Home-Based Telerehabilitation Exercise Programs for People Living with a Moderate or Severe Traumatic Brain Injury

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

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To my mom who have raised me to never give up. To my partner Chris and son Xavier who will always support my crazy dreams. To my Dad and aunt Lise who have showed me to fight until the end.

Authorization

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Acknowledgements

This journey started five years ago, nine months after giving birth to my amazing son Xavier. I can truly say that this doctoral research was the equivalent of raising a second child. Without the mentorship, expertise, constant support, and love from my academic mentors, family and friends, this journey would not have been possible.

Heidi, you are an amazing mentor, thesis supervisor, confident and advocate. I feel incredibly lucky to have worked and learned from you over the last years. Thank you for introducing me to the Bruyère Research Institute family where I have felt extremely supported. Special thanks to Anne, Megan, Alex, and Lisa. Cheers to future collaborations.

Mary, thank you for pushing me to think outside the box and expanding my research skills. I am so happy this project has allowed you to embrace technology in rehabilitation! Martin, thank you for your continuous support through the last five years. Your calm and peaceful personality has helped me push forward on many occasions. Shawn, it was a pleasure to learn from you and deepen my knowledge around brain injuries. Luc, my thesis took an interesting and positive turn after you joined the team. More than ever, I believe that we can positively influence the life of others. Thank you for your support, expertise, and for opening my world to new research areas.

Mom, thank you. Without your support as a mother and grand-maman, this thesis would still be a dream. You have sacrificed so much of your life allowing me to pursue my "big dreams" and I am incredibly grateful for your eternal support over the years.

Friends and colleagues, you were all a part of this journey with me and have influenced this research in one way or another. Dan, thanks for convincing me to join the Ph.D. program and showing me that publishing articles can be fun; Lisa and Jacquie thanks for showing me the ropes, for your mentoring and your kindness; Amy thanks for being my sociology mentor and Marie-Ève thanks for your friendship and the constant reminder that we are in this together. I have made incredible friends and colleagues during this time.

To all rehabilitation clinicians, people living with a disability and their families who have inspired me to pursue this work. I hope you find valuable information in this dissertation and I hope to inspire you in return. Special thanks to Action Potential Rehabilitation for your support.

Finally, Chris and Xavier, the two most important individuals in my life. Every day, you made sure I was fed, happy and felt loved. You are my heart and soul. Xavier, I hope I have inspired you to pursue your "big dreams". Thanks for always being team Jenn!

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Publications

Published peer-reviewed manuscripts included in dissertation

O'Neil J, van Ierssel J, Sveistrup H. **Remote supervision of rehabilitation interventions for survivors of moderate or severe traumatic brain injury: A scoping review**. Journal of Telemedicine and Telecare. 2020 Oct; 26 (9): 520-535.

O'Neil J, Egan M, Marshall S, Bilodeau M, Pelletier L, Sveistrup H. **Remotely Supervised Home-Based Intensive Exercise Intervention to Improve Balance, Functional Mobility, and Physical Activity in Survivors of Moderate or Severe Traumatic Brain Injury: Protocol for a Mixed Methods Study**. JMIR Res Protoc 2019;8(10): e14867.

Submitted (under review) peer-reviewed manuscripts included in this dissertation

O'Neil J, Egan M, Marshall S, Bilodeau M, Pelletier L, Sveistrup H. **Remotely Supervised Exercise Programs to Improve Balance, Mobility and Activity Among Survivors of Moderate to Severe TBI: Description and Feasibility**. Submitted to Physiotherapy Canada (under review, March 2021).

O'Neil J, Egan M, Marshall S, Bilodeau M, Pelletier L, Sveistrup H. **The Impact of Two Telerehabilitation Schedules for Physical activity, Mobility, and Balance Among Survivors of Moderate to Severe TBI: a mixed-method approach.** Submitted to Physiotherapy Canada Journal (under review, March 2021).

