers. Measures were categorized into vestibular, ocular, or both (vestibular and ocular) domains, and relevant psychometric properties were documented.
Results: Fifty-two studies were included in this review. Twenty-eight studies explored the use of vestibular measures, 12 explored ocular measures, and 12 explored both vestibular and ocular measures or explored the use of vestibulo-ocular reflex measures. Most studies explored the properties associated with balance measures, particularly the Balance Error Scoring System. Diagnostic accuracy (sensitivity, specificity metrics) of the associated measures was the most frequently documented characteristic in the literature.
Conclusion: Identification of clinical measures used to evaluate vestibular and ocular deficits post-concussion is needed to understand the evidence supporting their use in practice. Documenting the psychometric properties will allow clinicians and researchers to understand the status of the current literature and support for the use of certain measures in practice in terms of their ability to appropriately detect deficits in people with concussion when deficits are truly present.

Key words: mild traumatic brain injury, concussion, psychometric, vestibular, oculomotor

Open Science Framework (osf.io/f4te7)

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Background

Concussions are complex brain injuries, which can affect multiple body systems, making it challenging to use a single clinical measure to complete an assessment post-injury[1]. Commonly, symptoms and functional deficits experienced by people who have sustained a concussion are categorized into domains, including vestibular, ocular, neurocognitive, psychological, and headache among others[2]. Symptom presentation and severity can be diverse and varies between individuals. Different symptom presentations may also be experienced by the same individual if multiple concussions were sustained at different time points, and symptoms may vary over recovery[3]. Commonly reported symptoms following a concussion include headaches, dizziness, nausea, vision impairment, noise and light sensitivity, cognitive issues, vestibular deficits, and fatigue[4,5]. Evaluation and management of concussion is challenging because a single clinical measure does not exist that captures all the frequently experienced deficits, and these changes are often subtle.

To date, there are no direct objective indices available to confirm the diagnosis of concussion or monitor recovery[5]. Clinicians and researchers use criteria to diagnose concussion combined with a multi-faceted approach to assessment to address the diversity of deficits associated with concussion[6,7].

Due to the significant impact of concussion on the vestibular and ocular systems, accurate assessment and identification of deficits within these domains is needed. It is critical to use reliable and valid clinical measures so that intervention, management and monitoring strategies can be effectively executed based on the deficits identified[4]. Use of objective measures in practice are further recommended to assess and monitor recovery following concussion[8].

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Identifying the clinical measures with the most acceptable psychometric properties will support clinicians in understanding and using the most optimal approach to assessment in practice. The aim of this scoping review was to identify and document the psychometric properties of clinical measures used to evaluate the vestibular and ocular domains immediately following a concussion and the subsequent recovery.

Methods

Informed by processes outlined by Arksey and O'Malley[9], this scoping review follows five stages: i) identify research question, ii) identify studies, iii) study selection, iv) chart data, v) collect, summarize and report results. Inclusion criteria were developed to identify studies relevant to the research question. The protocol was registered on Open Science Framework (osf.io/f4te7).

Inclusion Criteria

The SPIDER framework[10] was used to outline the inclusion/exclusion criteria (see Table 1). While we hypothesized that most studies included in our review would be quantitative, this framework was selected due to the minimal restrictions placed on the research type of interest in our review (quantitative, qualitative, mixed methods) and due to the focus on observational studies rather than intervention-based studies. Inclusion criteria were established based on the sample, phenomenon, study designs, and research types of interest.

1) ***Sample***

Eligible studies involved adults (aged 18 years and older) with concussions that occurred in any setting and at all time-points post-concussion. Studies with mixed populations (e.g. both adults and pediatrics or mild and severe traumatic brain injury) and studies with healthy participants were excluded if they did not conduct subgroup analysis for people with concussion.

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2) ***Phenomena of interest***

Studies involving any performance-based measure used to evaluate the vestibular (measures that evaluate balance or gait), ocular (measures that evaluate eye movements), or combined (measures that evaluate vestibulo-ocular reflex (VOR) deficits) domains post-concussion and studies involving measures that contain documentation of at least one psychometric property (validity, reliability and responsiveness) were included. We were not interested in questionnaires or measures used in telehealth as a scoping review was previously conducted on telerehabilitation in people living with neurological conditions (includes concussion) and psychometric properties associated with those measures are available[11].

3) ***Design***

Any study design where the aim was to evaluate or compare the psychometric properties of the relevant measures was included.

4) ***Research type and other***

We were interested in all research types if the above criteria were achieved. Only full-text articles published in English were included.

Table 1: Inclusion and exclusion criteria following the SPIDER framework.

	Inclusion	**Exclusion**
Sample	Adult participants (≥ 18 years) with concussion (acute (< 48 hours), post-acute (> 48 hours)) Setting: any setting (sport, military, workplace, etc.)	• Healthy participants • Participants below the age of 18 years • Mixed population (e.g. adults and pediatrics, mild and severe TBI if the data were not reported separately for each group)
Phenomenon of interest (instruments)	• Any instruments and set of instruments to assess vestibular and/or ocular/oculomotor after concussion. • Can be used in person by healthcare professionals.	• Questionnaires • Instruments not publicly available • Virtual or remote administration of measures/telehealth measures
Design	• Any study testing psychometric properties of measures (reliability, validity, responsiveness) used after concussion or comparing psychometric properties of different measures.	• Reviews, editorials and, commentaries
Evaluation	NA	NA

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Research type, Others	• Any research type (qualitative, quantitative, or mixed methods) • No restrictions on the date of publication • English studies only • Full text /Published in a peer-review journal • Theses and conference papers	NA

NA: not applicable; **TBI**: traumatic brain injury

Search Strategy

A search strategy was developed with help from an experienced medical librarian. Medline (Ovid) and Embase were searched in May 2023 and updated in January 2024 using key words and Medical Subject Heading (MeSH) related to the clinical measures of interest (vestibular and ocular search terms), psychometric properties of instrument (includes search terms such as reliability, validity, sensitivity, specificity, responsiveness), and population of interest (brain injury and concussion search terms). A precise search filter for publications related to measurement properties was adopted[12]. No date restrictions were applied. An example of the search strategy is presented in Appendix A [SUPPLEMENTAL DIGITAL CONTENT].

Study Selection

Title and abstract followed by full-text screening was completed by two independent reviewers (KB and MK) using the Covidence platform (Covidence, AS)[13]. Only studies that met the defined inclusion criteria proceeded to subsequent stages in the screening process. Conflicts were resolved through discussion until consensus was reached. The reference lists from each of the included full-text articles were manually searched to identify additional relevant studies. Reference lists of relevant reviews identified during screening (but excluded from this review) were also manually searched.

Data Extraction

The same reviewers extracted data from eligible studies using a piloted extraction sheet. Piloting the extraction process ensured comprehensibility of the developed extraction sheet. Data

was categorized into four domains: general information (publication year, study design, sample size, study objectives), population information (time-point post-injury, setting, mean age of participants), clinical measure information (name of measure, developer, scoring), and psychometric property data. The Consensus based Standards for the selection of health Measurement INstruments (COSMIN)[14] was used to categorize the psychometric properties.

Data Analysis

Data was systematically collated and categorized based on the domain of the concussion assessment (vestibular, ocular, both). As the aim of this review was to identify the psychometric properties of the measures (and not evaluate the properties), quality appraisal of the included studies did not occur.

Summarize and Report Results

Results are reported following the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist (Appendix B [SUPPLEMENTAL DIGITAL CONTENT])[15].

Results

Study selection

A total of 3,943 and 500 studies were identified in the systematic search of the two databases when conducted in May 2023 and January 2024, respectively. A total of 2,846 studies were screened at the title/abstract stage and 229 at the full-text stage. One additional study was included through the manual search. Following removal of studies that did not meet the described inclusion criteria, 52 studies were included in the review. The PRISMA flow diagram presents the screening process and included studies (Figure 1).

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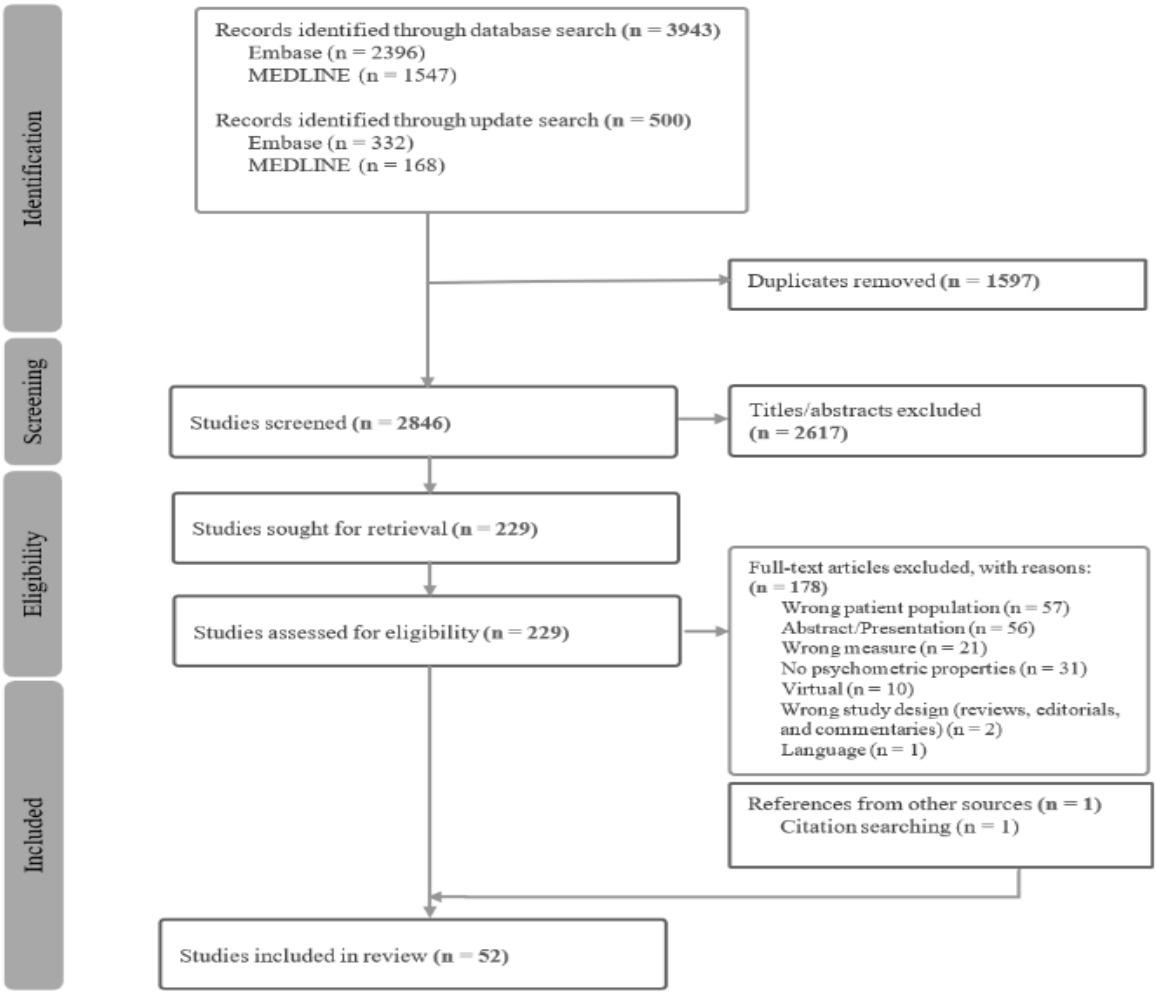


Figure 1. PRISMA flow diagram of screening

The studies were conducted between 2007 and 2023 with more than half published within the past five years. The studies had various designs, with the majority being cohort and cross-sectional studies. The sample size of the studies ranged between 16 to 1559 participants.

Population characteristics

Demographic information of the included studies is presented in Appendix C [SUPPLEMENTAL DIGITAL CONTENT]. Majority of studies occurred in the sport context (n=29) followed by the military context (n=6), community-dwelling context (n=3), and a mix of settings (n=3) (see Table 2). The rest of the studies occurred in unspecified contexts (n=11). Most

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assessments occurred ≤72 hours after concussion; the rest of the assessments were conducted between four days and > two years post-concussion. The mean age of the participants with concussion ranged from 18.9±0.8 to 44.48±11.24 years with most participants being less than 30 years old. Of the concussed participants, 67.7% were men.

Table 2 documents the clinical measures and psychometric properties from the included studies. Interpretations of the properties, derived directly from the articles, are included in Appendix D [SUPPLEMENTAL DIGITAL CONTENT]. Majority of studies evaluated vestibular measures and focused on clinical balance measures.

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Table 2: Psychometric properties of measures identified in included studies.

Clinical Measure	PSYCHOMETRIC PROPERTIES		First Author, year
VESTIBULAR			
BALANCE			
Balance testing	*Diagnostic accuracy*	AUC, Ratio: Unstable eyes open-stable eyes open: 0.74 Unstable eyes closed-stable eyes open: 0.78 Unstable eyes follow random target-stable eyes follow random target: 0.75	Baruch, 2016 (17)
BESS/ mBESS	*Reliability: internal consistency*	ICCs: **Standard BESS:** 0.829; Excluding firm double: 0.851; Excluding firm double and foam double: 0.846 **mBESS**: 0.615	Cushman, 2018 (21)
	Diagnostic accuracy	**BESS** AUC 95% CI: 0.508 Sensitivity: 0.447 (0.286–0.617) Specificity: 0.500 (0.334–0.666) **mBESS** AUC: 0.71 (0.60, 0.83) Sensitivity, %: Increase in three errors: 41 Increase in five errors: 40 Increase in eight errors: 14 Specificity, %: Increase in three errors: 61 Increase in five errors: 92 Increase in eight errors: 97	Harmon, 2022 (29)
	Diagnostic accuracy	**mBESS** Sensitivity, % (95% CI): 83.3% (58.6–96.4) Specificity, % (95% CI): 58.8% (32.9–81.6)	Sik, 2023 (40)
	Concurrent validity	*There was a moderate correlation between BESS and the SCAT3 symptom score (r_s = 0.38) in acute concussion.*	Ferris, 2021 (24)
	Diagnostic accuracy	Sensitivity with 95% CI reported for balance measures with an AUC curve >0.7 and a Youden Index > 0.5 *Double-leg stance, Hard surface:* COP ML velocity: <3 days: 0.94 [0.82–1.06] 1 week: 0.53 [0.30–0.75] 1 month: 0.46 [0.19–0.73] 6 months: 0.60 [0.35–0.85] *Tandem stance, Foam surface* COP velocity: <3 days: 0.81 [0.62–1.0] 1 week: 0.79 [0.61–0.97] 1 month: 0.92 [0.78–1.07] 6 months: 0.67 [0.43–0.91] COP AP velocity: <3 days: 0.69 [0.46–0.91] 1 week: 0.84 [0.68–1.0] 1 month: 0.85 [0.65–1.04] 6 months: 0.80 [0.60–1.0]	Pryhoda, 2020 (37)
	Diagnostic accuracy	*Sideline evaluation* *Raw score*: Sensitivity: 0.528; Specificity: 0.977 *Same year*: Sensitivity: 0.612; Specificity: 0.972 *Year prior*: Sensitivity: 0.500; Specificity: 0.979 *Post-event evaluation* *Raw score*: Sensitivity: 0.705; Specificity: 0.902 *Same year*: Sensitivity: 0.674; Specificity: 0.944 *Year prior*: Sensitivity: 0.596; Specificity: 0.966 *Clinic evaluation* *Raw score*: Sensitivity: 0.547; Specificity: 0.907 *Same year*: Sensitivity: 0.507; Specificity: 0.934 *Year prior:* Sensitivity: 0.370; Specificity: 0.980	Broglio, 2019 (43)
	Diagnostic accuracy	AUC= 0.59 (Lower band= 0.42, Upper band= 0.75) *Tandem stance, Foam surface* Sensitivity: COP velocity <3 days: 0.81 [0.62–1.0] 1 week: 0.79 [0.61–0.97] 1 month: 0.92 [0.78–1.07]	Fino, 2019 (25)

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		6 months: 0.67 [0.43–0.91] COP AP velocity <3 days: 0.69 [0.46–0.91] 1 week: 0.84 [0.68–1.0] 1 month: 0.85 [0.65–1.04] 6 months: 0.80 [0.60–1.0]	
	Diagnostic accuracy	**BESS**: Sensitivity = 0.60 Specificity = 0.40 **mBESS**: Sensitivity = 0.71 Specificity: mBESS = 0.29	Buckley, 2018 (19)
	Diagnostic accuracy	*Acute phase of injury* 0.70 RCI Sensitivity: 15.4% Specificity: 91.3% 0.80 RCI Sensitivity: 7.7% Specificity: 91.3% 0.90 RCI Sensitivity: 7.7% Specificity: 91.3% *Post-acute phase of injury* 0.70 RCI Sensitivity: 20% Specificity: 93.1% 0.80 RCI Sensitivity: 20% Specificity: 96.6% 0.90 RCI Sensitivity: 20% Specificity: 96.6%	Downey, 2018 (23)
	Diagnostic accuracy	Reported as follows: testing set estimate without baselines (training set estimate) BESS (change score) < 6 hours: Sensitivity = 0.93 (0.93) Specificity = 0.95 (0.98) AUC = 0.98 (0.99) BESS (raw score) 24-48 hours: Sensitivity = 0.84 (0.88) Specificity = 0.97 (0.96) AUC = 0.97 (0.97)	Garcia, 2018 (26)
	Diagnostic accuracy	*The mBESS had poor discriminative ability (AUC = 0.69, CI = 0.56–0.82). Baseline-adjusted post-injury scores had poor discriminative ability (AUC = 0.72, CI = 0.60–0.84).*	Hanninen, 2018 (42)
	Diagnostic accuracy	Instrumented measures characterized postural sway amplitude, velocity, variability, and frequency for each of the 3 mBESS stance conditions: *Clinical (subjective, not instrumented) mBESS* AUC 95% CI: 0.606 (0.503, 0.709) Sensitivity:35% *Double stance RMS ML* AUC (95% CI): 0.735 (0.637, 0.833) Sensitivity: 63% *Double stance RMS ML + double stance total power ML* AUC (95% CI): 0.750 (0.653, 0.847) Sensitivity: 59%	King, 2017 (30)
	Diagnostic accuracy	**mBESS** AUC 95% CI: 0.535 Sensitivity: 0.474 (0.310–0.642) Specificity: 0.632 (0.460–0.782) **BESS** AUC 95% CI: 0.508 Sensitivity: 0.447 (0.286–0.617) Specificity: 0.500 (0.334–0.666)	Oldham, 2018 (34)
	Diagnostic accuracy	90% CI Acute (< 7 days post-injury): 35%; Sub-acute (8–89 days post-injury): 31% 80% CI Acute (< 7 days post-injury): 39%; Sub-acute (8–89 days post-injury): 31%	Haran, 2016 (28)
	Concurrent validity	Correlation of concussion assessments with health status: Total BESS test: r = −0.13 Double leg firm: n/a Single leg firm: r = −0.16 Tandem leg firm: r = −0.08 Double leg foam: r = 0.15 Single leg foam: r = −0.26 Tandem leg foam: r = 0.10	McDevitt, 2016 (32)
	Diagnostic accuracy	*The sensitivity of the BESS was 8.3%. This indicates that 1 in 12 of people with concussion were correctly identified.*	McDevitt, 2016 (32)
	Diagnostic accuracy	mBESS: F = 0.988; p = 0.325; Cohen's d = 0.29	Silverberg, 2014 (41)
BESS/ mBESS with inertial	*Diagnostic accuracy*	Concussion versus control effect sizes: *Bilateral stance:* Sway volume: 0.25 Sway area: 0.26 *Tandem stance:*	Doherty, 2017 (22)

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sensor-based balance		Sway volume: 0.03 Sway area: 0.18 *Unilateral stance:* Sway volume: 0.06 Sway area: 0.00	
	Diagnostic accuracy	AUC 95% CI: Double stance RMS ML: 0.735 (0.637, 0.833) Double stance RMS ML + double stance total power ML: 0.750 (0.653, 0.847) Sensitivity: Double stance RMS ML: 63% Double stance RMS ML + double stance total power ML: 59%	King, 2017 (30)
BBT	*Diagnostic accuracy*	Sensitivity: 64.0%	Goble, 2016 (27)
CB&M	*Diagnostic accuracy*	AUC (95% CI): 0.92 (0.87, 0.97) Sensitivity: 0.78 Specificity: 0.91	Pape, 2020 (36)
	Diagnostic accuracy	AUC (95% CI): 0.98 (0.94, 1.00) Sensitivity: 1.00 Specificity: 0.88	Pape, 2016 (35)
Instrumented balance assessment	*Diagnostic accuracy*	**RMS sway** 0.5-SD cut-off value: Sensitivity: 54% Specificity: 71% 1-SD cut-off value: Sensitivity: 44% Specificity: 82% 1.5-SD cut-off value: Sensitivity: 40% Specificity: 89% 2-SD cut-off value: Sensitivity: 33% Specificity: 98% *The highest sensitivity (54%) was found using the RMS sway metric and a 0.5-SD cut-off value. The highest specificity (98%) occurred when using the RMS sway metric with a 2-SD cut-off value.* **95% ellipse sway area** *Double-legged stance* 0.5-SD cut-off value: Sensitivity: 52% Specificity: 80% 1-SD cut-off value: Sensitivity: 38% Specificity: 89% 1.5-SD cut-off value: Sensitivity: 27% Specificity: 91% 2-SD cut-off value: Sensitivity: 23% Specificity: 96% *Single-legged stance* 0.5-SD cut-off value: Sensitivity: 42% Specificity: 76% 1-SD cut-off value: Sensitivity: 40% Specificity: 87% 1.5-SD cut-off value: Sensitivity: 25% Specificity: 89% 2-SD cut-off value: Sensitivity: 21% Specificity: 93% *Tandem stance* 0.5-SD cut-off value: Sensitivity: 44% Specificity: 80% 1-SD cut-off value: Sensitivity: 35% Specificity: 93% 1.5-SD cut-off value: Sensitivity: 23% Specificity: 93% 2-SD cut-off value: Sensitivity: 19 % Specificity: 93%	Baracks, 2018 (16)
mCTSIB	*Diagnostic accuracy*	*The average sway area across the four mCTSIB conditions (mean AUC: 0.77) was significantly ($z = 14.0$; $p < 0.001$) better than the total mCTSIB score at differentiating between people with chronic symptoms post-mTBI and healthy controls. The sensitivity (71%) and specificity (71%) were optimal for the average sway area across the 4 mCTSIB conditions. Seventy-two percent of people with mTBI were classified correctly.*	Martini, 2022 (31)
	Diagnostic accuracy	*ECFIS significantly differed between the low and high mTBI subgroups ($p = 0.01$), between middle and high mTBI subgroups ($p = 0.02$), and between control group and high mTBI subgroup ($p = 0.02$).* *ECFOS significantly differed between control group and high mTBI subgroup ($p = 0.01$).* *ECFIS significantly differed between low and high mTBI subgroups ($p = 0.04$).* *The ECFIS significantly differed between low and high mTBI subgroups ($p = 0.04$).*	Chen, 2017 (20)

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	Concurrent validity	*Relationship between sensory integration (ECFIS) and the functional, emotional, and total aspects of the DHI was the following: functional (r = 0.13, p = 0.01), emotional (r = 0.14, p = 0.01), total (r = 0.13, p = 0.01).*	Chen, 2017 (20)
Postural stability test	*Concurrent validity*	*In the high mTBI subgroup, the relationship between the physical aspect of the DHI and OA and AP stability was the following: OA (r = 0.43, p = 0.03) and AP (r = 0.46, p = 0.02).*	Chen, 2017 (20)
SOT	*Diagnostic accuracy*	Acute group (<7 days post-injury), SOT composite score: Sensitivity: 90% CI = 50%; 80% CI = 58% Sub-acute group (8–89 days post-injury), SOT composite score: Sensitivity: 90% CI = 47%; 80% CI = 47%	Haran, 2016 (28)
	Diagnostic accuracy	*People with concussion scored significantly lower on the SOT in the individual conditions (F5,65 =3.26, p=0.011), The SOT demonstrated a sensitivity of 33.3% and a positive predictive value of 66.7%.*	McDevitt, 2016 (32)
	Diagnostic accuracy	Sensitivity: 72.5 Specificity: 85.0 Overall classification rate: 78.8 Positive likelihood ratio: 4.83 Negative likelihood ratio: 0.32	Resch, 2016 (39)
	Diagnostic accuracy	95% CI Sensitivity: 0.128 Specificity: 0.949 Combined sensitivity and specificity: 1.077 90% CI: Sensitivity: 0.152 Specificity: 0.949 Combined sensitivity and specificity: 1.101 80% CI: Sensitivity: 0.200 Specificity: 0.923 Combined sensitivity and specificity: 1.123	Register-Mihalik, 2013 (38)
	Diagnostic accuracy	Composite Balance 95% CI: Change score: 9.75 Sensitivity: 0.24 Specificity: 0.97 Total (sensitivity + specificity): 1.21 90% CI: Change score: 8.48 Sensitivity: 0.32 Specificity: 0.97 Total (sensitivity + specificity): 1.29 85% CI: Change score: 7.65 Sensitivity: 0.37 Specificity: 0.96 Total (sensitivity + specificity): 1.32 80% CI: Change score: 7.01 Sensitivity: 0.37 Specificity: 0.94 Total (sensitivity + specificity): 1.30 75% CI: Change score: 6.48 Sensitivity: 0.44 Specificity: 0.91 Total (sensitivity + specificity): 1.35 70% CI: Change score: 6.02 Sensitivity: 0.44 Specificity: 0.89 Total (sensitivity + specificity): 1.34	Broglio, 2008 (18)
	Diagnostic accuracy	Sensitivity: 61.9%	Broglio, 2007 (1)
Nintendo WBB	*Concurrent validity*	*Several correlations (p < 0.05) were found from baseline to day 3 post-concussion changes in the BESS and WBB.* *A positive correlation was found between tandem stance on a firm surface and all 7 WBB variables (log path velocity, log anterior-posterior path velocity, log anterior-posterior, log medial-lateral path velocity, log medial-lateral amplitude, log medial-lateral).* *Single-legged stance on a firm surface and the BESS total were both positively correlated with 2 of the 7 WBB variables.*	Merchant-Borna, 2017 (33)
GAIT			
Accelerometer-derived measurements to monitor gait balance	*Diagnostic accuracy*	*At 72 hours:* 95% CI = 2.72, 4.48 m/s^2 Sensitivity = 0.70 Specificity = 0.71 *1 week:* 95% CI = 2.18, 4.71 m/s^2 Sensitivity = 0.70 Specificity = 0.71 *2 weeks:* 95% CI = 2.88, 4.75 m/s^2 Sensitivity = 0.60 Specificity = 0.57 *1 month:* 95% CI = 2.59, 4.74 m/s^2 Sensitivity = 0.30 Specificity = 0.71 *2 months:* 95% CI = 2.35, 4.66 m/s^2 Sensitivity = 0.40 Specificity = 0.57	Howell, 2015 (46)

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FGA	*Diagnostic accuracy*	AUC (95% CI): 0.68 (0.57-0.77) Sensitivity = 68% Specificity = 60%	Fino, 2023 (44)
	Diagnostic accuracy	AUC (95% CI): 0.78 (0.69, 0.87) Sensitivity: 0.05 Specificity: 1.00	Pape, 2020 (36)
	Diagnostic accuracy	AUC (95% CI): 0.80 (0.57, 1.00) Sensitivity = 0.75 Specificity = 0.75	Pape, 2016 (35)
Gait Speed	*Diagnostic accuracy*	Fast speed: AUC (95% CI): 0.76 (0.77, 1.00) Sensitivity: 0.69 Specificity: 0.84 Comfortable speed: AUC (95% CI): 0.81 (0.66, 1.00) Sensitivity: 0.84 Specificity: 0.76	Pape, 2020 (36)
	Diagnostic accuracy	AUC = 0.57 (Lower band = 0.39, Upper band = 0.73)	Fino, 2019 (25)
	Diagnostic accuracy	Fast: AUC (95% CI): 0.92 (0.77, 1.00) Sensitivity: 0.88 Specificity: 0.75 Comfortable: AUC (95% CI): 0.86 (0.66, 1.00) Sensitivity: 0.88 Specificity: 0.75	Pape, 2016 (35)
HiMAT	*Intra-rater reliability*	*HiMAT sum score reliability was excellent (ICC = 0.95, 95% CI = 0.89 to 0.98), showing consistent test results.*	Kleffelgaard, 2013 (47)
	Diagnostic accuracy	AUC (95% CI): HiMAT:0.66 (0.52-0.73)	Fino, 2023 (44)
	Diagnostic accuracy	*3 months* AUC = 0.78, p = 0.001 *6 Months* AUC = 0.90, p = 0.001	Kleffelgaard, 2013 (47)
Tandem Gait	*Diagnostic accuracy*	95% CI If baseline thresholds applied AUC: 0.5 (0.5–0.6) Sensitivity: 46.8 (42.0–51.6) Specificity: 56.6 (52.5–60.5) If normative thresholds applied: AUC: 0.5 (0.5–0.5) Sensitivity: 1.79 (0.78–3.49) Specificity: 99.7 (98.9–100.0)	Fuller, 2020 (45)
	Diagnostic accuracy	Between concussed and non-injured players: AUC = 0.56, CI = 0.35–0.78 Baseline-adjusted post-injury scores: AUC = 0.55 CI = 0.32–0.78	Hanninen, 2018 (42)
	Diagnostic accuracy	AUC 95% CI: 0.704 Sensitivity = 0.632 (0.460–0.782) Specificity = 0.605 (0.434–0.760)	Oldham, 2018 (34)
VESTIBULAR AND OCULAR			
VOR			
DVA test	*Diagnostic accuracy*	AUROC (95% CI): Simple reaction time; reaction time, milliseconds: 0.81 (0.70-0.93) Discriminate reaction time, milliseconds: Reaction time: 0.80 (0.70-0.91), Visual reaction speed: 0.80 (0.66-0.94)	Feller, 2021 (52)

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		Choice reaction time; visual reaction speed, milliseconds: 0.76 (0.60-0.91) DVA 2; reaction time, ms:0.74 (0.62-0.86) DVA 3; reaction time, ms:0.72 (0.61-0.84) All 6 metrics combined: 0.90 (0.80-0.99)	
	Concurrent validity	*No significant differences were observed between concussion and control groups (p = 0.592) and no correlation was observed between the DVA test and health status (r = 0.06, p = 0.592).*	McDevitt, 2016 (32)
VOMS	*Diagnostic accuracy*	AUC = 0.8512 Sensitivity = 77% Specificity = 83%	Ferris, 2022 (50)
	Diagnostic accuracy	Modified VOMS (smooth pursuits, horizontal saccades, horizontal vestibulo-ocular reflex, visual motion sensitivity) AUC = 0.85 Sensitivity = 0.77 Specificity = 0. 83	Ferris, 2022 (49)
	Concurrent validity *Diagnostic accuracy*	Acute concussion correlations with the VOMS and SCAT3 symptom scores show a large correlation (r_s = 0.87). AUC = 0.819	Ferris 2021(24)
	Diagnostic accuracy	VOMS overall: AUC (95% CI): 0.91 (0.88-0.94) Smooth pursuit: 0.90 (0.86-0.93) Horizontal saccade: 0.90 (0.87-0.93) Vertical saccade: 0.90 (0.87-0.94) Near point of convergence: 0.51(0.46-0.57) Near point of convergence, cm: 0.90 (0.86-0.93) VOR: horizontal: 0.90 (0.87-0.93) VOR: vertical: 0.89 (0.86-0.92) Visual-motion sensitivity: 0.91 (0.88-0.94)	Kontos, 2021(51)
	Diagnostic accuracy	Estimate (95% CI) Sensitivity = 0.96 (0.86-1.00) Specificity = 0.46 (0.32-0.61) Positive predictive value = 64% Negative predictive value = 92%	Buttner, 2021(35)
	Diagnostic accuracy	*Sub-scores of the VOMS had the highest sensitivities for those with a baseline assessment in the same season which included the Smooth Pursuit (48–100%), Horizontal Saccades (44–83%), Vertical Saccades (46–82%), NPC Symptoms (38–80%), NPC (6–47%), Horizontal VOR (39–81%), Vertical VOR (38–81%), and VMS (43–81%).* *For those with a baseline assessment at 1 year before, VOMS sensitivities were similar for Smooth Pursuit (40–100%), Horizontal Saccades (39–88%), Vertical Saccades (42–87%), NPC Symptoms (35–84%), NPC (4–46%), Horizontal VOR (38–84%), Vertical VOR (36–84%), and VMS (37–82%).*	Broglio, 2019 (43)
Oculomotor, Vestibular and Reaction Time Tests	*Diagnostic accuracy*	AUC: 0.9727 Sensitivity: 89.0% Specificity: 97.5% Specific tests included in the battery of oculomotor, vestibular and reaction time tests: Optokinetic, Smooth Pursuit–Horizontal/Vertical, Predictive Saccade, Predictive Saccade, Anti-saccade Horizontal, Self-paced Saccade, Gaze Horizontal, Visual Reaction Time, Auditory Reaction Time, Saccade and Reaction Time, Computer Controlled Rotation Head Impulse Test, Sinusoidal Harmonic Acceleration, Visual Enhancement, Visual Suppression	Balaban, 2016 (53)
OCULOMOTOR			
SMOOTH PURSUITS			
EYE-SYNC smooth pursuit	*Diagnostic accuracy*	AUC=0.47 Sensitivity, % Any increase in tangential variability from baseline: 48 Any increase in radial variability from baseline: 52 Specificity, % Any increase in tangential variability from baseline: 58	Harmon, 2022 (29)

		Any increase in radial variability from baseline: 61	
Smooth pursuits	*Diagnostic accuracy*	*Radial Variability* *Baseline:* AUC: 0.879 Diagnostic sensitivity: 0.58 Screening specificity: 0.38 *1-back:* AUC: 0.783 Diagnostic sensitivity: 0.57 Screening specificity: 0.07 *2-back:* AUC: 0.946 Diagnostic sensitivity: 0.79 Screening specificity: 0.50 *Overall variability* *Baseline:* AUC: 0.796 Diagnostic sensitivity: 0.44 Screening specificity: 0.21 *1-back:* AUC: 0.717 Diagnostic sensitivity: 0.47 Screening specificity: 0.05 *2-back:* AUC: 0.904 Diagnostic sensitivity: 0.71 Screening specificity: 0.46	Stubbs, 2019 (50)
SACCADES			
KD test	*Test-retest reliability*	ICC (95% CI): 0.71 (0.49 to 0.84)	Harmon, 2022 (29)
	Intra-rater concordance	Kappa: 0.94 (0.85–1.00)	Hecimovich, 2018 (57)
	Test-retest reliability	ICC (95% CI) baseline vs. post-match total: 0.92 [0.87–0.95]	Hecimovich, 2018 (57)
	Test-retest reliability	Repeated tests: Spearman's ρ's: mTBI group: 0.949 ($p < 0.001$) Control group: 0.918 ($p < 0.001$)	Walsh, 2016 (60)
	Test-retest reliability	No head trauma, Pre-fight: ICC = 0.97 [95% confidence interval [CI] 0.90 –1.0]) Prefight and post-fight: ICC = 0.95 (95% CI 0.87–1.0)	Galetta, 2011 (56)
	Test-retest reliability	The ICC of KD test time scores between baseline and post-season tests resulted in a high degree of test-retest reliability (ICC 0.95 [95% CI 0.85---1.05]).	Leong, 2016 (46)
	Diagnostic accuracy	*At the 0- to 6-hour post-concussion time point* AUC = 0.724±0.2378 A cut-off score of -2.6 seconds yielded 80% sensitivity and specificity of 46%. *At 24 to 48 hours post-concussion* AUC = 0.701±0.01967 A cut-off score of -3.2 seconds yielded 80% sensitivity and specificity of 41%. A cut-off score of -1.5 seconds yielded 70% sensitivity, with a specificity of 57%. *Asymptomatic time point* AUC = 0.513±0.0199 The ROC curves were not different; thus, cut-off scores were not proposed. *At the unrestricted return to play time point* AUC = 0.640±0.0178 A cut-off score of -0.8 seconds yielded 80% sensitivity but specificity of 37%. A cut-off score of -1.9 seconds yielded 70% sensitivity but specificity of 47%. *At the 6-month post-concussion time point*	Le, 2023 (59)

		AUC=0.615±0.0222 A cut-off score of -0.4 seconds yielded 80% sensitivity but specificity of 34%. A cut-off score of -1.6 seconds yielded 70% sensitivity with specificity of 44%.	
	Diagnostic accuracy	AUC = 0.780 (0.686,0.872) Sensitivity, % Any prolongation in time from baseline: 85 3 seconds or greater prolongation from baseline: 68 5 s or greater prolongation from baseline: 54 Specificity, % Any prolongation in time from baseline: 76 3 seconds or greater prolongation from baseline: 88 5 seconds or greater prolongation from baseline: 95	Harmon, 2022 (29)
	Diagnostic accuracy	Baseline assessment in the same season: Sensitivity = 16–48% Baseline assessment 1 year ago: Sensitivity = 5–41%	Broglio, 2019 (43)
	Diagnostic accuracy	AUC = 0.60, p = 0.087, 95% CI [0.47, 0.72]	Dretsch, 2019 (43)
	Diagnostic accuracy	*The KD test demonstrated a sensitivity of 60% (95% CI 49.0 to 70) and a specificity of 39% (95% CI 26 to 54) in diagnosing concussion.* *The HIA-1 off-field screening tool sensitivity did not differ significantly from the KD test (74.8%, 95% CI 65.6% to 82.5%),), but specificity was significantly better than KD test (91.3%, 95% CI 82.0% to 96.7%).* *Combining HIA-1 and KD test performance achieved a sensitivity of 92.6% (95% CI 85.9% to 96.7%), with a specificity of 33.3% (95% CI 20.8% to 47.9%).*	Fuller, 2019 (61)
	Diagnostic accuracy	AUC: KD test time: 0.777	Capó-Aponte, 2018 (64)
	Diagnostic accuracy	Sensitivity (95% CI): 0.98 (0.87–1.00) Specificity (95% CI): 0.96 (0.80–1.00) Positive likelihood ratio: 11.6 (1.7–77.0) Positive predictive value: 89.0% (54.5–98.2%)	Hecimovich, 2018 (57)
	Concurrent validity	*There were no significant differences between concussed and non-concussed groups on the KD test (p = 0.40). The KD test did not correlate with health status (r = 0.18, p = 0.129)*	McDevitt, 2016 (32)
	Diagnostic accuracy	KD test trial 1: F=2.64; p=0.110; Cohen's d=0.43 KD test trial 2: F=2.28; p=0.137; Cohen's d=0.41 Best KD test score: F=2.16; p=0.148; Cohen's d=0.40	Silverberg, 2014 (41)
	Diagnostic accuracy	*KD scores that were worse post-fight (r_s = 0.79, p = 0.0001) and scores that had a greater level of worsening (r_s = 0.90, p = 0.0001) were correlated with post-fight MACE scores. KD scores post-fight were significantly worse for athletes with head trauma (59.1 ± 7.4 vs 41.0 ± 6.7 seconds, p = 0.0001, Wilcoxon rank sum test). KD scores that worsened by 5 seconds from baseline to post-fight, was a characteristic that was able to distinguish head trauma patients from non-injured participants.*	Galetta, 2011 (56)
CONVERGENCE			
NPC	*Diagnostic accuracy*	AUC: NPC break: 0.744	Capó-Aponte, 2018 (54)
	Concurrent validity *Diagnostic accuracy*	*The concussed group demonstrated a NPC distance of 6.0±4.1 cm and the control groups demonstrated a NPC distance of 3.6±2.2 cm, which was significantly correlated with health status (r = 0.337, p = 0.004).* *Using the NPC, OKS S/S, and GST S/S, the test was able to discriminate health status with a sensitivity of 91.7% and specificity of 81.7%.*	McDevitt, 2016 (32)
OTHER OCULAR MEASURES			

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COVS	*Diagnostic accuracy*	Sensitivity: 100% Specificity: 97%	Capó-Aponte, 2012 (64)
Eye tracking	*Diagnostic accuracy*	ROC curves: Angular tracking error of the fast circular motion eye test: AUC = 0.84 Angular tracking error as well as the saccade count between 1° and 2° and the Stance 5 (unstable surface, eyes closed)/Stance 1 (stable surface, eyes open) balance score: AUC = 0.92	Baruch, 2016 (17)
	Diagnostic accuracy	Excluding CT positive patients: *Best subset*: Misclassification rate: 14.2; True positive: 5; False positive: 34; False negative: 2; True negative: 213; Sensitivity: 0.714; Specificity: 0.862; AUC: 0.831 *LASSO*: Misclassification rate: 13.8; True positive: 5; False positive: 33; False negative: 2; True negative: 214; Sensitivity: 0.714; Specificity: 0.866; AUC: 0.833 *Random forest*: Misclassification rate: 13.0; True positive: 4; False positive: 30; False negative: 3; True negative: 217; Sensitivity: 0.571; Specificity: 0.879	Samadani, 2015 (62)
Optokinetic after-nystagmus	*Diagnostic accuracy*	ROC Curve (AUC = 0.73) Specificity: 0.7 Sensitivity: 0.3 With suggested an optimal operating point of the ROC curve =16.62 seconds: Specificity: 0.72 Sensitivity: 0.73	Bertolini, 2021 (65)
SSVEP using EEG	*Diagnostic accuracy*	Classifiers: Support Vector Machine: Sensitivity: 62.78 Specificity: 64.50 Naïve Bayes: Sensitivity: 65.28 Specificity: 46.63 Linear Discriminant Analysis: Sensitivity: 60.00 Specificity: 64.55 Logistic Regression: Sensitivity: 63.61 Specificity: 61.25	Hoang, 2023 (66)

AP: anterior-posterior; **AUC:** Area Under the Curve; **BBT**: BTrackS Balance Test; **BESS:** Balance Error Scoring System; **CB&M**: community balance and mobility scale; **CBIAS:** Computerized Brain Injury Assessment System; **CI:** confidence interval; **COVS**: computerized oculomotor vision screening; **CT**: computerized tomography; **DHI:** dizziness handicap inventory; **DVA**: Dynamic Visual Acuity; **ECFIS**: eyes closed while standing on a firm surface; **ECFOS**: eyes closed while standing on an unstable (foam) surface; **EEG**: electroencephalography; **EOFIS**: eyes open while standing on a firm surface; **EOFOS**: eyes open while standing on an unstable (foam) surface; **FGA:** Functional Gait Assessment; **GST:** horizontal gaze stabilization test; **HIA-1:** Head Injury Assessment; **HiMAT:** High Level Mobility Assessment Tool; **ICC:** intraclass correlation coefficient; **KD:** King-Devick; **LASSO:** least absolute shrinkage and selection operator**;** **MACE:** military acute concussion evaluation; **mBESS:** Modified Balance Error Scoring System; **mCTSIB**: modified clinical test of sensory interaction on balance; **ML**: medio-lateral; **NPC:** near point convergence; **OA**: overall; **OKS:** optokinetic stimulation; **RCI**: reliable change indices; **RMS**: Root Mean Square; **ROC:** Receiver Operating Characteristic; $\mathbf{r_s}$: Spearman correlation; **S/S:** signs and symptoms**;** **SCAT:** Sport Concussion Assessment Tool; **SCAT3:** Sport Concussion Assessment Tool- 3rd edition; **SD**: standard deviation; **SOT**: sensory organization test; **SSVEP**: steady-state visual evoked potentials; **VMS**: visual motion sensitivity; **VOMS:** vestibular ocular motor screening; **VOR**: vestibulo-ocular reflex; **WBB**: Wii Balance Board

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Detailed descriptions of the clinical measures reported are presented in Appendix E [SUPPLEMENTAL DIGITAL CONTENT] including scoring of the measures and interpretation, equipment needed, method of administration, and dimension evaluated. Measures varied in terms of method of scoring and interpretation, such as counting errors during balance tasks or evaluating centre of pressure during balance tasks. The equipment needed to administer the measures also varied ranging from no equipment to complex systems such as postural sway platforms. All measures require a clinician to administer the test on the patient.

Vestibular

Twenty-eight studies[16–43] reported psychometric properties of vestibular measures with the majority being balance measures (26 of the 28 studies included balance measures), followed by gait measures (nine of the 28 studies used gait measures)[25,34–36,42,44–47]. Specific balance measures included the balance error scoring system (BESS), modified BESS (mBESS), inertial sensor-based evaluation of the BESS/mBESS, sensory organization test (SOT), postural stability test, modified clinical test of sensory interaction and balance (mCTSIB), community balance and mobility scale (CB&M), instrumented balance assessment, BTrackS Balance Test (BBT), balance testing using a platform, and the Wii Balance Board. Gait measures included the functional gait assessment (FGA), high level mobility and assessment tool (HiMAT), tandem gait tests, accelerometer-derived gait, and gait speed tests. Twelve studies evaluated psychometric properties of both vestibular and ocular measures (such as the BESS and the King-Devick test)[17,29,32,41,43] or evaluated combined vestibular and ocular measures (VOR measures) and included the vestibular ocular motor screening (VOMS)[24,43,48–51], Dynamic Visual Acuity (DVA)[32,52], and a combined battery of oculomotor and vestibular tests[53].

Ocular

An additional 12 studies evaluated psychometric properties of ocular measures solely, with the majority evaluating saccadic eye measures, including the King-Devick test (n=12)[29,32,41,43,54–61] followed by eye tracking measures (n=2)[17,62], smooth pursuit measures (n=2)[29,63], near point convergence measures (n=2)[32,54], and other measures including a computerized oculomotor vision screening test (n=1)[64], an optokinetic after-nystagmus test (n=1)[65], and the evaluation of steady-state visual evoked potentials (SSVEP) using electroencephalography.[66]

Psychometric Properties

The majority of studies included in this review evaluated the diagnostic accuracy of the identified measures. The BESS was the most explored clinical measure in the identified studies. Sensitivity metrics of the BESS ranged from 0.35[30] to 0.93[26]. Most studies document these psychometric properties at the acute phase post-injury. Internal consistency of the BESS has a documented intraclass correlation coefficient (ICC) of 0.83[21]. Area under the curve (AUC) ranges from 0.51[34] to 0.97[26]. The mBESS has a documented sensitivity and specificity ranging from 14 to 83%[29,40] and 29-97%, respectively[19,40]. The sensor-based instrumented mBESS, which produces sway metrics, has an AUC of approximately 0.7 and a documented sensitivity of 59 to 63%[30]. The SOT has a documented sensitivity ranging from 13%[38] to 73%[39] and specificity ranging from 85%[39] to 95%[38]. The mCTSIB has a documented AUC of 0.77[31]. Inertial sensor-based balance measures were explored by Doherty et al.[22] and have effect sizes ranging from 0 to 0.26 for sway volume and area in bilateral, unilateral and tandem stances. The CB&M has a sensitivity ranging from 0.78 to 1.00 and specificity ranging from 0.88 to 0.91[35,36]. Balance testing using a platform, as explored by Baruch et al.[17], has sensitivity metrics ranging from 0.74

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to 0.78[17]. Similarly, balance testing using BBT and an instrumented balance assessment has sensitivity ranging from 19% to 54%[16] and specificity ranging from 76% to 96%[16].

Out of the possible gait measures, tandem gait assessments were most explored in the identified studies. Tandem gait measures have an AUC of approximately 0.5[45] to 0.7[34] and sensitivity metrics ranging from approximately 42% to 63%. The FGA has a documented sensitivity ranging from 5%[36] to 75%[35]. The HiMAT was explored in the post-acute phase post-injury by Kleffelgaard et al.[47] and has a sensitivity ranging from 70% to 92%.

The VOMS was the most explored VOR measure in the identified studies and contains sensitivity metrics ranging from 77%[49] to 96%[48]. A study by Broglio et al.[43], documented the sensitivity metrics of the individual components of the VOMS, and while majority had moderate sensitivity metrics, the NPC component of the VOMS had poor sensitivity ranging from 6 to 47%. The DVA is another VOR measure with a document AUC of approximately 0.7[52].

Use of oculomotor measures were less explored in the literature. The test-retest reliability of the King-Devick test was explored by Walsh et al.[60] and has a Spearman's ρ's of 0.949. The diagnostic accuracy was evaluated by Harmon et al.[29] and has a sensitivity ranging from 54 to 85%. However, Broglio et al.[43] documented a sensitivity ranging from 5 to 48% for those with baseline examinations. Area under the curve, as documented by Le et al.[59] was around 0.7 in the acute phase post-injury, however it was documented as 0.6 by Dretsch et al.[55], suggesting that its sensitivity and specificity may not be acceptable (acceptable AUC is considered 0.7 or higher). At the 6-month post-injury time point, AUC reduced to approximately 0.6. The use of tracking devices to evaluate eye tracking movements were assessed by Baruch et al.[17] and Samadani et al.[62] and have AUCs ranging from approximately 0.8 to 0.9. A clinical measure evaluating optokinetic after-nystagmus, explored by Bertolini et al.[65], has an AUC of 0.73, sensitivity of 0.3

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and specificity of 0.7. The evaluation of SSVEPs has a sensitivity and specificity ranging from approximately 60 to 65% and 47 to 65%, respectively[66].

Clinical Relevance

Table 3 presents a summary of the information included in Table 2 for the purposes of clinical relevance. It provides an overview of the measures, including frequency used in the included studies, usefulness based on the metrics included in the studies for both the pre-72-hour and post-72-hour timeframes, and the clinical accessibility of the measures.

Table 3: Overview of clinical relevance of identified measures.