O'Neil J, Pelletier L, Bilodeau M, Egan M, Marshall S, Sveistrup H. **How do People Living with a Disability Perceive the Physiotherapist Interpersonal Behaviours? Implications for home-based telerehabilitation**. Submitted to Physiotherapy Theory and Practice, Taylor & Francis publications (under review, April 2021)

Other peer-reviewed contributions based on the Ph.D. research

O'Neil J, Sheehy L, van Ierssel J. **Addressing Barriers of Telerehabilitation Implementation: A Collective Experience.** Virtual Workshop Session, Canadian Physiotherapy Association Congress, May 14-16th, 2021.

O'Neil J, Egan M, Marshall S, Bilodeau M, Pelletier L, Sveistrup H. **Two Teletherapy Supervision Schedule for Balance, Mobility and Activity Among Survivors of Moderate or Severe TBI: Alternating Single-Subject Design.** Platform Presentation. World Physiotherapy Congress, April 9-11, 2021

O'Neil J. **Spark-Centre for Again and Brain Health Innovation (CABHI) final grant report.** February 2021

O’Neil J, Sveistrup H. **Canadian Institute Military Veteran Health Research and True Patriot Love Final Grant report.** January 2021

O'Neil J, Egan M, Marshall S, Bilodeau M, Pelletier L, Sveistrup H. **Remotely Supervised Exercise programs to improve balance, mobility and activity among survivors of moderate to severe TBI: Description and feasibility.** Virtual Poster, American Congress of Rehabilitation Medicine, (virtual) October 22, 2020.

O’Neil J, van Ierssel J, Sveistrup H. **Remote Rehabilitation for survivors of moderate or severe traumatic brain injury: a scoping review.** American Congress of Rehabilitation Medicine, Chicago, IL, November 5-7th 2019.

O'Neil J, Egan M, Marshall S, Bilodeau M, Pelletier L, Sveistrup H. **Remotely Supervised Home Exercise Interventions in Survivors of Moderate or Severe Traumatic Brain Injury: A protocol.** CIMVHR FORUM, Ottawa, On, October 2019.

Jacquie van Ierssel, Jennifer O’Neil, Heidi Sveistrup, Shawn Marshall & Ian Graham (2020): **A qualitative study of persons with persistent postconcussion symptoms and clinicians with concussion expertise to inform the development of a concussion-specific questionnaire.** Disability and Rehabilitation, March 2020.

O’Neil J, von Schoenberg C. **Introducing technology in clinical practice to increase levels of physical activity for all patients.** Special Education Session. CPA Forum, Charlottown PEI, June 29, 2019.

O’Neil J, Barnes K, Morgan Donnelly E, Sheehy L, Sveistrup H. **Rehabilitation assessments conducted via telerehabilitation for neurological populations: a scoping review.** (in preparation for submission)

Funding

2019-2021	Ontario Graduate Scholarship, University of Ottawa Years of funding: 2
2019-2020	Spark-Center for Aging and Brain Health Innovation (34 792$) PI: Jennifer O'Neil, Team: Shawn Marshall MD, Jacquie Levy and Wendy Sarsons Years of funding: 1 (November 2019-January 2021)
2018-2020	Canadian Institute Military and Veterans Health Research and True Patriot Love PI: Heidi Sveistrup Ph.D., HQP: Jennifer O'Neil PT, Ph.D. (candidate) Team: Shawn Marshall MD; Mary Egan OT, Ph.D.; Martin Bilodeau PT, Ph.D.; Luc Pelletier, Ph.D. Grant prepared and managed by Jennifer O'Neil Years of funding: 2, total 47,516$
2018-2019	Bruyère Research Institute Graduate Award Years of funding: 1
2016-2018	Queen Elisabeth II Science and Technology Award QE II and private sector affiliation Action Potential Rehab, Years of funding: 2
2016-2020	Admission/Excellence Scholarship, University of Ottawa QE II-replacing admission scholarship during this period OGS-replacing admission scholarship during this period Years of funding: 4

Contribution of co-authors to publications

I conducted this Ph.D. research under the supervision of Heidi Sveistrup, Ph.D. after receiving research ethic approval from the Bruyère Research Institute REB and University of Ottawa REB. I followed the guidelines from the International Committee of Medical Journal Editors (ICMJE) (www.icmje.org) to describe the collaboration from co-authors.

Remote supervision of rehabilitation interventions for survivors of moderate or severe traumatic brain injury: A scoping review.

O'Neil J: methodology design, data collection, analysis, and writing of article for publication.
van Ierssel J: data collection, and second reviewer. Revised article before submission.
Sveistrup H: methodology design and substantial revisions leading to publication.

Remotely Supervised Home-Based Intensive Exercise Intervention to Improve Balance, Functional Mobility, and Physical Activity in Survivors of Moderate or Severe Traumatic Brain Injury: Protocol for a Mixed Methods Study.

O'Neil J: Reviewed the literature, conceptualized protocol, and prepared manuscript for publication.
Egan M, Marshall S, Bilodeau M, Pelletier L: Contributed their expertise to methodology and revised protocol for publication.
Sveistrup H: Contributed to redaction of protocol and provided revisions to the manuscript

Remotely Supervised Exercise Programs to Improve Balance, Mobility and Activity Among People with Moderate to Severe Traumatic Brain Injury: Description and Feasibility; and **The Impact of two Telerehabilitation Supervision Schedules on Physical Activity, Mobility, and Balance Among People with a Moderate or Severe Traumatic Brain Injury: a mixed-method approach.**

O'Neil J: Collected the data, performed the analysis, interpreted and reported the results. Developed two manuscripts and revised all suggestions brought by the team and reviewers prior to publication.
Egan M, Marshall S, Bilodeau M, Pelletier L: Contributed their expertise to the methodology and provided revision to both manuscript prior to publication.
Sveistrup H: Supervised the work and provided substantial revisions to the manuscript leading to the publication.

How do People Living with a Disability Perceive the Physiotherapist Interpersonal Behaviours? Implications for home-based telerehabilitation.

O'Neil J: Data collection, analysis, interpretation and writing of manuscript.
Egan M, Marshall S, Bilodeau M: Provided revision to the manuscript, and reviewed final version prior to publication.
Pelletier L, Sveistrup H: Brought their expertise to the conception of the manuscript. HS and LP both supervised the work of provided revisions to the manuscript leading to the publication.

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List of Key Abbreviations and Definitions

ABI	Acquired Brain Injury
AS	Autonomy support
AT	Autonomy thwarting
BPNT	Basic Psychological Needs Theory
CPA	Canadian Physiotherapy Association
CABHI	Centre for Aging and Brain Health Innovation
CB&M	Community Balance and Mobility Scale
COP	Center of pressure
CS	Competence support
CT	Competence thwarting
FES-I	Fall Efficacy Scale-International
FP	Family Partner
FTSTS	Five Time Sit to Stand
GCS	Glasgow Coma Scale
IBQ/	Interpersonal Behavioural Questionnaire /
IBQ-Self	Interpersonal Behavioural Questionnaire- Self
ICF	International Classification of Function
IM	Instant Messaging
M2PI	Mayo-Portland Participation Index
OTN	Ontario Telemedicine Network
PwD	Person living with a disability/ person living with a moderate or severe TBI
RS	Remote Supervision or Relatedness support
RT	Relatedness thwarting
SDT	Self-Determination Theory
SSD	Single Subject Design
SUS	System Usability Scale
SWLS	Satisfaction with Life Scale
TBI	Traumatic Brain Injury
WHO	World Health Organisation
2SDB	Two Standard Deviation Band Method

Autonomous motivation is: " people's inherent growth tendencies and innate psychological needs that are the basis for their autonomous-motivation and personality integration, as well as for the conditions that foster those positive processes " (Ryan & Deci, 2000).

Engagement is: " a co-constructed, occurring through a relationship with the clinician " (Bright, Kayes, Worrall, & McPherson, 2015).

Adherence is: " the extent to which a person's autonomous behaviour corresponds with agreed recommendations from a health care provider " (Sabaté, 2003).

Abstract

Background: People who have experienced a moderate or severe traumatic brain injury (TBI) will most likely live with motor and cognitive deficits including balance and poor mobility. These deficits may lead to limitations in activity participation, life satisfaction, and may increase the risk of falls. Improving access to rehabilitation care in the chronic phase of recovery is essential to prevent ongoing health issues. However, geographical restrictions, cost of transportation, or recently the COVID-19 pandemic restrictions may limit access to rehabilitation services. Telerehabilitation could serve as an alternative method to provide rehabilitation care while increasing access.