Measure	Frequency Used	Metrics suggest useful overall for pre-72-hour timeframe	Metrics suggest useful overall for post-72-hour timeframe	Clinically accessible: does not require complex tools
Balance Testing (17)	1	NR	Positive	No
BESS/mBESS (19,21,23, 25,26,28,29,30, 32,34,37,40,41,42,43,55)	16	Indeterminate	Indeterminate	Yes
BESS/mBESS with inertial sensor-based balance (22, 30)	2	Positive	Negative	No
BBT (27)	1	Positive	NR	No
CB&M (35,36)	2	Positive (timeframe NR)		Yes
Instrumented balance assessment (16)	1	Negative	NR	No
mCTSIB (20,31)	2	NR	Positive	No
Postural stability test (20)	1	NR	Negative	No
SOT (1,18, 28,32,38,39)	6	Indeterminate	Indeterminate	No
Nintendo WBB (33)	1	NR	Indeterminate	No
Accelerometer-derived measurements to monitor gait balance (46)	1	NR	Indeterminate	No
FGA (44,35,36)	3	Indeterminate (timeframe NR)		Yes
Gait Speed (25,35,36)	3	Positive	Positive	Yes
HiMAT (47, 44)	2	Positive (timeframe NR)		Yes
Tandem Gait (45,42,34)	3	Indeterminate	NR	Yes
DVA test (32,52)	2	NR	Indeterminate	No
VOMS (24,49,50,51,48,43)	6	Positive	Positive	Yes
Oculomotor, Vestibular and Reaction Time Tests (53)	1	Positive (timeframe NR)		No
EYE-SYNC smooth pursuit (29)	1	Indeterminate	NR	No
Smooth pursuits (63)	1	Positive (timeframe NR)		No
KD test (29,32, 41, 43, 55, 56, 57,58, 59, 60, 61)	12	Indeterminate	Indeterminate	Yes
NPC (32, 54)	2	Positive	Positive	Yes
COVS (64)	1	Positive (timeframe NR)		No
Eye tracking (17,62)	2	NR	Positive	No
Optokinetic after-nystagmus (65)	1	NR	Indeterminate	No
SSVEP using EEG (66)	1	Positive	NR	No

BBT: BTrackS Balance Test; **BESS:** Balance Error Scoring System; **CB&M**: community balance and mobility scale; **COVS**: computerized oculomotor vision screening; **DVA**: Dynamic Visual Acuity; **EEG**: electroencephalography; **FGA:** Functional Gait

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Assessment; **HiMAT:** High Level Mobility Assessment Tool; **KD:** King-Devick; **mBESS:** Modified Balance Error Scoring System; **mCTSIB:** modified clinical test of sensory interaction on balance; **NPC:** near point convergence; **NR:** not reported; **SOT**: sensory organization test; **SSVEP**: steady-state visual evoked potentials; **VOMS:** vestibular ocular motor screening; **WBB**: Wii Balance Board

Discussion

This scoping review identifies the existing vestibular and ocular clinical measures used to evaluate people post-concussion and documents their psychometric properties. Most measures included in this review assess balance deficits post-injury, were used in the sport context, and in the acute phase post-injury. Most studies explore the diagnostic accuracy of the measures, mainly the AUC, sensitivity, and specificity, when administered in the post-concussion population.

The findings suggest that multiple measures are available and are commonly used to evaluate the various domains impacted by a concussion. The vestibular and ocular domains are of particular interest in a concussion examination as they are two of the most common symptoms experienced by people following concussion. In fact, roughly 60% of people who experienced a concussion in the sport context reported symptoms related to these domains post-injury[67]. Our results emphasize the large variability in psychometric properties of vestibular and ocular measures. It highlights a need to evaluate and consolidate information on the psychometric properties of the relevant measures. These efforts enable clinicians to make an evidence-based selection regarding the most appropriate measures in clinical practice and optimal timepoint post-concussion for their utilization. Moreover, it calls attention to areas that are underdeveloped and understudied regarding the psychometric properties of clinical measures, such as the gap of information on responsiveness and reliability of the identified measures. The lack of documentation of reliability is likely because of challenges associated with conducting reliability studies that require tests to be administered at least twice, which is needed to determine test-

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retest, inter-rater, and intra-rater reliability, due to provocation of symptoms commonly experienced by people with concussion during clinical assessments[68], however, this is an area requiring future attention.

Vestibular evaluation in the concussion patient population presents with limitations, mainly due to the poor or unclear psychometric properties associated with frequently used clinical measures and limited guidance available for the selection of use of most appropriate measures in practice. A scoping review by Quintana et al.[67] explored vestibular and ocular measures used in the sport-related concussion context, with the majority of studies included in this review investigating the use of the BESS. Similar concerns were presented regarding the BESS in terms of its psychometric properties, particularly, its ability to identify deficits in concussed individuals. Leddy et al.[69] further reported that the utility of the BESS beyond the acute phase post-concussion is questionable. However, a systematic review by Bell et al.[70] reported moderate to good reliability properties (intra-rater reliability ICC = 0.60 to 0.92; inter-rater reliability ICC = 0.57 to 0.85; test-retest reliability ICC = 0.70) and moderate to high criterion-validity properties (r = 0.31 to 0.79) associated with the BESS. While the BESS appears to be well-researched, the variability in documented psychometric properties highlights a need to evaluate the properties and appraise the conducted studies. The balance measure that appears to provide the most promise for clinical use is the CB&M in that its' psychometric properties are positive, and the tool is clinically relevant, requiring minimal equipment (see Table 3). Further, there is a clear need for ongoing exploration and development of balance measures that are sensitive to vestibular deficits in the concussion patient population.

There is limited information in the literature on psychometric properties associated with commonly used ocular measures. The review by Quintana et al.[67] did not identify any ocular-

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only measures used in sport-related concussion contexts, however, identified, the VOMS, DVA, Head Impact Test, and gaze stabilization tests as measures used to evaluate VOR (both vestibular and ocular) deficits in this population. The VOMS tool appears to be the superior measure based on psychometric properties and clinical relevance out of all the identified vestibular, ocular, and VOR measures (see Table 3). We did not identify any studies evaluating the reliability of ocular measures assessed in people with concussion, aside from the King-Devick test. Aloosh et al.[71], however, documented good to moderate reliability in the NPC break (ICC = 0.65) and saccades (ICC = 0.61) in healthy individuals. The NPC test appears to present as the most promising ocular measure that has positive psychometric properties and clinical relevance (see Table 3).

This review highlights a need to develop and consolidate ocular measures that can be used in people experiencing visual deficits resulting from concussions. The identified studies included in our review rely on technology to evaluate ocular movements, which can make it challenging for clinicians to use the measures in clinical settings due to cost and time limitations. Poltavski et al.[72] highlighted the importance of incorporating ocular measures into a concussion assessment battery, reporting differences in performance on certain ocular measures when combined data on pediatrics and adults with a history of concussion were compared to healthy controls. Kapoor and Ciuffreda[73] further reported that people with concussion may experience a variety of visual symptoms post-injury, including impairments with visuo-motor coordination, accommodation, and perception, among others. As reported by Ciuffreda et al.[74], over 50% of people with concussion will experience vergence dysfunction post-injury. This was further supported by Brahm et al.[75], who reported that 50-90% of military personnel with post-concussive symptoms experience oculomotor problems. While there is a clear rationale to assess these ocular deficits so that interventions can be appropriately targeted, there is a gap in the

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current literature regarding available measures with sufficient evidence supporting use in practice.

Deciding what is the most appropriate measure requires an understanding of the ability of a measure to identify and be sensitive to deficits that are clinically meaningful[76]. This is a challenge according to Matuszak et al.[77] since most of the physical examinations conducted in the concussion population do not contain psychometric data, such as validity and reliability. It has been proposed by Murray et al.[4] that the balance measures currently used in clinical practice are not sensitive enough to identify balance deficits 72-hours post-injury (long-term deficits), therefore, reducing their utility and effectiveness in practice. Administering clinical measures with sufficient evidence for use in practice is of importance due to clinician reliance on findings on clinical assessments to inform intervention and monitor recovery[78,79]. It is, therefore, necessary to expand our understanding of the psychometric characteristics associated with clinical measures commonly used in the concussion context. Particularly for those experiencing persistent symptoms post-concussion, accurate assessment, and identification of deficits upon presentation to specialized assessment (such as when presenting to a neurologist or physiatrist for evaluation) is needed to optimally guide intervention and management. The findings of this review identify the clinical measures that have been most explored in the literature in people with concussion. This work highlights areas needing further exploration related to psychometric development in concussion measures.

Limitations

While relevant guidelines were followed for this scoping review, there are some important limitations to acknowledge. First, all studies included in this review were written in English, and therefore future work should aim to include studies in other languages. Certain

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equity, diversity and inclusion variables, such education, socioeconomic status, and ethnicity were minimally reported in the included studies and previous research suggests that these variables should be considered when using certain concussion measures[80,81]. Of the studies that did report this information, most participants were white, had some level of education, and were males. There is a highlighted need to further explore these variables in the concussion context in future studies.

In this review, we did not complete an evaluation of the psychometric properties, but rather aimed to identify the properties documented in the literature. Future work should expand on this review by including other domains impacted by a concussion, such as cognitive deficits, expanding on the population to include pediatrics, and completing an evaluation of the psychometric properties and quality of the studies.

Conclusion

The findings of this scoping review outline the clinical measures used to evaluate vestibular and ocular deficits post-concussion that contain documented psychometric properties. It documents these properties associated with each of the identified clinical measures. This review highlights the clinical measures that are most widely studied in the literature, which may reflect measures that are most commonly used in practice. While the psychometric properties and quality of studies were not evaluated, this review does highlight the variation in documented properties of the measures as presented in the literature. Future work should evaluate the quality of the studies and the documented properties and develop and explore the use of new measures with superior properties so that clinical measures can be effectively used to identify deficits post-injury. Once concrete measures containing acceptable properties have been established, clear recommendations on use of such measures can be provided to clinicians.

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Appendix A
Search Strategy

Medline

1	instrumentation.fs.
2	Validation Study.pt.
3	exp reproducibility of results/
4	reproducib*.ti,ab.
5	exp psychometrics/
6	(psychometr or clinimetr* or clinometr*).ti,ab.
7	exp observer variation/
8	observer variation.ti,ab.
9	exp discriminant analysis/
10	(reliab* or valid* or coefficient or internal consistency).ti,ab.
11	(cronbach* and (alpha or alphas)).ti,ab.
12	(item correlation or item correlations or item selection or item selections or item reduction or item reductions).ti,ab.
13	(agreement or precision or imprecision or precise values).ti,ab,kf.
14	test-retest.ti,ab.
15	(test and retest).ti,ab.
16	(reliab* and (test or retest)).ti,ab.
17	(stability or interrater or inter-rater or intrarater or intra-rater or intertester or inter-tester or intratester or intra-tester or interobserver or inter-observer or intraobserver or intra-observer or intertechnician or intertechnician or intratechnician or intra-technician or interexaminer or inter-examiner or intraexaminer or intra-examiner or interassay or inter-assay or intraassay or intra-assay or interindividual or inter-individual or intraindividual or intra-individual or interparticipant or inter-participant or intraparticipant or intra-participant or kappa* or coefficient of variation).ti,ab.
18	repeatab*.ti,ab,kf.
19	((replicab* or repeated) and (measure or measures or findings or result or results or test or tests)).ti,ab,kf.
20	(generaliza* or generalisa* or concordance).ti,ab.
21	(intraclass and correlation*).ti,ab.
22	(discriminative or known group or factor analysis or factor analyses or factor structure* or dimensionality or subscale* or multitrait scaling analys* or item discriminant or interscale correlation or interscale correlations).ti,ab.
23	((error or errors) and (measure* or correlat* or evaluat* or accuracy or accurate or precision or mean)).ti,ab.
24	(individual variability or interval variability or rate variability or variability analysis).ti,ab.
25	(uncertainty and (measurement or measuring)).ti,ab.
26	(standard error of measurement or sensitiv* or responsive*).ti,ab.
27	(limit and detection).ti,ab.
28	(minimal detectable concentration or interpretab*).ti,ab.

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29 (small* and (real or detectable) and (change or difference)).ti,ab.
30 (meaningful change or minimal important change or minimal important difference or minimally important change or minimally important difference or minimal detectable change or minimal detectable difference or minimally detectable change or minimally detectable difference or minimal real difference or ceiling effect or floor effect or Item response model or IRT or Rasch or Differential item functioning or DIF or computer adaptive testing or item bank or cross-cultural equivalence).ti,ab.
31 or/1-30
32 brain concussion/ or post-concussion syndrome/
33 mTBI.ti,ab,kf.
34 concuss*.ti,ab,kf.
35 ((mild or minor) adj3 traumatic adj3 brain adj3 injury).ti,ab,kf.
36 or/32-35
37 ((patient or self or carer or proxy) and (report or reported or reporting or rated or rating or ratings or based or assessed or assessment or assessments)).ti,ab,kf.
38 (test* or measure* or instrument* or method* or index or indices or assessment* or evaluation* or analys*).ti,ab,kf.
39 37 or 38
40 Gait/
41 gait.ti,ab,kf.
42 exp Postural Balance/
43 (postur* adj3 (balanc* or control)).ti,ab,kf.
44 (Function* adj3 balanc*).ti,ab,kf.
45 balanc*.ti,ab,kf.
46 (Core adj3 stability).ti,ab,kf.
47 Stability.ti,ab,kf.
48 (postur* or sit* or seat*).ti,ab,kf.
49 Reflex, Vestibulo-Ocular/
50 (vestibular or vestibulo-ocular or oculo-vestibular or vestibulo* or vestibulo-spinal).ti,ab,kf.
51 Vision, Ocular/
52 visuomotor.ti,ab,kf.
53 Vision*.ti,ab,kf.
54 (Vision* adj3 ocular).ti,ab,kf.
55 Oculomotor.ti,ab,kf.
56 Ocular motility.ti,ab,kf.
57 Eye Movements/
58 Eye movement*.ti,ab,kf.
59 (dizziness or visual or vertigo).ti,ab,kf.
60 or/40-59
61 31 and 36 and 39 and 60

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Appendix B
Demographic information of included studies

Study Information		Study Population Information							Injury information		Clinician Information
Study First author, year, country	**Study Design**	**Sample Size** Total (concussed: healthy)	**Mean Age, y**		**Sex/Gender Male: n (%)**		**Socio-economic Status/Education**	**Ethnicity**	**Setting of Injury**	**Time since injury**	**Type of clinician that administered the measure**
			Concussion	**Healthy**	**Concussion**	**Healthy**					
Vestibular Measures											
Fino, 2023, United States (44)	Cross-sectional	100 (53:57)	32.0±9.6	31.1±9.5	11 (21%)	16 (28%)	NR	NR	Not specified (individuals following mTBI)	Outside the subacute stage (>3 weeks post-injury)	Physical therapist
Sik, 2023, New Zealand (40)	Prospective observational	Total:49 Control:17 Head trauma without CT:19 Head trauma with CT:13	Median (Range) Head trauma without CT: 28 (24–49) Head trauma with CT: 49 (24.5–63.5)	Median (Range) 32 (25–46.5)	Head trauma without CT: 9 (47%) Head trauma with CT: 6 (46%)	8 (47%)	NR	Ethnicity (head trauma with CT/head trauma without CT/control): NZ European (9/10/9) NZ Maori (0/4/2) Other European (2/3/3) Asian (1/1/2) Pacific (0/1/1) Other (1/0/0)	Not Specified (people following head injury)	Acute (head trauma within the previous 24 hours)	NR
Martini, 2022, United States (31)	Cross-sectional	94 (41:53)	39.8±11.5	36.5±12.1	12 (29.3%)	21 (39.6%)	NR	NR	Not specified (people with chronic mTBI)	Mean = 2.3±2.0 y post-injury	NR
Fuller, 2020, United Kingdom (45)	Retrospective cohort	1118 (1118:NA)	NR	NA	NR	NA	NR	NR	Sport	NR	Team doctor
Pape, 2020, United States (36)	Cross-sectional	90 (45:45)	33.47±6.51	30.36±7.17	43 (95.6%)	41 (91.1%)	NR	NR	Military	NR	Physical therapist
Pryhoda,	Prospective cohort	117 (25:92)	19.58 (SD = NR)	19.60 (SD = NR)	9 (36%)	46 (50%)	NR	NR	Sport	Evaluated <3 days, 1 week, 1	NR

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2020, United States (37)										month, and 6 months post-injury	
Fino, 2019, United States (25)	Case-control longitudinal	49 (24:25)	20.3±1.3	20.9±1.4	18 (75%)	19 (76%)	NR	NR	Sport	Referred to the study within 48 hours of injury; measurements taken at Days 2, 5, 10 post-concussion	NR (athletic trainer identified concussions and physicians confirmed; unclear which clinician administered the measure)
Baracks, 2018, United States (16)	Cross-sectional	93 (45:48)	20.62±1.52	20.85 ± 1.42	35 (72.92%)	28 (62.22%)	NR	NR	Sport	Testing sessions for the study were ideally completed within 24 hours post-injury or within a maximum of 72 hours post-injury	NR (medical professionals diagnosed concussions, administrator monitored participant completion of test; unclear which clinician administered the measure)
Buckley, 2018, NR (19)	Prospective observational	35 (35:NA)	18.9±0.8	NA	17 (48.6%)	NA	NR	NR	Sport	Evaluated day after injury (acute) and re-evaluated daily until same or fewer errors committed when compared to baseline	NR
Garcia, 2018, United States (26)	Secondary analysis	1293 (560 6 h post-injury and 733 24–48 h post-injury: NA)	< 6 hours post-injury: 19.37±1.31 24-48 hours post-injury: 19.33±1.27	NA	< 6 hours post-injury: 360 (64.46%) 24-48 hours post-injury: 440 (60.03%)	NA	NR	NR	Military and Sport	Assessments occurred at < 6 hours, 24-48 hours, and at the time of unrestricted return to play post-injury	NR
Cushman, 2018, NR (21)	Retrospective review	102 (102:NA)	30.3±11.6	NA	43 (42.2%)	NA	NR	NR	Not specified (assessed at a sports medicine clinic)	Mean = 132±272 days post-injury	Physicians with training in Physical Medicine and Rehabilitation and/or Sports Medicine
Downey, 2018, Canada (23)	Prospective cohort	45 (23: 22)	20.04±1.99	19.24 (SD = NR)	10 (43.5%)	9 (40.9%)	NR	NR	Sport	Acute (3–5 days post-injury)	Research coordinator (athletic therapist identified

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											concussions and diagnosis was confirmed by physician)
Hanninen, 2018, Finland (42)	Prospective cohort	27 (27:NA)	27±4	NA	27 (100%)	NA	NR	NR	Sport	Day of injury	Team medical provider
Oldham, 2018, United States (34)	Prospective longitudinal cohort	72 (38:38)	20.2±1.4	20.8±1.0	NR	NR	NR	NR	Sport	Acute (≤48 hours post-injury)	NR (athletic trainer identified concussions and diagnosis was confirmed by physician; unclear which clinician administered the measure)
Chen, 2017, Taiwan (20)	Cross-sectional	349 (244 (144, 73, and 27 with low, middle, and high DHI scores, respectively): 105)	40.68±14.51, 38.18±12.94, and 44.48±11.24 (low, middle, and high DHI scores, respectively)	31.28±11.45	Low DHI: 65 (26.7%) Middle DHI: 28 (11.5%) High DHI: 9 (3.7%)	36 (34.3%)	Years of Education: Control: 10.8±3.2 Concussion: Low DHI: 11.3±3.8 Middle DHI: 11.0±3.9 High DHI: 10.9±3.3	NR	Community-dwelling	Mean = 3.9±1.4 days post-injury	NR
Doherty, 2017, NR (22)	Cross-sectional	30 (15:15)	21.83±3.5	22.46 ± 3.7	11 (73.3%)	11 (73.3%)	NR	NR	Not specified (people from ED)	Mean = 9±7 days post-injury	Physiotherapist
King, 2017, United States (30)	Cross-sectional	128 (52:76)	20.36±1.30	20.64±1.40	35 (67.3%)	38 (50%)	NR	NR	Sport	Mean = 2.21±1.19 days post-injury	Research assistant trained in the classification criteria of the mBESS
Merchant-Borna, 2017, United States (33)	Prospective cohort	19 concussed participants	19.2±1.2	NA	10 (53%)	NA	NR	n (%) White: 14 (74%) African American: 1 (5%) Biracial: 2 (11%) Unknown: 2 (11%)	Sport	Evaluated preinjury, and 3- and 7-days post-injury	Study staff and nonauthors who were trained on study procedures for administering the measures
Goble, 2016, United States (27)	Cross-sectional	35 (35: NA)	20.7 (SD = NR)	NA	11 (31.4%)	NA	NR	NR	Sport	Acute (≤48 hours post-injury)	Athletic training staff (verified by team physician)

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Haran, 2016, United States (28)	Retrospective cross-sectional	334 total Acute SOT Group: 173 Subacute SOT Group: 30 Acute BESS Group: 102 Subacute BESS Group: 29	Acute SOT Group: 25.63±2.64 Subacute SOT Group: 24.57±5.14 Acute BESS Group: 24.30±5.83 Subacute BESS Group: 25.00±10.78	NA	334 (100%)	NA	NR	NR	Military	Acute SOT Group: Mean time from injury = 2.64±1.54 days Subacute SOT Group: Mean time from injury = 15.33±10.40 days Acute BESS Group: Mean time from injury = 2.83±1.78 days Subacute BESS Group: Mean time from injury = 15.50±13.50 days	NR
Pape, 2016, United States (35)	Cross-sectional	16 (8:8)	31.8±7.7	31.3±8.9	7 (87.5%)	7 (87.5%)	NR	NR	Military	NR	Physical therapist
Resch, 2016, NR (39)	Cross-sectional	80 (40:40)	20.2±1.60	19.0±0.93	29 (72.5%)	29 (72.5%)	Years of Education: Concussion: 12.7±1.24 Control: 12.6±0.93	NR	Sport	NR	NR (diagnosed by certified athletic trainer(s) and/or physician; unclear which clinician administered the measure)
Howell, 2015, United States (46)	Prospective repeated measures	17 (10:7)	19.0±5.5	20.0±4.5	7 (70%)	4 (57%)	NR	NR	Not specified (diagnosed with concussion by a healthcare professional (physician/athletic trainer))	Evaluated within 72 hours and approximately 1 week, 2 weeks, 1 month, and 2 months post-injury	Study investigator (concussions diagnosed by physician or athletic trainer)
Kleffelgaard, 2013, Norway (47)	Cohort, pretest-post-test, comparison	92	37.1±13.8	NA	63 (69%)	NA	NR	NR	Not specified (assessed immediately after injury or at hospital admission)	3- and 6-months post-injury	Physical therapist

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Register-Mihalik, 2013, NR (38)	Cross-sectional	170 (132:38)	18.59±1.09	20.64±1.62	86 (65.2%)	38 (100%)	NR	NR	Sport	Mean = 2.36±1.41 days post-injury	NR
Broglio, 2008, NR (18)	Cross-sectional	129 (63:66)	20.27±1.35	NR	50 (79.4%)	NR	NR	NR	Sport	Not specified (within 24 hours of the physician-diagnosed concussion).	NR
Broglio, 2007, NR (1)	Cross-sectional	75 (75:NA)	NR	NA	62 (82.7%)	NA	NR	NR	Sport	Within 24 hours post-injury	NR
Le, 2023, United states (59)	Cross-sectional	1559 (320:1239)	19.80±1.41	20.31±1.18	51.3%	52.2%	NR	NR	Sport	Evaluated 0-6- and 24-48-hours post-injury, and when asymptomatic	NR (concussions diagnosed by sports medicine team; unclear which clinician administered the measure)
Ocular Measures											
Hoang, 2023, Australia (66)	Case-control	436 (36:400)	Whole population: Males = 23 (SD = NR) Females = 26 (SD = NR)		Whole population: 299 (68.6%)		NR	NR	Sport	Mean = 2±1.29 days	NR
Bertolini, 2021, Switzerland (65)	Cross-sectional	92 (71:21)	30.36±9.05	26.29±10.00	54 (76.4%)	8 (38.1%)	NR	NR	Not specified (evaluated at the Swiss Concussion Center)	Mean = 363±629 days (range between 6- and 4172-days post-injury)	NR (neurologists ordered OKAN testing; unclear which clinician administered the measure)
Dretsch, 2019, NR (55)	Prospective cohort	Post-assessments: 129 (31:98)	Post-training: 29.84±3.93	Post-training: 29.98±4.80	Post-training: 28 (90.3%)	Post-training: 92 (93.9%)	Education (concussed/ control) GED (0/1) High School (4/18) Some College (18/57) College Degree (8/19) Graduate Degree (1/3)	NR	Active-duty service members from mixed martial arts training school	Immediately following sparring match	NR
Fuller, 2019, NR (61)	Prospective cohort	(261:51)	27.6±2.6	NR	100%	NR	NR	NR	Sport	Not specified (off-field after head impact)	Physician
Capó-Aponte, 2018,	Case–control correlational	200 (100:100)	Whole population: 26±6		87 (52.4%)	79 (47.6%)	NR	Ethnicity (mTBI/control): White (60/58) Black (14/18)	Military	Acute (≤72 hours post-injury)	NR

United States (54)								Hispanic (14/13) Asian (3/6) Other (9/5)			
Hecimovich, 2018, Australia (57)	Prospective cohort	Total: 22 During game: 20 (7:13)	Whole population: 19.6±2.3		Whole population: 22 (100%)		NR	NR	Sport	Immediately on sideline	Physiotherapist
Leong, 2016, NR (58)	Cross-sectional	Total: 127 During playing season: 102 (11:91)	During playing season: 19.6±1.2	During playing season: 19.5±1.2	Whole population: 119 (93.7%)		NR	NR	Sport	Immediately on sideline	NR (judgments about the occurrence of concussion were made as per standard practice by the team physicians and athletic trainers; unclear which clinician administered the measure)
Stubbs, 2019, Canada (63)	Cross-sectional	31(16:15)	31.4±6.3	31.1±8.0	3 (18.8%)	2 (13.3%)	NR	NR	Not specified (mTBI within the past 2 y, and symptomatic at the time of evaluation)	5.2±3.8 months	NR
Walsh, 2016, United States (60)	Case-control	200 (100:100)	26.31±5.83	26.31 ± 5.83	87 (87%)	79 (79%)	NR	Ethnicity (% mTBI/% Control) Caucasian (60/58) African American (14/18) American Indian (3/1) Hispanic (14/13) Asian (3/6) Other (6/4)	Military	Acute mTBI (≤72 hours post-injury)	NR (mTBI diagnosed by primary care providers; unclear which clinician administered the measure)
Samadani, 2015, United States (62)	Cross-sectional	323(42:281)	40.91±11.83	41.55±12.61	34 (81%)	129 (45.9%)	NR	NR	Community-dwelling	NR	NR
Capó-Aponte, 2012, United States (64)	Pilot	40 (20:20)	29.70±7.68		32.65±8.94		14 (70%)	18 (90%)	NR	NR	Military

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Galetta, 2011, United States (56)	Cross-sectional	39 (8:31)	Median (Range) Whole population: 24 (16–53)		Whole population: 38 (97%)		NR	Race: n (%) Caucasian: 35 (90) African American: 4 (10)	Sport	Immediately after sparring session	NR (ringside physician was separate from the individuals who performed the KD testing; unclear which clinician administered the measure)
Vestibular and Ocular Measures and VOR Measures											
Ferris, 2022, United States (50)	Prospective cohort	3958 athlete evaluations (3958:NA)	19.44±1.48	NA	2069 (52.3%)	NA	NR	NR	Sport	Acute (≤ 48 hours post-injury)	NR
Ferris, 2022, United States (49)	Prospective cohort	3444 pre-season athletes (496 acute concussion assessments: 3958 pre-season assessments)	NR	NR	Whole population: 2069 (52%)		NR	NR	Sport	Acute (≤6-48 hours post-injury)	NR
Harmon, 2022, United States (29)	Case-control	82 (41:41)	NR	NR	24 (59%)	24 (59%)	Year in college/university (concussed/control): Year 1 (12/12) Year 2 (15/11) Year 3 (10/10) Year 4 (4/7) Year 5 (0/1)	NR	Sport	Acute (within 24 hours post-injury)	NR (concussions diagnosed by sports medicine physician; unclear which clinician administered the measure)
Buttner, 2021, Ireland (48)	Prospective longitudinal	100 (50:50)	22.9±5.1	23.8±4.6	36 (72%)	36 (72%)	Occupation status: Concussion Student:26 Professional:24 Control Student:32 Professional:18	NR	Sport	1-week post-injury	NR (concussions diagnosed by emergency department physician; unclear which clinician administered the measure)
Feller, 2021, United	Prospective cohort	88 (34:54)	19.7±2.4	20.8±2.2	20 (63%)	31 (57%)	NR	Ethnicity (with concussion/without concussion)	Sport	Median = 19 (range: 10-39) days	NR (concussions diagnosed by experienced

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States (52)								White (28/33) Asian (2/13) African American (2/1) Hispanic (0/2) Other (0/5)			clinicians; unclear which clinician administered the measure)
Ferris, 2021, United States (24)	Prospective cohort	388 (388:NA)	19.09 ±1.31	NA	245 (63.1%)	NA	NR	NR	Military and Sport	NR	Trained personnel (not specified)
Kontos, 2021, United States (51)	Case-control	570 (285:285)	19.2±1.4	19.8±1.2	220 (77.2%)	218 (76.5%)	NR	NR	Sport	Acute (≤72 hours post-injury)	Trained researcher
Broglio, 2019, United States (43)	Prospective cohort	1458 (1458:NA)	19.0±1.2	NA	918 (63.0%)	NA	NR	NR	Sport	Acute (≤72 hours post-injury)	NR (concussion diagnosed by local medical staff; unclear which clinician administered the measure)
Balaban, 2016, United States (53)	Case-control	300 (100:200)	Cohort 1 (accrued through August 2014) 26.7±6.4 Cohort 2 (accrued through October 2015) 26.0±7.0	Cohort 1 (accrued through August 2014) 29.7±6.2 Cohort 2 (accrued through October 2015) 26.3±6.0	Cohort 1 (accrued through August 2014) 29 (58%) Cohort 2 (accrued through October 2015) 38 (76%)	Cohort 1 (accrued through August 2014) 75 (75%) Cohort 2 (accrued through October 2015) 81 (81%)	NR	NR	Not specified (individuals following mTBI)	Most participants (52.8%) evaluated within 48 hours post-injury and 83.0% evaluated within 96 hours post-injury	NR (instructions provided by examiner)
Baruch, 2016, United States (17)	Preliminary validation	56 (28:28)	32.68±11.62	30.96±16.16	27 (96.4%)	25 (89.3%)	NR	NR	Military and Community-dwelling	12 tested within 2.5 y of injury (Mean = 1.08 y), and 16 tested within 5 y of injury (Mean = 4.2 y)	NR
McDevitt, 2016, United States (32)	Cross-sectional	72 (12:60)	20.5±1.8	21.7±3.6	7 (58.3%)	35 (58.3%)	NR	NR	Sport	Assessed people with symptoms for 4–90 days post-injury (6 participants	NR

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										assessed 2–10 days post-injury)	
Silverberg, 2014, Finland (41)	Prospective cohort	59 (26:33)	36.6±12.2	42.8±12.2	19 (73.1%)	17 (51.5%)	Education: mTBI: 14.0±3.3 y Control: 14.3±2.9 y	Caucasian: 59 (100%)	Motor vehicle accident, Fall, Sport, Other (not specified)	Time between injury and ED arrival = < 72 hours	NR

BESS: Balance error scoring system; **COVS**: computerized oculomotor vision screening; **CT**: computerized tomography; **DHI:** dizziness handicap inventory; **ED:** emergency department; **GED**: General Education Development; **KD**: King-Devick; **mTBI:** mild traumatic brain injury; **n**: number; **NR:** Not reported; **NA**: Not applicable; **NZ**: New Zealand; **OKAN**: Optokinetic after-nystagmus; **SD**: standard deviation; **SOT:** sensory organization test; **VOR:** vestibulo-ocular reflex**; y**: year

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Appendix C
Psychometric Properties of Measures Identified in Included Studies

Clinical Measure	PSYCHOMETRIC PROPERTIES		INTERPRETATION	First Author, year
VESTIBULAR				
BALANCE				
Balance testing	*Diagnostic accuracy*	AUC, Ratio: Unstable eyes open-stable eyes open: 0.74 Unstable eyes closed-stable eyes open: 0.78 Unstable eyes follow random target-stable eyes follow random target: 0.75	*The ability of the balance assessment to discriminate between people with and without concussion varied.*	Baruch, 2016 (17)
BESS/ mBESS	*Reliability: internal consistency*	ICCs: **Standard BESS:** 0.829; Excluding firm double: 0.851; Excluding firm double and foam double: 0.846 **mBESS**: 0.615	*The BESS contains good reliability properties, with ICCs greater than 0.75. The mBESS contains lower reliability properties.*	Cushman, 2018 (21)
	Diagnostic accuracy	**BESS** AUC 95% CI: 0.508 Sensitivity: 0.447 (0.286–0.617) Specificity: 0.500 (0.334–0.666) **mBESS** AUC: 0.71 (0.60, 0.83) Sensitivity, %: Increase in three errors: 41 Increase in five errors: 40 Increase in eight errors: 14 Specificity, %: Increase in three errors: 61 Increase in five errors: 92 Increase in eight errors: 97	*The mBESS had low sensitivity but higher specificity. This suggests that if balance deficits are experienced (when evaluated using the mBESS), there is a high likelihood of concussion presence, however if no deficits are experienced, then absence of concussion should not be ruled out.*	Harmon, 2022 (29)
	Diagnostic accuracy	**mBESS** Sensitivity, % (95% CI): 83.3% (58.6–96.4) Specificity, % (95% CI): 58.8% (32.9–81.6)	*The mBESS lacked sufficient ability to identify the concussion cohort.*	Sik, 2023 (40)
	Concurrent validity	*There was a moderate correlation between BESS and the SCAT3 symptom score (r_s = 0.38) in acute concussion.*		Ferris, 2021 (24)
	Diagnostic accuracy	Sensitivity with 95% CI reported for balance measures with an AUC curve >0.7 and a Youden Index > 0.5 *Double-leg stance, Hard surface:* COP ML velocity: <3 days: 0.94 [0.82–1.06] 1 week: 0.53 [0.30–0.75] 1 month: 0.46 [0.19–0.73] 6 months: 0.60 [0.35–0.85] *Tandem stance, Foam surface* COP velocity: <3 days: 0.81 [0.62–1.0] 1 week: 0.79 [0.61–0.97] 1 month: 0.92 [0.78–1.07] 6 months: 0.67 [0.43–0.91] COP AP velocity: <3 days: 0.69 [0.46–0.91] 1 week: 0.84 [0.68–1.0] 1 month: 0.85 [0.65–1.04] 6 months: 0.80 [0.60–1.0]	*COP ML velocity in the double-leg stance on foam had poor discriminative ability. In the double-leg stance on a hard surface, COP ML velocity had good discriminative ability, COP velocity had fair discriminative ability, and COP AP velocity had poor discriminative ability. For the tandem stance on foam, COP velocity and COP AP velocity had fair discriminative ability.*	Pryhoda, 2020 (37)
	Diagnostic accuracy	*Sideline evaluation* *Raw score*: Sensitivity: 0.528; Specificity: 0.977 *Same year*: Sensitivity: 0.612; Specificity: 0.972 *Year prior*: Sensitivity: 0.500; Specificity: 0.979	*Findings indicated that BESS scores collected on the firm surface was one of multiple clinical measures to offer the best performance in terms of its ability to identify deficits.*	Broglio, 2019 (43)

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		Post-event evaluation *Raw score*: Sensitivity: 0.705; Specificity: 0.902 *Same year*: Sensitivity: 0.674; Specificity: 0.944 *Year prior*: Sensitivity: 0.596; Specificity: 0.966 *Clinic evaluation* *Raw score*: Sensitivity: 0.547; Specificity: 0.907 *Same year*: Sensitivity: 0.507; Specificity: 0.934 *Year prior:* Sensitivity: 0.370; Specificity: 0.980		
	Diagnostic accuracy	AUC= 0.59 (Lower band= 0.42, Upper band= 0.75) *Tandem stance, Foam surface* Sensitivity: COP velocity <3 days: 0.81 [0.62–1.0] 1 week: 0.79 [0.61–0.97] 1 month: 0.92 [0.78–1.07] 6 months: 0.67 [0.43–0.91] COP AP velocity <3 days: 0.69 [0.46–0.91] 1 week: 0.84 [0.68–1.0] 1 month: 0.85 [0.65–1.04] 6 months: 0.80 [0.60–1.0]	*Clinical BESS error count was not able to classify participants (AUC < 0.6).*	Fino, 2019 (25)
	Diagnostic accuracy	**BESS**: Sensitivity = 0.60 Specificity = 0.40 **mBESS**: Sensitivity = 0.71 Specificity: mBESS = 0.29	*The BESS and mBESS had moderate sensitivity and low specificity.*	Buckley, 2018 (19)
	Diagnostic accuracy	*Acute phase of injury* 0.70 RCI Sensitivity: 15.4% Specificity: 91.3% 0.80 RCI Sensitivity: 7.7% Specificity: 91.3% 0.90 RCI Sensitivity: 7.7% Specificity: 91.3% *Post-acute phase of injury* 0.70 RCI Sensitivity: 20% Specificity: 93.1% 0.80 RCI Sensitivity: 20% Specificity: 96.6% 0.90 RCI Sensitivity: 20% Specificity: 96.6%	*The discriminative ability of the mBESS was limited at both the acute and post-acute phase post-injury.*	Downey, 2018 (23)
	Diagnostic accuracy	Reported as follows: testing set estimate without baselines (training set estimate) BESS (change score) < 6 hours: Sensitivity = 0.93 (0.93) Specificity = 0.95 (0.98) AUC = 0.98 (0.99) BESS (raw score) 24-48 hours: Sensitivity = 0.84 (0.88) Specificity = 0.97 (0.96) AUC = 0.97 (0.97)	*The BESS may add little value to the SCAT tool when symptom assessments are included.*	Garcia, 2018 (26)
	Diagnostic accuracy	*The mBESS had poor discriminative ability (AUC = 0.69, CI = 0.56–0.82). Baseline-adjusted post-injury scores had poor discriminative ability (AUC = 0.72, CI = 0.60–0.84).*		Hanninen, 2018 (42)
	Diagnostic accuracy	Instrumented measures characterized postural sway amplitude, velocity, variability, and frequency for each of the 3 mBESS stance conditions: *Clinical (subjective, not instrumented) mBESS* AUC 95% CI: 0.606 (0.503, 0.709) Sensitivity:35% *Double stance RMS ML* AUC (95% CI): 0.735 (0.637, 0.833) Sensitivity: 63% *Double stance RMS ML + double stance total power ML* AUC (95% CI): 0.750 (0.653, 0.847) Sensitivity: 59%	*The double stance condition demonstrated the best ability to discriminate between groups.*	King, 2017 (30)
	Diagnostic accuracy	**mBESS** AUC 95% CI: 0.535 Sensitivity: 0.474 (0.310–0.642) Specificity: 0.632 (0.460–0.782)	*BESS and mBESS demonstrated poor sensitivity and specificity properties.*	Oldham, 2018 (34)

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		BESS AUC 95% CI: 0.508 Sensitivity: 0.447 (0.286–0.617) Specificity: 0.500 (0.334–0.666)		
	Diagnostic accuracy	90% CI Acute (< 7 days post-injury): 35%; Sub-acute (8–89 days post-injury): 31% 80% CI Acute (< 7 days post-injury): 39%; Sub-acute (8–89 days post-injury): 31%	*Statistically significant differences ($p < 0.0001$, one-sample sign test) were found on the BESS, (median of the difference > 0). There were no differences between the acute and subacute groups ($p = 0.49$, Mann-Whitney U test).*	Haran, 2016 (28)
	Concurrent validity	Correlation of concussion assessments with health status: Total BESS test: r = −0.13 Double leg firm: n/a Single leg firm: r = −0.16 Tandem leg firm: r = −0.08 Double leg foam: r = 0.15 Single leg foam: r = −0.26 Tandem leg foam: r = 0.10	*BESS conditions did not correlate with health status.*	McDevitt, 2016 (32)
	Diagnostic accuracy	*The sensitivity of the BESS was 8.3%. This indicates that 1 in 12 of people with concussion were correctly identified.*		McDevitt, 2016 (32)
	Diagnostic accuracy	mBESS: F = 0.988; p = 0.325; Cohen's d = 0.29	*Performance on the mBESS was not different between control and mTBI groups.*	Silverberg, 2014 (41)
BESS/mBESS with inertial sensor-based balance	*Diagnostic accuracy*	Concussion versus control effect sizes: *Bilateral stance:* Sway volume: 0.25 Sway area: 0.26 *Tandem stance:* Sway volume: 0.03 Sway area: 0.18 *Unilateral stance:* Sway volume: 0.06 Sway area: 0.00	*There were no differences on the BESS when the concussed group was compared to the control group. During tandem and unilateral stance, sway volume reached asymptotic significance level ($p < 0.001$).*	Doherty, 2017 (22)
	Diagnostic accuracy	AUC 95% CI: Double stance RMS ML: 0.735 (0.637, 0.833) Double stance RMS ML + double stance total power ML: 0.750 (0.653, 0.847) Sensitivity: Double stance RMS ML: 63% Double stance RMS ML + double stance total power ML: 59%	*The clinical mBESS did not detect differences between concussed and control groups. The instrumented sensor-based mBESS demonstrated the ability to detect differences between the groups.*	King, 2017 (30)
BBT	*Diagnostic accuracy*	Sensitivity: 64.0%	*As reported by the authors, BBT has the greatest sensitivity out of the available balance tests.*	Goble, 2016 (27)
CB&M	*Diagnostic accuracy*	AUC (95% CI): 0.92 (0.87, 0.97) Sensitivity: 0.78 Specificity: 0.91	*The CB&M has the potential to detect mTBI impairments. The CB&M resulted in a large AUC (92%) and superior sensitivity and specificity ratio.*	Pape, 2020 (36)
	Diagnostic accuracy	AUC (95% CI): 0.98 (0.94, 1.00) Sensitivity: 1.00 Specificity: 0.88	*The CB&M has the potential to detect mTBI impairments. The CB&M contains high sensitivity and specificity metrics.*	Pape, 2016 (35)
Instrumented balance assessment	*Diagnostic accuracy*	**RMS sway** 0.5-SD cut-off value: Sensitivity: 54% Specificity: 71% 1-SD cut-off value: Sensitivity: 44% Specificity: 82% 1.5-SD cut-off value: Sensitivity: 40% Specificity: 89% 2-SD cut-off value: Sensitivity: 33% Specificity: 98% *The highest sensitivity (54%) was found using the RMS sway metric and a 0.5-SD cut-off value. The highest specificity (98%) occurred when using the RMS sway metric with a 2-SD cut-off value.* **95% ellipse sway area**	*The instrumented balance measures had relatively low sensitivity and high specificity. A lower cut-off value can be used to increase clinical sensitivity, but then specificity decreases. On the other hand, a higher cut-off value resulted in increasing specificity at the expense of sensitivity.*	Baracks, 2018 (16)

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		Double-legged stance 0.5-SD cut-off value: Sensitivity: 52% Specificity: 80% 1-SD cut-off value: Sensitivity: 38% Specificity: 89% 1.5-SD cut-off value: Sensitivity: 27% Specificity: 91% 2-SD cut-off value: Sensitivity: 23% Specificity: 96% *Single-legged stance* 0.5-SD cut-off value: Sensitivity: 42% Specificity: 76% 1-SD cut-off value: Sensitivity: 40% Specificity: 87% 1.5-SD cut-off value: Sensitivity: 25% Specificity: 89% 2-SD cut-off value: Sensitivity: 21% Specificity: 93% *Tandem stance* 0.5-SD cut-off value: Sensitivity: 44% Specificity: 80% 1-SD cut-off value: Sensitivity: 35% Specificity: 93% 1.5-SD cut-off value: Sensitivity: 23% Specificity: 93% 2-SD cut-off value: Sensitivity: 19 % Specificity: 93%		
mCTSIB	*Diagnostic accuracy*	*The average sway area across the four mCTSIB conditions (mean AUC: 0.77) was significantly (z = 14.0; p < 0.001) better than the total mCTSIB score at differentiating between people with chronic symptoms post-mTBI and healthy controls. The sensitivity (71%) and specificity (71%) were optimal for the average sway area across the 4 mCTSIB conditions. Seventy-two percent of people with mTBI were classified correctly.*		Martini, 2022 (31)
	Diagnostic accuracy	*ECFIS significantly differed between the low and high mTBI subgroups (p = 0.01), between middle and high mTBI subgroups (p = 0.02), and between control group and high mTBI subgroup (p = 0.02).* *ECFOS significantly differed between control group and high mTBI subgroup (p = 0.01).* *ECFIS significantly differed between low and high mTBI subgroups (p = 0.04).* *The ECFIS significantly differed between low and high mTBI subgroups (p = 0.04).*		Chen, 2017 (20)
	Concurrent validity	*Relationship between sensory integration (ECFIS) and the functional, emotional, and total aspects of the DHI was the following: functional (r = 0.13, p = 0.01), emotional (r = 0.14, p = 0.01), total (r = 0.13, p = 0.01).*	*The post hoc test (Bonferroni) revealed no significant differences between low and high mTBI subgroups.*	Chen, 2017 (20)
Postural stability test	*Concurrent validity*	*In the high mTBI subgroup, the relationship between the physical aspect of the DHI and OA and AP stability was the following: OA (r = 0.43, p = 0.03) and AP (r = 0.46, p = 0.02).*	*No significant relationship was observed between the physical DHI and OA, AP, and ML postural stability.*	Chen, 2017 (20)
SOT	*Diagnostic accuracy*	Acute group (<7 days post-injury), SOT composite score: Sensitivity: 90% CI = 50%; 80% CI = 58% Sub-acute group (8–89 days post-injury), SOT composite score: Sensitivity: 90% CI = 47%; 80% CI = 47%	*Statistically significant differences were observed for the SOT composite score (p < 0.001, one-sample sign test), SOT visual ratio (p < 0.001, one-sample sign test), and SOT vestibular ratio (p < 0.001, one-sample sign test) (median of the difference scores all < 0).*	Haran, 2016 (28)
	Diagnostic accuracy	*People with concussion scored significantly lower on the SOT in the individual conditions (F5,65 =3.26, p=0.011), The SOT demonstrated a sensitivity of 33.3% and a positive predictive value of 66.7%.*		McDevitt, 2016 (32)
	Diagnostic accuracy	Sensitivity: 72.5 Specificity: 85.0 Overall classification rate: 78.8 Positive likelihood ratio: 4.83 Negative likelihood ratio: 0.32	*The SOT vestibular ratio (0.95) and the SOT composite score (−0.55) demonstrated the ability to distinguish between people with concussion and healthy controls. The SOT demonstrated the ability to correctly classify people with concussion and healthy controls (~5.0–55% better than chance).*	Resch, 2016 (39)

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	Diagnostic accuracy	95% CI Sensitivity: 0.128 Specificity: 0.949 Combined sensitivity and specificity: 1.077 90% CI: Sensitivity: 0.152 Specificity: 0.949 Combined sensitivity and specificity: 1.101 80% CI: Sensitivity: 0.200 Specificity: 0.923 Combined sensitivity and specificity: 1.123	*The sensitivity values were low. The SOT composite score (80% CI, 0.20; 90% CI, 0.15; 95% CI: 0.13) demonstrated the highest sensitivity.*	Register-Mihalik, 2013 (38)
	Diagnostic accuracy	Composite Balance 95% CI: Change score: 9.75 Sensitivity: 0.24 Specificity: 0.97 Total (sensitivity + specificity): 1.21 90% CI: Change score: 8.48 Sensitivity: 0.32 Specificity: 0.97 Total (sensitivity + specificity): 1.29 85% CI: Change score: 7.65 Sensitivity: 0.37 Specificity: 0.96 Total (sensitivity + specificity): 1.32 80% CI: Change score: 7.01 Sensitivity: 0.37 Specificity: 0.94 Total (sensitivity + specificity): 1.30 75% CI: Change score: 6.48 Sensitivity: 0.44 Specificity: 0.91 Total (sensitivity + specificity): 1.35 70% CI: Change score: 6.02 Sensitivity: 0.44 Specificity: 0.89 Total (sensitivity + specificity): 1.34	*The highest combined sensitivity and specificity for the SOT composite score was 1.35 (75% CI). The combined sensitivity and specificity scores were lower for the somatosensory (1.05 (85% CI)), visual (1.11 (90% CI)), and vestibular (1.24 (70% CI)) ratios.*	Broglio, 2008 (18)
	Diagnostic accuracy	Sensitivity: 61.9%	*On at least one SOT variable, 39 athletes (61.9%) had identified postural control deficits.*	Broglio, 2007 (1)
Nintendo WBB	*Concurrent validity*	*Several correlations ($p < 0.05$) were found from baseline to day 3 post-concussion changes in the BESS and WBB.* *A positive correlation was found between tandem stance on a firm surface and all 7 WBB variables (log path velocity, log anterior-posterior path velocity, log anterior-posterior, log medial-lateral path velocity, log medial-lateral amplitude, log medial-lateral).* *Single-legged stance on a firm surface and the BESS total were both positively correlated with 2 of the 7 WBB variables.*		Merchant-Borna, 2017 (33)
GAIT				
Accelerometer-derived measurements to monitor gait balance	*Diagnostic accuracy*	*At 72 hours:* 95% CI = 2.72, 4.48 m/s^2 Sensitivity = 0.70 Specificity = 0.71 *1 week:* 95% CI = 2.18, 4.71 m/s^2 Sensitivity = 0.70 Specificity = 0.71 *2 weeks:* 95% CI = 2.88, 4.75 m/s^2 Sensitivity = 0.60 Specificity = 0.57 *1 month:* 95% CI = 2.59, 4.74 m/s^2 Sensitivity = 0.30 Specificity = 0.71 *2 months:* 95% CI = 2.35, 4.66 m/s^2 Sensitivity = 0.40 Specificity = 0.57	*Post-injury time points demonstrated a weak ability to distinguish between groups. ROC analysis revealed significant AUC values at the 72 hours (AUC = 0.889, p=0.01) and two-week (AUC = 0.810, p = 0.04) time points.*	Howell, 2015 (46)
FGA	*Diagnostic accuracy*	AUC (95% CI): 0.68 (0.57-0.77) Sensitivity = 68% Specificity = 60%	*Optimal sensitivity and specificity were 60% and 58%, respectively, for the FGA (cut point of 28.5).*	Fino, 2023 (44)
	Diagnostic accuracy	AUC (95% CI): 0.78 (0.69, 0.87) Sensitivity: 0.05 Specificity: 1.00	*The FGA demonstrated potential to detect impairments in the mTBI group.*	Pape, 2020 (36)
	Diagnostic accuracy	AUC (95% CI): 0.80 (0.57, 1.00) Sensitivity = 0.75 Specificity = 0.75	*The FGA demonstrated potential to detect impairments in the mTBI group.*	Pape, 2016 (35)

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Gait Speed	*Diagnostic accuracy*	Fast speed: AUC (95% CI): 0.76 (0.77, 1.00) Sensitivity: 0.69 Specificity: 0.84 Comfortable speed: AUC (95% CI): 0.81 (0.66, 1.00) Sensitivity: 0.84 Specificity: 0.76	*Gait speed demonstrated the potential to detect impairments in the mTBI group.*	Pape, 2020 (36)
	Diagnostic accuracy	AUC = 0.57 (Lower band = 0.39, Upper band = 0.73)	*Gait speed was unable to classify subjects in any condition (AUC < 0.6).*	Fino, 2019 (25)
	Diagnostic accuracy	Fast: AUC (95% CI): 0.92 (0.77, 1.00) Sensitivity: 0.88 Specificity: 0.75 Comfortable: AUC (95% CI): 0.86 (0.66, 1.00) Sensitivity: 0.88 Specificity: 0.75	*Gait speed demonstrated the potential to detect impairments in the mTBI group.*	Pape, 2016 (35)
HiMAT	*Intra-rater reliability*	*HiMAT sum score reliability was excellent (ICC = 0.95, 95% CI = 0.89 to 0.98), showing consistent test results.*		Kleffelgaard, 2013 (47)
	Diagnostic accuracy	AUC (95% CI): HiMAT:0.66 (0.52-0.73)	*Optimal sensitivity and specificity were 58% and 67%, respectively, for the HiMAT (cut point of 25.5).*	Fino, 2023 (44)
	Diagnostic accuracy	*3 months* AUC = 0.78, p = 0.001 *6 Months* AUC = 0.90, p = 0.001	*Participants with balance problems: n=28. Cut-off <47 points on the HiMAT shows the best balance between sensitivity (70%) and specificity (75%).* *Participants with balance problems: n=14. Cut-off <48 points on the HiMAT shows the best balance between sensitivity (92%) and specificity (86%).*	Kleffelgaard, 2013 (47)
Tandem Gait	*Diagnostic accuracy*	95% CI If baseline thresholds applied AUC: 0.5 (0.5–0.6) Sensitivity: 46.8 (42.0–51.6) Specificity: 56.6 (52.5–60.5) If normative thresholds applied: AUC: 0.5 (0.5–0.5) Sensitivity: 1.79 (0.78–3.49) Specificity: 99.7 (98.9–100.0)	*Of concussed players, 343 were removed from play after the HIA-1 off-field screen resulting in a sensitivity of 76.6% (95% CI 72.4–80.4). The specificity to correctly identify players without concussion in this study group was therefore 86.6% (95% CI 83.7–89.1). The positive and negative predictive values of removal-from-play decisions were 79.2% (95% CI 75.1–83.0) and 84.8% (81.8– 87.3) respectively.*	Fuller, 2020 (45)
	Diagnostic accuracy	Between concussed and non-injured players: AUC = 0.56, CI = 0.35–0.78 Baseline-adjusted post-injury scores: AUC = 0.55 CI = 0.32–0.78	*The tandem gait test demonstrated poor discriminatory ability. Baseline-adjusted post-injury scores also demonstrated poor ability to distinguish between people with and without concussions.*	Hanninen, 2018 (42)
	Diagnostic accuracy	AUC 95% CI: 0.704 Sensitivity = 0.632 (0.460–0.782) Specificity = 0.605 (0.434–0.760)	*Participants completed tandem gait significantly slower after concussion, whereas no change across time was detected for controls. The AUC analysis was acceptable for tandem gait.*	Oldham, 2018 (34)
VESTIBULAR AND OCULAR				
VOR				
DVA test	*Diagnostic accuracy*	AUROC (95% CI): Simple reaction time; reaction time, milliseconds: 0.81 (0.70-0.93)	*Eye-tracking metrics, not smooth pursuit eye movement, had high classification of athletes with and without concussion.*	Feller, 2021 (52)

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		Discriminate reaction time, milliseconds: Reaction time: 0.80 (0.70-0.91), Visual reaction speed: 0.80 (0.66-0.94) Choice reaction time; visual reaction speed, milliseconds: 0.76 (0.60-0.91) DVA 2; reaction time, ms:0.74 (0.62-0.86) DVA 3; reaction time, ms:0.72 (0.61-0.84) All 6 metrics combined: 0.90 (0.80-0.99)		
	Concurrent validity	*No significant differences were observed between concussion and control groups (p = 0.592) and no correlation was observed between the DVA test and health status (r = 0.06, p = 0.592).*		McDevitt, 2016 (32)
VOMS	*Diagnostic accuracy*	AUC = 0.8512 Sensitivity = 77% Specificity = 83%	*The VOMS Total score (AUC = 0.8512; sensitivity, 77%; specificity, 83%) demonstrated the ability to accurately identify concussed from controls, with a high predictive utility.*	Ferris, 2022 (50)
	Diagnostic accuracy	Modified VOMS (smooth pursuits, horizontal saccades, horizontal vestibulo-ocular reflex, visual motion sensitivity) AUC = 0.85 Sensitivity = 0.77 Specificity = 0. 83	*A modified VOMS demonstrated AUCs that were identical to Total VOMS. A score of ≥4 for Total VOMS and ≥4 for modified VOMS improves the ability to accurately identify concussion.*	Ferris, 2022 (49)
	Concurrent validity *Diagnostic accuracy*	Acute concussion correlations with the VOMS and SCAT3 symptom scores show a large correlation (r_s = 0.87). AUC = 0.819	*Individually, VOMS had the highest diagnostic capacity with an AUC of 0.819. When the process was repeated for 3- and 4-test combinations, VOMS significantly boosted the diagnostic accuracy of the SCAT3 battery from an AUC of 0.806 to an AUC of 0.851, increasing the sensitivity to 9% and the specificity to 3% (p < 0.0001).*	Ferris 2021(24)
	Diagnostic accuracy	VOMS overall: AUC (95% CI): 0.91 (0.88-0.94) Smooth pursuit: 0.90 (0.86-0.93) Horizontal saccade: 0.90 (0.87-0.93) Vertical saccade: 0.90 (0.87-0.94) Near point of convergence: 0.51(0.46-0.57) Near point of convergence, cm: 0.90 (0.86-0.93) VOR: horizontal: 0.90 (0.87-0.93) VOR: vertical: 0.89 (0.86-0.92) Visual-motion sensitivity: 0.91 (0.88-0.94)	*The VOMS individual items and overall VOMS score can accurately identify concussion, representing valid tools. Vertical saccades and horizontal vestibulo-ocular reflex demonstrated the best discriminatory ability.*	Kontos, 2021(51)
	Diagnostic accuracy	Estimate (95% CI) Sensitivity = 0.96 (0.86-1.00) Specificity = 0.46 (0.32-0.61) Positive predictive value = 64% Negative predictive value = 92%	*The VOMS exhibited a high test sensitivity and low test specificity. When accounting for the 50% concussion prevalence in the sample, a 64% positive predictive value was observed, meaning that if an athlete produced a positive score on the VOMS, there was only a 64% probability that he or she was concussed.*	Buttner, 2021(35)
	Diagnostic accuracy	*Sub-scores of the VOMS had the highest sensitivities for those with a baseline assessment in the same season which included the Smooth Pursuit (48–100%), Horizontal Saccades (44–83%), Vertical Saccades (46–82%), NPC Symptoms (38–80%), NPC (6–47%), Horizontal VOR (39–81%), Vertical VOR (38–81%), and VMS (43–81%).* *For those with a baseline assessment at 1 year before, VOMS sensitivities were similar for Smooth Pursuit (40–100%), Horizontal Saccades (39–88%), Vertical Saccades (42–87%), NPC Symptoms (35–84%), NPC (4–46%), Horizontal VOR (38–84%), Vertical VOR (36–84%), and VMS (37–82%).*		Broglio, 2019 (43)

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Oculomotor, Vestibular and Reaction Time Tests	*Diagnostic accuracy*	AUC: 0.9727 Sensitivity: 89.0% Specificity: 97.5% Specific tests included in the battery of oculomotor, vestibular and reaction time tests: Optokinetic, Smooth Pursuit–Horizontal/Vertical, Predictive Saccade, Predictive Saccade, Anti-saccade Horizontal, Self-paced Saccade, Gaze Horizontal, Visual Reaction Time, Auditory Reaction Time, Saccade and Reaction Time, Computer Controlled Rotation Head Impulse Test, Sinusoidal Harmonic Acceleration, Visual Enhancement, Visual Suppression	*These measures can discriminate mTBI patients from uninjured controls: (1) without requiring pre- concussion data, (2) independent of gender, and (3) can be used for a window of at least 4 days after concussion.*	Balaban, 2016 (53)
OCULOMOTOR				
SMOOTH PURSUITS				
EYE-SYNC smooth pursuit	*Diagnostic accuracy*	AUC=0.47 Sensitivity, % Any increase in tangential variability from baseline: 48 Any increase in radial variability from baseline: 52 Specificity, % Any increase in tangential variability from baseline: 58 Any increase in radial variability from baseline: 61	*EYE-SYNC Smooth Pursuit, without other measures, might not be a good indicator of concussion.*	Harmon, 2022 (29)
Smooth pursuits	*Diagnostic accuracy*	*Radial Variability* *Baseline:* AUC: 0.879 Diagnostic sensitivity: 0.58 Screening specificity: 0.38 *1-back:* AUC: 0.783 Diagnostic sensitivity: 0.57 Screening specificity: 0.07 *2-back:* AUC: 0.946 Diagnostic sensitivity: 0.79 Screening specificity: 0.50 *Overall variability* *Baseline:* AUC: 0.796 Diagnostic sensitivity: 0.44 Screening specificity: 0.21 *1-back:* AUC: 0.717 Diagnostic sensitivity: 0.47 Screening specificity: 0.05 *2-back:* AUC: 0.904 Diagnostic sensitivity: 0.71 Screening specificity: 0.46	*For baseline pursuit, 58% of mTBI individuals would be correctly classified on radial variability and 44% would be correctly classified on overall variability. The sensitivity was improved with a concurrent 2-back task (79% correctly classified with pursuit using radial variability and 71% using overall variability in the dual-task condition).*	Stubbs, 2019 (50)
SACCADES				
KD test	*Test-retest reliability*	ICC (95% CI): 0.71 (0.49 to 0.84)	*The KD had good reliability but did not exceed, the generally accepted threshold for clinical utility of 0.75.*	Harmon, 2022 (29)
	Intra-rater concordance	Kappa: 0.94 (0.85–1.00)	*The KD test demonstrated high intra-rater concordance.*	Hecimovich, 2018 (57)
	Test-retest reliability	ICC (95% CI) baseline vs. post-match total: 0.92 [0.87–0.95]	*High test-retest reliability was observed when baseline scores were compared to post-match scores.*	Hecimovich, 2018 (57)
	Test-retest reliability	Repeated tests: Spearman's ρ's: mTBI group: 0.949 ($p < 0.001$) Control group: 0.918 ($p < 0.001$)	*The test-re-test correlations were strong, indicating solid test-retest reliability in both the mTBI and control groups.*	Walsh, 2016 (60)
	Test-retest reliability	No head trauma, Pre-fight: ICC = 0.97 [95% confidence interval [CI] 0.90 –1.0]) Prefight and post-fight: ICC = 0.95 (95% CI 0.87–1.0)	*High test-retest reliability metrics were documented.*	Galetta, 2011 (56)
	Test-retest reliability	The ICC of KD test time scores between baseline and post-season tests resulted in a high degree of test-retest reliability (ICC 0.95 [95% CI 0.85---1.05]).		Leong, 2016 (46)

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	Diagnostic accuracy	*At the 0- to 6-hour post-concussion time point* AUC = 0.724±0.2378 A cut-off score of -2.6 seconds yielded 80% sensitivity and specificity of 46%. *At 24 to 48 hours post-concussion* AUC = 0.701±0.01967 A cut-off score of -3.2 seconds yielded 80% sensitivity and specificity of 41%. A cut-off score of -1.5 seconds yielded 70% sensitivity, with a specificity of 57%. *Asymptomatic time point* AUC = 0.513±0.0199 The ROC curves were not different; thus, cut-off scores were not proposed. *At the unrestricted return to play time point* AUC = 0.640±0.0178 A cut-off score of -0.8 seconds yielded 80% sensitivity but specificity of 37%. A cut-off score of -1.9 seconds yielded 70% sensitivity but specificity of 47%. *At the 6-month post-concussion time point* AUC=0.615±0.0222 A cut-off score of -0.4 seconds yielded 80% sensitivity but specificity of 34%. A cut-off score of -1.6 seconds yielded 70% sensitivity with specificity of 44%.	*The 0- to 6-hour and 24- to 48-hour post-concussion time points had acceptable discrimination for sensitivity and specificity, but other time points displayed fair discrimination.*	Le, 2023 (59)
	Diagnostic accuracy	AUC = 0.780 (0.686,0.872) Sensitivity, % Any prolongation in time from baseline: 85 3 seconds or greater prolongation from baseline: 68 5 s or greater prolongation from baseline: 54 Specificity, % Any prolongation in time from baseline: 76 3 seconds or greater prolongation from baseline: 88 5 seconds or greater prolongation from baseline: 95	*Of the objective concussion tests, the KD test performed the best for the diagnosis of concussion, although it still misclassified 15% of concussions.*	Harmon, 2022 (29)
	Diagnostic accuracy	Baseline assessment in the same season: Sensitivity = 16–48% Baseline assessment 1 year ago: Sensitivity = 5–41%	*The KD test had a sensitivity that ranged from 16-48% for those who had a baseline assessment the same season as the occurrence of concussion and a sensitivity ranging from 5-41% for those who had a baseline assessment 1 year prior.*	Broglio, 2019 (43)
	Diagnostic accuracy	AUC = 0.60, p = 0.087, 95% CI [0.47, 0.72]	*A lack of sensitivity and specificity was observed, demonstrating a limited ability to accurately classify people with and without concussion. An AUC is 0.70 or higher is considered acceptable.*	Dretsch, 2019 (43)
	Diagnostic accuracy	*The KD test demonstrated a sensitivity of 60% (95% CI 49.0 to 70) and a specificity of 39% (95% CI 26 to 54) in diagnosing concussion.* *The HIA-1 off-field screening tool sensitivity did not differ significantly from the KD test (74.8%, 95% CI 65.6% to 82.5%),), but specificity was significantly better than KD test (91.3%, 95% CI 82.0% to 96.7%).* *Combining HIA-1 and KD test performance achieved a sensitivity of 92.6% (95% CI 85.9% to 96.7%), with a specificity of 33.3% (95% CI 20.8% to 47.9%).*		Fuller, 2019 (61)
	Diagnostic accuracy	AUC: KD test time: 0.777	*The sensitivity (0.45) and specificity (0.92) of the KD test demonstrates a high number of false negatives detected (55%).*	Capó-Aponte, 2018 (64)

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	Diagnostic accuracy	Sensitivity (95% CI): 0.98 (0.87–1.00) Specificity (95% CI): 0.96 (0.80–1.00) Positive likelihood ratio: 11.6 (1.7–77.0) Positive predictive value: 89.0% (54.5–98.2%)	*High sensitivity and specificity metrics were observed.*	Hecimovich, 2018 (57)
	Concurrent validity	*There were no significant differences between concussed and non-concussed groups on the KD test ($p = 0.40$). The KD test did not correlate with health status ($r = 0.18$, $p = 0.129$)*		McDevitt, 2016 (32)
	Diagnostic accuracy	KD test trial 1: F=2.64; p=0.110; Cohen's d=0.43 KD test trial 2: F=2.28; p=0.137; Cohen's d=0.41 Best KD test score: F=2.16; p=0.148; Cohen's d=0.40	*The KD Test did not contribute incrementally [$x^2(1) = 1.71$, $p=0.191$] and did not demonstrate the ability to predict grouping (mTBI versus control) [$B = 0.039$, $p = 0.196$, 95% CI for odds = 0.980–1.103].* *The KD Test did not demonstrate the ability to distinguish between people with mTBI and controls.*	Silverberg, 2014 (41)
	Diagnostic accuracy	*KD scores that were worse post-fight ($r_s = 0.79$, $p = 0.0001$) and scores that had a greater level of worsening ($r_s = 0.90$, $p = 0.0001$) were correlated with post-fight MACE scores. KD scores post-fight were significantly worse for athletes with head trauma (59.1 ± 7.4 vs 41.0 ± 6.7 seconds, $p = 0.0001$, Wilcoxon rank sum test). KD scores that worsened by 5 seconds from baseline to post-fight, was a characteristic that was able to distinguish head trauma patients from non-injured participants.*		Galetta, 2011 (56)
CONVERGENCE				
NPC	*Diagnostic accuracy*	AUC: NPC break: 0.744	*The sensitivity (0.81) and specificity (0.49) of the NPC break indicates a high number of false positives (51%).*	Capó-Aponte, 2018 (54)
	Concurrent validity *Diagnostic accuracy*	*The concussed group demonstrated a NPC distance of 6.0±4.1 cm and the control groups demonstrated a NPC distance of 3.6±2.2 cm, which was significantly correlated with health status ($r = 0.337$, $p = 0.004$).* *Using the NPC, OKS S/S, and GST S/S, the test was able to discriminate health status with a sensitivity of 91.7% and specificity of 81.7%.*			McDevitt, 2016 (32)
OTHER OCULAR MEASURES				
COVS	*Diagnostic accuracy*	Sensitivity: 100% Specificity: 97%	*The results showed that COVS had high sensitivity and specificity for screening near oculomotor functions.*	Capó-Aponte, 2012 (64)
Eye tracking	*Diagnostic accuracy*	ROC curves: Angular tracking error of the fast circular motion eye test: AUC = 0.84 Angular tracking error as well as the saccade count between 1° and 2° and the Stance 5 (unstable surface, eyes closed)/Stance 1 (stable surface, eyes open) balance score: AUC = 0.92	*Variation was observed when assessing the effectiveness of the CBIAS-based eye-tracking and balance assessments in detecting differences between people with and without concussion.*	Baruch, 2016 (17)
	Diagnostic accuracy	Excluding CT positive patients: *Best subset*: Misclassification rate: 14.2; True positive: 5; False positive: 34; False negative: 2; True negative: 213; Sensitivity: 0.714; Specificity: 0.862; AUC: 0.831 *LASSO*: Misclassification rate: 13.8; True positive: 5; False positive: 33; False negative: 2; True negative: 214; Sensitivity: 0.714; Specificity: 0.866; AUC: 0.833 *Random forest*: Misclassification rate: 13.0; True positive: 4; False positive: 30; False negative: 3; True negative: 217; Sensitivity: 0.571; Specificity: 0.879	*Reasonably high sensitivity and specificity metrics were observed, demonstrating the ability to detect concussion.*	Samadani, 2015 (62)
Optokinetic after-nystagmus	*Diagnostic accuracy*	ROC Curve (AUC = 0.73) Specificity: 0.7 Sensitivity: 0.3 With suggested an optimal operating point of the ROC curve =16.62 seconds: Specificity: 0.72 Sensitivity: 0.73	*This implied that as the threshold value of 16.6 seconds, a test measuring the optokinetic after-nystagmus time constant has an accuracy of 0.73.* *The proposed optokinetic after-nystagmus test was twice as sensitive as the SOT.*	Bertolini, 2021 (65)

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SSVEP using EEG	*Diagnostic accuracy*	Classifiers: Support Vector Machine: Sensitivity: 62.78 Specificity: 64.50 Naïve Bayes: Sensitivity: 65.28 Specificity: 46.63 Linear Discriminant Analysis: Sensitivity: 60.00 Specificity: 64.55 Logistic Regression: Sensitivity: 63.61 Specificity: 61.25	*SSVEP-based features were used for the classification of mTBI using machine learning models. The Support Vector Machine and Linear Discriminant Analysis achieved the highest specificity (~65%) and the Naïve Bayes and Logistic Regression achieved the highest sensitivity (~63-64%).*	Hoang, 2023 (66)

AP: anterior-posterior; **AUC:** Area Under the Curve; **BBT**: BTrackS Balance Test; **BESS:** Balance Error Scoring System; **CB&M**: community balance and mobility scale; **CBIAS:** Computerized Brain Injury Assessment System; **CI:** confidence interval; **COVS**: computerized oculomotor vision screening; **CT**: computerized tomography; **DHI:** dizziness handicap inventory; **DVA**: Dynamic Visual Acuity; **ECFIS**: eyes closed while standing on a firm surface; **ECFOS**: eyes closed while standing on an unstable (foam) surface; **EEG**: electroencephalography; **EOFIS**: eyes open while standing on a firm surface; **EOFOS**: eyes open while standing on an unstable (foam) surface; **FGA:** Functional Gait Assessment; **GST:** horizontal gaze stabilization test; **HIA-1:** Head Injury Assessment; **HiMAT:** High Level Mobility Assessment Tool; **ICC:** intraclass correlation coefficient; **KD:** King-Devick; **LASSO:** least absolute shrinkage and selection operator**; MACE:** military acute concussion evaluation; **mBESS:** Modified Balance Error Scoring System; **mCTSIB**: modified clinical test of sensory interaction on balance; **ML**: medio-lateral; **NPC:** near point convergence; **OA**: overall; **OKS:** optokinetic stimulation; **RCI**: reliable change indices; **RMS**: Root Mean Square; **ROC:** Receiver Operating Characteristic; $\mathbf{r_s}$: Spearman correlation; **S/S:** signs and symptoms**; SCAT:** Sport Concussion Assessment Tool; **SCAT3:** Sport Concussion Assessment Tool- 3rd edition; **SD**: standard deviation; **SOT**: sensory organization test; **SSVEP**: steady-state visual evoked potentials; **VMS**: visual motion sensitivity; **VOMS:** vestibular ocular motor screening; **VOR**: vestibulo-ocular reflex; **WBB**: Wii Balance Board

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Appendix D
PRISMA Checklist

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	p. 1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	p. 1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	p. 3
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	p. 3
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	p. 3
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	p. 3-5
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	p. 5
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Appendix A
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	p. 5-6
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	p. 6
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	p. 6
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	NA
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	p. 6

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SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	p. 7
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	p. 9-16
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	NA
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	p. 18-27
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	p. 29-32
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	p. 33-37
Limitations	20	Discuss the limitations of the scoping review process.	p. 37
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	p. 38
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	p. 38-39

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.
* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.
† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).
‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.
§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

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Appendix E
Clinical Measure Descriptions

Clinical Measure	Description of Measure	Scoring of Measure and Interpretation	Dimensions evaluated	Method of Administration	Equipment Needed to Administer
Balance Tests					
Balance testing	Patient completes six stances with eyes open, closed and observing a target that moves randomly on a display, on two different platforms (flat and cushioned/foam)[1].	Stance scores (digitally integrating the signals of the sensors measuring posterior and anterior sway and then obtaining their difference)	Balance	Clinician-administered	Platform with sensors
BBT	Patients complete four, 20 second trials that involves standing still with hands on hips and eyes closed, feet shoulder distance apart[2].	Average centre of pressure calculated by the Sport Balance software.	Balance	Clinician-administered	2 minutes to administer. Balance Tracking System (BTrackS, Balance Tracking Systems Inc., San Diego, CA, USA) consists of a force plate (BTrackS Balance Plate) and software (BTrackS Sport Balance)
BESS/mBESS	Administrator counts errors while the patient completes balance testing in 3 different stances: double leg stance, single leg stance, and tandem stance for 20 seconds. Test is completed on two different standing surfaces: flat surface and foam pad surface. For mBESS, test is completed on one standing surface: flat only[3-19].	Errors	Balance	Clinician-administered	Foam pad, stopwatch, scorecard
CB&M	Patient completes 13 tasks such as single leg stance, tandem walking, tandem with pivot, hop forward, etc.[20,21].	Scored from 0 to 5 on each task (0 = poor performance; 5 = good performance)	Balance	Clinician-administered	15 minutes to administer. 8-meter track, stopwatch, weights, laundry basket, bean bag, visual target, staircase
Inertial sensor-based balance	On a force plate, patient completes three stances: double leg stance, single leg stance, and tandem stance[22].	Centre of Pressure	Balance	Clinician-administered	3D inertial sensor (Shimmer 3, Dublin, Ireland) containing accelerometers (±8 g) and gyroscopes (±1000°/s) along the three orthogonal axes in frontal, sagittal and transverse planes of motion
Instrumented mBESS producing postural sway metrics using sensors	Using sensors, accelerometers, and magnetometers, patients complete three stances for 30 seconds: double leg stance, single leg stance, and tandem stance[10].	Postural sway is recorded with an inertial sensor (Opal, APDM Inc) containing a tri-axial accelerometer, a tri-axial gyroscope and a tri-axial magnetometer; which was placed at L5 with an elastic belt	Balance	Clinician-administered	Sensor, accelerometer, magnetometer
Instrumented balance assessment	Patients performed three stances: double-leg stance, single-leg stance, and tandem stance for 30 seconds each[23].	Inertial sensor calculated measures of postural sway[23].	Balance	Clinician-administered	Inertial sensor (model Opal; APDM Wearable Technologies, Inc, Portland, OR)

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mCTSIB	Using the Biodex Stability System, the patient completes four conditions: eyes open on firm and foam surfaces and eyes closed on firm and foam surfaces[24,25].	Standard deviation of the stability index	Balance, sensory integration	Clinician-administered	Biodex Stability System
Nintendo WBB	Each WBB test consisted of 4 stances, including: double-legged standing with eyes open, single-legged standing (on the dominant limb) with eyes open, double-legged standing with eyes closed, and single-legged standing (on the dominant limb) with eyes closed[26].	The Wii software calculated the motion of a player's center of pressure and sampled points from this path at a frequency of 40 Hz. The result was a collection of coordinates specific to each stance, where the x-axis represented the mediolateral direction, and the y-axis represented the anteroposterior direction. Path velocity, Path amplitude, and Standard deviation were determined for each stance.	Postural stability	Clinician-administered	The Nintendo Wii Balance Board (WBB; Nintendo of America Inc, Redmond, WA), a portable and relatively inexpensive force platform
Postural stability test	Using the Biodex Stability System, the patient completes three trials of 20 seconds each and a 10 second rest[24].	Tracks three stability indices: overall, anterior-to-posterior, and medial-to-lateral	Balance	Clinician-administered	Biodex Stability System
SOT	Using the NeuroCom (force plate), the patient completes 20-second trials in the following conditions: eyes open on flat surface with sway referenced visual surround and with sway referenced support surface, and eyes closed with the same conditions[8,11,27-30].	Tracks and records the center of pressure motion through a force plate	Balance	Clinician-administered	NeuroCom
Gait Tests					
Accelerometer-derived measurements to monitor gait balance	Patients perform walking tasks[31].	Linear acceleration was measured along three orthogonal axes so that the reference coordinate system z-axis was oriented vertically downward, the y-axis was oriented to the right, and the z-axis was oriented orthogonal to the x- and y-axes, toward the front	Gait	Clinician-administered	Opal Sensor, APDM Inc., Portland
FGA	Patient performs 10 different tasks, such as walking on flat surface, walking with head turns, walking with pivot, etc.[7,17,20,21].	Scored from 0 to 3 on each task (0 = severe impairment); (3 = normal)	Gait	Clinician-administered	5 to 10 minutes to administer. Stopwatch, device to measure, shoeboxes, steps, walking area
Gait Speed	Patients walk at their normal walking speed and at a fast speed along a 10-meter walkway[19-21].	Gait speed is calculated by dividing the walking distance by the time taken to walk the distance. The	Gait	Clinician-administered	5 minutes to administer. Stopwatch

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		average of 2 trials at each speed is documented in meters per second.			
HiMAT	Patient performs tasks such as walking, running, and hopping, among others (measured with stopwatch or tape measure)[17,32].	The sum score range is 0 (worst) to 54 (best). Each item of the revised HiMAT is scored on a 0 to 4 ordinal scale primarily based on speed of completion time for a total of 32 points, with a higher score indicating better performance (ie, 32/32 = best possible score).	Mobility	Clinician-administered	Stopwatch, tape measure, stairs
Tandem Gait	Heel to toe walking[16].	Pass or fail	Gait	Clinician-administered	No equipment
Tandem Gait	Heel to toe walking along a 6-meter line[33].	Continuous: threshold for abnormality is > 14 seconds	Gait	Clinician-administered	Stopwatch
Tandem Gait	After a verbal cue, patients completed heel to toe walking along a 3-meter line. Once they reached the end, they completed a 180- turn and returned to the start[12].	Time required to complete the test (success defined as completing the trial in under 14 seconds)	Gait	Clinician-administered	Stopwatch
Vestibular and Ocular Tests					
VOR Tests					
DVA test	Patients rotate head left and right while keeping eyes focused on a black box in the center of the screen. A Landolt-C of varying orientation (up, down, left, right) appears in the center of the screen. Patients press the keyboard arrow key that corresponds to the Landolt-C orientation. For the second test, the patients head is fixed. For the third test, head moves freely[34]. A visual chart is used to document visual acuity when the head was not moving. Test was repeated while patient moves head left and right [11].	Acuity, speed of stimulus, reaction time	Vestibular ocular reflex	Clinician-administered	Metronome, computer, visual chart
EYE-SYNC smooth pursuit	Patient performs test by following a target moving in a circular direction[9].	Tablet software uses an algorithm to analyse the position of the eye compared with the target over time to complete the assessment, measuring tangential variability and radial variability.	Smooth pursuit	Clinician-administered	EYE-SYNC Smooth Pursuit uses goggles embedded with eye tracking sensors

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VOMS	Patients reports baseline symptoms on a 0-10 scale for symptoms including: headache, dizziness, fogginess, and nausea. Patient performs various tasks such as VOR, saccades, smooth pursuits, etc. and reports symptoms following each task [5,6,35-38].	Change in symptoms, near point convergence distance	Functionality of common vestibular and oculomotor tasks, symptom provocation	Clinician-administered	5 to 7 minutes to administer. Metronome, device to measure, pens/targets
Oculomotor, Vestibular and Reaction Time Tests	Battery of tests: Optokinetic: Left and Right Gain and Asymmetry for nystagmus beats Smooth Pursuit–Horizontal/Vertical: Percent of Saccadic Intrusions, Initiation Time Saccade-Random–Horizontal/Vertical: Saccade Onset Latency, Accuracy, Peak Velocity Predictive Saccade: Point in cycle at which subject anticipates/predicts the fixed timing interval and dot position as well as percent of correct predictions Anti-saccade: Horizontal Number of Pro-saccadic errors, correct anti-saccades, Latency, and Velocity Self-paced Saccade: Saccades per second Gaze Horizontal: Vertical peak and average slow phase velocity Computer Controlled Rotation Head Impulse Test: Left and Right Gain and Asymmetry Sinusoidal Harmonic Acceleration: Gain, Phase, and Asymmetry—High Frequencies Visual Enhancement: Gain, Phase, and Asymmetry—High Frequencies Visual Suppression: Gain, Phase, and Asymmetry—High Frequencies [39].	Movements of each eye were recorded with integrated video cameras	Nystagmus, smooth pursuits, saccades, VOR	Clinician-administered	Clinical I-Portal1 Neuro Otologic Test Center (I-Portal–NOTC, Neuro Kinetics Incorporated, 126 Gamma Drive, Pittsburgh, PA 15238). Participants were secured into a computer-controlled rotational chair from a black featureless enclosure wall.
Ocular Tests					
Combination of Tests					
COVS	These components of the examination were stereo acuity as measured by random dot stereograms using the Randot stereotest, NPC, ocular alignment at distance and at near determined by cover test, distance phoria (lateral and vertical) and gradient accommodative convergence/accommodation ratio using the von Graefe technique, and the amplitude of accommodation measured by phorometry using the minus lens to blur method [40].	Each symptom question had five possible answers with an associated value, where 4 = always, 3 = frequently, 2 = sometimes, 1 = rarely, and 0 = never. Thus, the cumulative symptoms score can vary from 0 to 60. An average normal adult should score	Oculomotor functions	Clinician-administered	The COVS system used a modified version of the commercially available Binocular Vision Assessment software which consisted of a metal baseplate that supported a linear translation stage, chinrest, and monitor jacks.
Saccades					
Eye tracking	Patient performs eye movements [41].	Generalized quantification of the overlap of target motion and eye movement. The eye tracker uses the principle of "limbus tracking", which is based on tracking the difference in reflection of infrared	Eye tracking movement	Clinician-administered	The head-mounted unit consists of a heads-up display, which is a modified i3PC (I-O Display Systems; and a custom-designed eye movement tracking module

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		light by the sides of the limbus margin between sclera and iris.			
Eye tracking	Patient performs eye movements with an eye tracker over 220 seconds[1].	The eye tracker sampled pupil position at 500 Hz, yielding 100,000 samples	Eye tracking movement	Clinician-administered	Eyelink 1000 eye
King-Devick	The patient reads numbers from cards out loud as fast as possible [7,9,11,42-49].	Time needed to complete test. Numbers of errors made in reading the test cards were recorded	Saccadic eye movement	Clinician administered	Less than 2 minutes to administer. Test cards, stopwatch
Smooth Pursuits					
Smooth Pursuits	Patients complete a task that involves following the target with their eyes around its trajectory as smoothly as possible. Tasks lasted 60 seconds each[50].	Eye movements were recorded monocularly at 500Hz	Smooth pursuit eye movement	Clinician-administered	EyeLink 1000 system with tower mount (SR Research, Canada)
Convergence					
NPC	The patients focus their eyes on a card with a line of 4 letters and was instructed to focus on the letter "F" on the top line of the card as the experimenter moved the card towards the patient's face, only stopping once the participant reported that the letter appeared double[11]. The patients focus on a target. A slider is moved towards the patients' eyes and stops when one eye deviates[42].	Test concludes when the participant indicated that target appears double. Measurement recorded in centimeters[11]. Test concludes when one eye deviates. Measurement recorded in centimeters[42].	Convergence eye movement and deviation	Clinician-administered	Card with a line of 4 letters or letter target, device to measure distance
Optokinetic after-nystagmus	Patients completed two tests whereby an optokinetic stimulus was delivered by rotating the drum for 30 seconds. Patients were instructed to keep the gaze within a horizontal grey band in front of them[51].	Recordings obtained while eye tracks moving targets	Eye movement	Clinician-administered	Chair mounted on a two servo-controlled motor-driven axes turntable system (Tönnies D561, Freiburg, Germany; control system: Acutrol® ACT2000, Acutronic, Switzerland Ltd.)
SSVEP using EEG	Using an SSVEP acquisition device, participants were instructed to fix their gaze on various visual stimuli while SSVEP signals were recorded[52].	Recordings obtained while eyes fixed to various stimuli	SSVEPs	Clinician-administered	SSVEP acquisition device (composed of a rear section that houses the unipolar electrodes for recording the signals, and a front visor section that delivers a 15 Hertz flickering visual stimulus using white light-emitting diodes)

BBT: BTrackS Balance Test; **BESS:** balance error scoring system**; CB&M:** community balance and mobility scale; **COVS**: computerized oculomotor vision screening; **DVA**: Dynamic Visual Acuity; **EEG**: electroencephalography; **FGA:** Functional Gait Assessment; **HiMAT**: High-Level Mobility Assessment Tool; **mBESS**: modified balance error scoring system; **mCTSIB**: modified clinical test of sensory interation and balance; **NPC**: near point convergence; **OKAN**: Optokinetic after-nystagmus; **SOT**: sensory organization test; **SSVEP**: steady-state visual evoked potentials; **VOMS**: vestibular ocular motor screening; **VOR:** vestibulo-ocular reflex; **WBB**: Wii Balance Board

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Chapter 7. Integrative Discussion and Conclusion

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This section presents an overview of the purpose and problem areas explored in this dissertation, along with key findings and implications associated with each of the projects. The document by Lewis et al. (2021), developed to guide the discussion section for article-based theses, was used as a framework for this integrated discussion.

7.1 Summary of Purpose and Problem Areas Explored in this Dissertation

Concussions affect thousands of Canadians (Langer et al., 2022) and impose substantial economic costs (Comper et al., 2023; Damji & Babul, 2018). Work-related injuries account for one in five concussions sustained in adults (Terry et al., 2018). People who sustain a workplace injury may be vulnerable to experiencing persistent symptoms post-concussion (Lilley et al., 2013), highlighting a demographic that would benefit from targeted investigation efforts.

The assessment of adults following a work-related concussion occurs in various settings such as emergency departments, in family physician offices, or through specialty assessment programs for those experiencing persistent symptoms (Leddy et al., 2021). The approaches taken to these concussion assessments, however, appear to vary amongst context and clinicians (Matuszak et al., 2016). This is likely because there is an absence of clear and standardized measures recognized as universally applicable across different assessment contexts and time points (Problem #1).

Contributing further to the complexity of concussion assessment, the COVID-19 pandemic prompted clinicians with a need to quickly adapt concussion assessment practices to virtual means, exacerbating existing challenges to accessing timely in-person care, particularly for those living in remote areas due to limited access to specialized clinicians (Caze II et al., 2020; Ellis & Russell, 2019; Marckmann & John, 2020; Vargas et al., 2012). Langer et al. (2022) reported that most concussions occur in individuals who reside in rural areas and therefore access

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to specialists following concussions is difficult for many Canadians. Those with mobility limitations may also experience difficulties when trying to access in-person services (Hale-Gallardo et al., 2020). Identification of some of these challenges associated with accessing in-person care suggests the possible utility of virtual care in concussion assessment and underscores a need to overcome associated barriers. While it is known that virtual approaches to assessment may improve access to needed care for people with concussion (Zhao et al., 2020), there are many barriers to this approach that need further exploration, along with an investigation of the factors that can facilitate virtual assessment (Problem #2).

The physical domains (including vestibular such as balance testing, ocular such as the evaluation of saccades, musculoskeletal such as the evaluation of the cervical spine, and the neurological examination such as the evaluation of coordination) that are assessed in concussion examinations have been particularly challenging to transition to the virtual context (Hill et al., 2021). This is due to the difficulties associated with obtaining objective information and the reliance on hands-on approaches during aspects of the evaluation (Al Hussona et al., 2020; Dorsey et al., 2018; Ellis et al., 2020; Tenforde et al., 2017; Wechsler et al., 2013). These limitations, in turn, require clinicians to adapt the way physical concussion assessments are conducted when a virtual platform is used, and thus the exploration of the feasibility associated with administering physical measures is imperative (McPherson et al., 2022; Womble et al., 2021) (Problem #3).

Beyond the identified need to explore the feasibility of virtual assessments, there is also a need to understand the properties associated with virtual administration of the measures (a problem area beyond the scope of this dissertation that warrants foundational investigation). Interpreting psychometric properties associated with virtual assessments relies on the

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understanding of the reliability and sensitivity characteristics associated with in-person measures for effective comparisons (Russell et al., 2017). It is, therefore, necessary for us to have a comprehensive understanding of the psychometric properties of in-person administration of clinical measures while establishing the properties associated with virtual administration of the measures (Problem #4).

This dissertation contributes to the field of concussion assessment through 1) documenting the clinical measures clinicians perceive as most relevant in the in-person physical assessment of concussion and documenting the perceived feasibility associated with administering the identified measures virtually; 2) identifying the barriers and facilitators associated with the virtual physical concussion assessment while also identifying the concussion measures most suited for virtual implementation; 3) investigating the practical feasibility of the virtual physical assessment and study procedures, and documenting preliminary insights into the reliability and sensitivity of the virtual assessment when compared to the in-person assessment; and 4) documenting the psychometric properties of certain vestibular and ocular measures when administered in-person. This dissertation highlights the novelty that is the virtual approach to physical assessment in concussion and provides a robust groundwork for virtual concussion assessment implementation, while also identifying future areas of study that should be explored. This work identifies commonly used clinical physical measures that can be used to assess people post-concussion both in-person and virtually.

This following section summarizes the findings related to each project included in this dissertation encapsulating study aims, designs, key results, discussion points, and implications. It highlights how the methodological approaches led to the outcomes of developing a virtual physical concussion assessment followed by determining feasibility of the assessment, in which

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preliminary reliability and sensitivity properties are reported. The findings are derived from and relevant to real-world clinical practice, providing valuable insights for practical applications.

7.2 Summary and Discussion of Findings and Implications per Project

This dissertation had the following aims, each targeting a problem area identified: To identify relevant in-person clinical measures for inclusion in a virtual physical assessment toolkit (Objective 1: Projects 1 and 2); To identify the barriers and facilitators associated with components of the virtual physical concussion assessment, drawing insights from both clinicians and individuals affected by workplace concussions, in order to inform development of a virtual physical assessment toolkit for investigation in a follow-up study (Objective 2: Project 2); To investigate the feasibility linked with the virtual physical assessment toolkit and associated study procedures and document preliminary information regarding the sensitivity and reliability of measures included in the virtual assessment toolkit (Objective 3: Project 3); To document the psychometric properties of vestibular and ocular measures used in concussion assessments when administered in-person (Objective 4: Project 4).

7.2.1 Project 1: Identification of Clinician-Prioritized Physical Measures

An evidence-based approach to virtual physical assessment development was used, which allowed for selection of the most appropriate measures to initially explore in a feasibility study (Project 3). In Project 1, I present the results of Delphi surveys and a working group of clinician-experts, where the aim was to first identify the most relevant physical measures clinicians are using in-person for concussion assessment and to determine the perceived feasibility of administering the measures virtually. Surveying practicing clinicians allowed us to build a virtual physical assessment toolkit. Round 1 of the Delphi survey led to the identification of almost 150 different clinical measures clinicians are using in-person to evaluate the following: neurological

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examination, vestibular, oculomotor, cervical spine assessment, along with evaluation of effort. Measures identified by at least 15% of clinicians surveyed were retained for Round 2. Reading materials consisting of psychometric properties associated with the identified measures from Round 1 that met the 15% cut-off criteria were provided to the survey and working group clinician-participants to help support measure selection. The Round 2 survey led to the identification of the most relevant measures (within the respective domains) that clinicians are using in their in-person practice, which included assessment of coordination (finger-to-nose test and rapid alternating movements), cervical spine range of motion, the VOMS, and smooth pursuits. The working group members then contextualized the use of the identified measures within a virtual environment. The perceived feasibility of administering all measures meeting the 15% cut-off criteria in a virtual context was discussed in this working group. The experts agreed that most of the measures identified would be feasible in a virtual environment, with occasional modifications required, such as adapting positioning of the patient to improve observability, having a trained assistant in-person with the patient, and with the assumption that technology would be adequate for visual and audio requirements. This working group discussion informed the selection of measures that should be further considered in focus groups (Project 2).

The findings of this study suggest that a variety of approaches are used by clinicians when conducting in-person concussion physical examinations. This reinforces the work by Matuszak et al. (2016) and Leddy et al. (2021) who reported a need for clearer guidance for concussion examinations and highlights an area that would benefit from standardization. The reading materials provided, which included psychometric properties associated with the measures identified in the literature, may have informed the selection of measures by the clinicians. The sensitivity properties associated with the measures that met the 15% cut-off

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criteria ranged from poor (11% for reflexes (Anderson, 2005) to excellent (96%) for the VOMS (Buttner et al., 2021)). As reported by Wedge et al. (2012), most physiotherapists desire access to information regarding the psychometric properties associated with measures they are using in practice, however, this information is not always available or easily accessible, thus limiting knowledge of characteristics of commonly used measures. Availability of such information may have therefore encouraged an evidence-based approach to the selection of measures by the clinician-participants. The measures identified in this study align well with measures included previously developed resources and previously conducted studies on the concussion examination, which includes measures related to balance, oculomotor, VOR, coordination, and the cervical spine (Al Hussona et al., 2020; Ellis et al., 2020; Johnston et al., 2022; Leddy et al., 2021; Marshall et al., 2023). Guided by work outlined by Montes et al. (2022) this study presents an evidenced-based approach to the development of a virtual assessment.

7.2.1.1 Implications.

7.2.1.1.1 Clinical Practice. Physical examination features will lead to determination of limitations and assist in directing treatment therapies. There is a need to standardize approaches to physical concussion assessment to improve consistency amongst clinician-assessors and over time (See et al., 2013). A variety of clinical professions may evaluate people with concussion including athletic trainers, sports medicine physicians, orthopedic surgeons, neurologists, among others, which in turn suggests that variation amongst institutions and amongst disciplines is not uncommon (Leddy et al., 2021; Wilkins et al., 2014). The findings of the Delphi surveys characterize this variation and highlights an area that requires knowledge translation efforts so that clinicians have a clear understanding of which clinical measures to use in practice and at what time points each measure should be used. Further, based on the feasibility discussion

amongst the working group members, certain measures are not recommended to be used in virtual practice. This needs to be clearly communicated to clinicians so that they are not relying on these potentially infeasible measures (such as the Dix-Hallpike, which was not recommended by the working group members, and potentially unsafe to complete virtually), to obtain important information required to make clinical decisions in their virtual practice.

7.2.1.1.2 Policy. Concussions may have an impact on cognitive, emotional, behavioural, and physical well-being (DuPlessis et al., 2022). These effects could impact one's ability to return to work post-injury. Delayed return to work resulting from the impact of a concussion could have significant economic and psychosocial consequences (Cancelliere et al., 2016). Theadom et al. (2017) reported that roughly 17% of people living with effects post-concussion must make changes to behaviours at work to cope with symptoms. Further, roughly 20% experience difficulties meeting work demands post-concussion. Salary loss in the year post-injury averages 4.2% in people aged 20-59, with the loss continuing to be notable for at least five years post-concussion (Fallesen & Campos, 2020). The Concussion Awareness Training Tool for Workers and Workplaces was developed to increase awareness of adults on prevention, recognition, and management of concussions. Karmali et al. (2022) presents outcomes related to the findings of the Concussion Awareness Training Tool for Workers and Workplaces, focusing on return to work. According to Karmali et al. (2022), workplace gaps were identified including challenges associated with reaching people who live in rural areas and lack of standardized processes when addressing concussion. Further, inadequate follow-ups with physicians were reported by injured workers. These challenges could be addressed using virtual care approaches and through policy changes related to return to work processes that involves use of recommended measures. Offering a standardized virtual assessment as part of the return-to-work

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process may improve the ability to reach those living in rural areas and may improve access to physicians for follow-ups.

Standardized assessments are valuable for clinicians to evaluate patient status and outcomes in a systematic manner (Fawcett, 2007). The integration of such assessments in practice, however, is challenging and may require policy changes to facilitate adoption. Policymakers are encouraged to establish regulatory frameworks to govern the development and use of assessment tools, ensuring processes are standardized and quality standards are met (Wang et al., 2022). Policy changes, such as mandatory clinician-training and education initiatives, including a competency assessment in relation to concussion assessment may further facilitate the integration of standardized assessments in practice (Wang et al., 2022).

7.2.1.1.3 Research. The research presented here identified a gap in knowledge in that there is no standardization across practices regarding both in-person and virtual concussion examinations. Future research efforts should focus on improving this standardization through consensus and synthesis work so that a clear process can be followed for concussion examinations. Particularly, a clear and readily available outline of clinical measures to use in the concussion examination is needed.

7.2.2 Project 2: Identification of Barriers and Facilitators to Virtual Physical Concussion Assessments and Selection of Measures to Include in the Virtual Assessment Toolkit

In Project 2, I present the barriers and facilitators identified by both clinicians with virtual assessment experience and by people living with workplace concussions in focus groups. I present the clinical measures selected as most appropriate by the clinicians when contextualized within a virtual environment, which included finger-to-nose testing, balance testing, the VOMS, saccades, and cervical spine range of motion within their respective domains (neurological

examination, vestibular, oculomotor, cervical spine assessment). Many key barriers were identified by clinician and patient-participants including the impact that exposure to technology screens can have on symptom aggravation, such as worsened headaches. Clinician and patient-participants further expressed safety concerns, communication and engagement challenges, concerns with technology, and challenges associated with the environmental set-up. Importantly, many participants were unsure of the accuracy of the virtual concussion assessment. The participants did, however, identify value in the availability of remote assessments. While there are barriers to completing a concussion assessment virtually, improving timely access to appropriate care can have a significant effect on overall healthcare utilization needs and return to work timelines. In addition, other elements of access including convenience for the patient, comfort and ability to have support nearby or in one's community may support recovery. The clinician and patient-participants believed that a hybrid approach to care (including both in-person and virtual assessments) would be most optimal to support patients, however, the elements of hybrid care that are most appropriate for concussion management should be further evaluated.

The focus group discussions highlight the positive experiences with this approach throughout the COVID-19 pandemic. Virtual assessment offers the capacity to overcome certain barriers to accessing care, such as transportation challenges, or for workers who are located rurally (Crockett et al., 2023; Hudon et al., 2024). Offering a patient-centered approach to assessment, in which patient versus clinician preferences and needs are considered, may be a superior strategy for concussion assessments in the future (Almathami et al., 2020; Yun & Choi, 2019). Having easy access to support, such as a readily available technical support contact, throughout the virtual assessment, may facilitate use of virtual approaches to care in practice

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(Hale-Gallardo et al., 2020). Having an initial in-person touchpoint with clinicians followed by virtual follow-up assessments seems to be the most widely desired approach to assessment (Almathami et al., 2020; van Ierssel et al., 2022). Identifying subtle abnormalities and accurately identifying deficits, however, may be a challenge when virtual approaches to assessment are solely used (Ellis et al., 2020; Hill et al., 2021). Further, it is not currently possible to complete all components of a concussion assessment virtually (Al Husonna et al., 2020; Dorsey et al., 2018; Ellis et al., 2020; Ellis & Russell, 2019; Tenforde et al., 2017; Wechsler et al., 2013).

7.2.2.1 Implications.

7.2.2.1.1 Clinical Practice. There is value in the virtual approach to assessment (van Ierssel et al., 2022). Both clinicians and people living with workplace concussions expressed that a virtual assessment could support recovery when used in conjunction with in-person approaches to care (Barnes et al., 2024). In practice, offering the option to complete a virtual assessment when needed will prioritize patient needs and potentially support and facilitate recovery (Almathami et al., 2020). Clinicians approve of the use of the virtual assessment to complete follow-ups (van Ierssel et al., 2022) and have expressed a desire to have this means to assessment as an option moving forward. Virtual assessments post-workplace injury facilitate access to multidisciplinary teams and enable treatment planning and evaluation of readiness to return to work (Bishop et al., 2023). However, typically, these assessments are conducted in ideal conditions, so when evaluating return to work readiness, it is important to rely on multiple measures, including patient-reported outcome measures, to plan for accommodations upon return to work. It is recommended that a gradual return to work occur to ensure that the readiness determined in these ideal conditions translates positively to the workplace.