Objectives: The overall objective of this dissertation was to understand the implementation of high-intensity telerehabilitation exercise programs for people living with a moderate or severe TBI and their family partners. This was accomplished by 1) determining the feasibility of using telerehabilitation, 2) investigating the effectiveness of high-intensity home-based telerehabilitation exercise programs on physical activity, functional mobility and dynamic balance, 3) understanding the perspectives and lived experiences of completing a telerehabilitation program, and 4) exploring how interpersonal behaviours can influence practice and be perceived in a telerehabilitation setting.

Methodology: Influenced by a people-centered approach and explained by the Self-Determination Theory, this dissertation followed a mixed-method alternating single-subject design methodology. Five dyads composed of five persons living with a moderate or severe TBI and their family partners completed two high-intensity telerehabilitation programs remotely supervised, daily and weekly. The feasibility and effectiveness of the telerehabilitation programs were measured from a quantitative and qualitative perspective to replicate the clinical realities and understand all perspectives.

Results: In this dissertation, the feasibility of using telerehabilitation with this population was highlighted by reporting high adherence, high usability, active engagement and safety. The effectiveness on physical activity levels, functional mobility, dynamic balance and concerns with falling was also demonstrated with no differences between the daily and weekly remote supervision schedule. The dyads described being highly satisfied, engaged, and enjoyed the remotely supervised exercise programs. The individuals with the TBI perceived more supportive behaviours than thwarting behaviours from the physiotherapist.

Conclusion: This dissertation advances knowledge on telerehabilitation implementation for people living with cognitive and motor deficits following a TBI. High-intensity home-based telerehabilitation programs were shown to be feasible and effective. I introduced the importance of assessing needs-supportive and needs-thwarting interpersonal behaviours in the telerehabilitation context. Integrating these novel telerehabilitation concepts within emerging telerehabilitation models of care could significantly impact long-lasting positive health outcomes for individuals living with a moderate or severe TBI.

Résumé

Contexte : Les personnes ayant subi un traumatisme crânien cérébral (TCC) modéré ou grave risquent de développer des déficiences motrices et cognitives affectant leurs niveaux d'équilibre et mobilité fonctionnelle. Ces déficits peuvent limiter la participation aux activités et la satisfaction de vie. Ils peuvent aussi augmenter le risque de chutes. L'amélioration de l'accès aux soins de réadaptation dans la phase chronique du rétablissement de ces personnes est essentielle pour prévenir les problèmes de santé persistants. Cependant, l'accès aux services de réadaptation peut être limité par les restrictions géographiques, le coût du transport ou, plus récemment, les restrictions liées à la pandémie COVID-19. La téléréadaptation pourrait servir de méthode alternative afin de fournir des soins de réadaptation tout en améliorant l'accès aux services.

Objectifs : Cette thèse de doctorat avait comme objectif général de mieux comprendre la mise en œuvre de programmes d'exercices à haute intensité par le biais de la téléréadaptation pour les personnes vivant avec un TCC modéré ou grave ainsi que les membres de leurs familles. Ceci a été réalisé en : 1) déterminant la faisabilité de l'utilisation de la téléréadaptation, 2) étudiant l'efficacité des programmes d'exercices intensifs de téléréadaptation à domicile sur l'activité physique, la mobilité fonctionnelle et l'équilibre dynamique, 3) documentant les perspectives et les expériences vécues lors de la réalisation d'un programme de téléréadaptation, et 4) explorant comment les comportements interpersonnels peuvent influencer la pratique et être perçus dans un contexte de téléréadaptation.

Méthodologie : Basé sur une approche centrée sur les personnes et s'inscrivant dans la théorie de l'autodétermination, une méthodologie mixte avec un devis à sujet unique alterné a été utilisé dans le cadre de cette thèse. Cinq dyades composées de cinq personnes vivant avec un TCC modéré ou grave et les membres de leur famille ont complété deux programmes de téléréadaptation à haute intensité supervisés à distance par un physiothérapeute, et ce, de façon quotidienne et hebdomadaire. La faisabilité et l'efficacité des programmes de téléréadaptation ont été mesurées d'un point de vue quantitatif et qualitatif pour reproduire le plus fidèlement possible les réalités cliniques et mieux comprendre les différentes perspectives.