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While acknowledging the barriers identified regarding triggering of symptoms associated with completing virtual assessments due to prolonged screen exposure and safety concerns with certain vestibular tests, appropriateness of use of virtual assessment should be considered. In-person assessments should be prioritized, with consideration of use of virtual assessments when indicated. In line with the clinical practice guidelines on telerehabilitation outlined by the American Physical Therapy Association (Lee et al., 2024), clinicians should prevent, manage, and document safety events during telerehabilitation. Specifically, considerations regarding length of time since injury (where they are on the rehabilitation continuum), goals and needs of the patient, access to technology and support at home, safety concerns regarding risk of falls, complexities of the patient (considering screen sensitivity, impairments), appropriateness of the hybrid model, and appropriateness of alternate options such as community referrals should be acknowledged (Andreoli et al., 2022).

Based on the findings of the focus groups, there was a highlighted challenge associated with building rapport over a screen. An initial in-person assessment may be needed to establish this rapport prior to engaging in virtual assessments. This points to the fundamental conclusion that a hybrid approach of both in-person and virtual assessment is optimal. Further, clinicians may need to adapt approaches to improve rapport building, such as completing more check-ins, and enhancing verbal communication. Implementing these strategies in virtual assessments may, therefore, have the capacity to improve relationships amongst patients and clinicians and facilitate recovery, as rapport has a positive impact on health outcomes (English et al., 2022).

Given the identified challenges associated with virtual assessments, it will be important for clinicians to make informed decisions regarding appropriateness of virtual assessments. In-person assessments should continue to be prioritized, however, based on evaluations of a cost

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analysis, clinical status, and distance from assessment centres, virtual assessments may be of benefit.

The findings of the focus groups present a potential future opportunity to develop and implement virtual assessment programs in clinical settings. These findings will contribute to the support for virtual assessments, underlining its capacity to improve the provision of care, and will inform future clinical practices and policies on virtual care in Ontario.

7.2.2.1.2 Policy. According to Fawcett (2007), United Kingdom policies have placed emphasis recently on giving the patient sufficient information to make an informed decision about their care. In this case, clinicians are encouraged to identify the needs of the patient, placing the patient at the centre of care, and developing a care plan targeting these needs (Fawcett, 2007; Yun & Choi, 2019). Following established guidelines, such as the clinical practice guidelines outlined by the American Physical Therapy Association on telerehabilitation (Lee et al., 2024), is recommended to determine the appropriateness of virtual care for individuals. Translating this idea to this work, offering patients and families the option of completing assessments or components of the assessment in-person or virtually when appropriate, could support this notion of patient-centered care, particularly for those who experience difficulties travelling to assessment centres, that would otherwise delay access to care.

Spithoff et al. (2024) reported on privacy concerns with the virtual care industry and these findings were reported in the lay media (Zafar, 2024). While the findings of this study document concern regarding privacy of patient data in commercial virtual care spaces, patients may be informed of these news stories, which in turn could shift their perspectives on willingness to engage in virtual care options. To prevent such issues, future policy work should

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explore placing restrictions on use of patient data for promotion or revenue purposes and should enforce mandatory consent from patients for use of their data (Hardcastle & Ogbogu, 2020). Necessitating policy changes is required to ensure the effective and ethical use of virtual care approaches.

7.2.2.1.3 Research. Future work should expand on the findings of the focus groups to include different concussion populations (pediatrics, athletes, Veterans, etc.) as well as different clinical professions such as neurologists, orthopedic surgeons, occupational therapists and others. Further, expansion of the measures discussed, and domains explored is recommended such as including discussion on cognitive and emotional measures, the value of a thorough subjective history, and the opportunity to provide early education via virtual care. Evaluation of new technologies that improve or enhance capabilities of current measures, and development of new tools that can be utilized virtually should be explored.

7.2.3 Project 3: Investigation of Feasibility and Documentation of Preliminary Information Regarding Reliability and Sensitivity of Physical Concussion Measures Administered Virtually

Project 3 presents the investigation of feasibility, and preliminary data related to reliability and sensitivity of clinical measures included in the developed virtual physical assessment toolkit. Based on this feasibility study findings, it is possible to administer the assessment developed and presented in Projects 1 and 2, in a virtual setting. The measures included in the virtual physical assessment toolkit and the approaches used to complete the assessment were acceptable to both clinicians and people with brain injuries. The environmental set-up was deemed adequate. Both clinician- and patient-participants felt confident in the clinician-findings on the virtual physical assessment most of the time, however confidence ratings were slightly lower in the virtual assessment when compared to the in-person assessment.

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The moderate-to-high rate of participant recruitment and apparent feasibility of the time requirement for completion of study procedures highlight the potential capability of carrying out a larger-scale study (currently underway, however goes beyond this dissertation). When the preliminary reliability data are considered, the measures show variation in their ability to produce consistent results when evaluated by two different assessors and when evaluated by the same clinician at two different time-points (Kappa=0.38-1.0). When the preliminary sensitivity data are considered, the measures showed variation in properties when the virtual assessment was compared to the in-person assessment (0.0-1.0).

The findings of this study support the feasibility and acceptability of components of the virtual physical concussion assessment and study procedures. Previous work in this area documented weak correlations between in-person and virtual administration of certain measures used in people with neurological conditions, including a functional reach test and the Nine Hole Peg Insertion Test (Tobler-Ammann et al., 2016; Wang et al., 2011), highlighting a need to compare in-person and remote assessment approaches in the concussion context, as properties associated with measures may differ in the in-person and virtual environments (Russell et al., 2017). Utilization of reliable equipment that optimizes video and audio capacities, as well as use of hybrid approaches to assessments, may improve the similarity between the approaches. The perceived similarity of the in-person and virtual assessment is consistent with previously documented perceptions in people with chronic back disorders, with 78.9% reporting that findings are “comparable” or “somewhat comparable” in the two contexts (Lovo et al., 2019). The findings of the feasibility study confirmed the capability to carry out the larger-scale study to document the reliability and sensitivity properties associated with the virtual physical measures.

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7.2.3.1 Implications.

7.2.3.1.1 Clinical Practice. This study provides preliminary support for the remote approach to physical concussion examination. The reported confidence regarding clinical findings obtained on the virtual assessment and procedures was acceptable to participants. The findings indicate that the evaluation of saccades, range of motion, and finger-to-nose testing may pose greater challenges when completed virtually (due to the poorer properties observed), thus highlighting a need for careful consideration in the administration to improve sensitivity and reliability in the virtual context.

Knowledge of characteristics associated with clinical measures is desired by clinicians to support the adoption of an evidence-based practice (Wedge et al., 2012), and therefore translation of such information to clinical settings will be important once the larger-scale study is complete. Further, clear guidance on the use of virtual care facilitates its use in practice (Tran et al., 2017), which suggests the importance of directing efforts to consolidate learnings from this work into a practical clinical guide.

The rapid shift in clinical service delivery to virtual care has its caveats. As reported by Womble et al. (2021), practices can be adopted by clinicians that are not widely researched or supported by evidence. This dissertation contributes to the evidence supporting the preliminary data on reliability and sensitivity of components of the virtual approach to physical concussion assessment, although it is important to emphasize that further work needs to occur so that clinicians can offer a sufficiently evidenced virtual assessment in their practice.

7.2.3.1.2 Policy. Policies, services, and care may be transformed by the foundational findings from this work. Driven by changes associated with COVID-19, virtual care has come into the mainstream of rehabilitation services (Toresdahl et al., 2021). The availability of

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sensitive and reliable measures that can be used virtually strengthens the health care system's capacity to effectively deliver care at a distance (Russell et al., 2017). Virtual assessment could become a mainstream option for concussion examination, improving access to concussion specialists and independence for people recovering from concussion (Forducey et al., 2003). The assessment approach developed and presented in this dissertation may be particularly useful to programs such as the WSIB assessment programs. WSIB workers are commonly first seen by their family practitioners and are then referred to programs offering specialized assessment if they are not improving within the expected timeframe post-work-related injury. Concussion-injured workers attending assessments at these programs or at complex care clinics when attending treatment could be targeted for a policy-level change (Noel et al., 2022) that could see the addition of virtual assessment as an acceptable means to assess injured workers.

The COVID-19 pandemic encouraged policy changes so that people could access care in a safe way, in attempts to minimize the risk of COVID-19 transmission (Gross et al., 2021; Rush et al., 2022). These changes consisted of adaptations in payment schedules for clinicians providing such services (Canadian Institute for Health Information, 2022). Since the COVID-19 restrictions have been lifted, there have been some shifts in policies around providing healthcare services virtually, mainly in relation to payment schedules to providers. Virtual care services provided by telephone are payable at 85% of the in-person rate (Bulletin 221203) (Government of Ontario, 2023). The virtual care policy documented by the College of Physicians and Surgeons of Ontario note that if virtual care is being provided, standards of care must be met, such as the obligation to conduct assessments that are needed to direct treatment intervention (College of Physicians and Surgeons of Ontario, 2022). The quality of care must not be compromised when using virtual care and circumstances must be considered such as distance of

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patient from the physician, the nature of the complaint, and technology available to the patient. Reimbursement policies should evolve to support the ongoing use of virtual concussion assessments. Appropriate billing codes for virtual concussion assessment need to be determined to allow virtual assessments to occur when appropriate, adequately compensating clinicians for their services.

In addition, policy efforts should be made to ensure equitable access to virtual concussion assessments. Potential solutions could include subsidizing costs associated with technology and internet or integrating virtual care options, including coverage, into the existing healthcare model (Thomas-Jacques et al., 2021).

7.2.3.1.3 Research. While this study does not support clinical implementation or transferability to clinical settings yet, it does provide a foundation upon which future work can be expanded. The findings of this study have informed future efforts to use an adequately powered sample and robust methodology to establish important psychometric properties of measures administered virtually so that a well-researched virtual assessment could be implemented in clinical settings. Further, there may be potential for future remotely delivered intervention studies to utilize measures with adequate characteristics to monitor change in clinical status of participants at follow-up timepoints (Shear et al., 2022).

7.2.4 Project 4: Documentation of Psychometric Properties Associated with Vestibular and Ocular Measures Used in Concussion Assessments When Administered In-Person

Project 4 of this dissertation presents a scoping review, which was completed to identify the associated psychometric properties of in-person measures used to evaluate vestibular and ocular deficits following a concussion. The findings of this review allow for comparison of some of the measures included in the virtual physical assessment toolkit (VOMS, saccades, balance

testing) to those documented in the literature exploring in-person administration of these measures. Properties associated with these measures are acceptable, with areas under the curve ranging from 0.7 to 0.9. The scoping review highlights the variability in documented psychometric properties of clinical measures used to evaluate vestibular and ocular deficits post-concussion in-person and provides some information regarding the in-person characteristics of certain measures included in the virtual assessment toolkit, so that comparisons of properties can occur once the larger-scale study is complete. Most studies included in the review document the diagnostic accuracy of the measures, while few studies explore the reliability properties.

This review provides information on the current state of the literature on vestibular and ocular measures most studied. Concerns regarding the properties associated with the currently available concussion vestibular measures has been previously noted (Bell et al., 2011; Leddy et al., 2021; Quintana et al., 2021), and therefore future work should work to develop and test measures with acceptable characteristics. Ocular measures with sufficient support for use in practice are limited in number, however, there is rationale for including ocular measures in concussion examinations, adding further support for the need to develop and test sound measures (Brahm et al., 2009; Ciuffreda et al., 2007; Kapoor and Ciuffreda, 2002; Poltavski et al., 2017). Based on this review, it appears that the Community Balance & Mobility scale (balance measure with sensitivity metrics ranging from 0.78-1.0) and near point convergence test (ocular measure with a sensitivity of 0.81) provide the most promise for clinical use in the concussion context, given their properties and clinical utility characteristics, however, there have been few studies conducted on their use in the concussion context and the use of additional tools is needed to fully characterize the problem.

7.2.4.1 Implications.

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7.2.4.1.1 Clinical Practice. Findings from this review will inform clinical practice in terms of providing evidence on measures that could be effectively used in-person. In practice, clinicians are encouraged to select and use tools that target specific dimensions of interest, have appropriate reliability and validity properties, as well as being feasible and practical (no specialized equipment, minimal time required) (Beattie, 2001). The data obtained from measures used in clinical examinations is needed to provide insight into symptoms, risk, and change in clinical status (Beattie, 2001), which highlights the importance of using measures with acceptable properties in practice. Clinical practice guidelines may benefit from including psychometric data and recommendations on the best measures for clinicians to use in practice.

7.2.4.1.2 Policy. Assessments during the intervention process are needed to assist with clinical reasoning and monitoring progress (Fawcett, 2007). When treatment is being funded by government or insurers, there is a need to assure the funders that the care being received is effective in terms of supporting the injured person towards recovery, while at the same time being cost-effective (Beattie, 2001; Fawcett, 2007). Funding for health care services is based on support or evidence of the effectiveness of interventions and efficiency of the services, which is determined by findings obtained on clinical measures (Fawcett, 2007). It is, therefore, critical to understand the psychometric properties associated with measures being used in practice, as they can act as important tools to determine recovery and rationalize ongoing care. Clinicians are, in turn, encouraged to use adequate measures in their practice and to adopt a practice that is evidence-based, which includes consideration of the current research, clinical expertise, and client or patient preference (Fawcett, 2007). There are, however, challenges and barriers to implementing evidence-based practice in clinical settings, such as time limitations, and lack of access to up-to-date research (Beattie, 2001). Further, there remains a gap between research and

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current practice in the fields of physiotherapy and occupational therapy (Schwab et al., 2023). More knowledge translation work needs to be executed to bridge this gap so that research findings are being communicated to clinicians and implemented in clinical settings.

7.2.4.1.3 Research. There is an opportunity for future work to address the limitations inherent within this scoping review. Completion of a formal evaluation of the properties associated with concussion measures is needed so that clear recommendations can be provided. There is also a potential to expand on the review and include other domains of a concussion examination (neurological examination, cervical spine, cognitive, emotional) and other populations, such as pediatrics.

7.3 Future Directions

Certain methodological limitations within this dissertation highlight the need further follow-up studies. First, challenges pertaining to recruitment and time limits prompted the initiation of a feasibility study (with a smaller sample size) to determine the potential to carry out the larger-scale study. Consequently, only inferences or estimations can be made regarding the possible psychometric properties of the measures used in the virtual assessment. The larger-scale clinical study is needed to ensure sufficient sample size for robust determination of the desired psychometric properties. Documentation of the psychometric properties will strengthen evidence-based virtual practices for clinicians. Additionally, future work should explore real-world implementation of the virtual assessment within home settings, considering unique factors such as variations in internet speeds, access to technology, and potential distractions. Furthermore, the virtual physical assessment toolkit developed in this dissertation was not comprehensive in nature. Future work should aim to broaden the scope of measures to include cognitive, emotional, and additional physical measures. The value of a thorough subjective

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history to improve rapport and trust and provide opportunity to implement early education via virtual care should be explored. Future work should compare different virtual platforms relative to enhancing audio and visual challenges identified in this work.

The psychometric properties of in-person administration of measures emerged as an area of consideration for future work. Some of the currently available clinical measures routinely used in the concussion assessment have properties that have been inadequately described. There exists a pressing need to improve the measures used to evaluate balance deficits following a concussion as well as to expand the literature on their psychometric properties. Importantly, establishing these properties at various timepoints post-concussion (acute, post-acute) would be beneficial.

7.4 Conclusions

In this dissertation, I documented the most relevant clinical measures employed by clinicians during in-person and virtual physical concussion assessments. These measures include finger-to-nose testing, the VOMS, saccades, balance testing, and cervical spine range of motion. I documented the expert-clinician perceived feasibility of utilizing these identified measures in a virtual context. While most of the clinical measures were perceived to be feasible when administered over a videoconferencing platform, occasional adjustments are reported to be necessary, such as omitting components of a measure or adapting the method of measurement. Through an exploration of lived experiences, I documented the barriers and facilitators associated with the virtual concussion assessment as perceived by people living with workplace concussions and clinicians. Concerns regarding the accuracy of the virtual approach to assessment were voiced alongside challenges related to symptom aggravation due to exposure to screens. Strategies, such as taking breaks to allow management of symptoms and preparation in advance of the appointment, however, could facilitate completion of the virtual concussion

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assessment. Further, I documented preliminary insights into the inter-rater and intra-rater reliability as well as the sensitivity of components of the virtual physical assessment (with properties ranging from poor to excellent). The real feasibility and acceptability of the virtual assessment and study procedures, along with perceived confidence of findings from the assessments from both clinician and patient-participant perspectives have been characterised. Notably, this work demonstrated the capacity to feasibly recruit needed participants and execute all study procedures. Participants expressed confidence in the virtual assessment findings and reported the acceptability of this approach and the environmental set-up based on their needs and experiences. Finally, I documented the psychometric properties associated with in-person administration of vestibular and ocular measures, identifying, and describing variability in associated metrics.

Facilitated by clinical practice changes catalyzed by COVID-19, virtual care had a surge in global usage, which appears to have been largely sustained. However, it is important to highlight some policy changes, such as those observed in Ontario, where fees associated with virtual care have been altered, which in turn disrupts the ability to offer such services (Fu et al., 2022). As evidenced by this work, virtual approaches to assessment can have positive implications for both clinicians and patients, often serving as a complement to in-person care. Despite acknowledging its limitations, this work serves as a foundational step to a more concrete understanding of the virtual physical concussion assessment. Effective virtual assessment options would improve the healthcare landscape for many adults and this work contributes to such advancement of knowledge. The importance of this dissertation stems from an under-researched area, the virtual physical concussion assessment. This work targets a current and practical issue related to concussion rehabilitation and provides important information regarding what is needed

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to further drive the understanding and eventual implementation of cost-effective, clinically useful, standardized virtual concussion assessments.

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References for Chapter 1 (Introduction and Review of the Literature) and Chapter 7 (Integrative Discussion and Conclusion)

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Appendices

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Appendix A: Ethics Approval Letters

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Delphi Surveys, Working Group, Focus Groups: OHSN-REB Approval Letter Initial Submission

Ottawa Health Science Network Research Ethics Board (OHSN-REB) / Conseil d'éthique de la recherche du réseau de science de la santé d'Ottawa (CÉR-RSSO)

Date:	September 24, 2021
Principal Investigator:	Dr. Shawn Marshall, TOH/OHRI
Protocol ID:	20210575-01H
Study Title:	Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions
Submission Type:	Initial Application
Review Type:	Delegated
Date of Approval:	September 24, 2021
Approval Expiry Date:	September 24, 2022

Dear Dr. Marshall,

An **Institutional approval (OHRI) letter is required prior to the conduct of the study** at this site. The institutional approval letter is an indication that you have satisfied ethics, contracts, departmental notifications, as applicable.

Thank you for submitting the above referenced study. The Ottawa Health Science Network Research Ethics Board (OHSN-REB) has reviewed the application and granted approval for your study. This approval is granted until the expiration date noted above. This research study is to be conducted by the investigator noted above.

The **OHSN-REB ethics approval** is applicable only for The Ottawa Hospital.

Documents Approved:

Document Name	Document Version Date
English-only Informed Consent Form- Surveys	September 23, 2021
English-only Delphi Survey Questions	June 28, 2021
English-only Delphi Survey Round 1 Demographic Questionnaire	September 17, 2021
English-only Email Script	September 17, 2021
English-only Focus Group Interview Guide	June 28, 2021
English-only Focus Groups Consent Form	September 23, 2021
English-only Survey Email Round 2	August 30, 2021
English-only Survey Reminder Email	September 17, 2021
English-only Verbal Consent Script	September 23, 2021
Protocol version 1.0	June 28, 2021

No deviations from, or changes to, the protocol should be initiated without prior written approval of an appropriate amendment from the OHSN-REB, except when necessary to eliminate immediate hazard(s) to study participants.

REB members involved in the research project do not participate in the review, discussion or decision.

If the study is to continue beyond the expiry date noted above, a Continuing Review Form must be received by the OHSN-REB on or prior to the full board submission deadline date of the meeting scheduled to occur a minimum of 30 days prior to the study expiry date. If the study has been completed by the expiry noted above, a Study Closure Report must be received by the OHSN-REB.

The OHSN-REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use; Integrated Addendum to ICH E6 (R1): Guideline for Good Clinical Practice E6 (R2); Part C, Division 5 of the Food and Drug Regulations; or with the definition in the Interim Order Respecting Clinical Trials for Medical Devices and Drugs Relating to COVID-19; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations; and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. OHSN-REB is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP).

Please do not hesitate to contact us if you have any questions.

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Delphi Surveys, Working Group, Focus Groups: OHSN-REB Amendment Approval

Ottawa Health Science Network Research Ethics Board (OHSN-REB) / Conseil d'éthique de la recherche du réseau de science de la santé d'Ottawa (CÉR-RSSO)

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Friday, January 21, 2022

Dr. Shawn Marshall
The Ottawa Hospital Rehabilitation Centre
Ottawa Hospital - General Campus
505 Smyth Road
Ottawa, ON
K1H 8M2

Dear Dr. Marshall:

RE: Protocol #20210575-01H - Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Thank you for the email dated January 20, 2022 from Keely Barnes. The information was reviewed by the Ottawa Health Science Network Research Ethics Board

The following documents were reviewed and approved as of; January 21, 2022
-Amendment dated January 18, 2022
-Protocol, version 2.0 date 18-Jan-22
-English Delphi Survey Demographic Questionnaire, version date 25-Oct-21
-English Delphi Survey Demographic Questionnaire, version date 25-Oct-21
-English Delphi Survey Questions, version date 06-Jan-22
-English Email Script, version date 10-Jan-22
-English Survey Email Round 2, version date 18-Jan-22
-English Survey Reminder Email Round 2, version date 18-Jan-22
-English Surveys Consent Form, version date 06-Jan-22
-English New Reading Material for Focus Groups and Surveys, version date 02-Nov-21
-English New Network Newsletter Paragraph, version date 03-Jan-22

Ethics approval remains in effect until September 24, 2022.

The OHSN-REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use; Integrated Addendum to ICH E6 (R1): Guideline for Good Clinical Practice E6 (R2); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations; or with the definition in the Interim Order Respecting Clinical Trials for Medical Devices and Drugs Relating to COVID-19; and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. OHSN-REB is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health

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Delphi Surveys, Working Group, Focus Groups: OHSN-REB Amendment Approval

Ottawa Health Science Network Research Ethics Board (OHSN-REB) / Conseil d'éthique de la recherche du réseau de science de la santé d'Ottawa (CÉR-RSSO)

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http://www.ohri.ca/ohsn-reb

Friday, February 11, 2022

Dr. Shawn Marshall
The Ottawa Hospital Rehabilitation Centre
Ottawa Hospital - General Campus
505 Smyth Road
Ottawa, ON
K1H 8M2

Dear Dr. Marshall:

RE: Protocol #20210575-01H - Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

I am pleased to inform you that your Amendment Request was reviewed by the Ottawa Health Science Network Research Ethics Board (OHSN-REB) and is approved.

Approval is for the following:
- Amendment form dated February 08, 2022
- Revised English Implied Informed Consent version dated January 27, 2022
- Revised English Email Recruitment Script version dated January 31, 2022
- Revised English Network Newsletter Script version dated January 31, 2022

Approval is effective as of: February 09, 2022

Ethics approval remains in effect until September 24, 2022.

The OHSN-REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use; Integrated Addendum to ICH E6 (R1): Guideline for Good Clinical Practice E6 (R2); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations; or with the definition in the Interim Order Respecting Clinical Trials for Medical Devices and Drugs Relating to COVID-19; and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. OHSN-REB is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP).

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Delphi Surveys, Working Group, Focus Groups: OHSN REB Amendment Approval

Ottawa Health Science Network Research Ethics Board (OHSN-REB) / Conseil d'éthique de la recherche du réseau de science de la santé d'Ottawa (CÉR-RSSO)

Date:	May 11, 2022
To:	Dr. Shawn Marshall, TOH/OHRI
Protocol ID:	20210575-01H
Post Form ID:	289
Study Title:	Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions
Amendment Type:	Changes to the Protocol (this includes changes to study design, methodology and radiological procedures and other tests); Changes to the consent, assent or debriefing process and/or consent form(s), assent form(s), debriefing material(s) or other participant material(s) such as instruments/questionnaires, surveys, participant diaries, wallet cards, etc.; Changes to recruitment methods/plan, material(s) (e.g., telephone, web or email scripts, flyers, posters, brochures, etc.) and/or participant compensation/reimbursement/financial incentives
Review Type:	Delegated
Approval Date:	May 11, 2022
Study Approval Expiry Date:	September 24, 2022

Dear Dr. Marshall,

The Ottawa Health Science Network Research Ethics Board has reviewed the application and approves the amendment, as of the date noted above.

Documents Approved:

Document Name	Document Version Date
Comprehensive List of All Potential Measures that may be Discussed	April 11, 2022
English Clinician-Participant Demographic Questionnaire	April 11, 2022
English Working Group Email Recruitment	April 11, 2022
English Working Group Information Sheet	April 11, 2022
English Working Group Verbal Consent Script	April 11, 2022
Revised Protocol version 3.0	April 11, 2022

No deviations from, or changes to, the protocol should be initiated without prior written approval of an appropriate amendment from the OHSN-REB, except when necessary to eliminate immediate hazard(s) to study participants.

REB members involved in the research project do not participate in the review, discussion or decision.

If the study is to continue beyond the expiry date noted above, a Continuing Review Form must be received by the OHSN-REB 40-50 days prior to the study expiry date. If the study has been completed by the expiry noted above, a Study Closure Form must be received by the OHSN-REB.

The OHSN-REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri¬-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use; Integrated Addendum to ICH E6 (R1): Guideline for Good Clinical Practice E6 (R2); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. OHSN-REB is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP).

Please do not hesitate to contact us if you have any questions.

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Delphi Surveys, Working Group, Focus Groups: Bruyère REB Initial Approval Letter

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Hôpital Saint-Vincent Hospital
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Téléc./Fax: 613-683-5001

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Téléc./Fax: 613-241-1971

Centre de médecine familiale Primrose
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Téléc./Fax: 613-230-7778

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Téléc./Fax: 613-562-4266

Fondation Bruyère Foundation
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Ottawa ON K1N 5C8
Tél./Tel.: 613-562-6319
Téléc./Fax: 613-562-6023

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Friday, February 11, 2022

Dr. Shawn Marshall

Re: "Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions" (Bruyère REB Protocol # M16-22-006)

Final Approval

Dear Dr. Marshall,

The Bruyère Continuing Care Research Ethics Board (REB) is pleased to give you ethical approval for the above noted study for the period of **February 11, 2022** to **February 11 2023.**

The following documents have been approved:

- ✓ IRIS Application;
- ✓ Protocol, version 2.0 date: January 18, 2022;
- ✓ Delphi Survey Demographic Questionnaire;
- ✓ Delphi Survey Questions;
- ✓ Email Script;
- ✓ Survey Email Round 2;
- ✓ Survey Reminder Email;
- ✓ Survey Reminder Email Round 2;
- ✓ Focus Group Interview Guide;
- ✓ ICF Surveys;
- ✓ ICF Focus Group Verbal Consent Script;
- ✓ ICF Focus Group Consent Form;
- ✓ Network Newsletter Paragraph;
- ✓ Reading Material for Focus Groups and Surveys

The following documents have been acknowledged:

- ✓ OHSN REB Approval Phase 1, dated September 24, 2021;
- ✓ Departmental Sign Off;
- ✓ TCPS 2 Certificates;
- ✓ Confidentiality Pledges

The Bruyère Continuing Care REB complies with the membership requirements and operates in compliance with the Tri-Council Policy Statement 2: Ethics Conduct for Research Involving Humans; the International Conference on Harmonization - Good Clinical Practice: Consolidated Guideline; the provisions of the Personal Health Information Protection Act 2004; and the Food and Drug Act of Health Canada and its applicable Regulations.

Please be advised that any complaints made by participants must be reported to the REB. All changes to the approved protocol must be approved by the REB.

À Bruyère, nous vous promettons... bonté • sécurité • bienveillance
At Bruyère, we promise you... Kind • Safe • Care

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Delphi Surveys, Working Group, Focus Groups: Bruyère REB Amendment Approval

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Téléc./Fax: 613-562-4266

Monday, March 14, 2022

Dr. Shawn Marshall

Re: "Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions" (Bruyère REB Protocol #M16-22-006)

Amendment Approval

Dear Dr. Marshall,

Thank you for submitting an amendment request for the above-named project.

The following has been approved:

- ✓ Surveys Consent Form (French), version date: January 27, 2022
- ✓ Surveys Consent Form
- ✓ Network Newsletter Paragraph (French), version date: January 31, 2022
- ✓ Network Newsletter Paragraph
- ✓ Delphi Survey Questions (French), version date: January 6, 2022
- ✓ Email Script (French), version date: January 31, 2022
- ✓ Email Script
- ✓ Delphi Demographic Questionnaire (French), version date: October 25, 2021

The following has been acknowledged:

- ✓ OHSN Amendment Approval, dated March 11, 2022
- ✓ OHSN Amendment Approval, dated February 8, 2022
- ✓ Certification of Translation, dated March 10, 2022

The Bruyère Continuing Care REB complies with the membership requirements and operates in compliance with the Tri-Council Policy Statement 2: Ethics Conduct for Research Involving Humans; the International Conference on Harmonization - Good Clinical Practice: Consolidated Guideline; the provisions of the Personal Health Information Protection Act 2004; and the Food and Drug Act of Health Canada and its applicable Regulations.

The information received has been reviewed and I hereby give approval on behalf of the REB.

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Delphi Surveys, Working Group, Focus Groups: University of Ottawa Research Ethics Board Initial Approval Letter

10/02/2022

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

Lettre d'approbation administrative | Letter of administrative approval

Numéro de dossier / Ethics File Number	H-02-22-7611
Titre du projet / Project Title	Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussion
Type de projet / Project Type	Thèse de doctorat / Doctoral thesis
CÉR primaire / Primary REB	Réseau de science de la santé d'Ottawa (RSSO) / Ottawa Health Science Network (OHSN)
Statut du projet / Project Status	Approuvé / Approved
Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)	10/02/2022
Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)	23/09/2022

Équipe de recherche / Research Team

Chercheur / Researcher	Affiliation	Role
Keely BARNES	École des sciences de la réadaptation / School of Rehabilitation Sciences	Chercheur Principal / Principal Investigator
Heidi SVEISTRUP	École des sciences de la réadaptation / School of Rehabilitation Sciences	Superviseur / Supervisor
Shawn MARSHALL		Co-superviseur / Co-supervisor
Monica TALJAARD	Département d'épidémiologie et santé publique / Department of Epidemiology and Public Health	Collaborateur / Collaborator
Rafik GOUBRAN	Carleton University	Collaborateur / Collaborator
Michel RATHBONE	McMaster University	Collaborateur / Collaborator

Conditions spéciales ou commentaires / Special conditions or comments:

OHSN REB Protocol ID: 20210575-01H (PI S. Marshall)

550, rue Cumberland, pièce 154
Ottawa (Ontario) K1N 6N5 Canada

550 Cumberland Street, Room 154
Ottawa, Ontario K1N 6N5 Canada

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Delphi Surveys, Working Group, Focus Groups: University of Ottawa Research Ethics Board Amendment Approval Letter

06/04/2022

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

CERTIFICAT D'APPROBATION ÉTHIQUE | CERTIFICATE OF ETHICS APPROVAL

Numéro du dossier / Ethics File Number	H-02-22-7611
Titre du projet / Project Title	Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions
Type de projet / Project Type	Thèse de doctorat / Doctoral thesis
Statut du projet / Project Status	Approuvé / Approved
Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)	10/02/2022
Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)	23/09/2022

Équipe de recherche / Research Team

Chercheur / Researcher	Affiliation	Role
Keely BARNES	École des sciences de la réadaptation / School of Rehabilitation Sciences	Chercheur Principal / Principal Investigator
Heidi SVEISTRUP	École des sciences de la réadaptation / School of Rehabilitation Sciences	Superviseur / Supervisor
Mark BAYLEY	Toronto Rehabilitation institute Universtity Health Network	Co-chercheur principal / Co-principal investigator
Shawn MARSHALL		Co-superviseur / Co-supervisor
Monica TALJAARD	Département d'épidémiologie et santé publique / Department of Epidemiology and Public Health	Collaborateur / Collaborator
Rafik GOUBRAN	Carleton University	Collaborateur / Collaborator
Michel RATHBONE	McMaster University	Collaborateur / Collaborator

Conditions spéciales ou commentaires / Special conditions or comments

Modifications to the project are approved, as per OHSN REB approval (Protocol #20210575-01H).

550, rue Cumberland, pièce 154 Ottawa (Ontario) K1N 6N5 Canada
550 Cumberland Street, Room 154 Ottawa, Ontario K1N 6N5 Canada

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Feasibility Study: OHSN-REB Approval Letter

The Ottawa Hospital | L'Hôpital d'Ottawa
RESEARCH INSTITUTE | INSTITUT DE RECHERCHE

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UNIVERSITY OF OTTAWA HEART INSTITUTE
INSTITUT DE CARDIOLOGIE DE L'UNIVERSITÉ D'OTTAWA

Ottawa Health Science Network Research Ethics Board (OHSN-REB) / Conseil d'éthique de la recherche du réseau de science de la santé d'Ottawa (CÉR-RSSO)

Date:	June 1, 2023
Principal Investigator:	Dr. Shawn Marshall, TOH/OHRI
Protocol ID:	20230311-01H
Study Title:	Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions
Submission Type:	Initial Application
Review Type:	Delegated
Date of Approval:	June 1, 2023
Study Approval Expiry Date:	June 1, 2024

Dear Dr. Marshall,

An **Institutional approval (OHRI) letter is required prior to commencing the study** . In order to obtain the institutional approval letter, the ethics, contracts, and departmental notifications tabs of the Clinical Research Registration Form (CRRF) must be approved/marked complete by the reviewing office.

Thank you for submitting the above referenced study. The Ottawa Health Science Network Research Ethics Board (OHSN-REB) has reviewed the application and granted approval for your study. This approval is granted until the expiration date noted above. This research study is to be conducted by the investigator noted above.

The **OHSN-REB ethics approval** for this study is for The Ottawa Hospital.

Documents Approved:

Document Name	**Document Version Date**
English Assessment Toolkit	May 4, 2023
English Patient Open-Ended Questions	February 7, 2023
English Patient-Participant Information Sheet	May 25, 2023
English Patient-Participant Informed Consent Form	May 25, 2023
English Patient-Participant Verbal Consent Script	May 25, 2023
English Reliability Phase Patient Demographic Questionnaire	March 13, 2023
English-only Clinician Open-Ended Questions	February 7, 2023
English-only Clinician-Participant Information Sheet	May 25, 2023
English-only Clinician-Participant Informed Consent Form	May 25, 2023
English-only Clinician-Participant Verbal Consent Script	May 25, 2023
English-only Reliability Phase Clinician Demographic Questionnaire	February 27, 2023
Protocol version 1.0	May 1, 2023

If applicable, the pending translated documents must be uploaded into the "Translated Documents" tab of the Clinical Research Registration Form within 90 days of REB approval (40 days for PI/Study Team translated documents).

No deviations from, or changes to, the protocol should be initiated without prior written approval of an appropriate amendment from the OHSN-REB, except when necessary to eliminate immediate hazard(s) to study participants.

REB members involved in the research project do not participate in the review, discussion or decision.

If the study is to continue beyond the expiry date noted above, a Continuing Review Form must be received by the OHSN-REB on or prior to the full board submission deadline date of the meeting scheduled to occur a minimum of 30 days prior to the study expiry date. If the study has been completed by the expiry noted above, a Study Closure Form must be received by the OHSN-REB.

The OHSN-REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use; Integrated Addendum to ICH E6 (R1): Guideline for Good Clinical Practice E6 (R2); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations; and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations or with the definition in the Interim Order Respecting Clinical Trials for Medical Devices and Drugs Relating to COVID-19. OHSN-REB is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP).

Please do not hesitate to contact us if you have any questions.

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Feasibility Study: OHSN-REB Amendment Approval Letter

Ottawa Health Science Network Research Ethics Board (OHSN-REB) / Conseil d'éthique de la recherche du réseau de science de la santé d'Ottawa (CÉR-RSSO)

Date:	December 11, 2023
To:	Dr. Shawn Marshall, TOH/OHRI
Protocol ID:	20230311-01H
Post Form ID:	7122
Study Title:	Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions
Amendment Type:	Changes to the consent, assent or debriefing process and/or consent form(s), assent form(s), debriefing material(s) or other participant material(s) such as instruments/questionnaires, surveys, participant diaries, wallet cards, etc.
Review Type:	Delegated
Approval Date:	December 11, 2023
Study Approval Expiry Date:	June 1, 2024

Dear Dr. Marshall,

The Ottawa Health Science Network Research Ethics Board has reviewed the application and approves the amendment, as of the date noted above.

Documents Approved:

Document Name	Document Version Date
20230311-01H Revised English- Clinician Information Sheet 16Nov2023	November 16, 2023
20230311-01H Revised English- Clinician Informed Consent Form 16Nov2023	November 16, 2023
20230311-01H Revised English- Clinician Verbal Consent Script 16Nov2023	November 16, 2023

ACTIONS TO BE TAKEN FOR COMMUNICATION WITH PARTICIPANTS

1. **Communication with participants who are in screening or currently enrolled in the study and receiving study treatment or intervention:**
   - Other
2. **Communication with participants who are currently on follow-up with occasional visits:**
   - No study participants are on follow-up with occasional visits
3. **Communication with participants on follow-up via phone contact only:**
   - Other
4. **Communication with participants no longer on follow up, but the new findings affect the long-term health of the participant:**
   - Not applicable

No deviations from, or changes to, the protocol should be initiated without prior written approval of an appropriate amendment from the OHSN-REB, except when necessary to eliminate immediate hazard(s) to study participants.

REB members involved in the research project do not participate in the review, discussion or decision.

If the study is to continue beyond the expiry date noted above, a Continuing Review Form must be received by the OHSN-REB 40-50 days prior to the study expiry date. If the study has been completed by the expiry noted above, a Study Closure Form must be received by the OHSN-REB.

The OHSN-REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri¬-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use; Integrated Addendum to ICH E6 (R1): Guideline for Good Clinical Practice E6 (R2); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. OHSN-REB is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP).

Please do not hesitate to contact us if you have any questions.

Sincerely,

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613-798-5555 extension 16719 Fax: 613-761-4311 http://www.ohri.ca/ohsn-reb

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Feasibility Study: OHSN-REB Amendment Approval Letter

Ottawa Health Science Network Research Ethics Board (OHSN-REB) / Conseil d'éthique de la recherche du réseau de science de la santé d'Ottawa (CÉR-RSSO)

Date:	January 16, 2024
To:	Dr. Shawn Marshall, TOH/OHRI
Protocol ID:	20230311-01H
Post Form ID:	7264
Study Title:	Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions
Amendment Type:	Changes to the Protocol (hover for list of what is included); Changes to the consent, assent or debriefing process and/or consent form(s), assent form(s), debriefing material(s) or other participant material(s) such as instruments/questionnaires, surveys, participant diaries, wallet cards, etc.; Changes to recruitment methods/plan, material(s) (e.g., telephone, web or email scripts, flyers, posters, brochures, etc.) and/or participant compensation/reimbursement/financial incentives
Review Type:	Delegated
Approval Date:	January 16, 2024
Study Approval Expiry Date:	June 1, 2024

Dear Dr. Marshall,

The Ottawa Health Science Network Research Ethics Board has reviewed the application and approves the amendment, as of the date noted above.

Documents Approved:

Document Name	Document Version Date
English Recruitment Poster, 2024.01.08	January 8, 2024
Revised Assessment Toolkit for Physician Participants, 2023.11.29	November 29, 2023
Revised Clinician Information Sheet, 2023.12.14	December 14, 2023
Revised Clinician Informed Consent Form, 2023.12.14	December 14, 2023
Revised Clinician Verbal Consent Script, 2023.12.14	December 14, 2023
Revised English Patient Participant Information Sheet, 2023.12.14	December 14, 2023
Revised English Patient Participant Informed Consent Form, 2023.12.14	December 14, 2023
Revised English Patient Participant Verbal Consent Script, 2023.12.14	December 14, 2023
Revised Protocol version 2.0, 2024.01.08	January 8, 2024

No deviations from, or changes to, the protocol should be initiated without prior written approval of an appropriate amendment from the OHSN-REB, except when necessary to eliminate immediate hazard(s) to study participants.

REB members involved in the research project do not participate in the review, discussion or decision.

If the study is to continue beyond the expiry date noted above, a Continuing Review Form must be received by the OHSN-REB 40-50 days prior to the study expiry date. If the study has been completed by the expiry noted above, a Study Closure Form must be received by the OHSN-REB.

The OHSN-REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri¬-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use; Integrated Addendum to ICH E6 (R1): Guideline for Good Clinical Practice E6 (R2); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. OHSN-REB is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP).

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Feasibility Study: Bruyère REB Approval

Bruyère

Contact the Research Ethics Office: REB@bruyere.org
Visit the REB Website: https://www.bruyere.org/en/researchethicsboard

BRUYÈRE RESEARCH ETHICS BOARD – APPROVAL LETTER

Date: 6 June 2023

Investigator Name(s): Dr. Shawn Marshall

REB Number: **M16-23-031**

Study Title: ***Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions***

Review Type: ☐ Full Board Review ☐ Delegated Review ☒ Administrative Review

Date of Approval: **6 June 2023**

Approval Expiry Date: **6 June 2024**

Thank you for submitting the above noted study to the Bruyère Research Ethics Board for review. The study has been reviewed by the REB and approval has been granted. This study is approved until the expiration date noted above.

The following documents are approved:

Document Name/Title	Document Version Date
IRIS REB Application	November 28, 2022
Protocol	March 13, 2023
Informed Consent Form – Written – Clinician	May 25, 2023
Informed Consent Form – Verbal – Clinician	May 25, 2023
Informed Consent Form – Written – Patient	May 25, 2023
Informed Consent Form – Verbal – Patient	May 25, 2023
Clinician Open-Ended Questions	February 7, 2023
Patient Open-Ended Questions	February 7, 2023
Information Sheet – Clinician	May 25, 2023
Information Sheet – Patient	May 25, 2023
Reliability Phase Demographic Questionnaire – Clinician	February 27, 2023
Reliability Phase Demographic Questionnaire – Patient	February 27, 2023

The following is acknowledged:

Document Name/Title	Document Version Date
OHSN REB Approval Letter	June 1, 2023

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Feasibility Study: Bruyère REB Amendment Approval

Bruyère

Contact the Research Ethics Office: REB@bruyere.org
Visit the REB Website: https://www.bruyere.org/en/researchethicsboard

BRUYÈRE RESEARCH ETHICS BOARD – AMENDMENT APPROVAL

Date: 22 January 2024

Investigator Name: Dr. Shawn Marshall

REB Number: **M16-23-031**

Study Title: ***Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions***

Review Type: ☐ Full Board Review ☐ Delegated Review ☒ Administrative Review

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In response to the amendment form, dated January-15-24, the amendment to the study noted above has been reviewed and approved.

The following is approved:

Item(s) for Approval	Document Version Date
Clinician Information Sheet – EN	November 16, 2023
Informed Consent Form – Clinician	November 16, 2023
Informed Consent Form – Clinician – Verbal	November 16, 2023
Recruitment Poster – EN	January 8, 2024
Assessment Toolkit – Physicians	November 29, 2023
Clinician Information Sheet	December 14, 2023
Informed Consent Form – Clinician	December 14, 2023
Informed Consent Form – Clinician – Verbal	December 14, 2023
Patient Participant Information Sheet – EN	December 14, 2023
Informed Consent Form – Patient – EN	December 14, 2023
Informed Consent Form – Patient – Verbal – EN	December 14, 2023
Protocol	January 8, 2024

The following is acknowledged:

Item(s) for Acknowledgment	Document Version Date
OSHN REB Amendment Approval Letter	December 11, 2023
OSHN REB Amendment Approval Letter	January 16, 2024

Approval of this study expires on June-6-24

In the event that changes to the BREB, Protocol or ICF are required, a completed amendment form and updated documents must be submitted to the REB for review and approval before the changes may be incorporated into the study.

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Feasibility Study: University of Ottawa Approval

04/07/2023

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

Lettre d'approbation administrative | Letter of administrative approval

Numéro de dossier / Ethics File Number	H-06-23-9348
Titre du projet / Project Title	Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions-Reliability Phase
Type de projet / Project Type	Thèse de doctorat / Doctoral thesis
CÉR primaire / Primary REB	Réseau de science de la santé d'Ottawa (RSSO) / Ottawa Health Science Network (OHSN)
Statut du projet / Project Status	Approuvé / Approved
Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)	04/07/2023
Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)	01/06/2024

Équipe de recherche / Research Team

Chercheur / Researcher	Affiliation	Role
Keely BARNES	École des sciences de la réadaptation / School of Rehabilitation Sciences	Chercheur Principal / Principal Investigator
Heidi SVEISTRUP	École des sciences de la réadaptation / School of Rehabilitation Sciences	Superviseur / Supervisor
Michel RATHBONE	McMaster University	Collaborateur / Collaborator
Monica TALJAARD	Département d'épidémiologie et santé publique / Department of Epidemiology and Public Health	Collaborateur / Collaborator
Mark BAYLEY	Toronto Rehabilitation institute Universtity Health Network	Co-chercheur / Co-investigator
Shawn MARSHALL		Co-superviseur / Co-supervisor

Conditions spéciales ou commentaires / Special conditions or comments:

OHSN REB Protocol ID: 20230311-01H

550, rue Cumberland, pièce 154
Ottawa (Ontario) K1N 6N5 Canada

550 Cumberland Street, Room 154
Ottawa, Ontario K1N 6N5 Canada

613-562-5387 • 613-562-5338 • ethique@uOttawa.ca / ethics@uOttawa.ca
www.recherche.uottawa.ca/deontologie | www.recherche.uottawa.ca/ethics

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Feasibility Study: University of Ottawa Amendment Approval Letter

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

H-06-23-9348 - MOD2-9348 - Modification approuvée / Modification Approved

(English message follows)

Cher/Chère Keely Barnes,

Merci d'avoir soumis une demande de modification pour votre projet de recherche intitulé «Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions- Reliability Phase».

Ces modifications ont été approuvées et sont assujetties au certificat d'approbation éthique, valide jusqu'au 01-06-2024.

Several changes have been made to the study and have been approved by the primary REB.

Si vous avez des questions, n'hésitez pas à communiquer avec le Bureau d'éthique au ethique@uottawa.ca ou au 613-562-5387.

Vous pouvez voir votre demande en vous connectant à votre compte eReviews .

Cordialement,

Coordonateur / Coordinator
Coordonnateur de l'éthique
Président(e) : Daniel Lagarec
CÉR : Comité d'éthique de la recherche en sciences de la santé et sciences / Health Sciences and Sciences Research Ethics Board

Ceci est une réponse automatisée, merci de ne pas répondre à ce courriel.

Dear Keely Barnes,

Thank you for submitting a modification request for your research project titled "Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions- Reliability Phase".

These modifications are now covered under the certificate of ethics approval, valid until 01-06-2024.

Several changes have been made to the study and have been approved by the primary REB.

If you have any questions, please contact the Ethics Office at ethics@uottawa.ca or 613-562-5387.

You can view your project at any time by logging into eReviews .

Best regards,

Coordonateur / Coordinator
Ethics Coordinator
Chair: Daniel Lagarec
REB: Comité d'éthique de la recherche en sciences de la santé et sciences / Health Sciences and Sciences Research Ethics Board

This is an automated message. Please do not reply directly to this email.

Attachement(s) / Attachment(s)

550, rue Cumberland, pièce 154
Ottawa (Ontario) K1N 6N5 Canada

550 Cumberland Street, Room 154
Ottawa, Ontario K1N 6N5 Canada

613-562-5387 • 613-562-5338 • ethique@uOttawa.ca / ethics@uOttawa.ca
www.recherche.uottawa.ca/deontologie I www.recherche.uottawa.ca/ethics

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Appendix B: Consent Forms and Recruitment Materials

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Delphi Survey Consent Form

Informed Consent Form

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions
The VirNA Study – Development Phase

OHSN-REB Number: 20210575-01H

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

Co Investigator: Dr. Mark Bayley, MD, FRCPC
Toronto Rehabilitation Institute
550 University Ave. Toronto, ON
M5G 2A2

Funding Agency: Workplace Safety and Insurance Board (WSIB)

INTRODUCTION
You are invited to participate in this research study because you are a clinician involved in concussion assessments. This study aims to develop a virtual neurological assessment for concussion patients. This study is being conducted by Dr. Shawn Marshall and Dr. Mark Bayley. The WSIB has provided funding for this project.

Participation in this study is voluntary. You have the option to not participate at all or you may choose to leave the study at any time. The decision will not affect your employment.

ARE THERE ANY CONFLICTS OF INTEREST?
There are no conflicts of interest to declare related to this study.

WHAT WILL HAPPEN DURING THIS STUDY?
Your participation in this study will require the completion of two surveys through the Delphi approach. The surveys ask questions about concussion assessment measures frequently used by clinicians. Each survey should take up to 5 minutes of your time to complete (per round).

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There will be two rounds of surveys in this component of the study:

- **Delphi Survey Round 1:** Clinician-participants will be sent a universal email, which will include a link to the first Delphi survey, consisting of 6 open-ended questions related to components of the concussion assessment. An additional link will be included in the email, which will direct participants to a separate survey requesting email input. If you would like to participate, you will be given 21 days to complete the first surveys for Round 1. A reminder email will be sent at Day 7 and Day 14 after initial distribution of the survey.

- **Delphi Survey Round 2:** Following analysis of the first round of surveys, clinician-participants will be informed of the results of the first round, and the second survey will be developed. Consented clinician-participants (participants who completed the first round of surveys and provided their emails in the second separate survey) will be emailed a link to the second Delphi survey, consisting of single-choice questions related to the concussion assessments that are prioritized. You will be given 21 days to complete the second survey round. A reminder email will be sent at Day 7 and Day 14 after initial distribution of the survey.

It is anticipated that the Delphi survey will be administered to approximately 200 clinicians across Canada and those interested will take part in the survey component of this study. The survey component of this study should take about three months to complete. The study in its entirety (development of the virtual concussion assessment and determination of reliability) should take approximately two years to complete.

VOLUNTARY PARTICIPATION AND WITHDRAWAL

You do not have to be in this study if you do not want to be. You can choose to end your participation in this research (called withdrawal) at any time without having to provide a reason.

The survey is anonymous. This means that you can withdraw from participating at any time while completing the survey simply by closing your browser; however, once the completed survey has been returned to the study team, it will not be possible to withdraw your information. Any information recorded before you withdraw will be used by the researchers for the purposes of the study, but no information will be collected after you withdraw your permission.

RISKS AND/OR BENEFITS

There are no known risks related to being in this study. Some of the questions may however make you feel uncomfortable. If you are uncomfortable answering any questions, you may skip the question.

You may not receive direct benefit from participating in this study. We hope the information learned from this study will help inform the development of a virtual neurological assessment for individuals who have sustained a workplace concussion injury. We hope this study will provide an important foundation in which the assessment being developed will be

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based upon. The aim is to identify key assessment measures to be included in the virtual neurological assessment, from the perspectives of the clinicians conducting the assessment.

PRIVACY/CONFIDENTIALITY

The survey is anonymous which means that your answers will not be linked to you in any way.

Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.
- Bruyère Research Institute, to oversee the conduct of research at this location.
- Toronto Rehabilitation Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, clinical field, age, and years in practice.

Communication via e-mail is not absolutely secure. We do not recommend that you communicate sensitive personal information via e-mail.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, scientific journals, or deposited in an online repository, information that links your study data directly to you will not be shared.

If information from this study is published, shared, or presented at scientific meetings, your name and other personal information will not be used.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

COST AND/OR PAYMENT

Participation in this study will not involve any additional costs to you.

You will not be paid for taking part in this study.

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RIGHTS OF PARTICIPANTS
You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

QUESTIONS
If you have any questions about taking part in this study, you may contact Dr. Shawn Marshall at 613-737-7350 ext. 75590.

If you have questions about your rights as a participant or about ethical issues related to this study, you can talk to someone who is not involved in the study at all. Please contact The Ottawa Health Science Network Research Ethics Board, Chairperson at 613-798-5555 extension 16719.

CONSENT
By completing this survey your consent to participate is implied.

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Information Sheet

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

OHSN-REB Number: 20210575-01H

IS THERE A CONFLICT OF INTEREST?

There are no conflicts of interest to declare related to this study.

WHY IS THIS STUDY BEING DONE?

The aim of this component of the study is to determine which clinical assessment measures should be included in a virtual concussion assessment and to identify the measures that would be feasible in a virtual context. Once developed, the virtual assessment will be tested in a follow-up study.

WHAT WILL HAPPEN DURING THIS STUDY?

Your participation in this study would involve completion of a working group. A working group is a small group of experts who work together to achieve a specific goal as part of the research. A moderator will organize the working group. The working group will occur over the Microsoft Teams platform. Participation in the working group will last approximately 2 hours. The working group will consist of a number of clinician-participants (up to 10 participants) who will discuss the feasibility of specific concussion assessment measures. You will be asked to discuss your opinion on which measures should be included and would be feasible in a virtual concussion assessment and to administer/trial the specific measures over the Microsoft Teams platform with other clinician-participants in the working group. Open discussion would be encouraged among participants

You will be audio-video recorded during the working group.

WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?

If you choose to participate in this study, you will be expected to:

- Not discuss any information you learn in the working group with others. This includes information about and opinions from other members.

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VOLUNTARY PARTICIPATION AND WITHDRAWAL

Taking part in this study is voluntary.

You have the option to not participate at all, or you may choose to leave the study (called withdrawal) at any time without having to provide a reason. Your decision will not affect your employment.

HOW LONG WILL PARTICIPANTS BE IN THE STUDY?

You will be involved in this study for one working group. Your participation in this study will take approximately 2 hours over the Microsoft Teams platform.

CAN PARTICIPANTS CHOOSE TO LEAVE THE STUDY?

You can choose to end your participation in this research (called withdrawal) at any time without having to provide a reason. If you choose to withdraw from the study, you are encouraged to contact the study doctor or study staff.

WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?

Taking part in this study may make you feel uncomfortable.

You may become uncomfortable while discussing your experiences. You may choose not to answer questions or leave the group at any time if you experience any discomfort.

While the study team will take precautions to protect your confidentiality, we cannot guarantee that other members of the working group will respect your privacy or keep the discussions of the group confidential. For this reason, you should avoid using names of other people when describing scenarios or experiences.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?

You may not receive direct benefit from participating in this study. We hope the information learned from this study will help inform the development of a virtual neurological assessment for people who have sustained a workplace concussion injury. We hope this study will provide an important foundation in which the virtual assessment being developed will be based upon. The aim is to identify feasible assessment measures to use in the virtual neurological assessment.

HOW WILL PARTICIPANT INFORMATION BE KEPT CONFIDENTIAL?

If you decide to participate in this study, the research team will only collect the information they need for this study.

Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

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Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.
- Bruyère Research Institute, to oversee the conduct of research at this location.
- Toronto Rehabilitation Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, clinical field, and years in practice.

During the discussions, you will be encouraged to refrain from using names. If names or other identifying information is shared during the discussion, it will not be included in the written records.

The audio-video recordings will be stored in a secure location and viewed only by members of the research team. The recordings will be kept until they have been transcribed (turned into written records), and then they will be destroyed.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, scientific journals, or deposited in an online repository, information that links your study data directly to you will not be shared.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

WHAT IS THE COST TO PARTICIPANTS?

Participation in this study will not involve any additional costs to you.

ARE STUDY PARTICIPANTS PAID TO BE IN THIS STUDY?

You will not be paid to participate in this study.

WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?

You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

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You have the right to be informed of the results of this study once the entire study is complete. If you would like to be informed of the results of this study, please let the research team know.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

WHOM DO PARTICIPANTS CONTACT FOR QUESTIONS?

In case you have any questions, here are some contact numbers that are good to have.

If you have any questions about taking part in this study, you may contact Dr. Shawn Marshall at 613-737-7350 ext. 75306.

If you have questions about your rights as a participant or about ethical issues related to this study, you can talk to someone who is not involved in the study at all. Please contact The Ottawa Health Science Network Research Ethics Board, Chairperson at 613-798-5555 extension 16719.

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Working Group Verbal Consent Script







Working Group Verbal Consent Script

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

OHSN-REB Number: 20210575-01H

Participant name:	**Person calling:**
Date Called:	**Time Called:**

Call to/from clinicians.

If call to clinician: Hello, may I please speak with [name of the potential participant].

***If potential participant is unavailable:**
Do not leave a message regarding call back information as this may reveal personal health information.
Is there a better time to call back? Date/time:

***If potential participant indicates they are not interested:**
Thank you for your time. Goodbye.

***If potential participant is respondent:**
Continue with script below

***If respondent asks who the caller is:**
Thank you for [calling/agreeing] to further discuss the working group component of this research study. My name is [name of caller] and I am a [Clinical Research Coordinator/PhD student] from the Ottawa Hospital Research Institute.

Is this an ok time to talk about the study?

☐ No ***If no →** Is there a better time? Date/time:
☐ Yes ***If yes →** *Continue with script below*

As you know, the study is being conducted by Dr. Shawn Marshall at The Ottawa Hospital.

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The goal of the research study is to discuss and trial the use of specific assessment measures over a virtual (remote) platform to determine feasibility of the measures in a virtual context.

I am going to read you the consent form and ask for your verbal consent once I have finished.

Conflicts of Interest:

There are no conflicts of interest to declare related to this study.

Research Activities:

Your participation in this study would involve completion of a working group. A working group is a small group of experts who work together to achieve a specific goal as part of the research. A moderator will organize the working group. The working group will occur over the Microsoft Teams platform. Participation in the working group will last approximately 2 hours. The working group will consist of a number of clinician-participants (up to 10 participants) who will discuss the feasibility of specific concussion assessment measures. You will be asked to discuss your opinion on which measures should be included and would be feasible in a virtual concussion assessment and to administer/trial the specific measures over the Microsoft Teams platform with other clinician-participants in the working group. Open discussion would be encouraged among participants

You will be audio-video recorded during the working group.

Do you have questions about the activities this study involves?

☐ No ***If no →** *Continue with script below*

☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Voluntary Participation and Withdrawal:

Taking part in this study is voluntary.

You have the option to not participate at all, or you may choose to leave the study at any time (this is called withdrawal), without having to provide a reason. Your decision will not affect your employment.

Do you have questions about the voluntary nature and ability to withdraw from of this study?

☐ No ***If no →** *Continue with script below*

☐ Yes ***If yes →** *Answer questions and document all questions and answers*

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before continuing with script below

Questions: _____

Answers: _____

Other Comments: _____

Potential Risks, Harms, Discomforts:
Taking part in this study may make you feel uncomfortable.

You may become uncomfortable while discussing your experiences. You may choose not to answer questions or leave the group at any time if you experience any discomfort.

While the study team will take precautions to protect your confidentiality, we cannot guarantee that other members of the working group will respect your privacy or keep the discussions of the group confidential. For this reason, you should avoid using names of other people when describing scenarios or experiences.

Do you have questions about the potential risks this study involves?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Potential Benefits:

You may not receive direct benefit from participating in this study. We hope the information learned from this study will help inform the development of a virtual neurological assessment for individuals who have sustained a workplace concussion injury. We hope this study will provide an important foundation in which the virtual assessment being developed will be based upon. The aim is to identify feasible assessment measures to be used in the virtual neurological assessment.

Do you have questions about the potential benefits this study involves?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

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Other Comments: _____

Privacy/Confidentiality:

If you decide to participate in this study, the research team will only collect the information they need for this study.

Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.
- Bruyère Research Institute, to oversee the conduct of research at this location.
- Toronto Rehabilitation Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, clinical field, and years in practice.

During the discussions, you will be encouraged to refrain from using names. If names or other identifying information is shared during the discussion, it will not be included in the written records.

The audio-video recordings will be stored in a secure location and viewed only by members of the research team. The recordings will be kept until they have been transcribed (turned into written records), and then they will be destroyed.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, scientific journals, or deposited in an online repository, information that links your study data directly to you will not be shared.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

Do you have questions about the how your privacy will be protected?

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☐ No *If no → *Continue with script below*
☐ Yes *If yes → *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Cost to participation:
Participation in this study will not involve any additional costs to you.

Payment or Reimbursement:
You will not be paid to participate in this study.

Do you have questions about the costs of participation or payment/reimbursement?
☐ No *If no → *Continue with script below*
☐ Yes *If yes → *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Participant Rights:
You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

You have the right to be informed of the results of this study once the entire study is complete. If you would like to be informed of the results of this study, please let the research team know.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

Questions:

In case you have any questions, here are some contact numbers that are good to have. Do you have a pen and paper ready?

For questions about your rights as a research participant or about ethical issues related to the study, you can contact The Ottawa Health Science Network Research Ethics Board at 613-798-5555, extension 16719, and speak to someone who isn't involved in the study at all.

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I can answer any questions that you may have about the research study right now, but if you think of additional questions later on, you can contact me or the Principal Investigator, Dr. Shawn Marshall at 613-737-7350 ext. 75306.

Have all of your questions been answered?

☐ No ***If no →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

☐ Yes ***If yes →** *Continue with script below*

Consent:

Based on the description of the study, would you like to participate? Or would you like some time to think about it?

☐ No ☐ Yes ☐ More time to think about it

***If they do not want to participate:** Thank you for your time. Goodbye.

***If they do want to participate:** *Continue with script below*

***If they would like more time:** *Continue with script below*

***If they wanted more time:** When would be a good time for me to call you back to answer any further questions you may have and obtain your decision? Date/time:

Wrap up with a reminder of the next steps and end the call.

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Documentation of Verbal Consent

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

OHSN-REB Number: 20210575-01H

Name of Participant: _____

Date of Discussion: _____

Duration of Discussion: _____

SIGNATURES

- The participant's questions have been answered,
- The participant understands the information within this Verbal Consent Script,
- Each page of the Verbal Consent Script has been read to the participant.
- The participant agrees to take part in this study.

Investigator or Delegate Statement

I have carefully explained the study to the study participant. To the best of my knowledge, the participant understands the nature, demands, risks and benefits involved in taking part in this study.

_____	_____	_____
Signature of Person Conducting Consent Discussion	Printed Name and Role	Date

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Focus Group Clinician Information Sheet

The Ottawa Hospital | L'Hôpital d'Ottawa
RESEARCH INSTITUTE | INSTITUT DE RECHERCHE

Information Sheet

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

OHSN-REB Number: 20210575-01H

IS THERE A CONFLICT OF INTEREST?
There are no conflicts of interest to declare related to this study.

WHY IS THIS STUDY BEING DONE?
Currently there is no reliable virtual neurological examination available for concussion patients. The aim of this component of the study is to determine which outcome measures should be included in a virtual assessment for concussion patients and to identify barriers and facilitators to conducting virtual concussion assessments.

WHAT WILL HAPPEN DURING THIS STUDY?
Your participation in this study will require completion of one focus group. A focus group is a small group of representative people who are asked to speak about their opinions as part of the research. A moderator will organize the focus group. The focus group will consist of a number of clinician-participants (5-7 clinicians). The focus group will occur over the Microsoft Teams platform. Participation in the focus group will last approximately 1 to 2 hours over the Microsoft Teams platform. It is expected that 4-10 focus groups will be needed, however, you will only need to participate in one focus group. All focus groups should take about a month to complete.

You will be asked to speak about your experiences with virtual concussion assessment and discuss barriers and facilitators to conducting virtual concussion assessments.

All focus groups will be audio-video recorded through the Microsoft Teams platform record function.

WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?
If you choose to participate in this study, you will be expected to:

- Not discuss any information you learn in the focus group with others. This includes information about and opinions from other members.

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VOLUNTARY PARTICIPATION AND WITHDRAWAL
Taking part in this study is voluntary.

You have the option to not participate at all, or you may choose to leave the study (called withdrawal) at any time without having to provide a reason. Your decision will not affect your employment.

HOW LONG WILL PARTICIPANTS BE IN THE STUDY?
You will be involved in this study for one focus group. Your participation in this study will take approximately one to two hours over the Microsoft Teams platform.

CAN PARTICIPANTS CHOOSE TO LEAVE THE STUDY?
You can choose to end your participation in this research (called withdrawal) at any time without having to provide a reason. If you choose to withdraw from the study, you are encouraged to contact the study doctor or study staff.

If you decide to leave the study, you can ask that the information that was collected about you not be used for the study. Let the research team know if you choose this.

WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?
Taking part in this study may make you feel uncomfortable.
While the study team will take precautions to protect your confidentiality, we cannot guarantee that other members of the focus group will respect your privacy or keep the discussions of the group confidential. For this reason, you should avoid using names of other people when describing scenarios or experiences.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?
You may not receive direct benefit from participating in this study. We hope the information learned from this study will help inform the development of a virtual neurological assessment for individuals who have sustained a workplace concussion injury. We hope this study will provide an important foundation in which the virtual assessment being developed will be based upon. The aim is to identify key assessment measures to be included in the virtual neurological assessment, from the perspectives of the clinicians conducting the assessment.

HOW WILL PARTICIPANT INFORMATION BE KEPT CONFIDENTIAL?
If you decide to participate in this study, the research team will only collect the information they need for this study.

Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

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Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.
- Bruyère Research Institute, to oversee the conduct of research at this location.
- Toronto Rehabilitation Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, clinical field, age, pseudo-initials, and years in practice.

Communication via e-mail is not absolutely secure. We do not recommend that you communicate sensitive personal information via e-mail.

During the discussions, you will be encouraged to refrain from using names. If names or other identifying information is shared during the discussion, it will not be included in the written records.

The audio-video recordings will be stored in a secure location and viewed only by members of the research team. The recordings will be kept until they have been transcribed (turned into written records), and then they will be destroyed.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, scientific journals, or deposited in an online repository, information that links your study data directly to you will not be shared.

If information from this study is published, shared, or presented at scientific meetings, your name and other personal information will not be used.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

WHAT IS THE COST TO PARTICIPANTS?

Participation in this study will not involve any additional costs to you.

ARE STUDY PARTICIPANTS PAID TO BE IN THIS STUDY?

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As a token of our appreciation, you will be given a $20 gift card for your participation in this study. The gift card will be sent to you by email after completion of the focus group.

WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?
You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

WHOM DO PARTICIPANTS CONTACT FOR QUESTIONS?
If you have any questions about taking part in this study, you may contact Dr. Shawn Marshall at 613-737-7350 ext. 75306.

If you have questions about your rights as a participant or about ethical issues related to this study, you can talk to someone who is not involved in the study at all. Please contact The Ottawa Health Science Network Research Ethics Board, Chairperson at 613-798-5555 extension 16719

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Focus Group Clinician Verbal Consent Script

The Ottawa Hospital | L'Hôpital d'Ottawa
RESEARCH INSTITUTE | INSTITUT DE RECHERCHE

Verbal Consent Script

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

OHSN-REB Number: 20210575-01H

Participant name:	**Person calling:**
Date Called:	**Time Called:**

Call to interested clinicians.

Hello, thank you for agreeing to further discuss the focus group component of this research study. My name is [name of caller] and I am a [Clinical Research Assistant/Clinical Research Coordinator] from the Ottawa Hospital Research Institute.

Is this an ok time to talk about the study?

☐ No *If no → Is there a better time? Date/time:
☐ Yes *If yes → *Continue with script below*

As you know, the study is being conducted by Dr. Shawn Marshall at The Ottawa Hospital.

The goal of the research study is to discuss barriers and facilitators to conducting virtual concussion assessments.

I am going to read you the consent form and ask for your verbal consent once I have finished.

Conflicts of Interest:

There are no conflicts of interest to declare related to this study.

Research Activities:

Your participation in this study will require completion of one focus group. A focus group is a small group of representative people who are asked to speak about their opinions as part of the research. A moderator will organize the focus group. The focus group will consist of a number of clinician-participants (5-7 clinicians). The focus group will occur over the Microsoft Teams

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platform. Participation in the focus group will last approximately 1 hour to 2 hours over the Microsoft Teams platform.
It is expected that 4-10 focus groups will be needed, however, you will only need to participate in one focus group. All focus groups should take about a month to complete.

You will be asked to speak about your experiences with virtual concussion assessment and discuss barriers and facilitators to conducting virtual concussion assessments.

All focus groups will be audio-video recorded through the Microsoft Teams platform record function.

Do you have questions about the activities this study involves?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Voluntary Participation and Withdrawal:

Taking part in this study is voluntary.

You have the option to not participate at all, or you may choose to leave the study at any time (called withdrawal) at any time without having to provide a reason. Your decision will not affect your employment.

If you decide to leave the study, you can ask that the information that was collected about you not be used for the study.

Do you have questions about the voluntary nature and ability to withdraw from of this study?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Potential Risks, Harms, Discomforts:

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Taking part in this study may make you feel uncomfortable.
While the study team will take precautions to protect your confidentiality, we cannot guarantee that other members of the focus group will respect your privacy or keep the discussions of the group confidential. For this reason, you should avoid using names of other people when describing scenarios or experiences.

Do you have questions about the potential risks this study involves?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Potential Benefits:

You may not receive direct benefit from participating in this study. We hope the information learned from this study will help inform the development of a virtual neurological assessment for individuals who have sustained a workplace concussion injury. We hope this study will provide an important foundation in which the virtual assessment being developed will be based upon. The aim is to identify key assessment measures to be included in the virtual neurological assessment, from the perspectives of the clinicians conducting the assessment.

Do you have questions about the potential benefits this study involves?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Privacy/Confidentiality:

If you decide to participate in this study, the research team will only collect the information they need for this study.

Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

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Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.
- Bruyère Research Institute, to oversee the conduct of research at this location.
- Toronto Rehabilitation Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, clinical field, age, pseudo-initials, and years in practice.

Communication via e-mail is not absolutely secure. We do not recommend that you communicate sensitive personal information via e-mail.

During the discussions, you will be encouraged to refrain from using names. If names or other identifying information is shared during the discussion, it will not be included in the written records.

The audio-video recordings will be stored in a secure location and viewed only by members of the research team. The recordings will be kept until they have been transcribed (turned into written records), and then they will be destroyed.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, scientific journals, or deposited in an online repository, information that links your study data directly to you will not be shared.

If information from this study is published, shared, or presented at scientific meetings, your name and other personal information will not be used.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

Do you have questions about the how your privacy will be protected?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

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Answers: _____

Other Comments: _____

Cost to participation:
Participation in this study will not involve any additional costs to you.

Payment or Reimbursement:
As a token of our appreciation, you will be given a $20 gift card for your participation in this study. The gift card will be sent to you by email after completion of the focus group.

Do you have questions about the costs of participation or payment/reimbursement?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Participant Rights:

You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

Questions:

In case you have any questions, here are some contact numbers that are good to have. Do you have a pen and paper ready?

For questions about your rights as a research participant or about ethical issues related to the study, you can contact The Ottawa Health Science Network Research Ethics Board at 613-798-5555, extension 16719, and speak to someone who isn't involved in the study at all.

I can answer any questions that you may have about the research study right now, but if you think of additional questions later on, you can contact me or the study doctor, Dr. Shawn Marshall at 613-737-7350 ext. 75306.

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Have all of your questions been answered?

☐ No ***If no →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

☐ Yes ***If yes →** *Continue with script below*

Consent:

Based on the description of the study, would you like to participate? Or would you like some time to think about it?

☐ No ☐ Yes ☐ More time to think about it

***If they do not want to participate:** Thank you for your time. Goodbye.

***If they do want to participate:** *Continue with script below*

***If they would like more time:** *Continue with script below*

***If they wanted more time:** When would be a good time for me to call you back to answer any further questions you may have and obtain your decision? Date/time:

Wrap up with a reminder of the next steps and end the call.

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Documentation of Verbal Consent

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

OHSN-REB Number:

Name of Participant: _____

Date of Discussion: _____

Duration of Discussion: _____

SIGNATURES

- The participant's questions have been answered,
- The participant understands the information within this Verbal Consent Script,
- Each page of the Verbal Consent Script has been read to the participant.
- The participant agrees to take part in this study.

Investigator or Delegate Statement

I have carefully explained the study to the study participant. To the best of my knowledge, the participant understands the nature, demands, risks and benefits involved in taking part in this study.

_____	_____	_____
Signature of Person Conducting Consent Discussion	Printed Name and Role	Date

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Focus Group Clinician Informed Consent Form

The Ottawa Hospital | L'Hôpital d'Ottawa
RESEARCH INSTITUTE | INSTITUT DE RECHERCHE

Informed Consent Form
Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions
The VirNA Study – Development Phase

OHSN-REB number: 20210575-01H

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

Co Investigator: Dr. Mark Bayley, MD, FRCPC
Toronto Rehabilitation Institute
550 University Ave. Toronto, ON
M5G 2A2

Funding Agency: Workplace Safety and Insurance Board (WSIB)

INTRODUCTION

You are invited to participate in this research study because you are a clinician involved in concussion assessments. This study involves participation in a focus group with the aim to discuss barriers and facilitators to conducting virtual concussion assessments, rationalize responses on the Delphi surveys, and determine what is needed to standardize and carry out a virtual concussion assessment. The results of the focus groups will inform the development of a virtual neurological assessment for concussion patients, which will occur in a follow-up phase in this study.

This consent form provides you with information to help you make an informed choice. Please read this document carefully and ask any questions you may have. All your questions should be answered to your satisfaction before you decide whether to participate in this research study.

Participation in this study is voluntary. You have the option to not participate at all or you may choose to leave the study at any time. The decision will not affect your employment.

If you agree to participate in this study, you would be asked to participate in one focus group consisting of up to 7 clinicians from various fields. Questions would be asked regarding

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barriers and facilitators to conducting virtual concussion assessment, rationalization of which assessment measures to include in the virtual assessment, and discussion on how to standardize and conduct the virtual assessment. Open discussion would be encouraged among participants.

IS THERE A CONFLICT OF INTEREST?
There are no conflicts of interest to declare related to this study.

WHY IS THIS STUDY BEING DONE?
Currently there is no valid or reliable virtual neurological examination available for concussion patients. The aim of this component of the study is to determine which outcome measures should be included in a virtual assessment for concussion patients and to identify barriers and facilitators to conducting virtual concussion assessment so that supportive strategies are adequately developed.

HOW MANY PEOPLE WILL TAKE PART IN THIS STUDY?
It is anticipated that about 5-7 participants will participate in each focus group. It is expected that 6-10 focus groups will be needed, however you will only need to participate in 1 focus group. All focus groups should take about a month to complete. The study in its entirety (development of the virtual concussion assessment and determination of reliability and validity) should take approximately two years to complete.

WHAT WILL HAPPEN DURING THIS STUDY?
Your participation in this study will require participation in one focus group. A focus group is a small group of representative people who are asked to speak about their opinions as part of the research. A moderator will organize the focus group. The focus group will be guided by a researcher. The focus group will consist of a number of clinician-participants (5-7 clinicians). The focus group will occur over the Microsoft Teams platform. Participation in the focus group will last approximately 1 to 2 hours over the Microsoft Teams platform.

You will be asked to speak about your experiences with virtual concussion assessment and what you think is needed to carry out these assessments, your opinion on which measures should be included in a virtual concussion assessment and discuss barriers and facilitators to conducting virtual concussion assessments.

All focus groups will be audio-video recorded through the Microsoft Teams platform record function.

You may become uncomfortable while discussing your experiences. You may choose not to answer questions or leave the group at any time if you experience any discomfort.

While the study team will take precautions to protect your confidentiality, we cannot guarantee that other members of the focus group will respect your privacy or keep the

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discussions of the group confidential. For this reason, you should not share information that you would not want others to learn.

The overarching objective of the research is to develop and determine reliability and validity of a virtual neurological assessment for concussion patients.

WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?

If you choose to participate in this study, you will be expected to:

- Not discuss any information you learn in the focus group with others. This includes information about and opinions from other members.

HOW LONG WILL PARTICIPANTS BE IN THE STUDY?

You will be involved in this study for one focus group. Your participation in this study will take approximately 1 to 2 hours over the Microsoft Teams platform.

CAN PARTICIPANTS CHOOSE TO LEAVE THE STUDY?

You can choose to end your participation in this research (called withdrawal) at any time without having to provide a reason. If you choose to withdraw from the study, you are encouraged to contact the study doctor or study staff.

You may withdraw your permission to use information that was collected about you for this study at any time by letting the study doctor know. However, this would also mean that you withdraw from the study.

If you decide to leave the study, you can ask that the information that was collected about you not be used for the study. Let the research team know if you choose this.

WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?

There are no known risks related to being in this study. Some of the questions may however make you feel uncomfortable. If you are uncomfortable answering any questions, you may skip the question or leave the group at any time if you experience any discomfort.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?

You may not receive direct benefit from participating in this study. We hope the information learned from this study will help inform the development of a virtual neurological assessment for individuals who have sustained a workplace concussion injury. We hope this study will provide an important foundation in which the virtual assessment being developed will be based upon. The aim is to identify key assessment measures to be included in the virtual neurological assessment, from the perspectives of the clinicians conducting the assessment.

HOW WILL PARTICIPANT INFORMATION BE KEPT CONFIDENTIAL?

If you decide to participate in this study, the research team will only collect the information they need for this study.

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Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.
- Bruyère Research Institute, to oversee the conduct of research at this location.
- Toronto Rehabilitation Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, clinical field, age, and years in practice.

The audio-video recordings will be stored in a secure location and viewed only by members of the research team. The recordings will be kept until they have been transcribed (turned into written records), and then they will be destroyed.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, scientific journals, or deposited in an online repository, information that links your study data directly to you will not be shared.

If information from this study is published, shared, or presented at scientific meetings, your name and other personal information will not be used.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

WHAT IS THE COST TO PARTICIPANTS?
Participation in this study will not involve any additional costs to you.

ARE STUDY PARTICIPANTS PAID TO BE IN THIS STUDY?
Honorarium will be provided to clinician-participants in the form of a $20 gift card for those participating in the focus group component of the study.

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WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?
You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

WHOM DO PARTICIPANTS CONTACT FOR QUESTIONS?
If you have any questions about taking part in this study, you may contact Dr. Shawn Marshall at 613-737-7350 ext. 75590.

If you have questions about your rights as a participant or about ethical issues related to this study, you can talk to someone who is not involved in the study at all. Please contact The Ottawa Health Science Network Research Ethics Board, Chairperson at 613-798-5555 extension 16719

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SIGNATURES

- All my questions have been answered,
- I have read, or someone has read to me, each page of this informed consent form,
- I understand the information within this informed consent form,
- I do not give up any of my legal rights by signing this consent form,
- I agree to take part in this study.

Signature of Participant	Printed Name	Date

Signature of Person Conducting the Consent Discussion	Printed Name and Role	Date

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Focus Group Patient Information Sheet

The Ottawa Hospital | L'Hôpital d'Ottawa
RESEARCH INSTITUTE | INSTITUT DE RECHERCHE

Information Sheet

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

OHSN-REB Number: 20210575-01H

IS THERE A CONFLICT OF INTEREST?
There are no conflicts of interest to declare related to this study.

WHY IS THIS STUDY BEING DONE?
Currently there is no reliable virtual assessment available for concussion patients. The aim of this component of the study is to identify barriers/challenges and facilitators/benefits to participating in a virtual concussion assessment.

WHAT WILL HAPPEN DURING THIS STUDY?
Your participation in this study will require completion of one focus group. A focus group is a small group of representative people who are asked to speak about their opinions as part of the research. A moderator will organize the focus group. The focus group will consist of a number of people that are currently living with or that previously lived with a concussion (5-7 participants). The focus group will occur over the Microsoft Teams platform. Participation in the focus group will last approximately 1 to 2 hours over the Microsoft Teams platform.

You will be asked to speak about your experiences with virtual concussion assessment and discuss challenges and benefits to engaging in virtual concussion assessments.

All focus groups will be audio-video recorded through the Microsoft Teams platform record function.

Review of your health record at The Ottawa Hospital will occur. Information about your concussion injury, your symptoms following the injury and during your virtual assessments, and treatment/management of the injury will be collected from your health record. This will be accessed once only.

WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?
If you choose to participate in this study, you will be expected to:

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- Participate in one focus group.
- Not discuss any information you learn in the focus group with others. This includes information about and opinions from other members.

VOLUNTARY PARTICIPATION AND WITHDRAWAL
Taking part in this study is voluntary.

You have the option to not participate at all, or you may choose to leave the study (called withdrawal) at any time without having to provide a reason. Whatever you choose, it will not affect the usual medical care that you receive outside the study.

HOW LONG WILL PARTICIPANTS BE IN THE STUDY?
You will be involved in this study for one focus group. Your participation in this study will take approximately 1 to 2 hours over the Microsoft Teams platform.

CAN PARTICIPANTS CHOOSE TO LEAVE THE STUDY?
You can choose to end your participation in this research (called withdrawal) at any time without having to provide a reason. If you choose to withdraw from the study, you are encouraged to contact the study doctor or study staff.

If you decide to leave the study, you can ask that the information that was collected about you not be used for the study. Let the research team know if you choose this.

WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?
You may become uncomfortable while discussing your experiences. You may choose not to answer questions or leave the group at any time if you experience any discomfort.

While the study team will take precautions to protect your confidentiality, we cannot guarantee that other members of the focus group will respect your privacy or keep the discussions of the group confidential. For this reason, you should avoid using names of other people when describing scenarios or experiences.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?
You may not receive direct benefit from participating in this study. We hope the information learned from this study will help inform the development of a virtual assessment for individuals who have sustained a workplace concussion injury. We hope this study will provide an important foundation in which the virtual assessment being developed will be based upon.

HOW WILL PARTICIPANT INFORMATION BE KEPT CONFIDENTIAL?
If you decide to participate in this study, the research team will only collect the information they need for this study.

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Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.
- Bruyère Research Institute, to oversee the conduct of research at this location.
- Toronto Rehabilitation Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, sex, work status, date of injury, and age.

Communication via e-mail is not absolutely secure. We do not recommend that you communicate sensitive personal information via e-mail.

During the discussions, you will be encouraged to refrain from using names. If names or other identifying information is shared during the discussion, it will not be included in the written records.

The audio-video recordings will be stored in a secure location and viewed only by members of the research team. The recordings will be kept until they have been transcribed (turned into written records), and then they will be destroyed.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, scientific journals, or deposited in an online repository, information that links your study data directly to you will not be shared.

If information from this study is published, shared, or presented at scientific meetings, your name and other personal information will not be used.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

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WHAT IS THE COST TO PARTICIPANTS?
Participation in this study will not involve any additional costs to you.

ARE STUDY PARTICIPANTS PAID TO BE IN THIS STUDY?
As a token of our appreciation, you will be given a $20 gift card for your participation in this study. The gift card will be sent to you by email after completion of the focus group.

WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?
You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

WHOM DO PARTICIPANTS CONTACT FOR QUESTIONS?
If you have any questions about taking part in this study, you may contact Dr. Shawn Marshall at 613-737-7350 ext. 75306.

If you have questions about your rights as a participant or about ethical issues related to this study, you can talk to someone who is not involved in the study at all. Please contact The Ottawa Health Science Network Research Ethics Board, Chairperson at 613-798-5555 extension 16719

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Focus Group Patient Verbal Consent Script

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Verbal Consent Script

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

OHSN-REB Number: 20210575-01H

Participant name:	**Person calling:**
Date Called:	**Time Called:**

Call to patients.

Hello, may I please speak with [name of the potential participant].

***If respondent asks who the caller is:**
My name is [name of caller] and I am calling from [The Ottawa Hospital] about a research study.

***If potential participant is unavailable:**
Is there a better time to call back? Date/time:

***If potential participant indicates they are not interested:**
Thank you for your time. Goodbye.

***If potential participant is respondent:**

This is [name of caller] calling from [The Ottawa Hospital].

Is this an ok time to talk?

☐ No ***If no →** Is there a better time? Date/time:
☐ Yes ***If yes →** *Continue with script below*

***When permission to contact for research purposes is documented in Epic (i.e. patient is flagged as "OK to contact"):**

- I'm calling because your medical record indicates that you have agreed to be contacted about research and we have a research study that you might be interested in

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***When permission to contact for research was obtained and documented in a clinic note by a member of the circle of care:**

- We've been informed by a member of your circle of care that you have agreed to be contacted for research.

The study is being conducted by Dr. Shawn Marshall at The Ottawa Hospital

You are a candidate for this research because you have previously sustained a concussion injury and attended a virtual (remote) assessment where you were in a different location than the assessing doctor, such as at your home while the doctor was in the hospital.

The goal of the research study is to discuss and explore, the barriers or challenges and benefits or facilitators associated with virtual concussion assessments.

Are you willing to hear more about the study?

☐ No ***If no →** Thank you for your time. Goodbye
☐ Yes ***If yes →** *Continue with script below*

Conflicts of Interest:

There are no conflicts of interest to declare related to this study.

Research Activities:

Your participation in this study will require completion of one focus group. A focus group is a small group of representative people who are asked to speak about their opinions as part of the research. A moderator will organize the focus group. The focus group will consist of a number of people that are currently living with or that previously lived with a concussion (5-7 participants). The focus group will occur over the Microsoft Teams platform. Participation in the focus group will last approximately 1 to 2 hours over the Microsoft Teams platform.

You will be asked to speak about your experiences with virtual concussion assessment and discuss challenges and benefits to engaging in virtual concussion assessments.

All focus groups will be audio-video recorded through the Microsoft Teams platform record function.

Review of your health record at The Ottawa Hospital will occur. Information about your concussion injury, your symptoms following the injury and during your virtual assessments, and treatment/management of the injury will be collected from your health record. This will be accessed once only.

Do you have questions about the activities this study involves?

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☐ No *If no → *Continue with script below*
☐ Yes *If yes → *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Voluntary Participation and Withdrawal:

Taking part in this study is voluntary.

You have the option to not participate at all, or you may choose to leave the study at any time (this is called withdrawal), without having to provide a reason. Whatever you choose, it will not affect the usual medical care that you receive outside the study.

If you decide to leave the study, you can ask that the information that was collected about you not be used for the study. Let the research team know if you choose this.

Do you have questions about the voluntary nature and ability to withdraw from of this study?

☐ No *If no → *Continue with script below*
☐ Yes *If yes → *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Potential Risks, Harms, Discomforts:

You may become uncomfortable while discussing your experiences. You may choose not to answer questions or leave the group at any time if you experience any discomfort.

While the study team will take precautions to protect your confidentiality, we cannot guarantee that other members of the focus group will respect your privacy or keep the discussions of the group confidential. For this reason, you should avoid using names of other people when describing scenarios or experiences.

Do you have questions about the potential risks this study involves?

☐ No *If no → *Continue with script below*
☐ Yes *If yes → *Answer questions and document all questions and answers before continuing with script below*

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Questions: _____

Answers: _____

Other Comments: _____

Potential Benefits:

You may not receive direct benefit from participating in this study. We hope the information learned from this study will help inform the development of a virtual assessment for individuals who have sustained a workplace concussion injury. We hope this study will provide an important foundation in which the virtual assessment being developed will be based upon.

Do you have questions about the potential benefits this study involves?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Privacy/Confidentiality:

If you decide to participate in this study, the research team will only collect the information they need for this study.

Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

Authorized representatives of the following organizations may look at your original (identifiable) research and medical records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.
- Bruyère Research Institute, to oversee the conduct of research at this location.
- Toronto Rehabilitation Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly

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identify you will not be used. The records received by these organizations may contain your participant code, sex, work status, date of injury, pseudo-initials, and date of birth.

Communication via e-mail is not absolutely secure. We do not recommend that you communicate sensitive personal information via e-mail.

During the discussions, you will be encouraged to refrain from using names. If names or other identifying information is shared during the discussion, it will not be included in the written records.

The audio-video recordings will be stored in a secure location and viewed only by members of the research team. The recordings will be kept until they have been transcribed (turned into written records), and then they will be destroyed.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, scientific journals, or deposited in an online repository, information that links your study data directly to you will not be shared.

If information from this study is published, shared, or presented at scientific meetings, your name and other personal information will not be used.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

Do you have questions about the how your privacy will be protected?

☐ No ***If no →** *Continue with script below*

☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Cost to participation:
Participation in this study will not involve any additional costs to you.

Payment or Reimbursement:
As a token of our appreciation, you will be given a $20 gift card for your participation in this study. The gift card will be sent to you by email after completion of the focus group.

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Do you have questions about the costs of participation or payment/reimbursement?

☐ No ***If no →** *Continue with script below*

☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Participant Rights:

You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

Questions:

In case you have any questions, here are some contact numbers that are good to have. Do you have a pen and paper ready?

For questions about your rights as a research participant or about ethical issues related to the study, you can contact The Ottawa Health Science Network Research Ethics Board at 613-798-5555, extension 16719, and speak to someone who isn't involved in the study at all.

I can answer any questions that you may have about the research study right now, but if you think of additional questions later on, you can contact me or the study doctor, Dr. Shawn Marshall at 613-737-7350 ext. 75306.

Have all of your questions been answered?

☐ No ***If no →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

☐ Yes ***If yes →** *Continue with script below*

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Consent:

Based on the description of the study, would you like to participate? Or would you like some time to think about it?

☐ No ☐ Yes ☐ More time to think about it

***If they do not want to participate:** Thank you for your time. Goodbye.

***If they do want to participate:** *Continue with script below*

***If they would like more time:** *Continue with script below*

For your records and to help in making your decision, I can send you the Information Sheet by email.

☐ Email (as a Microsoft 365 SharePoint link or password protected attachment)

Before I can initiate email contact with you, I'm required to inform you of the risks associated with use of email. I'm going to read a series of statements to you. Please stop me at any time if you have questions.

Read the 'Research Participant Consent to Communicate by Email'

Discussed on: _____/____/____ Time: _____ hours

Consenting Process completed by: _____ Date: _____/____/____

Record and confirm email address: _____

***If they wanted more time:** When would be a good time for me to call you back to answer any further questions you may have and obtain your decision? Date/time:

Wrap up with a reminder of the next steps and end the call.

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Documentation of Verbal Consent

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

OHSN-REB Number: 20210575-01H

Name of Participant: _____

Date of Discussion: _____

Duration of Discussion: _____

SIGNATURES

- The participant's questions have been answered,
- The participant understands the information within this Verbal Consent Script,
- Each page of the Verbal Consent Script has been read to the participant.
- The participant will allow access to medical records as explained in this consent form
- The participant agrees to take part in this study.

Investigator or Delegate Statement

I have carefully explained the study to the study participant. To the best of my knowledge, the participant understands the nature, demands, risks and benefits involved in taking part in this study.

Signature of Person Conducting Consent Discussion	Printed Name and Role	Date

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Delphi Survey Recruitment Emails
Email Recruitment

Subject Line: WSIB Post-Concussion Research Project: Invitation to participate in research

Hello,

You are being asked to participate in a research study that we are conducting focused on identifying concussion assessment tools that are typically used by expert clinicians in the clinic setting. The ultimate objective of the research is to develop a standardized virtual (remote) physical concussion assessment.

Participation is voluntary.

Briefly, the study involves completion of two rounds of surveys. These surveys would be completed through a link sent through email. The aim of round 1 of the survey is to identify what physical assessment tools are currently used by clinicians. Following completion of round 1, a round 2 survey will be developed based on participant responses to round 1, which will be completed at a later date. Round 2 will aim to identify what assessments are most relevant to clinicians.

Participation in this study would take approximately 5 minutes of your time per round of survey.

The Informed Consent Form is available to you for review and is attached as a password protected document (contact the research team at the coordinates below if you have not already been provided with the password to the document).

If you would like to participate in this study, please click on the link below to access the Informed Consent Form and Survey:
https://forms.office.com/Pages/ResponsePage.aspx?id=tkGbhQ8TE02mkx_-xOfLWh7sqlovTZFOvo_gEInNOtpUQU1YQTdLN01LMjQzWTQwTk5CWlRBUjBNTSQlQCN0PWcu

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Delphi Survey Newsletter Script

We are seeking clinicians to participate in a voluntary survey-based research study with the aim of developing a standardized virtual physical assessment for concussion patients. The study involves completion of two rounds of surveys. The aim of round 1 of the survey is to identify what concussion assessment measures are typically used by clinicians in the clinic setting.
If you would like to participate, please click on the link to access the Consent Form and Survey:
https://forms.office.com/Pages/ResponsePage.aspx?id=tkGbhQ8TE02mkx_-xOfLWh7sqlovTZFOvo_gEInNOtpUQU1YQTdLN01LMjQzWTQwTk5CWlRBUjBNTSQlQCN0PWcu
Please click on the link to provide your email address for the second survey to be sent to:
https://forms.office.com/Pages/ResponsePage.aspx?id=tkGbhQ8TE02mkx_-xOfLWh7sqlovTZFOvo_gEInNOtpUNzlGVkRBWjZGM0tFUFdSTUdZSUNRSTIwNiQlQCN0PWcu

Dr. Shawn Marshall, MD, FRCPC
The Ottawa Hospital Research Institute
smarshall@toh.ca
613-737-7350 ext. 75306

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Delphi Survey Round 2 Email Script

Subject Line: Private/Confidential: Research Survey

Hi, You are receiving this email because you are participating in a research study. Round 2 of the survey is now available for completion. Round 2 of the survey consists of more specific questions and aims to identify what assessments are most relevant to clinicians. Participation in this study will take approximately 5-10 minutes of your time. The Informed Consent Form is available to you for review and is attached as an encrypted/password protected document (contact the research team at the coordinates below if you have not already been provided with the password to the document). The study survey is available at the following link: https://forms.office.com/Pages/ResponsePage.aspx?id=tkGbhQ8TE02mkx_-xOfLWhjPnG6_edVCnrHrdP3TVspURExGREZFSFgzUUE2VExZQVJVMkZUVVg1TS4u

A reminder email will be sent in 7 days and in 14 days. You will have 3-4 weeks to complete Round 2 Survey.

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Delphi Survey Round 2 Reminder Email Script

Survey Reminder Email Round 2 Subject Line: Private/Confidential: Research Survey

Hi, You are receiving this email because you are participating in a research study. Round 2 of the survey is now available for completion. Round 2 of the survey consists of more specific questions and aims to identify what assessments are most relevant to clinicians. Participation in this study will take approximately 5-10 minutes of your time. The Informed Consent Form is available to you for review and is attached as an encrypted/password protected document (contact the research team at the coordinates below if you have not already been provided with the password to the document). This is a reminder to complete a study survey at the following link: https://forms.office.com/Pages/ResponsePage.aspx?id=tkGbhQ8TE02mkx_-xOfLWhjPnG6_edVCnrHrdP3TVspURExGREZFSFgzUUE2VExZQVJVMkZUVVg1TS4u

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Working Group Email Recruitment Script
Working Group Email Recruitment

Subject Line: WSIB Post-Concussion Research Project: Invitation to participate in research

Hello,

You are being asked to participate in a research study that we are conducting focused on determining the feasibility of specific concussion assessment measures in a virtual (remote) context. The ultimate objective of the research is to develop a standardized virtual physical concussion assessment.

Participation is voluntary.

Briefly, this study involves participation in a working group (small group of 5-10 clinicians) with the aim of discussing and trialing the use of specific concussion assessment measures over a virtual platform (Microsoft Teams) to determine feasibility of the measures in a virtual context. The results of the working group will inform the development of a virtual neurological assessment for concussion patients, which will be tested in a follow-up phase in this study.

The Information Sheet is available to you for review and is attached in this email.

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Focus Group Email Recruitment Script

Focus Group Email Recruitment Subject Line: WSIB Post-Concussion Research Project: Invitation to participate in research

Hello, You are being asked to participate in a research study that we are conducting focused on identifying barriers and facilitators to conducting virtual (remote) concussion assessments. The ultimate objective of the research is to develop a standardized virtual physical concussion assessment. Participation is voluntary. Briefly, this study involves participation in a focus group with the aim of discussing barriers and facilitators to conducting virtual concussion assessments. The results of the focus groups will inform the development of a virtual neurological assessment for concussion patients, which will occur in a follow-up phase in this study.

The Information Sheet is available to you for review and is attached in this email.

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Feasibility Study Clinician Information Sheet

The Ottawa Hospital RESEARCH INSTITUTE | L'Hôpital d'Ottawa INSTITUT DE RECHERCHE

Information Sheet

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

OHSN-REB Number: 20230311-01H

IS THERE A CONFLICT OF INTEREST?
There are no conflicts of interest to declare related to this study.

WHY IS THIS STUDY BEING DONE?
Currently there is limited information available on the reliability and validity of the virtual neurological examination. The aim of this component of the study is to determine reliability of a previously developed virtual physical assessment.

WHAT WILL HAPPEN DURING THIS STUDY?
Your participation in this study will require completion of in-person and virtual assessments, as well as potential observation and evaluation of audio-video recorded virtual assessments. Acquired brain injury individuals already attending an assessment with a clinician will be approached to participate in the study. Additional components of the in-person assessment may be required for this study, along with completion of the virtual assessment. The virtual assessment will occur at the hospital and will be done through the Microsoft Teams platform. We would record the tests using the Microsoft Teams record function, so that a different clinician can view these again at a later time.

Upon providing consent, you will be asked to complete components of a physical assessment (finger to nose test, balance testing, oculomotor tests, cervical spine test) and document your findings on a paper copy, which will then be inputted into REDCap. Injured participants will be randomized to complete either the in-person or virtual assessment first. They will then complete the opposing assessment after completion of the first. As a clinician-assessor, you would be asked to complete whichever assessment the participant had been randomized to first, followed by the opposing assessment. You would be asked to document your findings. A different clinician will observe and rate the recording of the virtual assessment which you completed. You would be asked to complete a demographic form on the day of consenting to participate in the study and a feedback form following completion of each study assessment. At a later time, you may be asked to observe and rate audio-video recordings of the virtual

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assessments in which you did not complete. You would be asked to observe and rate the recording twice (soon after assessment was initially completed by the first clinician and approximately one month after you first observed the recording).

WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?

If you choose to participate in this study, you will be expected to:

- Complete components of an in-person physical assessment and document findings.
- Complete a virtual physical assessment consisting of the same components of the in-person assessment and document findings.
- Observe and evaluate audio-video recordings of assessments and document findings.
- Maintain confidentiality of patient assessments.

VOLUNTARY PARTICIPATION AND WITHDRAWAL

Taking part in this study is voluntary.

You have the option to not participate at all, or you may choose to leave the study (called withdrawal) at any time without having to provide a reason. Your decision will not affect your employment.

HOW LONG WILL PARTICIPANTS BE IN THE STUDY?

You will be involved in this study for up to one year. Your participation in this study will take approximately 15 extra minutes per acquired brain injured participant.

CAN PARTICIPANTS CHOOSE TO LEAVE THE STUDY?

You can choose to end your participation in this research (called withdrawal) at any time without having to provide a reason. If you choose to withdraw from the study, you are encouraged to contact the study doctor or study staff.

You may withdraw your permission to use information that was collected about you for this study at any time by letting the study doctor know. However, this would also mean that you withdraw from the study.

WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?

There are no known risks related to being in this study.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?

You may not receive direct benefit from participating in this study. We hope the information learned from this study will help determine how accurate and reliable our virtual assessment is. We hope this study will provide an important foundation for brain injury assessments being done remotely.

HOW WILL PARTICIPANT INFORMATION BE KEPT CONFIDENTIAL?

If you decide to participate in this study, the research team will only collect the information they need for this study.

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Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, clinical field, age, and years in practice.

The following organizations may also receive study data as members of these institutions may help with the analysis and reporting of results:

- Bruyère Research Institute.
- Toronto Rehabilitation Institute.

The audio-video recordings of the study assessments will be stored in a secure location and viewed only by members of the research team and a second clinician-assessor.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/ presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, information that links your study data directly to you will not be shared.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

WHAT IS THE COST TO PARTICIPANTS?

Participation in this study will not involve any additional costs to you.

ARE STUDY PARTICIPANTS PAID TO BE IN THIS STUDY?

You will not be paid directly to participate in this study, however, compensation for your time will be made to the program in which the assessment occurred.