Résultats : Un taux d'adésion élevé, une facilité d'utilisation ainsi qu'un engagement actif et sécuritaire a supportent la faisabilité de la téléréadaptation avec cette population. Nos observations suggèrent également une efficacité sur les niveaux d'activité physique, de mobilité fonctionnelle, d'équilibre dynamique et des craintes de chute. Aucune différence entre l'horaire de supervision à distance quotidien et hebdomadaire n'a été démontrée. Les dyades ont rapporté un haut niveau de satisfaction, d'engagement, et ont beaucoup apprécié les programmes d'exercices intensifs supervisés à distance. Les comportements interpersonnels du physiothérapeute ont été perçus par les personnes atteintes de TCC comme étant plus favorables que frustrants envers l'autonomie, la compétence et le rapprochement pendant le programme d'exercices de téléréadaptation.

Conclusion : Cette thèse de doctorat ajoute aux preuves existantes dans la littérature concernant les bénéfices de la téléréadaptation notamment en ce qui concerne la mise en œuvre de la téléréadaptation pour les personnes vivant avec des déficits cognitifs et moteurs suite à un TCC. Nous avons démontré que les programmes d'exercices intensifs de téléréadaptation à domicile étaient faisables et efficaces. Mais plus encore, nous avons démontré l'importance d'évaluer les comportements interpersonnels dans le contexte de la téléréadaptation. L'intégration de ces nouveaux concepts dans le domaine de la téléréadaptation pourraient avoir un impact significatif sur la santé des personnes vivant avec un TCC modéré ou grave.

Chapter 1. Introduction and review of the literature

1.1 Barriers to Access to Specialized Rehabilitation Services

A recent article by Cieza et al. (2020) reported that 2.41 billion individuals need rehabilitation globally. In the WHO America regions, including Canada, 310 million people need rehabilitation (Cieza et al., 2020). Worldwide, it is estimated that 5.5 million people will sustain a moderate or severe traumatic brain injury every year (Dewan et al., 2019) requiring rehabilitation. This is the equivalent to 19 % of all traumatic brain injuries (TBI) (Dewan et al., 2019). In Canada, the prevalence of traumatic brain injuries in 2016 was reported to be 110 332 individuals (James et al., 2019).

An impact report from the Ontario Brain Injury Association documented in 2012 that in Ontario 90% of respondents living with an acquired brain injury voiced that physiotherapy was helpful, but 32% of respondents voiced that physiotherapy services were unavailable to them. Possible barriers to accessing specialized rehabilitation services include location, and cost linked to in-person services (Ontario Brain Injury Association, 2012). Recently the impact of COVID-19 has demonstrated that infection prevention and control (IPAC) can also create a barrier to accessing rehabilitation services (Bury, Clague-Baker, Deutsch, Finucane, Hobbelen, Morris, Van der Wees, Stokes, 2020; Jachak, Phansopkar, Naqvi, & Kumar, 2020; Malec et al., 2020).

Research shows that people living in rural or remote areas often have poor health status when compared to people living in urban locations (Pong, DesMeules, & Lagacé, 2009). A recent report from the Canadian Physiotherapy Association (CPA)(2016) highlights that reduced accessibility to physiotherapy services is associated with geographical location (60%), and the lack of available specialized physiotherapy services (62%). Poor access to rehabilitation services is often linked to limited transportation options (64%) (Canadian Physiotherapy Association, 2016; Passalent, Landry, & Cott, 2010; Shah, Milosavljevic, Trask, & Bath, 2019). Accessibility and gaps in the continuity of care during relocation were also highlighted by Canadian veterans and their families (Mahar et al., 2018). This confirms the need for alternative delivery models to increase access to services regardless of the location.