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WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?
You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

WHOM DO PARTICIPANTS CONTACT FOR QUESTIONS?
If you have any questions about taking part in this study, you may contact Dr. Shawn Marshall at 613-737-7350 ext. 75306.

If you have questions about your rights as a participant or about ethical issues related to this study, you can talk to someone who is not involved in the study at all. Please contact The Ottawa Health Science Network Research Ethics Board, Chairperson at 613-798-5555 extension 16719

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Feasibility Study Clinician Verbal Consent Script

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Verbal Consent Script

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

OHSN-REB Number: 20230311-01H

Participant name:	**Person calling:**
Date Called:	**Time Called:**

Call to interested clinicians.

Hello, thank you for agreeing to further discuss this research study. My name is [name of caller] and I am a [Clinical Research Assistant/Clinical Research Coordinator/PhD student] from the Ottawa Hospital Research Institute.

Is this an ok time to talk about the study?

☐ No ***If no →** Is there a better time? Date/time:
☐ Yes ***If yes →** *Continue with script below*

As you know, the study is being conducted by Dr. Shawn Marshall at The Ottawa Hospital.

The aim of this study is to determine reliability of a previously developed virtual neurological assessment.

I am going to read you the consent form and ask for your verbal consent once I have finished.

Conflicts of Interest:
There are no conflicts of interest to declare related to this study.

Research Activities:
Your participation in this study will require completion of in-person and virtual assessments, as well as potential observation and evaluation of audio-video recorded virtual assessments. Acquired brain injury individuals already attending an assessment with a clinician will be approached to participate in the study. Additional components of the in-person assessment may be required for this study, along with completion of the virtual assessment. The virtual assessment will occur at the hospital and will be done through the Microsoft Teams platform.

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We would record the tests using the Microsoft Teams record function, so that a different clinician can view these again at a later time.

Upon providing consent, you will be asked to complete components of a physical assessment (finger to nose test, balance testing, oculomotor tests, cervical spine test) and document your findings on a paper copy, which will then be inputted into REDCap. Injured participants will be randomized to complete either the in-person or virtual assessment first. They will then complete the opposing assessment after completion of the first. As a clinician-assessor, you would be asked to complete whichever assessment the participant had been randomized to first, followed by the opposing assessment. You would be asked to document your findings. A different clinician will observe and rate the recording of the virtual assessment which you completed. You would be asked to complete a demographic form on the day of consenting to participate in the study and a feedback form following completion of each study assessment. At a later time, you may be asked to observe and rate audio-video recordings of the virtual assessments in which you did not complete. You would be asked to observe and rate the recording twice (soon after assessment was initially completed by the first clinician and approximately one month after you first observed the recording).

Do you have questions about the activities this study involves?

☐ No ***If no →** *Continue with script below*

☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Voluntary Participation and Withdrawal:

Taking part in this study is voluntary.

You have the option to not participate at all, or you may choose to leave the study at any time (called withdrawal) at any time without having to provide a reason. Your decision will not affect your employment.

If you decide to leave the study, you can ask that the information that was collected about you not be used for the study.

Do you have questions about the voluntary nature and ability to withdraw from of this study?

☐ No ***If no →** *Continue with script below*

☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

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Answers: _____

Other Comments: _____

Potential Risks, Harms, Discomforts:
There are no known risks related to being in this study.

Do you have questions about the potential risks this study involves?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Potential Benefits:
You may not receive direct benefit from participating in this study. We hope the information learned from this study will help determine how accurate and reliable our virtual assessment is. We hope this study will provide an important foundation for brain injury assessments being done remotely.

Do you have questions about the potential benefits this study involves?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Privacy/Confidentiality:
If you decide to participate in this study, the research team will only collect the information they need for this study.

Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

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Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, clinical field, age, and years in practice.

The following organizations may also receive study data as members of these institutions may help with the analysis and reporting of results:

- Bruyère Research Institute.
- Toronto Rehabilitation Institute.

The audio-video recordings of the study assessments will be stored in a secure location and viewed only by members of the research team and a second clinician-assessor.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/ presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, information that links your study data directly to you will not be shared.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

Do you have questions about the how your privacy will be protected?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Cost to participation:
Participation in this study will not involve any additional costs to you.

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Payment or Reimbursement:
You will not be paid directly to participate in this study, however, compensation for your time will be made to the program in which the assessment occurred.
Do you have questions about the costs of participation or payment/reimbursement?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Participant Rights:
You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

Questions:
In case you have any questions, here are some contact numbers that are good to have. Do you have a pen and paper ready?

For questions about your rights as a research participant or about ethical issues related to the study, you can contact The Ottawa Health Science Network Research Ethics Board at 613-798-5555, extension 16719, and speak to someone who isn't involved in the study at all.

I can answer any questions that you may have about the research study right now, but if you think of additional questions later on, you can contact me or the study doctor, Dr. Shawn Marshall at 613-737-7350 ext. 75306.

Have all of your questions been answered?

☐ No ***If no →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

☐ Yes ***If yes →** *Continue with script below*

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Consent:

Based on the description of the study, would you like to participate? Or would you like some time to think about it?

☐ No ☐ Yes ☐ More time to think about it

***If they do not want to participate:** Thank you for your time. Goodbye.

***If they do want to participate:** *Continue with script below*

***If they would like more time:** *Continue with script below*

***If they wanted more time:** When would be a good time for me to call you back to answer any further questions you may have and obtain your decision? Date/time:

Wrap up with a reminder of the next steps and end the call.

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Documentation of Verbal Consent

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

OHSN-REB Number: 20230311-01H

Name of Participant: _____

Date of Discussion: _____

Duration of Discussion: _____

SIGNATURES

- The participant's questions have been answered,
- The participant understands the information within this Verbal Consent Script,
- Each page of the Verbal Consent Script has been read to the participant.
- The participant agrees to take part in this study.

Investigator or Delegate Statement

I have carefully explained the study to the study participant. To the best of my knowledge, the participant understands the nature, demands, risks and benefits involved in taking part in this study.

_____	_____	_____
Signature of Person Conducting Consent Discussion	Printed Name and Role	Date

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Feasibility Study Clinician Informed Consent Form

The Ottawa Hospital | L'Hôpital d'Ottawa
RESEARCH INSTITUTE | INSTITUT DE RECHERCHE

Informed Consent Form for Participation in a Research Study

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

OHSN-REB Number: **20230311-01H**

Study Doctor: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

Funder: Workplace Safety and Insurance Board (WSIB)

INTRODUCTION
You are invited to participate in this research study because you are a clinician involved in acquired brain injury assessments at the Ottawa Hospital. This study involves completion of in-person and virtual assessments (both completed at the Ottawa Hospital) with the aim of determining the reliability of a developed virtual concussion assessment. This consent form provides you with information to help you make an informed choice. Please read this document carefully and ask any questions you may have. All your questions should be answered to your satisfaction before you decide whether to participate in this research study.

Participation in this study is voluntary. You have the option to not participate at all or you may choose to leave the study at any time. The decision will not affect your employment.

ARE THERE ANY CONFLICTS OF INTEREST?
There are no conflicts of interest to declare related to this study.

WHY IS THIS STUDY BEING DONE?
Currently there is limited information available on the reliability and validity of the virtual neurological examination. The aim of this component of the study is to determine reliability of a previously developed virtual physical assessment.

HOW MANY PEOPLE WILL TAKE PART IN THIS STUDY?
It is anticipated that about 80 acquired brain injury patients will participate and require assessment. The study in its entirety (development of the virtual assessment and determination of reliability) should take approximately 2.5 years to complete. This component of the project should take approximately 1 year to complete and 1.5 years for the results to be ready.

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WHAT WILL HAPPEN DURING THIS STUDY?

Your participation in this study will require completion of in-person and virtual assessments, as well as potential observation and evaluation of audio-video recorded virtual assessments. Acquired brain injury individuals already attending an assessment with a clinician will be approached to participate in the study. Additional components of the in-person assessment may be required for this study, along with completion of the virtual assessment. The virtual assessment will occur at the hospital and will be done through the Microsoft Teams platform. We would record the tests using the Microsoft Teams record function, so that a different clinician can view these again at a later time.

Upon providing consent, you will be asked to complete components of a physical assessment (finger to nose test, balance testing, oculomotor tests, cervical spine test) and document your findings on a paper copy, which will then be inputted into REDCap. Injured participants will be randomized to complete either the in-person or virtual assessment first. They will then complete the opposing assessment after completion of the first. As a clinician-assessor, you would be asked to complete whichever assessment the participant had been randomized to first, followed by the opposing assessment. You would be asked to document your findings. A different clinician will observe and rate the recording of the virtual assessment which you completed. You would be asked to complete a demographic form on the day of consenting to participate in the study and a feedback form following completion of each study assessment. At a later time, you may be asked to observe and rate audio-video recordings of the virtual assessments in which you did not complete. You would be asked to observe and rate the recording twice (soon after assessment was initially completed by the first clinician and approximately one month after you first observed the recording).

WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?

If you choose to participate in this study, you will be expected to:

- Complete components of an in-person physical assessment and document findings.
- Complete a virtual physical assessment consisting of the same components of the in-person assessment and document findings.
- Observe and evaluate audio-video recordings of assessments and document findings.
- Maintain confidentiality of patient assessments.

HOW LONG WILL PARTICIPANTS BE IN THE STUDY?

You will be involved in this study for up to one year. Your participation in this study will take approximately 15 extra minutes per acquired brain injured participant.

CAN PARTICIPANTS CHOOSE TO LEAVE THE STUDY?

You can choose to end your participation in this research (called withdrawal) at any time without having to provide a reason. If you choose to withdraw from the study, you are encouraged to contact the study doctor or study staff.

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You may withdraw your permission to use information that was collected about you for this study at any time by letting the study doctor know. However, this would also mean that you withdraw from the study.

WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?
There are no known risks related to being in this study.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?
You may not receive direct benefit from participating in this study. We hope the information learned from this study will help determine how accurate and reliable our virtual assessment is. We hope this study will provide an important foundation for brain injury assessments being done remotely.

HOW WILL PARTICIPANT INFORMATION BE KEPT CONFIDENTIAL?
If you decide to participate in this study, the research team will only collect the information they need for this study.

Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, clinical field, age, and years in practice.

The following organizations may also receive study data as members of these institutions may help with the analysis and reporting of results:

- Bruyère Research Institute.
- Toronto Rehabilitation Institute.

The audio-video recordings of the study assessments will be stored in a secure location and viewed only by members of the research team and a second clinician-assessor.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/ presented to the scientific community at meetings and in journals.

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Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, information that links your study data directly to you will not be shared.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

WHAT IS THE COST TO PARTICIPANTS?
Participation in this study will not involve any additional costs to you.

ARE STUDY PARTICIPANTS PAID TO BE IN THIS STUDY?
You will not be paid directly to participate in this study, however, compensation for your time will be made to the program in which the assessment occurred.

WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?
You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

By signing this form, you do not give up any of your legal rights against the researcher, funder or involved institutions for compensation, nor does this form relieve the researcher, funder or their agents of their legal and professional responsibilities.

You will be given a copy of this signed and dated consent form.

WHOM DO PARTICIPANTS CONTACT FOR QUESTIONS?
If you have any questions about taking part in this study, you may contact Dr. Shawn Marshall at 613-737-7350 ext. 75306.

If you have questions about your rights as a participant or about ethical issues related to this study, you can talk to someone who is not involved in the study at all. Please contact The Ottawa Health Science Network Research Ethics Board, Chairperson at 613-798-5555 extension 16719.

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Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

SIGNATURES

- All my questions have been answered,
- I understand the information within this informed consent form,
- I do not give up any of my legal rights by signing this consent form,
- I agree to take part in this study.

Signature of Participant	Printed Name	Date

Signature of Person Conducting the Consent Discussion	Printed Name and Role	Date

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Feasibility Study Patient Information Sheet

The Ottawa Hospital | L'Hôpital d'Ottawa
RESEARCH INSTITUTE | INSTITUT DE RECHERCHE

Information Sheet

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

OHSN-REB Number: 20230311-01H

IS THERE A CONFLICT OF INTEREST?
There are no conflicts of interest to declare related to this study.

WHY IS THIS STUDY BEING DONE?
Currently there is no virtual assessment with sufficient evidence and support available for brain injury patients. The aim of this research will be to determine how reliable a virtual brain injury assessment is (are consistent findings obtained when completed by different clinicians?).

WHAT WILL HAPPEN DURING THIS STUDY?
If you decide to participate you would be asked to complete two separate assessments, one in-person and one virtually. You would be randomized (like flipping a coin) to either complete the in-person assessment first or the virtual assessment first, however, you would complete both assessments at some point. You will be told which assessment you will complete first after randomization occurs.

These assessments will both be done at the hospital, however for the virtual assessment, the clinician will be located in a different room than you. The virtual assessment will be done through the Microsoft Teams platform, and we would record the tests using the Microsoft Teams record function, so that a clinician (different from the clinician that completed your original assessments) can view these again at a later time. The two assessments will be separated by a rest period to ensure management of any symptoms.

If you need to complete all tests included in the research study:

- We would ask you to complete a neck movement test, balance test, eye test, and coordination test both in-person and virtually.

If you already completed some of these tests required for the research study as part of your scheduled in-person assessment:

- You will not have to repeat these tests.

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- We would ask that you complete any tests that are part of the research that have not yet been completed in-person, as well as all of the tests included in the research, virtually.

If you are unable to complete all tests in both assessments (in-person and virtual) at the time of your scheduled appointment, we may ask that you:

- Return to the Ottawa Hospital at a later date.
- Complete the remaining tests that are part of the research that have not yet been completed both in-person and virtually.

It usually takes approximately 1-1.5 hours to complete your scheduled in-person assessment, in which you are already attending with your clinician. We may ask that you stay at the hospital for an additional 45 minutes (including up to a 30-minute rest period), if needed, to complete the extra tests for this research. We will also ask you to complete a brief feedback form following the research assessments.

Review of your health record at the Ottawa Hospital will occur. Information about your brain injury, medications, health status, symptoms, treatment/management of the injury, and demographic information will be collected from your health record. This will be accessed once only.

WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?

If you choose to participate in this study, you will be expected to:

- Tell the study doctor about your current medical conditions and relevant diagnoses;
- Participate in two assessments (one in-person and one virtually)

VOLUNTARY PARTICIPATION AND WITHDRAWAL

Taking part in this study is voluntary.

You have the option to not participate at all or you may choose to leave the study at any time. Whatever you choose, it will not affect the usual medical care that you receive outside the study. Your choice to participate will not have any bearing on the treatment you receive.

Please note, if you are currently a patient being treated through the WSIB, none of the research data obtained for the purposes of this study will be shared with the WSIB.

HOW LONG WILL PARTICIPANTS BE IN THE STUDY?

You will be involved in this study for one day. It usually takes approximately 1-1.5 hours for your clinician to complete a full assessment. The study may require you to stay for some additional time due to the added virtual and feedback components of the study. If study procedures cannot be completed on the day of your previously scheduled assessment at the Ottawa Hospital, you may be asked to return to the assessment centre to complete the remaining components of the study (remaining tests and feedback form).

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CAN PARTICIPANTS CHOOSE TO LEAVE THE STUDY?
You can choose to end your participation in this research (called withdrawal) at any time without having to provide a reason. If you choose to withdraw from the study, you are encouraged to contact the study doctor or study staff.

If you decide to leave the study, you can ask that the information that was collected about you not be used for the study. Let the research team know if you choose this.

WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?
You may experience an increase in your pre-existing symptoms during some of the assessment components. Some symptoms may include an increase in pre-existing brain injury symptoms such as headaches, dizziness, tinnitus, nausea, and fatigue. Some increases in symptoms are expected. Taking part in this study may make you feel uncomfortable.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?
You may not receive direct benefit from participating in this study. We hope the information learned from this study will help determine how accurate and reliable our virtual assessment is. We hope this study will provide an important foundation for assessments being done remotely.

HOW WILL PARTICIPANT INFORMATION BE KEPT CONFIDENTIAL?
If you decide to participate in this study, the research team will only collect the information they need for this study.

Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

Authorized representatives of the following organizations may look at your original (identifiable) research records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, age, diagnosis, sex, work status, and information about your injury.

The following organizations may also receive study data as members of these institutions may help with the analysis and reporting of results:

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- Bruyère Research Institute.
- Toronto Rehabilitation Institute.

The audio-video recordings of the study assessments will be stored in a secure location and viewed only by members of the research team and clinician-assessors. The recordings will be assessed by a second clinician assessor employed at the Ottawa Hospital that did not complete your original assessments.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/ presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, information that links your study data directly to you will not be shared.

If information from this study is published, shared, or presented at scientific meetings, your name and other personal information will not be used.

Even though the likelihood that someone may identify you from the study data is very small, it can never be completely eliminated.

A copy of the consent form that you sign to enter the study may be included in your health record/hospital chart.

WHAT IS THE COST TO PARTICIPANTS?
Participation in this study will not involve any additional costs to you.

ARE STUDY PARTICIPANTS PAID TO BE IN THIS STUDY?
If you decide to participate in this study, you will receive a parking pass voucher to pay for your parking at the Ottawa Hospital and a $30 gift card to Amazon. If you need to return to complete study assessment components, you will receive the parking voucher and $30 honorarium again.

WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?
You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

WHOM DO PARTICIPANTS CONTACT FOR QUESTIONS?

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If you have any questions about taking part in this study, you may contact Dr. Shawn Marshall at 613-737-7350 ext. 75306.

If you have questions about your rights as a participant or about ethical issues related to this study, you can talk to someone who is not involved in the study at all. Please contact The Ottawa Health Science Network Research Ethics Board, Chairperson at 613-798-5555 extension 16719.

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Feasibility Study Patient Verbal Consent Script

The Ottawa Hospital | L'Hôpital d'Ottawa
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Verbal Consent Script

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

Principal Investigator: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

OHSN-REB Number: 20230311-01H

Participant name:	**Person calling:**
Date Called:	**Time Called:**

Call to patients.

Hello, may I please speak with [name of the potential participant].

***If respondent asks who the caller is:**
My name is [name of caller] and I am calling from [The Ottawa Hospital] about a research study.

***If potential participant is unavailable:**
Is there a better time to call back? Date/time:

***If potential participant indicates they are not interested:**
Thank you for your time. Goodbye.

***If potential participant is respondent:**

This is [name of caller] calling from [The Ottawa Hospital].

Is this an ok time to talk?

☐ No *If no → Is there a better time? Date/time:
☐ Yes *If yes → *Continue with script below*

***When permission to contact for research purposes is documented in Epic (i.e. patient is flagged as "OK to contact"):**

- I'm calling because your medical record indicates that you have agreed to be contacted about research and we have a research study that you might be interested in

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***When permission to contact for research was obtained and documented in a clinic note by a member of the circle of care:**

- We've been informed by a member of your circle of care that you have agreed to be contacted for research.

The study is being conducted by Dr. Shawn Marshall at the Ottawa Hospital

You are a candidate for this research because you have previously sustained a brain injury and are attending an assessment at the Ottawa Hospital, in-person.

The goal of the research study is to determine how reliable (meaning are consistent findings obtained when completed by different clinicians?) a virtual (where you are in a different location than the assessing doctor) assessment is.

Are you willing to hear more about the study?

☐ No ***If no →** Thank you for your time. Goodbye
☐ Yes ***If yes →** *Continue with script below*

Conflicts of Interest:

There are no conflicts of interest to declare related to this study.

Research Activities:

If you decide to participate you would be asked to complete two separate assessments, one in-person and one virtually. You would be randomized (like flipping a coin) to either complete the in-person assessment first or the virtual assessment first, however, you would complete both assessments at some point. You will be told which assessment you will complete first after randomization occurs.

These assessments will both be done at the hospital, however for the virtual assessment, the clinician will be located in a different room than you. The virtual assessment will be done through the Microsoft Teams platform, and we would record the tests using the Microsoft Teams record function, so that a clinician (different from the clinician that completed your original assessments) can view these again at a later time. The two assessments will be separated by a rest period to ensure management of any symptoms.

If you need to complete all tests included in the research study:

- We would ask you to complete a neck movement test, balance test, eye test, and coordination test both in-person and virtually.

If you already completed some of these tests required for the research study as part of your scheduled in-person assessment:

- You will not have to repeat these tests.

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- We would ask that you complete any tests that are part of the research that have not yet been completed in-person, as well as all of the tests included in the research, virtually.

If you are unable to complete all tests in both assessments (in-person and virtual) at the time of your scheduled appointment, we may ask that you:

- Return to the Ottawa Hospital at a later date.
- Complete the remaining tests that are part of the research that have not yet been completed both in-person and virtually.

It usually takes approximately 1-1.5 hours to complete your scheduled in-person assessment, in which you are already attending with your clinician. We may ask that you stay at the hospital for an additional 45 minutes (including up to a 30-minute rest period), if needed, to complete the extra tests for this research. We will also ask you to complete a brief feedback form following the research assessments.

Review of your health record at the Ottawa Hospital will occur. Information about your brain injury, medications, health status, symptoms, treatment/management of the injury, and demographic information will be collected from your health record. This will be accessed once only.

Do you have questions about the activities this study involves?

☐ No ***If no →** *Continue with script below*

☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Voluntary Participation and Withdrawal:

Taking part in this study is voluntary.

You have the option to not participate at all, or you may choose to leave the study at any time (this is called withdrawal), without having to provide a reason. Whatever you choose, it will not affect the usual medical care that you receive outside the study. Your choice to participate will not have any bearing on the treatment you receive.

Please note, if you are currently a patient being treated through the WSIB, none of the research data obtained for the purposes of this study will be shared with the WSIB.

If you decide to leave the study, you can ask that the information that was collected about you not be used for the study. Let the research team know if you choose this.

Do you have questions about the voluntary nature and ability to withdraw from of this study?

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☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Potential Risks, Harms, Discomforts:

You may experience an increase in your pre-existing symptoms during some of the assessment components. Some symptoms may include an increase in pre-existing brain injury symptoms such as headaches, dizziness, tinnitus, nausea, and fatigue. Some increases in symptoms are expected. Taking part in this study may make you feel uncomfortable.

Do you have questions about the potential risks this study involves?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Potential Benefits:

You may not receive direct benefit from participating in this study. We hope the information learned from this study will help determine how accurate and reliable our virtual assessment is. We hope this study will provide an important foundation for assessments being done remotely.

Do you have questions about the potential benefits this study involves?

☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Privacy/Confidentiality:

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If you decide to participate in this study, the research team will only collect the information they need for this study.

Records identifying you at this center will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

Authorized representatives of the following organizations may look at your original (identifiable) research and medical records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.
- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, age, diagnosis, sex, work status, and information about your injury.

The following organizations may also receive study data as members of these institutions may help with the analysis and reporting of results:

- Bruyère Research Institute.
- Toronto Rehabilitation Institute.

The audio-video recordings of the study assessments will be stored in a secure location and viewed only by members of the research team and clinician-assessors. The recordings will be assessed by a second clinician assessor employed at the Ottawa Hospital that did not complete your original assessments.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, scientific journals, or deposited in an online repository, information that links your study data directly to you will not be shared.

If information from this study is published, shared, or presented at scientific meetings, your name and other personal information will not be used.

Even though the risk of identifying you from the study data is very small, it can never be completely eliminated.

Do you have questions about the how your privacy will be protected?

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☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Cost to participation:
Participation in this study will not involve any additional costs to you.

Payment or Reimbursement:
If you decide to participate in this study, you will receive a parking pass voucher to pay for your parking at the Ottawa Hospital and a $30 gift card to Amazon. If you need to return to complete study assessment components, you will receive the parking voucher and $30 honorarium again.

Do you have questions about the costs of participation or payment/reimbursement?
☐ No ***If no →** *Continue with script below*
☐ Yes ***If yes →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

Participant Rights:

You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

Questions:

In case you have any questions, here are some contact numbers that are good to have. Do you have a pen and paper ready?

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For questions about your rights as a research participant or about ethical issues related to the study, you can contact The Ottawa Health Science Network Research Ethics Board at 613-798-5555, extension 16719, and speak to someone who isn't involved in the study at all.

I can answer any questions that you may have about the research study right now, but if you think of additional questions later on, you can contact me or the study doctor, Dr. Shawn Marshall at 613-737-7350 ext. 75306.

Have all of your questions been answered?

☐ No ***If no →** *Answer questions and document all questions and answers before continuing with script below*

Questions: _____

Answers: _____

Other Comments: _____

☐ Yes ***If yes →** *Continue with script below*

Consent:

Based on the description of the study, would you like to participate? Or would you like some time to think about it?

☐ No ☐ Yes ☐ More time to think about it

***If they do <u>not</u> want to participate:** Thank you for your time. Goodbye.

***If they <u>do</u> want to participate:** *Continue with script below*

***If they would like <u>more time</u>:** *Continue with script below*

For your records and to help in making your decision, I can send you the Information Sheet by email. I will also provide the Informed Consent Form to you when I see you in-person for your assessment.

☐ Email (as a Microsoft 365 SharePoint link or password protected attachment)

Before I can initiate email contact with you, I'm required to inform you of the risks associated with use of email. I'm going to read a series of statements to you. Please stop me at any time if you have questions.

Read the 'Research Participant Consent to Communicate by Email'

Discussed on: _____/____/____ Time: _____ hours

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Consenting Process completed by: _____ Date: _____/____/____

Record and confirm email address: _____

***If they wanted more time:** When would be a good time for me to call you back to answer any further questions you may have and obtain your decision? Date/time:

Wrap up with a reminder of the next steps and end the call.

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Documentation of Verbal Consent

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

OHSN-REB Number: 20230311-01H

Name of Participant: _____

Date of Discussion: _____

Duration of Discussion: _____

SIGNATURES

- The participant's questions have been answered,
- The participant understands the information within this Verbal Consent Script,
- Each page of the Verbal Consent Script has been read to the participant.
- The participant will allow access to medical records as explained in this consent form
- The participant agrees to take part in this study.

Investigator or Delegate Statement

I have carefully explained the study to the study participant. To the best of my knowledge, the participant understands the nature, demands, risks and benefits involved in taking part in this study.

Signature of Person Conducting Consent Discussion	Printed Name and Role	Date

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Feasibility Study Patient Informed Consent Form

The Ottawa Hospital | L'Hôpital d'Ottawa
RESEARCH INSTITUTE | INSTITUT DE RECHERCHE

Informed Consent Form for Participation in a Research Study

Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

OHSN-REB Number: **20230311-01H**

Study Doctor: Dr. Shawn Marshall, MD, MSc, FRCPC
The Ottawa Hospital
Rehabilitation Centre, Room 1104
505 Smyth rd. Ottawa, ON
K1H 8M2

INTRODUCTION
You are being invited to participate in a clinical study (a type of study that involves research). You are invited to participate in this study because you have sustained a brain injury. This consent form provides you with information to help you make an informed choice. Please read this document carefully and ask any questions you may have. All your questions should be answered to your satisfaction before you decide whether to participate in this research study.

The study staff will tell you about the study timelines for making your decision.

Taking part in this study is voluntary. You have the option to not participate at all or you may choose to leave the study at any time. Whatever you choose, it will not affect the usual medical care that you receive outside the study. Your choice to participate will not have any bearing on the treatment you receive.

Please note, if you are currently a patient being treated through the WSIB, none of the research data obtained for the purposes of this study will be shared with the WSIB.

IS THERE A CONFLICTS OF INTEREST?
There are no conflicts of interest to declare related to this study.

WHY IS THIS STUDY BEING DONE?
Currently there is no virtual assessment with sufficient evidence and support available for brain injury patients. The aim of this research will be to determine how reliable a virtual brain injury assessment is (are consistent findings obtained when completed by different clinicians?).

HOW MANY PEOPLE WILL TAKE PART IN THIS STUDY?
It is anticipated that about 80 people will take part in this study, from research sites located at the Ottawa Hospital.

This study should take 1 year to complete, and the results should be known in about 1.5 years.

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WHAT WILL HAPPEN DURING THIS STUDY?

If you decide to participate you would be asked to complete two separate assessments, one in-person and one virtually. You would be randomized (like flipping a coin) to either complete the in-person assessment first or the virtual assessment first, however, you would complete both assessments at some point. You will be told which assessment you will complete first after randomization occurs.

These assessments will both be done at the hospital, however for the virtual assessment, the clinician will be located in a different room than you. The virtual assessment will be done through the Microsoft Teams platform, and we would record the tests using the Microsoft Teams record function, so that a clinician (different from the clinician that completed your original assessments) can view these again at a later time. The two assessments will be separated by a rest period to ensure management of any symptoms.

If you need to complete all tests included in the research study:

- We would ask you to complete a neck movement test, balance test, eye test, and coordination test both in-person and virtually.

If you already completed some of these tests required for the research study as part of your scheduled in-person assessment:

- You will not have to repeat these tests.
- We would ask that you complete any tests that are part of the research that have not yet been completed in-person, as well as all of the tests included in the research, virtually.

If you are unable to complete all tests in both assessments (in-person and virtual) at the time of your scheduled appointment, we may ask that you:

- Return to the Ottawa Hospital at a later date.
- Complete the remaining tests that are part of the research that have not yet been completed both in-person and virtually.

It usually takes approximately 1-1.5 hours to complete your scheduled in-person assessment, in which you are already attending with your clinician. We may ask that you stay at the hospital for an additional 45 minutes (including up to a 30-minute rest period), if needed, to complete the extra tests for this research. We will also ask you to complete a brief feedback form following the research assessments.

Review of your health record at the Ottawa Hospital will occur. Information about your brain injury, medications, health status, symptoms, treatment/management of the injury, and demographic information will be collected from your health record. This will be accessed once only.

WHAT ARE THE RESPONSIBILITIES OF STUDY PARTICIPANTS?

If you choose to participate in this study, you will be expected to:

- Tell the study doctor about your current medical conditions and relevant diagnoses;
- Participate in two assessments (one in-person and one virtually)

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HOW LONG WILL PARTICIPANTS BE IN THE STUDY?
You will be involved in this study for one day. It usually takes approximately 1-1.5 hours for your clinician to complete a full assessment. The study may require you to stay for some additional time due to the added virtual and feedback components of the study. If study procedures cannot be completed on the day of your previously scheduled assessment at the Ottawa Hospital, you may be asked to return to the assessment centre to complete the remaining components of the study (remaining tests and feedback form).

CAN PARTICIPANTS CHOOSE TO LEAVE THE STUDY?
You can choose to end your participation in this research (called withdrawal) at any time without having to provide a reason. If you choose to withdraw from the study, you are encouraged to contact the study doctor or study staff.

You may withdraw your permission to use information that was collected about you for this study at any time by letting the study doctor know. However, this would also mean that you withdraw from the study.

WHAT ARE THE RISKS OR HARMS OF PARTICIPATING IN THIS STUDY?
You may experience an increase in your pre-existing symptoms during some of the assessment components. Some symptoms may include an increase in pre-existing brain injury symptoms such as headaches, dizziness, tinnitus, nausea, and fatigue. Some increases in symptoms are expected. Taking part in this study may make you feel uncomfortable.

WHAT ARE THE BENEFITS OF PARTICIPATING IN THIS STUDY?
You may not receive direct benefit from participating in this study. We hope the information learned from this study will help determine how accurate and reliable our virtual assessment is. We hope this study will provide an important foundation for assessments being done virtually.

HOW WILL PARTICIPANT INFORMATION BE KEPT CONFIDENTIAL?
If you decide to participate in this study, the study doctors and study staff will only collect the information they need for this study.

Records identifying you at this centre will be kept confidential and, to the extent permitted by the applicable laws, will not be disclosed or made publicly available, except as described in this consent document.

Authorized representatives of the following organizations may look at your original (identifiable) medical/clinical and study records at the site where these records are held, to check that the information collected for the study is correct and follows proper laws and guidelines.

- The Ottawa Health Science Network Research Ethics Board who oversees the ethical conduct of this study.

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- Ottawa Hospital Research Institute, to oversee the conduct of research at this location.

Information that is collected about you for the study (called study data) may also be sent to the organizations listed above. Your name, address, email, or other information that may directly identify you will not be used. The records received by these organizations may contain your participant code, age, diagnosis, sex, work status, and information about your injury.

The following organizations may also receive study data as members of these institutions may help with the analysis and reporting of results:

- Bruyère Research Institute.
- Toronto Rehabilitation Institute.

This research study is collecting information on ethnicity as well as other characteristics of individuals because these characteristics may influence how people recover following a brain injury. Providing information on your ethnic origin is voluntary.

The audio-video recordings of the study assessments will be stored in a secure location and viewed only by members of the research team and clinician-assessors. The recordings will be assessed by a second clinician assessor employed at the Ottawa Hospital that did not complete your original assessments.

If the results of this study are published, your identity will remain confidential. It is expected that the information collected during this study will be used in analyses and will be published/ presented to the scientific community at meetings and in journals.

Your de-identified data from this study may be used for other research purposes. If your study data is shared with other researchers, information that links your study data directly to you will not be shared.

If information from this study is published, shared, or presented at scientific meetings, your name and other personal information will not be used.

Even though the likelihood that someone may identify you from the study data is very small, it can never be completely eliminated.

A copy of the consent form that you sign to enter the study may be included in your health record/hospital chart.

WHAT IS THE COST TO PARTICIPANTS?

Participation in this study will not involve any additional costs to you or your private health care insurance.

ARE STUDY PARTICIPANTS PAID TO BE IN THIS STUDY?

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If you decide to participate in this study, you will receive a parking pass voucher to pay for your parking at the Ottawa Hospital and a $30 gift card to Amazon. If you need to return to complete study assessment components, you will receive the parking voucher and a $30 honorarium again.

WHAT ARE THE RIGHTS OF PARTICIPANTS IN A RESEARCH STUDY?
You will be told, in a timely manner, about new information that may be relevant to your willingness to stay in this study.

You have the right to be informed of the results of this study once the entire study is complete.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected.

By signing this form you do not give up any of your legal rights against the study doctor or involved institutions for compensation, nor does this form relieve the study doctor or their agents of their legal and professional responsibilities.

You will be given a copy of this signed and dated consent form prior to participating in this study.

WHOM DO PARTICIPANTS CONTACT FOR QUESTIONS?
If you have questions about taking part in this study, or if you suffer a research-related injury, you can talk to your study doctor, or the doctor who oversees the study at this institution. That person is:

Dr. Shawn Marshall	613-737-7350 ext. 75306
Principal Investigator Name	Telephone

If you have questions about your rights as a participant or about ethical issues related to this study, you can talk to someone who is not involved in the study at all. Please contact The Ottawa Health Science Network Research Ethics Board, Chairperson at 613-798-5555 extension 16719.

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Study Title: Development and Determination of Reliability of a Virtual Neurological Assessment for Workplace Concussions

SIGNATURES

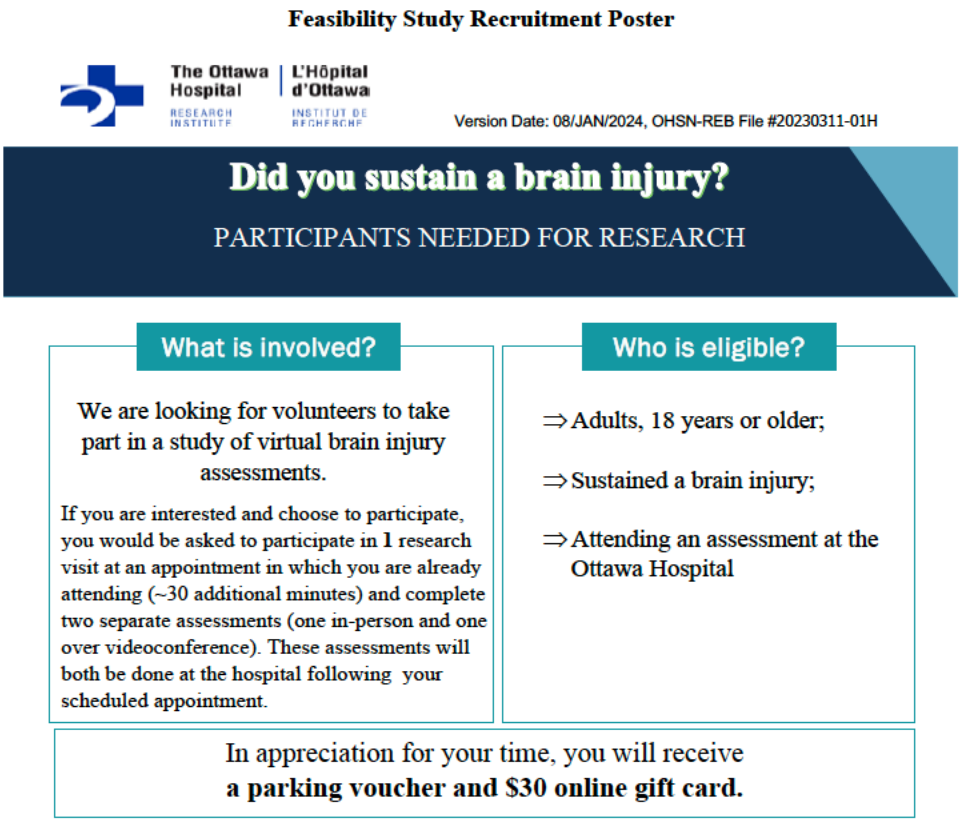
- All my questions have been answered,
- I understand the information within this informed consent form,
- I allow access to medical records and related personal health information as explained in this consent form,
- I do not give up any of my legal rights by signing this consent form,
- I understand that my family doctor/health care provider may be informed of my participation in this study by the study team, or may learn of my participation when reviewing my electronic health record,
- I agree to take part in this study.

Signature of Participant	Printed Name	Date

Signature of Person Conducting the Consent Discussion	Printed Name and Role	Date

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Feasibility Study Recruitment Poster



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Appendix C: Research Instruments

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Delphi Survey Demographic Questionnaire

Delphi Survey Round 1 Demographic Questionnaire

Age	☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ 60+ ☐ Prefer not to respond
Clinical Profession	☐ Physiatrist ☐ Neurologist ☐ Sport Medicine Physician ☐ Family Medicine Physician ☐ Neurosurgeon ☐ Physiotherapist ☐ Other: *insert text*
Years in practice	☐ 1-5 ☐ 5-10 ☐ 10+
Volume of practice of concussion patients	☐ 0-25 concussion patients assessed annually ☐ 25-50 concussion patients assessed annually ☐ 50+ concussion patients assessed annually ☐ Other: *insert text*
Self-report of competency of in-person neurological assessment	Strongly Incompetent, Incompetent, Neutral, Competent, Strongly Competent
Self-report of competency of virtual neurological assessment	Strongly Incompetent, Incompetent, Neutral, Competent, Strongly Competent
Unique Identifier Questions The following questions are included to provide a unique identifier that will allow linkage of round 1 and 2 responses, while maintaining anonymity.	First initial of mother's first name:
	First letter of middle name (if you do not have a middle name, use 'Z'):
	Birth month (1-12):
	Number of older siblings:
	First letter of the name of the city where you born:

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Working Group and Clinician Focus Group Demographic Questionnaire

Clinician-Participant Working Demographic Questionnaire

Study ID :	
Age	☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ 60+ ☐ Prefer not to respond
Clinical Profession	☐ Physiatrist ☐ Neurologist ☐ Sport Medicine Physician ☐ Family Medicine Physician ☐ Physiotherapist ☐ Other: *insert text*
Years in practice	☐ 1-5 ☐ 5-10 ☐ 10+
Volume of practice of concussion patients	☐ 0-25 concussion patients assessed annually ☐ 25-50 concussion patients assessed annually ☐ 50+ concussion patients assessed annually ☐ Other: *insert text*
Self-report of competency of in-person neurological assessment	Strongly Incompetent, Incompetent, Neutral, Competent, Strongly Competent
Self-report of competency of virtual neurological assessment	Strongly Incompetent, Incompetent, Neutral, Competent, Strongly Competent

Link: https://forms.office.com/Pages/ResponsePage.aspx?id=tkGbhQ8TE02mkx_-xOfLWhjPnG6_edVCnrHrdP3TVspUMFRBUjhTUktONDdMNlBJM1M1TUE2QzhCNS4u

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Focus Group Patient Demographic Questionnaire

Patient-Participant Focus Group Demographic Questionnaire

Study ID :	
1. Sex	☐ Male ☐ Female ☐ Prefer not to respond ☐ Other: *insert text*
2. Age at time of injury	*insert text*
3. Work status	☐ Off work ☐ Modified return to work, same occupation ☐ Full return to work, same occupation ☐ Modified return to work, different occupation ☐ Full return to work, different occupation ☐ Other: *insert text*
4. Date of injury	*insert text*
5. Commonly experienced concussion symptoms (list 3)	1. 2. 3.
6. Number of virtual assessments completed	*insert text*

Link: https://forms.office.com/Pages/ResponsePage.aspx?id=tkGbhQ8TE02mkx_-xOfLWhjPnG6_edVCnrHrdP3TVspUQUs3RzJOSk9FNjhQQ1pHWFhNN0tWV0RKTC4u

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Delphi Survey Questions

Delphi Survey Guide

Delphi Survey Questions Round 1

Thank you for agreeing to participate in a survey for the VirNA project. Your participation remains completely voluntary. Confidentiality and anonymity will be maintained throughout your participation. The data obtained in this project will help inform the development of the VirNA, a virtual neurological assessment for concussion patients. The Delphi survey approach will be followed to obtain this information, which will involve survey completion at two separate time-points. The following survey is round 1 of the Delphi survey. The aim of round 1 of the Delphi survey is to identify what assessment tools are currently used by clinicians when conducting in-person concussion assessments. Open-ended questions are listed below for your response at this time. Following completion of round 1, a round 2 survey will be developed based on participant responses to round 1, which will be completed at a later date. Round 2 will consist of more specific questions and will aim to identify what assessments are preferred and prioritized.

The questions listed below are open-ended and aim to gather information on your personal opinion.

1. What components of the neurological screen/examination are you currently completing with your concussion patients?
   Free text
2. What vestibular assessments are you currently completing with your concussion patients?
   Free text
3. What oculomotor assessments are you currently completing with your concussion patients?
   Free text
4. What assessments are you currently completing with your concussion patients for the cervical spine?
   Free text
5. What effort/malingering/symptom/performance validity assessments (if any) are you currently completing with your concussion patients?
   Free text
6. What other assessments are you currently completing with your concussion patients?
   Free text

Survey Link:
https://forms.office.com/Pages/ResponsePage.aspx?id=tkGbhQ8TE02mkx_-xOfLWhjPnG6_edVCnrHrdP3TVspUQU1YQTdLN01LMjQzWTQwTk5CWlRBUjBNTS4u

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Delphi Survey Questions Round 2 (with expected adjustments based on analysis from Round 1)

Thank you for agreeing to participate in a survey for the VirNA project. Your participation remains completely voluntary. Confidentiality and anonymity will be maintained throughout your participation. The data obtained in this project will help inform the development of the VirNA, a virtual neurological assessment for concussion patients. The Delphi survey approach will be followed to obtain this information, which will involve survey completion at two separate time-points. The following survey is round 2 of the Delphi survey. The aim of round 2 of the Delphi survey is to identify what assessments are preferred and prioritized.

The questions listed below aim to gather information on which of the identified assessments used in the concussion patient population are prioritized or preferred.
Select the best option(s) for each question.

1. **Neurological Examination**
   Which components of the neurological examination are prioritized? Select up to X.
   a. Cranial nerve
   b. Coordination
   c. Sensory
   d. Motor
   e. Gait
   f. Mental Status
   g. Other [*Free text*]

2. **Cervical Spine Assessment**
Which cervical spine assessment is prioritized? Select one option.
a. Cervical spine range of motion
b. Cervical spine proprioception (JPE)
c. Deep neck flexor
d. Other [*Free text*]

3. **Vestibular Assessment**
Which vestibular assessment is prioritized? Select one option.
a. Tandem stance (eyes open and closed)
b. BESS
c. Romberg
d. Single leg stand (eyes open and closed)
e. Dynamic Gait Index
f. Functional Gait Assessment
g. Other [*Free text*]

4. **Oculomotor Assessment**
Which oculomotor assessment is prioritized? Select one option.
a. Vestibular Oculomotor Screen (VOMS)
b. King-Devick Test

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c. Dynamic Visual Acuity
d. Other [*Free text*]

5. **Effort/Malingering/Symptom/Performance Validity Testing.**
   Which effort/malingering/symptom/performance validity assessment is prioritized? Select one option. Hoover's Test
   a. Test of Memory Malingering
   b. Medical Symptom Validity Test
   c. Honest Palm Sign
   d. Other [*Free text*]

Are you willing to be contacted to participate in a focus group to further explore barriers and facilitators to conducting virtual concussion assessment?

a. Yes. If yes, please email kebarnes@ohri.ca to inquire about participation in the focus group.
b. No

Survey Link:
https://forms.office.com/Pages/ResponsePage.aspx?id=tkGbhQ8TE02mkx_-xOfLWhjPnG6_edVCnrHrdP3TVspURExGREZFSFgzUUE2VExZQVJVMkZUVVg1TS4u

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Focus Group Interview Guides

Clinician Focus Group Interview Guide

The semi-structured interview guide will explore the practical/technical issues, barriers, and enablers to using assessment tools in a virtual context.

1. How many virtual assessments have you completed in the last 3 months? 6 months?
2. What components of an assessment have you assessed virtually?
3. Have you experienced any adverse events while completing a virtual assessment? (If so, could you discuss?)
4. For each of the identified measures from the second Delphi round and working group, the following questions will be asked:
    a. What are some barriers to using the measure in a virtual concussion assessment?
        i. What are some practical issues associated with using the measure in a virtual context?
        ii. What are some technical issues associated with using the measure in a virtual context?
    b. What are some facilitators to using the measure in a virtual context?
        i. What are some practical facilitators associated with using the measure in a virtual context?
        ii. What are some technical facilitators associated with using the measure in a virtual context?

Patient Focus Group Interview Guide

The focus groups with patient-participants will identify practical/technical issues associated with virtual assessments and will facilitate discussion of the challenges and benefits experienced by patients along with provide opportunity to give feedback based on their experiences. The semi-structured interview guide will explore these areas.

1. How many virtual assessments have you completed in the last 3 months? 6 months? 1 year?
2. Based on your experience, what are some challenges/barriers you faced when completing a virtual assessment?
    a. Practical barriers?
    b. Technical facilitators?
3. What are some benefits/facilitators you experienced?
    a. Practical facilitators?
    b. Technical facilitators?
4. Do you have any recommendations that could improve virtual assessments?
5. Do have any other feedback based on your experiences with virtual assessment?

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Survey, Focus Group, and Working Group Reading Material

Reading Material for Focus Groups and Surveys

The following reading material is provided for review prior to engagement in the [survey/focus group]. The following table outlines measures frequently used in the concussion patient population. Sensitivity and specificity metrics are presented for each measure, when available. Sensitivity is defined as the ability of a measure to accurately detect deficits and specificity refers to the ability of a measure to accurately rule out deficits. These properties are important for the measures being used in the context of this project where the aim is to identify deficits on assessments in a virtual context for the purposes of determining the need for treatment intervention. Feasibility and additional considerations are also presented.

Clinical Measure	Description	Important Properties	Feasibility and Additional Considerations
Vestibular and Oculomotor Assessment Measure			
Vestibular Ocular Motor Screen	**Smooth pursuits:** The patient is instructed to maintain focus on the target as the examiner moves the target smoothly in the horizontal and vertical direction. **Saccades:** The examiner holds two single points horizontally. Instruct the patient to move their eyes as quickly as possible from point to point. Repeat the test with 2 points held vertically. **Convergence:** The patient focuses on a small target at arm's length and slowly brings it toward the tip of their nose. **Vestibular-Ocular Reflex:** The patient is asked to rotate their head horizontally while maintaining focus on the target. The test is repeated with the patient moving their head vertically. **Visual Motion Sensitivity:** The patient holds arm outstretched and focuses on their thumb. Maintaining focus on their thumb, the patient rotates, together as a unit, their head, eyes and trunk to the right and left. Retrieved from: https://www.physiotherapyalberta.ca/files/vomstool.pdf	**Sensitivity:** 96% (Buttner et al., 2021) **Specificity:** 46% (Buttner et al., 2021)	• Minimal equipment (metronome, pen, ruler/measuring tape)/equipment readily available • Minimal training required • Quick (less than 10 minutes), easy to administer • Demonstrated the ability to detect deficits in the post-acute phase post-concussion injury (Sinnott et al., 2019) • Symptom provocation with testing • Relies on symptom reporting, which can result in recall bias (Wallace & Lifshitz, 2016)
Dynamic Visual Acuity	Examiner grasps the patient's head with both hands just above the ears. Next examiner oscillates the head at a magnitude of 20-30 degrees from midline. The patient will read the letters on the lowest line of the Snellen chart possible. Retrieved from: https://www.sralab.org/rehabilitation-measures/dynamic-visual-acuity-test-non-instrumented	In patients with vestibular hypofunction: **Sensitivity:** 55% (Schubert et al., 2002) **Specificity:** 90% (Schubert et al., 2002)	• Minimal equipment (eye chart) and training required • Quick (3 minutes), easy to administer • Low cost • Requires hands-on approaches to assessment
Gaze Stabilization Test	Computer-based platform and head mounted rate sensor measures rapid head movement at which the patient can correctly maintain visual acuity on a fixed optotype size. Patient is instructed to fix gaze on monitor while rotating head. Retrieved from: https://www.sralab.org/rehabilitation-measures/gaze-stabilization-test	In patients with vestibular hypofunction: **Sensitivity:** 44% (Mohammad, 2011) **Specificity:** 90% (Mohammad, 2011)	• Quick (10 minutes), to administer • Requires hands-on approaches • Equipment: computer, InVision application
Oculomotor Assessment Measures			
King-Devick	Saccadic eye movement. Speed of rapid number naming recorded (reading aloud single-digit numbers from 3 test cards). Retrieved from: Galetta et al., 2011	**Sensitivity:** 86% (Yorke et al., 2017) **Specificity:** 90% (Yorke et al., 2017)	• Minimal equipment and training required • Quick, easy to administer • Useful for those experiencing persistent symptoms (3 or more months post-injury) (Subotic et al., 2017)
Vestibular Assessment Measures			
Balance Error Scoring System	Single leg stance (stand on one leg), tandem (stand in heel to toe position), and double leg stance (stand feet together) on flat ground and foam surfaces, with eyes closed. Examiner records errors during each condition (open eyes, lift hands off hips, etc.)	**Sensitivity:** 34-60% (in acute phase) (Buckley et al., 2018; Haran et al., 2016) **Specificity:** 91-93% (in acute phase) (Haran et al., 2016)	• Minimal equipment (foam pad, stopwatch) and training required • Quick (10 minutes), easy to administer • Low cost • Use in the post-acute phase (10+ days post-injury) less studied • Learning effects potentially present (Wood et al., 2019) • Less studied in non-athletic adult population
Single leg stance eyes opened/closed	Standing on one leg, eyes open and eyes closed. Time-based tests.	**Unknown**	• Low cost, easy and quick to administer, minimal equipment required • *'Static single-leg postural stability tests are not recommended for concussion assessment because of poor reliability'* (Schneiders et al., 2010) • Limited information on its use in the concussion patient population
Tandem stance eyes closed	Stand in heel to toe stance, eyes closed. Time-based test.	**Unknown**	• Low cost, easy and quick to administer, minimal equipment required • Limited information on its use in the concussion patient population
Sensory Organization Test	Stand on force-place in a 3-sided surround. Six sensory conditions recorded: eyes open on firm surface, eyes closed on firm surface, eyes open with sway referenced visual surface, eyes closed on sway references support surface, eyes closed on sway referenced support surface, eyes open on sway referenced support surface and surround. Retrieved from: https://www.sralab.org/rehabilitation-measures/sensory-organization-test	**Sensitivity:** 34-38% (in acute phase) (Haran et al., 2016) **Specificity:** 88-95% (in acute phase) (Haran et al., 2016)	• Sway values (objective data) captured through force plate technology • Quick to administer (15 minutes) • Use in the post-acute phase (10+ days post-injury) less studied • Specialized training and equipment required (force plate, visual surround) • High cost
Modified Clinical Test of Sensory Interaction in Balance	Four conditions: eyes open, firm surface; eyes closed, firm surface; eyes open, foam surface; eyes closed, foam surface. Time conditions. Retrieved from: https://www.sralab.org/sites/default/files/2017-06/204Lmctsib.pdf	**Unknown**	• Minimal equipment (stopwatch and foam) and training required • Quick (less than 10 minutes), easy to administer • Low cost • Use in the post-acute phase (10+ days post-injury) less studied
Dynamic Gait Index	Eight walking tests: normal walk, change in gait speed, gait with horizontal head turns, gait with vertical head turns, gait and pivot turn, step over obstacle, step around obstacles, steps. Retrieved from: https://www.physio-pedia.com/Dynamic_Gait_Index	**Sensitivity:** 85% (Lei-Rivera et al., 2013) **Specificity:** 69% (Lei-Rivera et al., 2013)	• Minimal equipment (Box (Shoebox), Cones (2), Stairs, 20' walkway, 15" wide) and training required • Quick (15 minutes to administer), easy to administer • Low cost • Components may be challenging to administer virtually (stairs)
Functional Gait Assessment	Gait level surface, change in gait speed, gait with horizontal head turns, gait with vertical head turns, gait and pivot turn, step over obstacle, gait with narrow base of support, gait with eyes closed, ambulating backwards, steps. Retrieved from: https://www.physio-pedia.com/Functional_Gait_Assessment	Unknown	• Minimal equipment (stopwatch, measuring device to mark off area, obstacle of 9-inch height, set of steps) and training required • Quick (5-20 minutes), easy to administer • Low cost

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			• Components may be challenging to administer virtually (stairs, gait with eyes closed) • Limited information on its use in the concussion patient population
Romberg	Stand with feet together on a flat, hard surface. The examinee asked to stand still and keep their eyes open for about 30 seconds. Next, the examinee asked to close their eyes and stand for 30 seconds. Time-based test. Retrieved from: https://www.physio-pedia.com/Romberg_Test	**Sensitivity:** 0.55 (in acute phase) (Murray et al., 2014) **Specificity:** 0.64 (in acute phase) (Murray et al., 2014)	• Minimal equipment (stopwatch) and training required • Quick (2 minutes), easy to administer • No cost • Lacks information on its use in the concussion patient population experiencing persistent symptoms (Guskiewicz, 2011)
Tandem gait	Heel to toe walking	In vestibular patients: **Sensitivity:** 0.77 (Cohen et al., 2018) **Specificity:** 0.72 (Cohen et al., 2018)	• Minimal equipment and training required • Quick, easy to administer • No cost
Head Thrust Test/Head Impulse Test	Grasp patient's head with both hands and tilt head forward to 30 degrees. Slowly move the patient's head side to side, then quickly rotate the patient's head in one direction and stop. Retrieved from: https://www.physio-pedia.com/Head_Impulse_Test	In patients with vestibular hypofunction: **Sensitivity:** 63-72% (Mohammad, 2011) **Specificity:** 64-78% (Mohammad, 2011)	• No equipment and minimal training required • Quick (1 minute), easy to administer • Low cost • Requires hands-on approaches to assessment
Motion Sensitivity Test	Sixteen quick changes to head or body position: sitting to supine, supine to left side, supine to right side, supine to sitting, left Dix-Hallpike, head up from left Dix-Hallpike, right Dix-Hallpike, head up from right Dix-Hallpike, sitting with head tipped to left knee, head up from left knee, sitting with head tipped to right knee, head up from right knee, head turns while sitting, sitting head tilts, 180° turn to right while standing, 180° turn to left while standing. Retrieved from: https://www.sralab.org/rehabilitation-measures/motion-sensitivity-quotient-test	In patients with motion-provoked dizziness: **Sensitivity:** 100% (Akin & Davenport, 2003) **Specificity:** 80% (Akin & Davenport, 2003)	• Minimal equipment (couch, score sheet, pencil, stopwatch) and training required • Low cost • Time to administer: 20-30 minutes
Dizziness Differentiation	Seated in swivel chair. Examiner stabilises head, patient rotates body on chair for 10 seconds. Retrieved from: https://www.physiopedia.com/Cervicogenic_dizziness:_screening	**Sensitivity:** unknown **Specificity:** 90% (Treleaven et al., 2020)	• Minimal equipment (swivel chair) and training required, quick to administer • Low cost • Requires hands on approaches
Cervical Spine Assessment Measures			
Range of Motion	Active range of motion: head turn left, right, up, down, side flexion left and right	**Unknown**	• Could be augmented using sensor technology (Maselli et al., 2018) • Objective values with sensor technology (Maselli et al., 2018) • Easy and quick to administer • Cost and risk of technology
Joint Position Error Test	A target is placed on a wall. A laser pointer is mounted onto a headband on the patient's head. With eyes closed, the patient will actively move their head in one plane of motion and attempt to return to the starting position as accurately as possible. Retrieved from: https://www.physiopedia.com/Cervical_Joint_Position_Error_Test	Cervical spine injury patients: **Sensitivity:** 82% (Cheever et al., 2016) **Specificity:** 90% (Cheever et al., 2016)	• Minimal equipment and training required • Quick to administer (5-10 minutes) • Low cost

Cranio-cervical flexion test	The patient is positioned on the table in a supine crook lying position, with the neck in a neutral position. Before performing the test, an uninflated pressure sensor pressure biofeedback unit must be placed beneath the neck. The pressure sensor is inflated by moving head in nodding motion. Patient maintains position for 10 seconds and repeats increasing the pressure by 2 mmHg each time. Retrieved from: https://www.physio-pedia.com/Cranio%E2%80%90cervical_Flexion_Test	In patients with migraines: **Sensitivity:** 46-71% (Rodrigues et al., 2021) **Specificity**: 35-75% (Rodrigues et al., 2021)	• Quick to administer • Requires pressure sensors • Cost of sensors, risk of technical issues with the use of sensors
Cervical Flexion-rotation test	Patient is seated in chair that swivels. Patient closes eyes and shakes head left to right (as far and as quickly as possible). Examiner then stands behind the patient and provides manual traction to neck. Patient is then instructed to rotate their trunk from the neck down. Retrieved from: https://www.physio-pedia.com/Cervical_Flexion-Rotation_Test	In patients with cervicogenic headache: **Sensitivity:** 90% (Hall et al., 2008) **Specificity:** 88% (Hall et al., 2008)	• Minimal equipment and training required • Quick to administer (less than 5 minutes) • Low cost • Requires stool or chair that swivels • Requires hands-on approaches
Smooth Pursuit Neck Torsion Test	The head remains in neutral while the trunk is rotated 45 degrees in either direction. An object is moved slowly from side to side in front of the patient and the patient should follow only with the eyes. Retrieved from: https://www.physio-pedia.com/Sensorimotor_Impairment_in_Neck_Pain	Cervicogenic dizziness patients: **Sensitivity:** 90% (Cheever et al., 2016) **Specificity:** 91% (Tjell & Rosenhall, 1998)	• Minimal equipment and training required • Quick to administer (less than 5 minutes) • Low cost

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Feasibility Study Patient Demographic Form

Reliability Phase Patient-Participant Demographic Questionnaire

Study ID :	
Demographics	
1. Sex	☐ Male ☐ Female ☐ Prefer not to respond ☐ Other: *insert text*
2. Gender	☐ Man ☐ Woman ☐ Gender diverse ☐ Prefer not to respond ☐ Other: *insert text*
3. Age	*insert text*
4. Ethnicity	☐ White ☐ South Asian (e.g., East Indian, Pakistani, Sri Lankan) ☐ Chinese ☐ Black ☐ Filipino ☐ Latin American ☐ Arab ☐ Southeast Asian (e.g., Vietnamese, Cambodian, Malaysian, Laotian) ☐ West Asian (e.g., Iranian, Afghan) ☐ Korean ☐ Japanese ☐ Do not know ☐ Prefer not to respond ☐ Other: *insert text*
5. Highest Educational Attainment	☐ Less than secondary (high) school graduation ☐ Secondary (high) school diploma or equivalent ☐ Some postsecondary education ☐ Postsecondary certificate, diploma or degree ☐ Prefer not to respond
6. Household annual income	☐ Less than $30,000 ☐ $30,000 to less than $40,000 ☐ $40,000 to less than $50,000 ☐ $50,000 to less than $60,000 ☐ $60,000 to less than $70,000 ☐ $70,000 to less than $80,000 ☐ $80,000 to less than $90,000 ☐ $90,000 to less than $100,000 ☐ $100,000 and over ☐ Prefer not to respond
7. Number of earners in household	*insert text*
8. Do you have someone at home or nearby to care for you if needed?	☐ Yes ☐ No
9. Relationship to person at home or nearby	☐ Parent/Guardian

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	☐ Partner/Spouse ☐ Friend ☐ Other: *insert text*
10. Current work status	☐ Off work ☐ Modified return to work, same occupation ☐ Full return to work, same occupation ☐ Modified return to work, different occupation ☐ Full return to work, different occupation ☐ Other: *insert text*
10.A) If modified, please specify modifications:	*insert text*
10.B) If different occupation, please specify previous occupation:	*insert text*
11. If applicable, date initiated gradual return to work plan?	*insert text*
12. Current occupation	*insert text*
13. Are you currently working full-time or part-time?	☐ Full-time ☐ Part-time ☐ Other: *insert text*
14. Are you a student?	☐ Yes ☐ No
14.A) If yes, are you receiving accommodations at school?	☐ Yes ☐ No
14.B) If yes, are you full-time or part-time?	☐ Full-time ☐ Part-time ☐ Other: *insert text*
Health Status	
15. Now I'm going to read a list of activities that you might do during a typical day. As I read each item, please tell me if your health now limits you a lot, limits you a little, or does not limit you at all in these activities.	
15.A) Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf. Does your health now limit you a lot, limit you a little, or not limit you at all?	☐ Yes, limited a lot ☐ Yes, limited a little ☐ No, not limited at all
15.B) Climbing several flights of stairs. Does your health now limit you a lot, limit you a little, or not limit you at all?	☐ Yes, limited a lot ☐ Yes, limited a little ☐ No, not limited at all
16. Perceived mental health	☐Excellent or very good (perceived mental health) ☐Good (perceived mental health) ☐Fair or poor (perceived mental health)
17. Environmental aids needed because of your brain injury (select all that apply)	☐ Walking aid ☐ Sunglasses ☐ Earplugs ☐ Hat ☐ Blue light glasses ☐ Other: *insert text*
Injury Details	

18. Date of injury	*insert text*
19. Diagnosis (mild, moderate, severe brain injury, stroke, etc.)	*insert text*
20. Mechanism of injury	*insert text*
21. Place of injury	*insert text*
22. Currently experienced symptoms	1. 2. 3.
Virtual Assessment Experience Details	
23. Have you attended a virtual physical assessment over video?	☐ Yes ☐ No
24. If yes, how many?	*insert text*
25. If yes, list location(s) of virtual assessment(s) (OWN, rehabilitation clinic, etc.)	*insert text*
26. How far do you live from the assessment centre (in minutes)?	*insert text*
27. What technology do you have available for a video virtual assessment (smartphone, computer, etc.)?	*insert text*
28. How are you connected to the Internet for a virtual video assessment:	☐ Fiber-optic ☐ Cable Internet ☐ Digital subscriber line (DSL) ☐ Dial-up through telephone line ☐ Other fixed 5G hotspot ☐ Fixed wireless, point-to-point ☐ Satellite broadband ☐ Municipal wireless ☐ Mobile data plan ☐ Other: *insert text*
29. How often do you, or other members of your household, experience connectivity issues with your home Internet connection while using basic video services (video conferencing, such as using Microsoft Teams or Zoom or streaming services such as Netflix)?	☐ Frequent problems ☐ Occasional problems ☐ No problems ☐ Not applicable ☐ Other: *insert text*
30. How often do you use technology (computer, smartphone)?	☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always
31. How often do you seek assistance when using technology?	☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always

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Feasibility Study Clinician Demographic Form

Reliability Phase Clinician-Participant Demographic Questionnaire

Study ID :	
1. Age	☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ 60+ ☐ Prefer not to respond
2. Clinical profession	☐ Physiatrist ☐ Neurologist ☐ Sport Medicine Physician ☐ Family Medicine Physician ☐ Other: *insert text*
3. Years in practice with ABI patients	☐ 1-5 ☐ 5-10 ☐ 10+
4. Volume of practice of ABI patients annually	☐ 0-25 ☐ 25-50 ☐ 50+
5. Self-report of competency of in-person neurological assessment	Strongly Incompetent, Incompetent, Neutral, Competent, Strongly Competent
6. Self-report of competency of virtual neurological assessment	Strongly Incompetent, Incompetent, Neutral, Competent, Strongly Competent

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Feasibility Study Assessment Toolkit

In-Person/Virtual Assessment

Study ID: _____

Clinician Study ID: _____

Time Commenced Assessment: _____

Coordination (finger-to-nose)	
Right: Normal ☐ Abnormal ☐	**Left:** Normal ☐ Abnormal ☐

Balance Testing (eyes open and closed)		
Double Leg Stance	Eyes Open Normal ☐ Abnormal ☐ Eyes Closed Normal ☐ Abnormal ☐	
Single Leg Stance	**Right:** Eyes Open Normal ☐ Abnormal ☐ Eyes Closed Normal ☐ Abnormal ☐	**Left:** Eyes Open Normal ☐ Abnormal ☐ Eyes Closed Normal ☐ Abnormal ☐
Tandem Stance	**Right:** Eyes Open Normal ☐ Abnormal ☐ Eyes Closed Normal ☐ Abnormal ☐	**Left:** Eyes Open Normal ☐ Abnormal ☐ Eyes Closed Normal ☐ Abnormal ☐

Cervical ROM (degrees)	
Flexion	
Extension	
Right Side Flexion	
Left Side Flexion	
Right Rotation	
Left Rotation	

VOMS						
	Not tested	Headache 0-10	Dizziness 0-10	Nausea 0-10	Fogginess 0-10	Comments
Baseline						
Saccades-Horizontal						
Saccades-Vertical						
Smooth Pursuits						
NPC						
VOR-Horizontal						
VOR-Vertical						
Visual motion sensitivity (VMS)						
Near Point Convergence (average in cm of 3 trials)						

Saccades
Normal ☐ Abnormal ☐

Effort
Was the patient employing optimal effort throughout the assessment? Yes ☐ No ☐ On a scale of 0-10, rate the patient's level of effort throughout the assessment: 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

Adverse Events

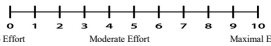
Time Completed Assessment:

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Instructions for Clinicians

The following instructions have been obtained from the Virtual Concussion Exam Training Manual developed by Johnston et al. (2021). Permission was granted by Dr. Johnston to use the manual for this research study.

Assessments	Instructions
Coordination: finger-to-nose	**Finger-to-nose:** "I want you to hold your left index finger out about 18 inches in front of your left shoulder and use your right index finger to touch your nose, then touch your left finger- move your left finger across to in front of your right shoulder and touch your nose with your right finger then touch your left finger again." "Now I want you to do this with your eyes closed: move your right finger from your nose to your left finger on your left side then repeat over on your right side." "Now I want you to switch hands and hold your right index finger out in front of your right shoulder and use your left hand to touch your nose, then your finger, and repeat moving your right finger over to the other side." "Now, one more time with your left hand touching your nose with your eyes closed." (Johnston et al., 2021)
VOMS	"Before we begin, do you have any dizziness, nausea, fogginess or headache? If yes please rate each rate on a scale for 0 (none) to 10 (severe)." "Now, I am going to ask you to move your eyes in different directions and after each test I want you to tell me if you feel any new symptoms or worsened symptoms compared to before the test and rate them on a scale for 0 (none) to 10 (severe). **Smooth Pursuits** "The first thing I want you to do is hold your thumb right in front of your nose, about 18 inches away – your arm bent a little at the elbow, and I want you to look at your thumb without moving your head and follow your thumb. Move your thumb side to side just beyond your shoulders on either side taking about two seconds to go each direction. Follow it with your eyes twice from left to right then back and again left to right then back." o "Do you feel any new symptoms or worsened symptoms compared to before the test? Rate them on a scale for 0 (none) to 10 (severe)." "Now, I want you to move your thumb in front of your nose and go up and down just above your head and then down to just below your lungs. Take about two seconds to go each direction, up and down and again up and down." o "Do you feel any new symptoms or worsened symptoms compared to before the test? Rate them on a scale for 0 (none) to 10 (severe)." **Saccades** "Now, I want you to take your index fingers on both hands and hold them up just beyond your shoulder width, about 18 inches in front of you- arm with elbow a little bent. Without moving your head, I want you to look back and forth to your fingers, with both eyes at the same time, as fast as you can 20 times. Did that make you feel anything?" o "Do you feel any new symptoms or worsened symptoms compared to before the test? Rate them on a scale for 0 (none) to 10 (severe)." "Now, I want you to do the same thing with your fingers 18 inches in front of you just above your head and at just below your lungs. Without moving your head, look up and down so that you're looking at your fingers back and forth back and forth as fast as you can twenty times." o "Do you feel any new symptoms or worsened symptoms compared to before the test? Rate them on a scale for 0 (none) to 10 (severe)." **Near Point Convergence** Now focus on a small target (approximately 14 point font size) at arm's length and slowly bring it toward the tip of your nose. Stop moving the target when you see two distinct images or when you are instructed by me (when observe an outward deviation of one eye). Do you feel any new symptoms or worsened symptoms compared to before the test? Rate them on a scale for 0 (none) to 10 (severe)." **Vestibulo-ocular reflex** "Now, I want you to focus directly on my nose and move your head side to side quickly ten times while continually looking at my nose. Did that give you any new symptoms or make your dizziness or headache worse?" o "Do you feel any new symptoms or worsened symptoms compared to before the test? Rate them on a scale for 0 (none) to 10 (severe)." "Now, I want you to do the same thing, look at my nose, but go up and down with your head ten times. Always keep your eyes focused on my nose. Did that give you any symptoms?" o "Do you feel any new symptoms or worsened symptoms compared to before the test? Rate them on a scale for 0 (none) to 10 (severe)." (Johnston et al., 2021)

	IF STABLE- Visual Motion Sensitivity Now I want you to stand with feet shoulder width apart, facing the screen. Hole your arms outstretched and focus on your thumbs. Maintaining focus on thumbs, rotate, together as a unit, (head, eyes and trunk). A metronome is used to ensure the speed of rotation is maintained at 50 beats/min (one beat in each direction). One repetition is complete when the trunk rotates back and forth to the starting position, and 5 repetitions are performed. Do you feel any new symptoms or worsened symptoms compared to before the test? Rate them on a scale for 0 (none) to 10 (severe)." (Johnston et al., 2021)
Balance Testing	"I am going to check your balance now. For this I need you to stand up preferably next to a counter or table or a dresser or something in case you are swaying a bit and need to catch your balance. I need you to stand so that I can see your whole body in the camera, especially your midsection and upper legs and feet." "I want you to stand with your feet together side by side, your hands at your side," OBSERVE FOR STEADINESS BEFORE PROCEEDING. "Now close your eyes and hold that position standing steady for 20 seconds. If you step out of it, sway, or need to move your arms out for balance just get back into the position as soon as you can." (Johnston et al., 2021) Additional test (not included in training manual): "Now I was you to stand on one leg and hold that position for 20 seconds." Repeat this test on the opposite foot and with eyes closed. "Now, I want you to try a heel toe alignment of your feet with your dominant foot, the foot with which you would kick a soccer ball, in front and your back foot toes right up against your heel. Put your hands on your hips, close your eyes, and try to hold that position for 20 seconds." (Johnston et al., 2021)
Saccades	"Now, I want you to take your index fingers on both hands and hold them up just beyond your shoulder width, about 18 inches in front of you- arm with elbow a little bent. Without moving your head, I want you to look back and forth to your fingers, with both eyes at the same time, as fast as you can 20 times." (Johnston et al., 2021) Note: you do not need to repeat this test if already completed as part of the VOMS, however you do need to document if normal or abnormal findings were observed.
Range of motion	"I am going to look at the range of motion of your neck, which is how well your neck is moving and if it is sore. For this I need you to sit up and angle your camera down so I can see the top of your shoulders and chest." "First, I want you to look down to the floor and then look up to the ceiling and tell me if you feel any discomfort or any new symptoms when you do that. Now, I want you to look as far as you can to the right side and then all the way over as far as you can to the left side and tell me if you feel anything. Now I want you to tilt your head to your right shoulder and then up and tilt your head to your left shoulder, as far as you can. Tell me if you feel anything." (Johnston et al., 2021)
Effort	Was the patient employing optimal effort throughout the assessment? On a scale of 0-10, rate the patient's level of effort throughout the assessment: 

Additional Tips:

- Try not to verbalize/comment on your findings as you are going through the assessments.
- Try to center the patient on the camera for assessment, if possible, especially for range of motion testing.
- Ask the patient to turn sideways for tests when needed (such as for cervical spine flexion/extension, NPC, finger-to-nose).
- Try to announce the measure you are completing prior to completion of it.
- If the patient is unable to complete one of the assessments due to symptom aggravation or any other reason, you do not have to complete it.
- You do not need to use a metronome for the VOMS due to time limitations.

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Feasibility Study Patient Feedback Form

Study ID: _____

Patient-Participant Feedback

1. Do you have any feedback about the environmental set-up of the virtual assessment (screen size, lighting, space, etc.)?

2. Do you think your clinician obtained the same information in the virtual assessment when compared to the in-person assessment?

3. I feel confident in my clinicians' findings on the virtual assessment:

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

4. I feel confident in my clinicians' findings on the in-person assessment:

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

5. Do you have any other feedback regarding the virtual assessment?

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Feasibility Study Clinician Feedback Form

Clinician ID: _____

Patient ID: _____

Clinician Feedback

1. Do you have any feedback about the environmental set-up of the virtual assessment (screen size, lighting, space, etc.)?

2. Do you think you obtained the same information in the virtual assessment when compared to the in-person assessment?

3. I feel confident in my findings on the virtual assessment:

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

4. I feel confident in my findings on the in-person assessment:

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

5. Do you have any other feedback regarding the virtual assessment?

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Appendix D: Protocol for a Method-Comparison Study (Extension of Thesis Work)

The following manuscript contains the protocol of a method-comparison study that is an extension of my thesis work. This paper includes a protocol for a study evaluating the reliability and sensitivity of the virtual physical concussion assessment using an adequately powered sample size. This paper was published in the Journal of Medical Internet Research-Research Protocols (International Registered Report Identifier (IRRID): DERR1-10.2196/57663). Ethics approval was obtained by the Ottawa Health Sciences Network Research Ethics Board (20210575-01H), the Bruyère Research Ethics Board (M16-22-006) and the University of Ottawa Board of Ethics (H-02-22-7611).

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Protocol

Reliability and Sensitivity of a Virtual Assessment Developed for Workplace Concussions: Protocol for a Method-Comparison Study

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Abstract

Background: Workplace mild traumatic brain injuries are frequently associated with persistent symptoms, leading to a reduction in productivity at work or even disability. People who sustain workplace injuries frequently need rehabilitation and support, and the challenges of delivering these services was heightened during the COVID-19 pandemic as injured workers had to be cared for remotely. Currently, clinicians are conducting both in-person and virtual (remote) concussion assessments; however, the measures that are being used to complete these assessments have undocumented psychometric properties.

Objective: This study will document the psychometric properties of the clinical measures that are being used remotely and their ability to produce similar results to in-person assessments. Specifically, through this method-comparison study, we aim to (1) evaluate the sensitivity of the measures included in a virtual assessment toolkit when compared to an in-person assessment and (2) determine the interrater and intrarater reliabilities of the measures included in a virtual assessment toolkit.

Methods: Patient participants (people living with acquired brain injuries) will attend two assessments (in person and virtual) at the Ottawa Hospital. The two assessments will be identical, consisting of the measures included in our previously developed virtual concussion assessment toolkit, which includes finger-to-nose testing, the Vestibular/Ocular Motor Screening tool, balance testing, cervical spine range of motion, saccades testing, and evaluation of effort. All virtual assessments will occur using the Microsoft Teams platform and will be audio/video-recorded. The clinician assessor and patient participant will complete a feedback form following completion of the assessments. A different clinician will also document the findings on observed videos of the virtual assessment shortly after completion of both in-person and virtual assessments and approximately 1 month later. Interrater reliability will be assessed by comparing the second clinician's observation with the first clinician's initial virtual assessment. Intrarater reliability will be evaluated by comparing the second clinician's observation with their own assessment approximately 1 month later. Sensitivity will be documented by comparing the findings (identification of abnormality) of the in-person assessment completed by the initial clinician assessor with those of the second clinician assessor on the observation of the recording of the virtual assessment.

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Results: As of May 2024, we have recruited 7 clinician assessors and completed study assessments with 39 patient participants. The study recruitment is expected to be completed by September 2024.

Conclusions: Currently, it is unknown if completing concussion assessments virtually produces similar results to the in-person assessment. This work will serve as a first step to determining the similarity of the virtual assessment to the matching in-person assessment and will provide information on the reliability of the virtual assessment.

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(JMIR Res Protoc 2024;13:e57663) doi: 10.2196/57663

KEYWORDS

telehealth; virtual care; concussion; mTBI; mild traumatic brain injury; assessment; examination

Introduction

Background

A direct or indirect head impact leading to a concussion is a form of mild traumatic brain injury [1], which results in an alteration of brain functioning [2,3]. Most individuals who sustain a concussion experience rapid recovery within the first 2 weeks to 1 month following the injury. There are, however, instances where individuals continue to experience persistent symptoms after a concussion, with a reported occurrence of approximately 15%-20% [4]. These symptoms may persist beyond 1 year following the injury [3,5]. Factors such as premorbid characteristics (age, sex, concussion history), psychological factors, and injury-related factors (ie, severity of injury) are likely contributors to the persistence of the symptoms [6]. Postconcussion symptom presentation can vary widely, including cognitive deficits such as memory issues, vestibular deficits such as balance issues or dizziness, and ocular deficits such as blurred vision, among others [1,7-9]. There is a need for a multifactorial assessment approach due to the diversity in symptom presentation. Specifically, it is recommended to incorporate measures targeting each of the commonly experienced symptoms into a battery of tests [10].

There is evidence suggesting a growing documented incidence of concussion in the workplace context [11]. Kristman et al [12] reported that there are approximately 39-58 workplace concussions per 10,000 claims annually in Ontario, Canada [12]. Workplace concussions often lead to greater delays in return to work compared to injuries sustained outside of the workplace context [5,13]. It is estimated that roughly 60% to 90% of adults return to work within 6 months postconcussion injury, with the remainder continuing to be off work at this time point [5]. Compensation associated with a workplace injury may be a contributor to this delay in return to work [5,13].

Several factors can contribute to delays in return to work following concussion, including a lower level of education, more severe immediate symptoms post injury, and other injuries sustained [5]. In general, workplace concussions pose significant challenges. These include financial burdens that are felt by the health care system, employers, the Workplace Safety and Insurance Board (WSIB), and the workers themselves [14]. For the patient, lives are disrupted due to prolonged recovery times [13], resulting in the need for additional support from the WSIB for individuals presenting for specialized assessments.

The onset of the COVID-19 pandemic affected how specialized postconcussion assessments could be completed along with a need to switch to virtual care [15]. However, it is not known whether the measures being used by clinicians in virtual assessments are the same as those used for in-person assessments [16]. Additionally, the reliability of the virtual concussion assessments being conducted is unknown. Measures used in person that have shown strong psychometric properties may not produce the same or similar results when administered virtually [17]. Furthermore, the level of agreement between measures used in the in-person concussion assessment and those used in the virtual assessment has not yet been established. Currently, clinicians are continuing to complete both in-person and virtual concussion assessments; however, there is limited information on the measures used in the virtual assessment. It is important to gain an understanding of the properties of the clinical measures and their ability to produce similar results to the in-person assessment to inform the effectiveness of use in a virtual context [18].

The preparatory work for this study was initiated by developing a virtual assessment toolkit. Clinician surveys were used to identify relevant measures for assessing the physical domains of concussion [19]. A working group refined the measures feasible for virtual administration based on expert opinion. Focus groups then identified barriers and facilitators for virtual concussion assessments. The resulting virtual assessment toolkit was then used in a feasibility study to evaluate recruitment rates, procedure acceptability, and time to assess; the manuscript reporting these findings is currently being prepared for submission.

Objectives

The objectives of this method-comparison study are two-fold: (1) to evaluate the sensitivity of the virtual assessment against the gold standard of the in-person assessment and (2) to determine interrater and intrarater reliabilities of the measures in the virtual assessment. This study will further contribute to the development of a virtual toolkit of assessments across four physical domains along with the evaluation of effort, specifically designed for the WSIB context.

Methods

Design

This study will follow a prospective method-comparison study design [17].

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Participants

Patient Participants

Eligible participants will be adults 18 years or older who have sustained an acquired brain injury (concussion or other form) and are being assessed by a physician, physician assistant, and/or physiotherapist at the Ottawa Hospital. In addition to people with concussions, people living with acquired brain injuries, including moderate to severe traumatic brain injury or hypoxic brain injury, will be recruited. In this study, we are assessing the consistency of physical examination findings; people with other forms of acquired brain injury such as severe traumatic brain injury more frequently have signs of central nervous system deficits, whereas these assessments are often normal during a postconcussion examination [20,21]. This inclusion is thus intended to ensure recruitment of participants with a broad range of identifiable deficits on all components of the assessment. Those unable to complete the study assessments and unable to speak English or French will be excluded from the study. Participant information will be documented, including demographics, functional status, environmental aids used, socioeconomic and work status, injury information, and information related to technology experience.

Clinician Participants

Clinicians with expertise in conducting assessments for people with acquired brain injuries will be invited to participate in this project. Demographic information for participating clinicians will be documented, including age, years practicing with patients who have an acquired brain injury, professional background (physiotherapist, physician assistant, physiatrist, other), and self-reports of competency with in-person and virtual neurological assessments.

Sample Size

The target sample size of this method-comparison study is 60 patient participants. For the objective of assessing the sensitivity of the virtual assessment against the gold standard of in-person assessment, with a total of 60 participants, 50 (83%) of whom are expected to have an abnormal finding, and an estimated sensitivity ranging from 77% to 96%, the two-sided 95% CI around the estimated sensitivity will have a total width ranging from 8.7% to 25.3% (or margin of error 4.4%-12.7%). For the objective of assessing interrater agreement between two clinicians conducting a virtual assessment using the κ statistic, a sample size of 60 participants achieves 80% power to detect a true κ value of 0.89 using a one-sided test at the 5% significance level, assuming that 90% of participants are classified as abnormal; κ under the null hypothesis was specified as 0.5.

Recruitment and Consent

Patient Participants

Purposive sampling methods will be used to recruit individuals living with acquired brain injuries with impairments spanning all domains of interest. The participants will be recruited through the Ontario Workers Network and relevant rehabilitation clinics at the Ottawa Hospital. Electronic medical records will be screened to identify eligible patients, who will then be called or approached in person for consent.

Clinician Participants

Clinicians will be recruited from the Ontario Workers Network and relevant rehabilitation clinics at the Ottawa Hospital to participate as clinician assessors in the study. Consent will be obtained over the telephone or face to face.

Outcomes

The virtual toolkit of assessments will include the following outcome measures: the classification of abnormality (binary variable) on the finger-to-nose test, Vestibular/Ocular Motor Screening tool, balance testing, cervical spine range of motion, saccades testing, and evaluation of effort. The procedures outlined below provide details for these outcome measures, including the methods used for evaluating the sensitivity of the virtual assessment when compared to the in-person assessment and the interrater and intrarater reliabilities of the virtual assessment.

Procedures

Training

Training of the assessing clinicians on the outcome measures will occur prior to commencement of patient-participant recruitment. A previously developed training manual [22] will be used to complete the training. Training will be uniform with the goal of standardizing clinician completion of the assessments.

Assessments

Data collection will occur in Research Electronic Data Capture (REDCap), a secure electronic data capture application. An assessing clinician will conduct two assessments: one in person and one virtual. Both assessments will be identical consisting of all measures from the virtual assessment toolkit (see Table 1). Both assessments will be completed at the Ottawa Hospital. When possible, assessments will occur on the same day with a brief rest period in between [23,24]. The order of assessment completion (in person vs virtual) will be randomized and counter-balanced. A random-numbers table will be generated and imported into REDCap and the randomization will occur through REDCap. In addition to the assessments identified in Table 1, clinicians will document adverse events (if any) and will record findings from the assessments on a paper copy, which will be directly input into REDCap by a research team member.

For the virtual assessment, the patient participants will be located in a separate room from the assessing clinicians within the Ottawa Hospital. All patient participants will use the same computer and will be provided with technical support from a research team member as needed. The virtual assessments will be conducted in the clinical environment to standardize as many components of the assessment as possible, including computer screen, lighting, image size, and room setup. During the virtual assessment, several safety measures will be implemented: (1) a research team member will be present in the room throughout and (2) the patient participant will stand in front of a wall/bed/chair or with their back at a corner during the vestibular

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assessments in case of loss of balance. All the virtual assessments will occur through the Microsoft Teams platform. The study assessments will be audio/video-recorded using the record function on Microsoft Teams.

Where possible, both assessments will be completed on the same day. It is estimated that a portion (~5%) of participants may be unable to complete both the in-person and virtual assessments on the same day, either due to lack of time or inability to tolerate a second assessment as a result of symptom aggravation (eg, headaches, dizziness, nausea, sensitivity to noise and light). For these participants, the second assessment (virtual or in person) will be scheduled for completion within 1 week of the initial assessment.

Following completion of the assessments, the patient participants and clinician assessors will complete a feedback form. Participants will complete a feedback form (see Multimedia Appendix 1) related to completion of the virtual assessment, the environmental setup, and confidence in the assessment findings.

Table 1. Outline of measures included in the virtual assessment toolkit to be completed in both in-person and virtual assessments[a].

Domain	Measures	Documentation of findings by clinicians
Neurological examination	Coordination: finger-to-nose test	Abnormal (hesitation, tremor, over- or undershooting [25])/normal
Vestibular	VOMS[b]	Change in symptoms (≥2 point increase indicates abnormality [26]); average distance for 3 trials of near-point convergence in centimeters (≥5 cm convergence indicates abnormality [26])
Vestibular	Balance (feet together, single-leg stance, tandem stance) with eyes open and eyes closed for 20 seconds each	Abnormal (unable to complete 20-second balance [22])/normal
Oculomotor	Saccades	Abnormal (observe saccade initiation, range of motion and conjugacy, speed, accuracy, intrusions, or oscillations [27])/normal
Cervical	Range of motion (flexion, extension, right and left lateral flexion, right and left rotation)	Estimated angles for each recorded abnormality (determined by comparison to norms in people aged 20-59 years: flexion=50°-72°, extension=58°-77°, lateral flexion=37°-47°, rotation=67°-81° [28])
Effort	Rating scale	Full use of effort documented as yes or no (clinician discretion); rating scale documented from 0 (no effort) to 10 (maximum effort) (clinician discretion)

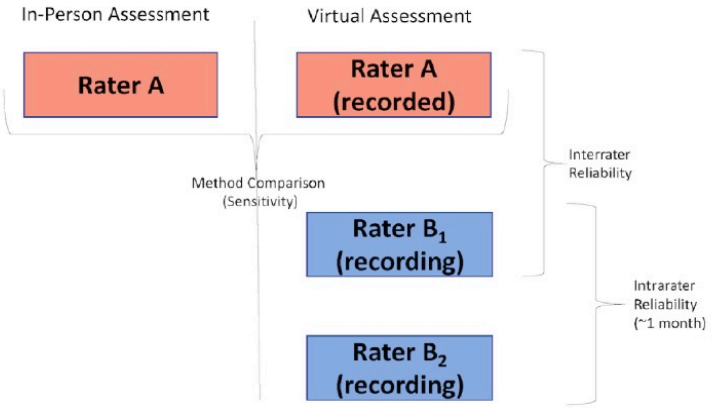
[a]For a complete presentation of the instructions used to administer the measures, see Johnston et al [22].

[b]VOMS: Vestibular/Ocular Motor Screening.

Observation and Rating of Audio-Video Recordings

A second clinician (rater B in Figure 1 [17]) will complete two ratings of the recording of the virtual assessment (in a randomized order for participants) at 1-month intervals. Clinicians will record findings from the assessments on paper or electronic copies, which will be input directly into REDCap by a research team member. See Figure 1 [17] for an outline of study assessment procedures.

Figure 1. Assessment procedures (adapted from Russell et al [17]).



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Analysis

Assessments Overview

Patient and clinician participant characteristics will be descriptively analyzed. IBM SPSS (version 28) will be used to calculate the sensitivity of virtual assessments versus in-person assessments, along with the κ values (interrater and intrarater reliabilities) of the virtual assessments (see Figure 1 for comparisons).

Method-Comparison (Sensitivity) Analysis

The sensitivity of the virtual assessment compared to the gold-standard in-person assessment (rater A in person vs rater A virtual) will be determined, where the assessment of the uncertain classification of the measures used virtually will occur against the gold standard or "true" classification, which is the in-person assessment in this study. The findings of the initial clinician assessor (rater A) that completed the in-person and virtual assessments will be compared to determine the sensitivity of the measures administered virtually. In this case, sensitivity (true positives divided by the sum of true positives and false negatives multiplied by 100) refers to the ability of the virtual measure to identify a deficit or positive finding when the in-person measure identifies the deficit or positive finding. Values closer to 100% indicate greater sensitivity.

Reliability

To calculate the interrater reliability of the virtual assessment, the findings of rater A (virtual assessment) will be compared to the findings of rater B_1 (initial observation of the virtual assessment recording). To determine the intrarater reliability of the virtual assessment, the findings of rater B_1 (initial observation of the virtual assessment) will be compared to the findings of rater B_2 (second observation of the virtual assessment) approximately 1 month after the initial observation. Estimates of reliability will be calculated using the κ statistic (classification of abnormal vs normal) for all measures included in the toolkit.

Adverse Events

Adverse events, including the type and severity, will be summarized by assessment type (in person or virtual).

Ethical Considerations

Ethics approval was obtained from the Ottawa Health Sciences Network Research Ethics Board (20230311-01H), the Bruyère Research Ethics Board (M16-22-006), and the University of Ottawa Board of Ethics (H-06-23-9348). All potential risks and adverse consequences will be relayed to participants verbally and all participants will provide verbal consent over the telephone or informed consent in person prior to their scheduled appointment. A wet-ink signature will be obtained from all participants on the day of their scheduled assessment. Privacy and confidentiality will be maintained by using deidentified data. Patient participants will be provided with a CAD $30 (~US $22) gift card and parking voucher as a token of appreciation for their participation in the study.

Results

As of May 2024, we enrolled and completed both the in-person and virtual assessments for 39 patient participants. We have recruited 7 clinician assessors. Recruitment and testing are expected to be completed by September 2024.

Discussion

Projected Significance

This study will establish the reliability and sensitivity properties associated with 5 physical components of the virtual concussion assessment. There is an identified gap in current knowledge with limited research conducted on the reliability and comparability of virtual concussion assessments in comparison to in-person assessments. While virtual care has demonstrated to be a valuable approach to concussion assessment and management [29,30], there is a need for additional information regarding the psychometric properties of outcome measures. This information is essential for instilling confidence in the administration of these measures in a practical setting. Virtual approaches to care have been used for many years; however, the COVID-19 pandemic significantly increased their use in an effort to reduce hospital visits [15]. While the COVID-19 pandemic initiated this increased use of virtual care, some assessments are continuing to be offered virtually. Using measures with acceptable properties in a virtual context is important in practice to ensure accurate identification of problem areas on virtual assessments so that treatment interventions can be appropriately directed [31]. Despite measures showing adequate properties when administered in person, they may produce different results when administered in a virtual context [17,32], thereby providing a rationale to carry out this work. The aim of completing this method-comparison study is to obtain preliminary information on the virtual assessment in relation to the WSIB context.

Strengths and Limitations of the Methodological Approach

The strengths of this method-comparison approach include the use of commonly adopted technology and software for virtual brain injury assessments in a practical setting. Further, including a wide range of acquired brain injury severities in our sample ensures the inclusion of abnormalities spanning all relevant domains. This will make the findings not only applicable to current practice but also potentially generalizable to different types of acquired brain injury.

We plan to assess the virtual evaluation in a controlled hospital setting. Moving forward, it would be beneficial to evaluate the virtual assessment in environments that are less standardized such as patients' homes or community clinics where physician specialists are in a different location than the patient.

Finally, due to constraints in clinic scheduling, a methodological decision was made to have the same clinician (rater A) conduct both the in-person and virtual assessments with the participants. In attempts to address this concern, the order of study assessments (in person and virtual) will be randomized and counter-balanced.

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Conclusion

This method-comparison study is an important endeavor considering the limited exploration of virtual concussion assessments in the literature despite their increasing use in practice. This study aims to determine whether virtual and in-person assessments yield similar results in terms of the identification of abnormality in common physical domains of a concussion assessment. The study will also assess the interrater and intrarater reliabilities of the virtual assessment, contributing valuable insights to the field of concussion rehabilitation.

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Authors' Contributions

All authors have made substantial contributions to the work presented in this paper.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Feedback forms.
[PDF File (Adobe PDF File), 180 KB-Multimedia Appendix 1]

Multimedia Appendix 2

Peer-review reports from the Strategic Research - Workplace Safety and Insurance Board (WSIB) (Ontario, Canada).
[PDF File (Adobe PDF File), 164 KB-Multimedia Appendix 2]

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Abbreviations

REDCap: Research Electronic Data Capture
WSIB: Workplace Safety and Insurance Board

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Edited by D Khajeei; The proposal for this study was externally peer-reviewed by the Strategic Research - Workplace Safety and Insurance Board (WSIB) (Ontario, Canada). See the Multimedia Appendix for the peer-review report; Submitted 04.03.24; accepted 14.06.24; published 26.07.24.

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Appendix A
Feedback Forms

Patient-Participant Feedback

1. Do you have any feedback about the environmental set-up of the virtual assessment (screen size, lighting, space, etc.)?

2. Do you think you your clinician obtained the same information in the virtual assessment when compared to the in-person assessment?

3. I feel confident in my clinicians' findings on the virtual assessment:

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

4. I feel confident in my clinicians' findings on the in-person assessment:

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

5. Do you have any other feedback regarding the virtual assessment?

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Clinician Feedback

1. Do you have any feedback about the environmental set-up of the virtual assessment (screen size, lighting, space, etc.)?

2. Do you think you obtained the same information in the virtual assessment when compared to the in-person assessment?

3. I feel confident in my findings on the virtual assessment:

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

4. I feel confident in my findings on the in-person assessment:

- ○ Strongly Disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly Agree

5. Do you have any other feedback regarding the virtual assessment?

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Appendix E: Published Manuscripts

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Protocol

Identification of Clinical Measures to Use in a Virtual Concussion Assessment: Protocol for a Mixed Methods Study

Keely Barnes[1,2,3*], MHK; Heidi Sveistrup[1,2*], PhD; Mark Bayley[4,5], MD; Mary Egan[1,2], PhD; Michel Rathbone[6], MD, PhD; Monica Taljaard[3,7], PhD; Shawn Marshall[2,3,8*], MD, MSc

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[*]these authors contributed equally

Abstract

Background: Workplace concussions can have a significant impact on workers. The impact of concussion symptoms, combined with challenges associated with clinical environments that are loud, bright, and busy, create barriers to conducting effective in-person assessments. Although the opportunity for remote care in rural communities has long been recognized, the COVID-19 pandemic has catalyzed the transition to virtual assessments and care into the mainstream. With this rapid shift, many clinicians have been completing remote assessments. However, the approaches and measures used in these assessments have not yet been standardized. Furthermore, the psychometric properties of the assessments when completed remotely using videoconference have not yet been documented.

Objective: Through this mixed methods study, we aim to (1) identify the concussion assessment measures clinicians are currently using in person and are most relevant to the following 5 physical domains: neurological examination (ie, cranial nerve, coordination, motor, and sensory skills), cervical spine, vestibular, oculomotor, and effort assessment; (2) document the psychometric properties of the measures identified; (3) identify measures that appear feasible in a virtual context; and (4) identify practical and technical barriers or challenges, facilitators, and benefits to conducting or engaging in virtual concussion assessments.

Methods: This study will follow a sequential mixed methods design using a survey and Delphi approach, working groups with expert clinicians, and focus groups with experienced clinicians and people living with concussions. Our target sample sizes are 50 clinicians for the Delphi surveys, 4 clinician-participants for the working group, and 5-7 participants for each focus group (roughly 6-10 total groups being planned with at least two groups consisting of people living with concussions). The results from this study will inform the decision regarding the measures that should be included in a virtual assessment tool kit to be tested in a future planned prospective evaluation study.

Results: The study is expected to be completed by January 2023.

Conclusions: This mixed methods study will document the clinical measures that are currently used in person and will identify those that are most relevant to assessing the physical domains impacted by concussions. Potential feasibility of using these measures in a virtual context will be explored.

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International Registered Report Identifier (IRRID): DERR1-10.2196/40446

(JMIR Res Protoc 2022;11(12):e40446) doi: 10.2196/40446

KEYWORDS

telehealth; virtual care; concussion; mild traumatic brain injury; assessment; examination

Introduction

Background

Concussions or mild traumatic brain injuries affect thousands of Canadians every year [1]. Workplace injuries account for a notable portion of nonsport concussions [2]. Terry et al [3] reported that approximately 25% of adult concussions occur at work. Workplace injuries resulting in concussions pose a significant challenge for employers and insurers while disrupting the lives of the workers due to greater recovery times compared to non–work-related concussions [4]. In general, roughly 10%-20% of individuals who sustain a concussion experience symptoms lasting beyond the one- to two-week typical recovery time frame [5,6]. In the workplace context specifically, prolonged symptoms lead to reduction in productivity at work or even disability, which in turn has an economic impact on people, companies, and government agencies [3]. Although it is apparent that there is a need for further support and research in the workplace concussion rehabilitation field, a focus on the evaluation of concussion will be an important starting point to individualizing care.

Assessing symptoms and function after concussion presents clinicians with challenges due to the complex and diverse symptom presentation and a lack of sensitive and reliable clinical assessment measures [7]. Symptoms may be physical (such as dizziness, balance issues, headaches, neck pain, and vision difficulties), emotional (such as irritability and disinhibition) or cognitive (such as memory and concentration difficulties) [7-11]. All the domains of concussion symptoms must be considered [8]. Currently, however, a gold standard test to evaluate all concussion symptoms does not exist. Commonly, a battery of tests and symptom self-reports are relied upon [7,12,13]. For example, the Balance Error Scoring System and the Sensory Organization Test are used to assess balance deficits following a concussion injury [14]. The King-Devick test and the Vestibular Ocular Motor Screen may be used to evaluate oculomotor deficits [14,15]. Furthermore, the psychometric properties of the tools involved are often underdeveloped, and clinical utility varies. There is an additional challenge with all assessments of injured workers because of access to compensation that may interfere with the validity of effort provided during the assessment [3]. Measures that allow the examiner to ensure that a valid effort was made to complete the assessment should be considered.

With the shift in clinical service delivery to virtual health care driven by the COVID-19 pandemic, the need for valid and reliable approaches to virtual concussion assessments has become more pressing. In addition, people living in remote areas or for whom travel is difficult due to comorbidities continue to have a great need for assessment that can be carried out at distance [16,17]. Such assessment would also be helpful for people whose symptoms are aggravated by travel and environmental factors such as noise and light [18].

Clinicians are currently completing virtual concussion assessments using a variety of clinical assessment measures; however, as with in-person assessments, there is no standardized approach to assessing adult concussions virtually. Resources have been developed to support completion of the virtual concussion examination, including a training manual for the examination and a living guideline that outlines considerations for the pediatric examination [19,20]. Comparison of the measures identified in these resources when administered in an in-person and virtual context has not yet occurred.

The psychometric properties of many of the assessment measures being used have not been established for use in person or virtually. Accelerated adoption of information and communication technology has been occurring globally to enhance service delivery during the COVID-19 pandemic; however, it is unclear whether the outcomes of assessments completed virtually are consistent with assessments performed in person [21,22]. It is, therefore, important to understand if the measures used to assess concussions in person could provide equivalent results when used virtually [23].

Overall, there are multiple clinical assessment measures being used by clinicians to assess the physical domains impacted by a concussion injury. There is no standardized tool kit of measures available with established psychometric properties that are relevant and feasible in a virtual context, nor are there guidelines outlining specific measures to use in the adult population [12-14].

Objective

The objective of this mixed methods study is to produce a tool kit of measures that can be used in virtual assessments of concussion's physical symptoms.