The cost associated with travel time, fuel, method of transportation and the need to be accompanied was also reported to be a significant factor for individuals with chronic physical limitations who should continue to access rehabilitation services (Chia et al., 2018; Hartley & Stockley, 2013; Keating, Lee, & Holland, 2011; van den Berg, Gafni, & Portrait, 2017). A few studies have reported that telerehabilitation services are lower in cost than in-person rehabilitation services, even in the urban context (Nelson, Russell, Crossley, Bourke, & McPhail, 2019; Shaw, Best, Frontario, & Charvet, 2021; Tousignant et al., 2015). Providing financially accessible therapy options such as telerehabilitation is crucial for the improvement and overall well-being of people living with a TBI (Hyder, Wunderlich, Puvanachandra, Gururaj, & Kobusingye, 2007).

The COVID-19 pandemic has demonstrated more than ever the need for an alternative model of health service delivery (Bettger & Resnik, 2020; Lee, 2020; Shelton et al., 2020). It has shown that alternative rehabilitation delivery models are necessary when facing infection prevention and control (IPAC) restrictions (Dorsey, Okun, & Bloem, 2020; Malec et al., 2020; Shelton et al., 2020). Restricted physical contact limiting in-person physiotherapy services has impacted 86% of all physiotherapy services worldwide (Physiotherapy, 2021). The COVID-19 pandemic has brought an additional barrier to in-person services and provided a reason to rapidly implement alternative models of physiotherapy delivery.

The use of telerehabilitation is allowing physiotherapists faced with IPAC restrictions to deliver rehabilitation services while remaining safe and physically distanced from their patients. Due to the barriers to accessing specialized rehabilitation services, it is crucial to develop and implement telerehabilitation programs tailored to each individual's situation, environmental context and overall health status including those who are living with a moderate or severe TBI.

1.2 Overview of a Traumatic Brain Injury

Traumatic brain injuries (TBI) are caused by external force directed to the head causing focal or diffuse brain damage resulting in physical, emotional and cognitive impairments (Bayley, Swaine, Lamontagne, Marshall, Allaire, Kua, Marier-Deschênes, 2016; Ontario Neurotrauma Foundation, 2020). Primary causes of TBI can vary depending on a multitude of factors including an individual's age or occupation. For example, in younger adults, frequent causes of moderate or severe TBI are motor vehicle accidents (MVA) or assaults, while in older adults brain injuries are often the result of a fall (Bushnik, Hanks, Kreutzer, & Rosenthal, 2003). In specialized groups such as veterans or individuals with military backgrounds, primary blast injury from explosion waves are often the cause of TBI (Farooqui, 2018; Maas, Stocchetti, & Bullock, 2008; Thompson, Scott, & Dubinsky, 2008; Troyanskaya et al., 2015).

All moderate and severe TBI bring structural and molecular changes to the brain, alter motor abilities, change behavioural and emotional regulation, and decrease cognitive functions (Irimia & Van Horn, 2015; Wang & Josey, 2019). A moderate or severe TBI to the frontal lobe can impact judgement, insight, self-regulation, awareness, problem-solving skills, and difficulty with multitasking (Marshall et al., 2013; Marshall et al., 2015; Hart & Evans, 2006; Kusec, Velikonja, Dematteo, & Harris, 2019; Rebetez, Rochat, Ghisletta, Walder, & Linden, 2015). Injuries to the parietal or temporal lobe can impact the vestibular-ocular systems leading to balance deficits and spatial processing issues (Padula, Capo-Aponte, Padula, Singman, & Jenness, 2017; Zaninotto et al., 2017).

The severity of a TBI is commonly identified by assessing the presence and duration of post-traumatic amnesia, loss of consciousness duration, and the Glasgow Coma Scale (GCS) scores (Bayley, Swaine, Lamontagne, Marshall, Allaire, Kua, Marier-Deschênes, 2016a; National Academies of Sciences, Engineering, 2019; Rimel, Jane, & Edlich, 1979). A GCS score of 13+ out of 15 reflects a mild injury, 9 to 12 a moderate injury and scores of 8 and under suggest severe and extensive brain damage (Rimel et al., 1979).