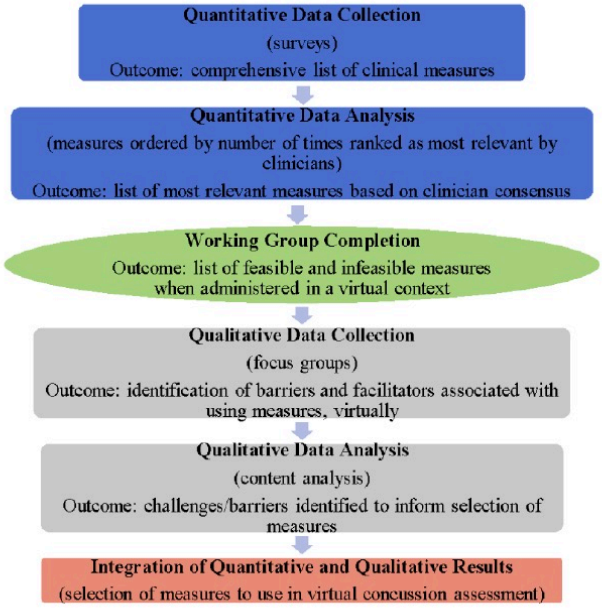
Methods

This study will follow a sequential mixed methods design [24] that will include a Delphi survey, a working group consultation, and focus groups. The methodological approach is outlined in Figure 1.

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Figure 1. Sequential explanatory approach commencing with survey administration guided by the Delphi methods and working group completion (quantitative) followed by focus group completion (qualitative) to expand on and explain survey and working group results.



Participants

Delphi Survey

Expert clinicians (ie, physiatrists, neurologists, sports medicine physicians, and physiotherapists) from across Canada will be identified through both regional and national professional and brain injury or concussion organizations and networks. Members of these networks represent an accessible and meaningful sample that will include many practicing clinicians with concussion assessment experience. The survey will be sent through these networks and associations by including the survey link in a newsletter or by sending the survey link through email to all members of the networks and associations. To ensure 'experts' are completing the survey, respondents will be asked to rate their concussion expertise using a 5-point Likert scale ("strongly not competent" to "strongly competent"). Any responses from participants self-reporting their competency as below 3 or "neutral" will be excluded. When needed, targeted emails will be sent to expert clinicians with publicly available contact information to ensure representation (minimum of 2 responses) of each profession.

Sample Size for Delphi Survey

Our target sample size is 50 clinicians, which we consider adequate to reach saturation on the types of clinical measures used in practice. This sample size is feasible based on an anticipated 25% response rate and assuming that approximately 200 clinicians will view the survey [25,26]. Clinicians who complete the first-round survey will be sent the second-round survey. It is expected that the second round of surveys will elicit a response rate of approximately 60% (~30 clinicians) [27].

Working Group Membership

A working group consisting of expert clinicians, including at least one neurologist, physiatrist, sports medicine physician, and physiotherapist, will meet to discuss the feasibility of virtual use of each measure identified in the survey. Members of the research team will be offered the opportunity to participate. Targeted emails to Canadian practicing clinicians will also be used to ensure representation from each clinical field. A final list of potentially feasible outcome measures will be identified in the working group, which will then be further explored in the focus groups.

Focus Group Membership

Focus groups consisting of 5 to 7 participants [28,29] will be conducted following the methodological framework outlined by Breen [30]. It is hypothesized that 6 to 10 focus groups will be adequate to reach saturation (2-3 groups consisting of people living with concussions who have experience with virtual assessment and 4-8 focus groups consisting of clinician-experts) [28,29]. Patient-participants who have attended a virtual concussion assessment will be identified and recruited from the Ottawa Hospital Rehabilitation Centre. The remaining focus groups will contain mixes of neurologists, physiatrists, sports medicine physicians, and physiotherapists. Participants who complete the Delphi surveys will have the option to express interest in participating in a focus group. Additional recruitment strategies include face-to-face recruitment at the Ottawa Hospital Rehabilitation Centre and through Ontario Workers Network

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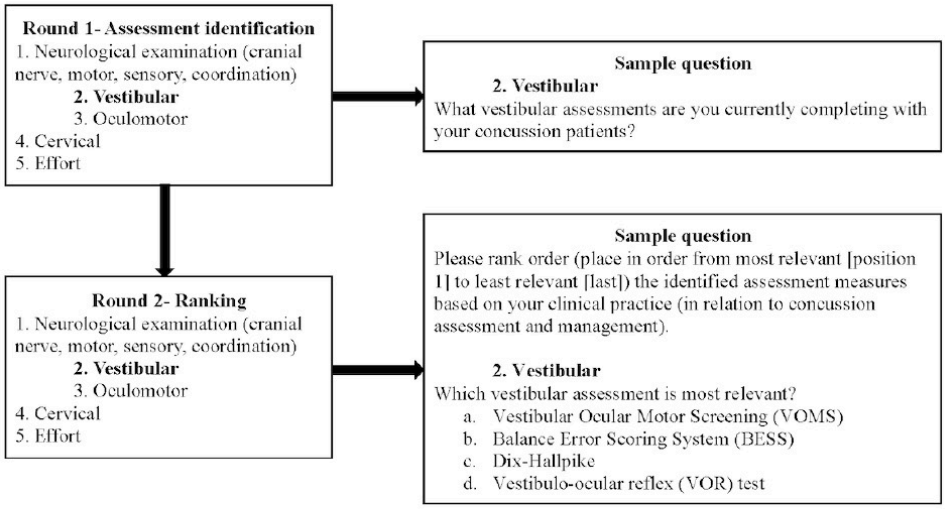
clinics. Targeted emails to Canadian practicing clinicians will also be used.

Procedures

Quantitative Delphi Survey Data Collection

The survey process will follow a Delphi method, which aims to seek consensus among the participants [31]. In round one, clinicians will receive a link for participation, which includes the implied consent form and a demographic questionnaire with open-ended questions; the questionnaire will have free-text boxes asking participants to identify multiple outcome measures they currently use to assess each 5 domains of interest (Figure 2). The invitation to participate in the surveys will be undersigned by a physiatrist (SM), including the affiliation, to secure buy-in and encourage responses. Measures identified by at least 15% of all participants (eg, 8/50 participants) or at least 60% of participants from one profession will be retained for the survey in round two.

Figure 2. Clinical domains of interest for identification of assessment measures and sample questions for the vestibular domain for round one and two surveys. Similar questions were provided for each domain.



In round two, all participants from round one will be asked to rank order, according to perceived usefulness for their practice, the concussion assessment measures from each domain (ie, neurological exam, cervical spine, oculomotor, vestibular, and effort) retained from the first round (Figure 2). Prior to completing the second-round survey, participants will be invited to review reading materials with information on the retained measures, including information on sensitivity, specificity, and feasibility from the literature, when available.

Delphi Survey Questionnaire Administration

To increase response rates, reminder emails will be sent at 7-day and 14-day time points following the initial emails in the first and second rounds [25,30]. A universal level of consensus does not yet exist for the Delphi survey approach; however, various works have suggested a range of 51%-80% agreement [27]. For the purposes of this study, an above 51% agreement level for rankings of assessments has been set for the second round. Assessments that reach 15% in round one will be considered for clinical feasibility by the expert clinician working group.

Working Group to Derive Consensus on the List of Feasible Measures

A working group consisting of expert clinicians will meet over a videoconferencing platform, which involves bidirectional visual and audio communication technology, to discuss the current feasibility of the identified measures in a virtual context. Any measures deemed not feasible in the working group will be eliminated from further discussion in the focus groups. The final list of measures will be further explored in the clinician focus groups.

Qualitative Focus Group Data Collection

Focus groups with both clinician and patient-participants will be conducted. An interview guide with broad open-ended questions will be used as a prompt for the conduct of the focus groups. All focus groups will occur over a videoconferencing platform and will be audio and video recorded for later transcription. Multimedia Appendix 1 includes the semistructured interview guide for both patient-participants and clinician-participants.

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Clinician-Participant Focus Groups

Prior to conducting the focus group, clinician-participants will be provided with available psychometric properties documented in the literature of the in-person measures that were identified from the second round of the surveys as well as descriptions of the assessments and instructions on how to complete the assessments. Clinician-participants in the focus groups will be prompted about the practical and technical issues associated with using each of the final measures. Barriers and facilitators associated with the assessments, including adverse events experienced or observed, will also be explored.

Patient-Participant Focus Groups

Patient-participants will be prompted to discuss the benefits and challenges associated with virtual concussion assessments based on their experiences.

Data Analysis

Quantitative Analysis of Delphi Surveys

Clinical measures identified in round one of the Delphi surveys will be categorized into the preestablished domains (ie, neurological examination, cervical spine, vestibular, oculomotor, and effort assessment). Frequency counts of the measures will be used to identify most commonly identified measures [32], and consistency of wording for the description of measures will be documented. For example, some clinicians may describe the measure rather than providing the name of the measure.

The quantitative data obtained in the second round of surveys (ie, rank order of measures) will be analyzed descriptively (ie, summary statistics to demonstrate patterns in the data). Measures of frequency and agreement percentages will be calculated.

Qualitative Analysis of Focus Groups

NVivo will be used to organize the qualitative data analysis. Recordings from the focus groups will be transcribed verbatim. Content analysis will be used to analyze the focus group data [33]. Two research assistants will independently identify codes related to barriers or challenges, benefits, and facilitators associated with using each of the identified measures. Codes will be sorted into 2 levels of categories: categories related to assessment of specific symptoms or domains and categories related to virtual assessment in general.

Ethics Approval

Ethics approval was obtained by the Ottawa Health Sciences Network Research Ethics Board (20210575-01H) in September 2021 followed by the Bruyère Research Institute Research Ethics Board (M16-22-006) and the University of Ottawa Board of Ethics (H-02-22-7611) in February 2022.

Results

Survey administration and the working group have been completed. Focus group recruitment is underway. The final results of the surveys, working group, and focus groups will lead to the identification of clinical measures to use in a virtual assessment tool kit, which will be tested in a future planned evaluation study.

Discussion

Expected Outcomes

We presented a protocol for a mixed methods study to identify the most appropriate clinical measures to include in a virtual assessment. We hypothesize that the measures identified in the surveys will vary based on clinical profession. We anticipate reliability properties of the identified measures to range from moderate to strong (intraclass correlation coefficients=0.41 to above 0.81). It is anticipated that the working group and focus group discussions will lead to an understanding of some of the real and perceived barriers and facilitators related to participating in or completing a virtual concussion assessment. We expect patient-perceived challenges to relate to the technical issues with technology and clinician-perceived challenges to relate to the challenges associated with engaging in hands-on approaches in virtual care.

A toolbox of concussion physical assessments has been proposed by Matuszak et al [14], which includes measures to assess domains that are frequently impacted by a concussion injury; however, many of the physical assessment measures used in the concussion population have limited psychometric data. The proposed toolbox includes evaluation of vital signs, mental status, neurological examination (ie, cranial nerves, manual muscle testing, and reflexes), head and cervicothoracic evaluation, balance or coordination assessment, and vestibulo-ocular evaluation [14]. This toolbox is proposed for the in-person examination. However, many of the virtual resources and guidelines include similar evaluations [19,20].

Although telehealth has existed for a long time, the COVID-19 global pandemic has increased both its need and its use in delivering health care services [34]. The COVID-19 pandemic has accelerated the need for telemedicine-supported remote assessments and has pushed both clinicians and researchers to determine what aspects of medical care could be feasible in a telehealth context [34,35]. A scoping review by O'Neil et al [36] noted that videoconferencing could be a valid means to remotely assess patients with moderate to severe traumatic brain injury. In addition, according to Fjeldstad-Pardo et al [37], no adverse events have been identified during participation in telerehabilitation, indicating that it is a safe approach to deliver services. Specifically, telerehabilitation has been reported to be feasible and effective for the intervention and management of neurological patients [38]. There has been a significant increase in the use of virtual assessments, with a rapid transition due to the pandemic. This transition limited the ability to implement virtual care using a planned and organized approach. The transition was a reaction to the pandemic rather than a planned response [39]. Due to this reactionary response, clinicians have been forced to complete remote assessments with limited information on the accuracy and reliability of the measures used in these assessments.

It is, therefore, important to understand which assessments clinicians are completing both in person and virtually in the context of the concussion examination. A study by Tobler-Amman et al [40] found that correlation values were low when measures assessing similar constructs in people living

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with stroke were administered in person and virtually. Although clinicians thought the measures were assessing the same construct, the low correlation values indicate that administering the measures in the two different contexts may not provide the same information. Similarly, a study by Wang et al [41] on people living with Parkinson disease found that participants elicited a weaker reach when an assessment was completed virtually compared to in person. In the context of the concussion examination, understanding which assessments are being conducted and how the assessments are being conducted both in person and virtually is necessary to determine the equivalence of the assessments when administered in both contexts. Psychometric properties should be established in both in-person and virtual contexts of use to ensure accurate and reliable implementation in both contexts [23]. If the outcome measures used in person have poor documented psychometric properties or no documented psychometric properties, there may be additional challenges to validity and reliability when using the measure in a virtual context. It is important to gain an understanding of the properties of the clinical measures and their ability to produce equivalent results to the in-person assessment to inform decision-making in terms of their use in practice and their potential use in the virtual context [42].

With the increase in need for the uptake of telehealth in rural and remote areas, and now globally due to the COVID-19 pandemic, standardization of a feasible virtual concussion assessment is needed. The identification of the clinical measures that are most relevant and contribute the most reliable information in an adult concussion examination and the identification of the barriers and facilitators associated with using these specific measures in a telehealth context is an important first step to lead to this standardization. The results of this study and the future planned prospective evaluation study will be published and disseminated to targeted end users and networks.

Strengths and Limitations of Methodological Approaches

An important strength of the Delphi method is that it is a useful approach when lack of clarity exists, which is likely the case in the concussion assessment field [43]. It is apparent that although the Delphi approach has many strengths, it also has some limitations. Generally, the Delphi approach lacks agreed-upon standards or consensus [43].

Focus groups have been reported to be beneficial when participants are in different geographical locations [30], which will occur in this project due to the need to gain input from various clinicians and from people living with concussions to inform the follow-up studies. Some important limitations of focus groups include the following: the group setting nature of the focus groups may discourage participants from sharing their input; similarly, one single participant may dominate the focus group discussion (ie, overpower other participants) [30].

Conclusions

This mixed methods study will identify the assessment measures that are currently being used in person to evaluate people living with concussions. This study will further identify the barriers and facilitators as well as the challenges and benefits associated with using the identified measures, virtually. Psychometric properties documented in the literature of the in-person measures that will be discussed in the focus groups will be described. Results from this study will inform the selection of measures to include in a virtual assessment tool kit, which will be tested in follow-up studies. It is apparent that there are multiple gaps in the clinical assessment of concussion. There appears to be a need to further explore and expand on the understanding of the measures used to assess individuals experiencing prolonged symptoms in person; however, there is currently a need to explore the use of these measures in a virtual context. The limitations of the COVID-19 pandemic have highlighted the need for a rapid change in service delivery to virtual means, and although limited information exists regarding concussion assessment in a virtual context, remote assessments are currently being conducted in clinical practice, and therefore, need to be better understood.

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Data Availability

Data sharing is not applicable to this study, as no data sets were analyzed during the study.

Authors' Contributions

All authors have made substantial contribution to the work presented in this paper.

Conflicts of Interest

None declared.

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Multimedia Appendix 1

Interview guide.
[DOCX File , 14 KB-Multimedia Appendix 1]

Multimedia Appendix 2

Peer reviewed by Workplace Safety & Insurance Board (WSIB) Grants Program (Toronto, Ontario, Canada).
[PDF File (Adobe PDF File), 164 KB-Multimedia Appendix 2]

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Original Paper

Clinician-Prioritized Measures to Use in a Remote Concussion Assessment: Delphi Study

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Abstract

Background: There is little guidance available, and no uniform assessment battery is used in either in-person or remote evaluations of people who are experiencing persistent physical symptoms post concussion. Selecting the most appropriate measures for both in-person and remote physical assessments is challenging because of the lack of expert consensus and guidance.

Objective: This study used expert consensus processes to identify clinical measures currently used to assess 5 physical domains affected by concussion (neurological examination, cervical spine, vestibular, oculomotor, or effort) and determine the feasibility of applying the identified measures virtually.

Methods: The Delphi approach was used. In the first round, experienced clinicians were surveyed regarding using measures in concussion assessment. In the second round, clinicians reviewed information regarding the psychometric properties of all measures identified in the first round by at least 15% (9/58) of participants. In the second round, experts rank-ordered the measures from most relevant to least relevant based on their clinical experience and documented psychometric properties. A working group of 4 expert clinicians then determined the feasibility of virtually administering the final set of measures.

Results: In total, 59 clinicians completed survey round 1 listing all measures they used to assess the physical domains affected by a concussion. The frequency counts of the 146 different measures identified were determined. Further, 33 clinicians completed the second-round survey and rank-ordered 22 measures that met the 15% cutoff criterion retained from round 1. Measures ranked first were coordination, range of motion, vestibular ocular motor screening, and smooth pursuits. These measures were feasible to administer virtually by the working group members; however, modifications for remote administration were recommended, such as adjusting the measurement method.

Conclusions: Clinicians ranked assessment of coordination (finger-to-nose test and rapid alternating movement test), cervical spine range of motion, vestibular ocular motor screening, and smooth pursuits as the most relevant measures under their respective domains. Based on expert opinion, these clinical measures are considered feasible to administer for concussion physical examinations in the remote context, with modifications; however, the psychometric properties have yet to be explored.

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KEYWORDS

telehealth; remote care; concussion; mTBI; mild traumatic brain injury; assessment; examination; telemedicine; remote care; TBI; traumatic brain injury; brain injury; Delphi; measure; measures; measurement; mobile phone

Introduction

Concussions also known as mild traumatic brain injuries can occur in a variety of different settings such as within sports, in the workplace, and from falls that occur during activities of daily living [1]. A diverse group of clinicians including sports medicine physicians, neurologists, physiatrists, and physiotherapists may complete physical assessments post concussion. Approaches to completing the concussion physical examination appear to be variable among clinicians. While the available guidelines provide an overview of the important components of a vocational assessment following a concussion [2], there are no widely agreed-upon guidelines outlining specific measures to use in the concussion assessment. This is particularly important in the context of work-related injuries where benefits and treatment are related to clinical findings. Roughly 1 in 5 adults are unable to return to work at 6 months post injury following their concussion [1], many of whom require specialized assessment at this time point post injury.

Several domains, each with various potential measures, should be assessed in the concussion examination [2]. Furthermore, different measures may be used when the person who is injured is evaluated immediately following a concussion injury, a few days following the injury, and a few months following the injury. Leddy et al [3] outlined an evidence-based physical examination for neurologists assessing adults presenting with persistent symptoms post concussion; however, specific measures for certain domains remain undefined.

Identification of appropriate measures for remote concussion assessment is an important challenge that moved to the forefront of health care with the COVID-19–driven shift in clinical practice to remote care. Remote concussion assessments are increasingly common; yet, the measures used to complete these assessments continue to vary due to the lack of standardization and consistency regarding best practices among clinicians. In response to this shift, remote examination resources targeting family medicine physicians have been developed to support the diagnosis and acute evaluation of concussion through remote assessment [4]. These resources outline approaches that can be transferred from the typical in-person concussion examination to a remote context. Specific limitations include orthostatic vitals, dynamic gait, and cardiovascular or respiratory evaluation which are very difficult to complete in a remote context without special equipment being sent to the patient. Also, in response to the shift to remote care, McPherson et al [5] published adaptations to the evaluation of cranial nerves, oculomotor, vestibular, and cervical spine deficits along with an assessment of orthostatic intolerance from the Buffalo Concussion Physical Examination for use in the remote assessment of sport outpatients (in both acute and persistent symptom contexts). Finally, a living guideline for the acute assessment and management of pediatric concussion presents approaches to completing the remote concussion examination in the pediatric population [6]. These resources are based on expert opinion and support the feasibility of completing components of the concussion examination remotely. Variations in the approaches to remote assessment presented in the above-noted resources highlight the lack of standardized approaches to the remote assessments currently used in clinical practice. Furthermore, most of these resources were developed in the context of the sports setting or the pediatric patient population. Information is lacking on the measures recommended for use in remote concussion examination of community-dwelling adults who may have sustained a concussion injury in the workplace and are experiencing persistent symptoms.

In the absence of evidence or sufficient information to support clinical decisions, such as decisions on clinical measures to use in practice, expert consensus is often sought [7,8]. Further, 1 approach to finding consensus on possible clinical measures is to use the Delphi method which typically involves at least 2 rounds of survey administration to expert clinicians. Commonly, exploratory questions are asked in the first round followed by more targeted, specific questions in a subsequent round. The Delphi method is a useful approach for obtaining anonymous opinions from several participants across disciplines and wide-spread locations [7]. Expert opinions on the topic of interest transform into consensus in this approach [9]. Importantly, consensus does not indicate that the measures selected are the correct measures to use in a concussion assessment. Rather, the results from the consensus act to structure follow-up discussions (in working groups) and inform subsequent decisions [10].

Previous work has used the Delphi approach to identify clinical measures in various populations. Reneker et al [11] aimed to document the cervical spine measures used in concussion to distinguish between cervicogenic and other factors contributing to dizziness postsport-related concussion. Consensus on the clinical utility of the identified measures was determined by the clinicians who participated in this study. Similarly, while not specific to concussion, Winser et al [12] used a Delphi approach to identify balance measures used by clinicians to evaluate people with cerebellar ataxia. Clinicians were first asked to list the measures that they use in practice and then select the most appropriate measure for the assessment of balance. This study identified 3 balance measures (Berg Balance Scale, the scale for the assessment and rating of ataxia, and the Timed Up and Go) as most appropriate; however, it noted that an evaluation of test psychometric properties is needed. While these studies identify balance and cervical spine measures for specific purposes, there remains limited information on the identification

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of clinical measures to use in the evaluation of physical domains impacted by a concussion.

The purpose of this work was to identify clinical measures currently used to assess 5 predefined domains following a concussion injury (neurological examination, vestibular, oculomotor, cervical spine, and effort); and determine the feasibility of administering the measures remotely. Findings from this study will inform the selection of measures for use in a remote concussion assessment that will be tested in a planned evaluative study. We focused on the physical domains of a concussion examination since they appear to be more challenging and require more adaptations to administer virtually when compared to measures of cognitive or emotional health. Further, while there is overlap in concussion symptom domains, classification systems typically segregate physical symptoms from cognitive and emotional symptoms. For example, Ellis et al [13] presented a classification system in which signs and symptoms post concussion are grouped into physiologic, vestibulo-ocular, cervicogenic, and cognitive or mood-related domains.

Methods

Study Design

The complete methodology is presented in a study by Barnes et al [14]. The published protocol presents a flow diagram of the methodological process, which includes a round 1 survey to identify clinical measures used to evaluate physical domains impacted by a concussion, a round 2 survey to rank-order the identified measures from round 1, and a working group to document the perceived feasibility of administering the identified measures from the surveys in a virtual environment.

Delphi Survey Approach

Round 1

An open invitation was sent to clinician-members of 8 regional and 4 national brain injury or concussion professional associations or networks through email and monthly newsletters over 3 months (February to May 2022). Wherever possible, targeted emails to clinicians with publicly available contact information were used to ensure there was a representative sample of at least 2 participants from each clinical profession of interest (physiatry, sports medicine, neurology, and physiotherapy). Purposive sampling techniques were used to recruit at least 50 expert Canadian-practicing clinicians with experience completing in-person concussion assessments in any setting (sports contexts, emergency departments, rehabilitation centers, family medicine offices, etc). Justification of the sample size is presented in the published protocol [14]. As reported by Hasson et al [10], the inclusion of participants who have an interest in the topic and knowledge about the topic may aid in increasing the content validity of the findings of the Delphi approach. Through the open invitation and self-reports of competency, we were able to recruit participants who were interested in concussion assessment and management and who had sufficient experience completing concussion assessments, potentially strengthening the content validity of the survey findings.

A comprehensive list of clinical measures used to assess 5 domains of concussion (neurological examination, vestibular, oculomotor, cervical spine, and effort assessment) at all time points post injury (acute, subacute, or persistent) was compiled. An "other" domain was also included in round 1 of the survey due to the anticipated classification variations between clinicians for certain clinical measures. For example, balance or gait tests were included in the vestibular as well as in the "other" domain by clinicians. An adjusted list of measures was created to group all clinical measures under the predetermined domains. The adjusted list of measures was rank ordered by frequency. Only measures that reached at least 15% agreement ([number of participants that identified measure total number of participants] 100) were included in round 2. Due to the number of measures anticipated to be identified in the survey, we previously set the 15% criteria so that we could narrow down the most relevant measures in the subsequent round, with a relatively good level of agreement among clinicians. Further, to ensure representation from each clinical profession, we planned to include any measures reaching at least 60% agreement with a professional group in round 2. All participants who completed round 1 were invited to complete round 2. To ensure the survey responses were anonymous, in line with the Delphi approach, a separate form was created for email input so that we could send the round 1 participants the round 2 survey.

Development of Reading Materials (Review of the Literature)

As we were particularly interested in the accuracy with which the tools identified pathology, a literature review of the sensitivity and specificity of retained measures was carried out following round 1 using the following databases: PubMed (Ovid; National Library of Medicine), MEDLINE (Ovid), CINAHL (Cumulative Index to Nursing and Allied Health Literature; EBSCO Information Services), and Google Scholar. Search terms used were related to the population of interest (all brain injuries due to limited information in the literature on psychometric properties in concussion), psychometric properties of interest (sensitivity and specificity), and clinical measures of interest (measures presented in Table 1). No date limitations were set. The findings from the review of the literature were used to develop descriptions of the identified measures and their psychometric properties; this information was provided in written form to all round 2 participants. The measures' sensitivity and specificity metrics identified from the review of the literature that were used to develop the reading materials provided to round 2 participants are presented in Multimedia Appendix 1 [12,15-27].

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Table 1. Round 1: list of measures that reached at least 15% agreement (N=58).

Domain and measures	Frequency, n (%)
Neurological examination	
Coordination: finger-to-nose or heel-to-shin; rapid alternating movements	37 (64)
Cranial nerve	34 (59)
Sensation	20 (34)
Reflexes	19 (33)
Motor (tone, pronator drift, or strength or power using MRC[a] grading or MMT[b])	16 (28)
Myotomes	13 (22)
Vestibular	
VOMS[c]	25 (43)
Balance (feet together, single leg stance, or tandem stance)	23 (39)
VOR[d] assessment	21 (36)
BESS[e] or mBESS[f]	21 (36)
Dix-Hallpike	20 (34)
Head thrust or head impulse test	14 (24)
Gait or tandem gait	13 (22)
Romberg	12 (20)
Dynamic visual acuity	10 (17)
Oculomotor	
Saccades	21 (36)
Convergence	20 (34)
Smooth pursuits	15 (26)
Cervical	
Range of motion	49 (84)
Palpation	26 (44)
Strength (MMT or DNF[g] endurance)	21 (36)
Joint position error test	9 (16)

[a]MRC: medical research council.
[b]MMT: manual muscle testing.
[c]VOMS: vestibular ocular motor screening.
[d]VOR: vestibulo-ocular reflex.
[e]BESS: balance error scoring system.
[f]mBESS: modified balance error scoring system.
[g]DNF: deep neck flexor.

Round 2

The expert clinicians were provided with the results of round 1 and reading materials before completing the second-round surveys and were given a month to complete the second survey. Round 1 results were summarized in tables outlining all measures that were at or above the 15% level of agreement and all additional measures that did not meet the cutoff. The sensitivity, specificity, and additional considerations for the administration of each measure (eg, equipment needed or time for administration) identified in the review of the literature were presented. The clinicians were then asked to rerank the identified measures from most to least relevant to their in-person clinical practice. Mean rankings were calculated by summing the product of the weight and frequency count for each measure and dividing by the total number of responses. The weight was determined by the number of measures within each domain.

Working Group

A working group, consisting of a physiatrist, neurologist, physiotherapist-researcher, and sports medicine physician, met in June 2022 to determine the feasibility of administering the

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measures virtually. The working group members were recruited through targeted emails. A moderator (KB) facilitated the working group. The group was audio and video recorded, transcribed into a written format, and analyzed using content analysis. A physiatrist (M Bayley; member of the working group but did not attend working group discussion) reviewed the measures independently and commented on the feasibility of the remote application of the measures based on personal experience and expertise.

Ethical Considerations

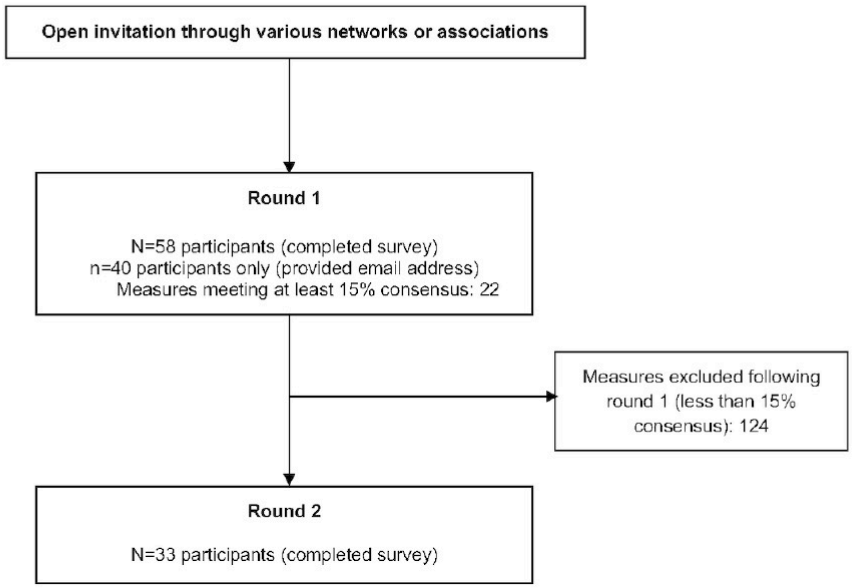
This study was approved by the Ottawa Health Sciences Network Research Ethics Board (20210575-01H), the Bruyère Research Institute Research Ethics Board (M16-22-006), and the University of Ottawa Board of Ethics (H-02-22-7611).

Results

Round 1

Figure 1 presents a flow diagram of the survey process. In total, 59 clinicians participated in round 1 of the Delphi survey. The demographic information of the included participants is presented in Table 2. Most participants were physiotherapists followed by sports medicine physicians, physiatrists, and neurologists. The "other" category of clinical professions included 5 occupational therapists, 3 kinesiologists or athletic therapists, 2 speech-language pathologists, 2 trainees (medical and physiotherapy), a physician's assistant, an orthopedic surgeon, and a family medicine physician. The majority of participants had over 10 years of experience in clinical practice and assessed over 50 people with concussions annually. Further, 1 participant self-reported as "strongly incompetent" for their competency of completing the in-person concussion assessment, and, therefore, their responses were excluded from data analysis as the aim was to survey experts leaving 58 participants in round 1.

Figure 1. Delphi survey flow diagram.



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Table 2. Demographic information of clinicians that completed round 1 survey (N=58).

	Frequency, n (%)
Age (years)	
20-29	10 (17.2)
30-39	25 (43.1)
40-49	8 (13.8)
50-59	10 (17.2)
60+	5 (8.6)
Prefer not to respond	0 (0)
Clinical profession	
Physiatrist	5 (8.6)
Neurologist	2 (3.4)
Sports medicine physician	10 (17.2)
Physiotherapist	26 (44.8)
Other	15 (25.9)
Clinical practice (years)	
1-5	17 (29.3)
5-10	13 (22.4)
10+	27 (46.6)
Did not respond	1 (1.7)
Volume of practice (patients with concussion assessed per year)	
0-25	20 (34.5)
25-50	16 (27.6)
50+	22 (37.9)
Self-report competency in-person	
Strongly incompetent	0 (0)
Incompetent	0 (0)
Neutral	10 (17.2)
Competent	31 (53.4)
Strongly competent	17 (29.3)
Self-report competency virtual	
Strongly incompetent	2 (3.4)
Incompetent	6 (10.3)
Neutral	24 (41.4)
Competent	23 (39.7)
Strongly competent	3 (5.2)

After categorizing the measures identified in round 1 based on the definitions of the domains, 146 different measures were identified (31 measures were identified in the neurological examination domain, 41 were identified in the vestibular domain, 26 in the oculomotor domain, 37 in the cervical spine domain, and 11 in the effort domain). The measures that reached the predefined cutoff level of agreement (at least 15%) are presented in Table 1. The list of clinical measures that did not meet the 15% cutoff is presented in Multimedia Appendix 2. The majority of clinicians reported not using any measures to evaluate effort, malingering, or symptom validity in their clinical practice. No relevant measures met the cutoff criteria for the effort domain, and it was, therefore, not included in the second survey. Further, when responses were grouped and analyzed based on the clinical profession (physiotherapist, neurologist, physiatrist, or sports medicine physician) of the respondents, no additional measures met the criteria of at least 60%.

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Round 2

In total, 33 of the 40 clinicians who agreed to be contacted for round 2 completed this survey. Table 3 presents the mean rankings for each of the measures and presents the final rank orders for each of the domains. Multimedia Appendix 3 includes all ranking values, weights, and frequency counts. Multimedia Appendix 4 includes consensus values for round 2.

Table 3. Round 2: mean rankings of measures.

Domain and measures	Mean ranking
Neurological examination (mean ranking /6)	
Coordination: finger-to-nose or heel-to-shin; rapid alternating movements	4.67
Cranial nerve (evaluation of 12 cranial nerves)	4.52
Motor (tone, pronator drift, or strength or power using MRC[a] grading or MMT[b])	4.09
Reflexes	2.85
Myotomes	2.45
Sensation	2.42
Vestibular (mean ranking /9)	
VOMS[c]	7.52
Balance (feet together, single leg stance, or tandem stance)	6.45
VOR[d] test	6.18
BESS[e] or mBESS[f]	5.61
Dix-Hallpike	4.58
Gait or tandem gait	4.36
Head thrust or head impulse test	3.91
Dynamic visual acuity	3.52
Romberg	2.88
Oculomotor (mean ranking /3)	
Smooth pursuits	2.24
Saccades	1.91
Convergence	1.85
Cervical (mean ranking /4)	
Range of motion	3.67
Palpation	2.94
Strength (MMT or DNF[g] endurance)	1.88
Joint position error test	1.52

[a]MRC: medical research council.
[b]MMT: manual muscle testing.
[c]VOMS: vestibular ocular motor screening.
[d]VOR: vestibulo-ocular reflex.
[e]BESS: balance error scoring system.
[f]mBESS: modified balance error scoring system.
[g]DNF: deep neck flexor.

Working Group

All participants in the working group had over 10 years of experience in clinical practice and self-reported as "competent" or "strongly competent" in completing in-person concussion assessments. Only 1 working group participant self-reported a neutral competency in completing the remote assessment; however, all participants had sufficient experience with conducting remote concussion assessments. All others self-reporting as "competent" or "strongly competent." Reports of competency were subjective and based on self-perception.

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When asked what technologies were used to complete remote assessments, participants reported using either a laptop, desktop, or laptop with a large external monitor. Further, 3 participants reported not always being able to see the whole body of the patients and only 1 participant reported being able to see the whole body of patients when completing assessments when requested. The physiatrist who reviewed the measures independently identified similar concerns to those of the members of the working group.

In total, 16 measures were deemed feasible to complete virtually but of these, the majority would require modifications (see Tables 4-7). Further, 6 measures were deemed infeasible to complete virtually.

Table 4. Working group: feasibility of completing identified neurological examination measures virtually as reported by the working group members.

Domain and measures	Considerations of administering a measure virtually as identified by experts	Feasible when administered virtually?
Neurological examination		
Coordination: finger-to-nose or heel-to-shin; rapid alternating movements	• Need to see end point (stable end point) for finger-to-nose: touch camera on screen • Heel-to-shin is much more challenging due to the positioning of the camera: possible if someone is holding the camera • Rapid alternating movements is feasible	Yes[a]
Cranial nerve	• Taste and smell are a challenge (would see the object before smelling) • Use of a Snellen chart is a challenge • Consistency of instructions for administration is a barrier	Yes (for the majority)
Motor (tone, pronator drift, or strength or power using MRC[b] grading or MMT[c])	• Tone is not feasible • Pronator drift is feasible • Manual muscle testing is feasible up to 3/5 • Cannot complete traditional power testing of muscles • Feasible if incorporating a functional test (squat) to provide insight into strength	Yes (for the majority)
Reflexes	• Only feasible if a trained clinician is with the person in-person	No[d]
Myotomes	• Feasible up to 3/5 grading	Yes, but not recommended
Sensation	• Could self-assess but may not be useful information • Risk of false negative is high: not recommended virtually	Yes with modifications, but not recommended

[a]Yes: measure is feasible when administered virtually.

[b]MRC: medical research council.

[c]MMT: manual muscle testing.

[d]No: measure is not feasible when administered virtually.

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Table 5. Working group: feasibility of completing identified vestibular measures virtually as reported by the working group members.

Domain and measures	Considerations of administering a measure virtually as identified by experts	Feasible when administered virtually?
Vestibular		
VOMS[a]	• Smooth pursuits, saccades, VOR[b]: feasible (most clinicians only complete these 3 components); need a well-placed camera • VOR: feasible, but keeping at the right speed is a challenge; could use a metronome smartphone app • Convergence: feasible, measurement is the barrier (unless having a person helping in-person) • Visual motion sensitivity: feasible; however, safety concern if standing, need to have enough range (cannot do this in seated position unless while having a swivel chair) • If solely using VOMS to capture subjective changes in symptoms, then it would be feasible	Yes[c] with modifications
Balance (feet together, single leg stance, or tandem stance)	• The challenge is obtaining a full view of the person completing the test • Concerns regarding safety, especially with single-leg stance • Modify environment: have a table in front to grab on to, a couch nearby to fall into, another person in-person	Yes
VOR test	• The challenge is seeing eye movements • Feasible if evaluating subjective response	Yes
BESS[d] or mBESS[e]	• Full BESS would not be feasible due to safety concerns when standing on a foam surface • mBESS may be feasible; however, safety is still a concern • Seeing errors may be a challenge depending on the camera angle	Yes (mBESS only)
Dix-Hallpike	• Not feasible unless someone trained is with the person in-person	No[f]
Head thrust or head impulse test	• Not feasible as the movement must be unexpected • Neck pain is a barrier even in-person	No
Gait or tandem gait	• Feasible; however, safety is a concern • Modify the environment (couch or wall nearby) or have another person in-person • Camera angle is a challenge: prefer profile view when observing gait	Yes
Dynamic visual acuity	• The computerized dynamic visual acuity test may be feasible; however, there is a need for specialized equipment on the head, likely making it unfeasible • Clinical dynamic visual acuity requires a specific set-up (Snellen chart or specific distance from chart), identifying the objective difference would be a challenge and therefore likely not feasible • Requires a person in-person	No
Romberg	• Feasible; however, safety is a concern and may not be sensitive to balance deficits, especially if administered virtually	Yes

[a]VOMS: vestibula ocular motor screening.

[b]VOR: vestibulo-ocular reflex.

[c]Yes: measure is feasible when administered virtually.

[d]BESS: balance error scoring system.

[e]mBESS: modified balance error scoring system.

[f]No: measure is not feasible when administered virtually.

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Table 6. Working group: feasibility of completing identified oculomotor measures virtually as reported by the working group members.

Domain and measures	Considerations of administering a measure virtually as identified by experts	Feasible when administered virtually?
Oculomotor		
Smooth pursuits	• Feasible, person follows finger on the screen, could use YouTube videos with object moving to standardize	Yes[a]
Convergence	• Feasible; however, measurement is a challenge	Yes with modifications
Saccades	• Feasible, look at the top corner of 1 side of the screen to the top corner of the other side	Yes

[a]Yes: measure is feasible when administered virtually.

Table 7. Working group: feasibility of completing identified cervical spine measures virtually as reported by the working group members.

Domain and measures	Considerations of administering a measure virtually as identified by experts	Feasible when administered virtually?
Cervical		
Range of motion	• Only feasible for active range of motion • Feasible, side view for neck flexion and extension, anterior view for lateral flexion, rotation is a challenge (could use a smartphone app to detect angle for rotation) • The challenge is not being able to complete passive evaluation	Yes[a] with modifications
Palpation	• Feasible if self-palpate • Subjective but useful information	Yes with modifications
Strength (MMT[b] or DNF[c] endurance)	• DNF endurance: not feasible (camera angle would be a challenge, person needs a specific positioning of the neck which would be a challenge to obtain virtually, usually need a hard surface) • MMT: can obtain an idea of up to 3/5 grading, could complete self-resistance • May not be useful for concussion	No[d]
Joint position error test	• Not feasible, specialized equipment and specific positioning are needed • Could use a modified version where the person looks at the light on the computer and the clinician monitors for repositioning of the head • May not be generalizable or useful as a screening assessment	No

[a]Yes: measure is feasible when administered virtually.

[b]MMT: manual muscle testing.

[c]DNF: deep neck flexor.

[d]No: measure is not feasible when administered virtually.

A discussion regarding the sensitivity and specificity of the balance measures occurred during the working group deliberations. Specifically, some clinicians reported that based on their experience with in-person administration, remote administration of certain measures, such as coordination assessments, provided less reliable information. The balance error scoring system or modified balance error scoring system was judged by them to have a poor ability to distinguish between healthy participants and participants with concussion. The working group participants; however, reported that the modified balance error scoring system and Romberg may be useful tools to screen for gross motor balance deficits in a remote examination. These measures were, therefore, deemed feasible and potentially useful to include in the remote concussion assessment for people presenting with persistent symptoms. Based on the round 2 survey results, balance testing (single leg stance, tandem stance, or feet together) and vestibular ocular motor screening (VOMS) may be more relevant to clinical practice and therefore more suitable to include in the remote assessment toolkit. Similarly, the clinicians reported that the objective measurement of convergence in the convergence oculomotor measure and the near point convergence component of the VOMS are extremely challenging to assess in a remote context; however, it could be a useful tool if solely using the test as a screening tool to document subjective changes in symptoms. Some clinicians reported that the amount of reliable information that they receive with remote administration of the VOMS is minimal; however, components of the test may be useful.

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Discussion

Principal Findings

In this study, we used a Delphi survey methodology to identify all clinical measures clinicians use to evaluate the physical domains impacted by a concussion injury at all time points post injury. This was followed by an expert-clinician working group that documented the current perceived feasibility and use of the measures for remote assessments.

This study confirmed that clinicians use varied approaches when completing in-person evaluations of the physical domains impacted by a concussion injury with almost 150 different concussion evaluation measures identified by the survey clinician-participants. Based on the findings, it appears that there is no widely accepted, standardized approach to assessing concussions; however, the use of coordination testing, the VOMS, smooth pursuits, and cervical spine range of motion may be the most relevant measures. This is therefore a prime area for some standardization work. Matuszak et al [28] documented that the concussion examination in still-symptomatic participants has not yet been standardized or supported by evidence, and the variation in measures identified in this study may reflect this lack of standardization. According to the Living Concussion Guidelines, valid, standardized tools are needed to assess and monitor symptoms [29]; however, specific measures containing these characteristics have not yet been outlined. Concussions are a unique condition in which assessments are conducted in a variety of different locations and by a heterogeneous group of clinicians [3]. This, therefore, may have contributed to the variety of measures identified by the clinicians who participated in the survey. Further, many factors may have contributed to the selection of measures by the clinician-participants such as time since injury, clinician practice type, cost of clinical measures, equipment needed, ease of use, time needed to administer a measure, accessibility, familiarity, among others [30,31].

It is possible that the reading material provided to the participants outlining the psychometric properties of the tools based on the review of the literature did not influence the responses and rankings in the second-round survey resulting in a maintenance in ranking of measures from round 1 to round 2. Presenting the reading material, which included information about the measure properties, may have reinforced the participants' original opinions about the clinical measures, leading clinicians to rank the most common measures from round 1 as first in round 2. Reasoning for this may be due to the psychometric properties associated with the measures. As demonstrated in Multimedia Appendix 1 [12,15-27], the documented psychometric properties are commonly weak to moderate or undefined for many of the measures used in a concussion assessment whether performed virtually or in-person. Clinician rankings for coordination testing, VOMS and cervical range of motion in round 1 and round 2 (within their respective domains) did not change, where all 3 measures were found to have acceptable sensitivity properties (above 70%); however, the properties available for coordination testing and cervical range of motion are not specific to concussion. Stokes and O'Neill [32] documented that physiotherapists are aware of how to administer clinical measures and track progress using the measures; however, their confidence is lower in terms of their knowledge regarding the properties of the measures. Wedge et al [33] similarly reported that physiotherapists need more information on the psychometric properties of clinical measures. Most physiotherapists included in the study by Wedge et al [33] indicated that they did not critically assess the properties of the clinical measures they use in their practice; however, there is a desire to have this information more readily available. Many of the physiotherapists further reported that they were unaware of publications providing relevant psychometric property information [33]. Awareness and knowledge of the relevant psychometric properties may therefore inform the selection of clinical measures. In practice, clinicians are encouraged to adopt an approach to assessment that is evidence-based, which includes consideration of the current research, clinical expertise, and client or patient preference [34]. There are, however, challenges and barriers to implementing evidence-based practice in clinical settings, such as time limitations, and lack of access to up-to-date research [34]. These factors may have further influenced the clinicians' selections of measures in the surveys in this study. Clinicians selecting measures without the information provided in this study may have come to different, less evidence-based ranking decisions.

The measures identified in the surveys and discussed in the working group are in line with the recommendations presented in concussion assessment and management guidelines and remote concussion resources [2-4,6]. Guidance for the remote general neurologic examination was presented by Al Hussona et al [35] and aligns with the findings of the working group in this study. According to this guidance, the majority of the cranial nerve examination can be feasibly completed virtually, including the motor (muscle bulk, pronator drift, antigravity power, or squat), sensory (compare light touch or cold on both index fingers and tops of both of the big toes), coordination (including finger-to-nose, heel-to-shin, and rapid alternating movements), and gait (that includes double leg stance, normal gait, and tandem gait) examinations. Similarly, according to Ellis et al [6], a modified cranial nerve examination (in the concussion context) can be completed virtually and includes evaluation of extraocular movements, smooth pursuits, facial symmetry, facial sensation, and movement of palate and tongue. Motor and coordination evaluation according to this guideline includes pronator drift assessment and rapid alternating hand movements. Some limitations identified by Al Hussona et al [35] for the remote examination include the inability to perform a fundoscopy examination, detailed power examination, and neuro-otology maneuvers such as the Dix-Hallpike. While the guidance by Al Hussona et al [35] is not specific to the concussion examination, it does support the findings of the working group in this study per the concussion assessment as the concerns and considerations that were brought up by the working group members are similar to those presented in the guidance.

Montes et al [36] developed a roadmap for remote assessment in neuromuscular disorders, and this roadmap could be used across various conditions, including concussion. According to

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Montes et al [36], effective adoption of measures in remote practice should include identifying measures that are clinically relevant and patient-centered. Further, expert opinion and consensus are needed to identify the feasibility of remote assessments in various populations and conditions. Measures that could be safely and feasibly administered in remote environments should be the first point of consideration for adaption to remote environments. Guided by this work by Montes et al [36], the findings from this study provide an informed foundation on which to base the remote concussion assessment. It is important to note that this study identifies the clinician-perceived measures that are most relevant to assessing certain physical domains affected by concussion [3]. By identifying the most relevant measures (and some of their associated psychometric properties) used to evaluate the physical domains impacted by a concussion injury that are feasible virtually, we now have an understanding of the clinician-perceived measures that should be initially explored when commencing to determine measures that should be administered in the different contexts, both in-person and virtually.

Limitations

The majority of participants in the Delphi survey were physiotherapists and there was an uneven distribution of participants based on clinical profession. Physiotherapists' opinions may, therefore, be relatively overrepresented in this survey compared to the other clinical professions. To address this, we included a cutoff of consensus among each clinical profession as well as among all participants; however, with only 2 neurologist, 2 speech-language pathologist, and 3 kinesiologist or athletic therapist responses, reaching that cutoff would be a challenge for those professions. Similarly, while the working group included representation from clinical professionals who typically complete a concussion examination, input may be missing from other clinical professions such as athletic therapists, trainers, or kinesiologists, nurses, and neurosurgeons. Furthermore, concussion injuries may occur in different contexts and may be assessed by different clinician professionals and at different time points; these factors may contribute to the low level of consensus and the broad range of measures identified in both rounds of surveys in our study. There may have been greater consensus if the questions were specific to assessments conducted on people experiencing persistent symptoms post injury; however, based on the lack of guidance available on the specific measures to use in the assessment of people experiencing persistent symptoms, variation would be expected.

Conclusion

The Delphi approach resulted in low to moderate agreement among the clinician-participants regarding the most relevant measures used to evaluate certain physical domains impacted by a concussion injury. This work highlights the broad range of measures being used in practice; however, it points to the use of coordination testing, the VOMS, smooth pursuits, and cervical spine range of motion as measures that may be most relevant in a concussion examination, within their respective domains. These measures ranked first among the survey clinician-participants determined to be feasible with modifications in a remote context as decided upon by expert clinicians in the working group. While these measures have been included in most of the remote concussion assessment guidelines and resources, the psychometric properties are underdeveloped for all in the concussion context. These measures, therefore, present a clear starting point for the investigation of psychometric properties associated with remote administration given their rankings and perceived feasibility in the remote environment.

Acknowledgments

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Data Availability

All data generated or analyzed during this study are included in this published paper.

Authors' Contributions

All authors have made substantial contributions to the work presented in this paper.

Conflicts of Interest

None declared.

Multimedia Appendix 1

List of measures with identified psychometrics that reached at least 15% agreement in round 1.
[DOCX File , 21 KB-Multimedia Appendix 1]

Multimedia Appendix 2

Delphi survey round one: measures that did not meet the 15% cut-off criteria.
[DOCX File , 19 KB-Multimedia Appendix 2]

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Multimedia Appendix 3

Round 2 mean rankings.
[DOCX File , 29 KB-Multimedia Appendix 3]

Multimedia Appendix 4

Round 2 consensus values.
[DOCX File , 27 KB-Multimedia Appendix 4]

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Abbreviations

CINAHL: Cumulative Index to Nursing and Allied Health Literature
VOMS: vestibular ocular motor screening

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