These cognitive and behavioural deficits can influence motor learning, making it harder to recover completely (Gooijers et al., 2016). Cognitive, behavioural, and motor deficits combined with impaired motor learning can lead to chronic ongoing challenges including low physical activity, decreased functional mobility, poor balance, and limited participation for people living with a moderate or severe TBI.

Clinical presentation of moderate or severe TBI

As per the International Classification of Functioning, Disability and Health (ICF) (Koskinen, Hokkinen, Sarajuuri, & Alaranta, 2007; Scarponi, Sattin, Leonardi, Raggi, & Zampolini, 2009) the following body impairments, activity limitation and participation will be described: 1) impaired balance, 2) reduced functional mobility, and 3) decrease physical activity levels. The social, psychological factors, as well as the environmental setting, will also be discussed since they have the power to facilitate or create barriers in the recovery of a person (Mandich, 2007) and can influence the effectiveness of exercise programs.

Balance and Functional Mobility

Poor balance is frequently documented in people living with chronic deficits resulting from a TBI (Jourdan et al., 2013; McKechnie, Fisher, & Pryor, 2016; Row et al., 2019). The underestimated feelings of unsteadiness combined with clinical measures of balance deficits can lead to mobility issues in their daily lives (Hays et al., 2019; McKechnie, Fisher, & Pryor, 2016). Studies of individuals living with all severities of TBI have also identified longer motor-response latencies, changes in vertical perception, and disruptions in sensory information organization resulting in a greater displacement of the centre of mass within the base of support (Perez, Green, & Mochizuki, 2020; Horak, 2006; Padula et al., 2017; Segalowitz, Dywan, & Unsal, 1997; Shumway-Cook, 1990). It is clear from the literature that standing balance deficits are chronically present in this population (Buster, Chernyavskiy, Harms, Kaste, & Burnfield, 2016; Jourdan et al., 2016; Klima et al., 2019).

Functional mobility, the ability to move in one's environment to accomplish an activity or participate in daily living, is also impaired in people who experienced a TBI (Bayley, Swaine, Lamontagne, Marshall, Allaire, Kua, Marier-Deschênes, 2016; O'Connor, Colantonio, & Polatajko, 2005). Impaired functional mobility presents as difficulty in walking from point A to point B, standing from a chair, climbing stairs, reaching forwards or carrying objects while walking. Reduced mobility can contribute to decreased participation in community-based activities (Cohen, Ivanovo, Brouwer, Miller, Bryant, Garland, 2018).

Functional mobility challenges, low muscle strength and impaired dynamic balance were reported to increase the risk of falls in people living with a moderate or severe TBI (Perez et al., 2020; Klima et al., 2019; Mckechnie, Pryor, & Fisher, 2015). Deficits in balance and mobility must be addressed in the rehabilitation of people living with a moderate or severe TBI, especially in people ageing with chronic deficits from a TBI (Delano-Wood et al., 2015) to reduce the risks of falls and improve activity participation. Ultimately, balance deficits and concerns with falling result in lower physical activity and an overall decrease in activity engagement.

Physical Activity

The lack of physical activity and poor activity engagement for people living with a moderate or severe TBI can further contribute to deconditioning (Self et al. 2013). As a result, low physical activity predisposes each individual who has sustained a moderate or severe TBI to potential comorbidities including hypertension, back pain, and fractures (Hammond et al., 2019). It has also been suggested that low physical activity can lead to further cardiorespiratory deconditioning in the chronic phase of a moderate or severe TBI (Hamel & Smoliga, 2019; Hassett, Moseley, & Harmer, 2016). As reported in two systematic reviews, it is essential to support the delivery of programs targeting the improvement in balance, mobility and physical activity to prevent such comorbidities in people living with a moderate or severe TBI (Hassett, Moseley, Tate, & Harmer, 2008; Medica et al., 2021).

In the adult population, the levels of physical activity can be measured using self-reported questionnaires, activity tracking devices, simple pedometers, heart rate monitors or a combination of all the above (Dowd et al., 2018). Step count is a simple measure that can quantify the level of physical activity while being easy to understand and motivating for individuals (Bassett, Lindsay, Samuel, & Scott, 2017). Respectively, averages step per day between 7500 and 9999 steps, between 10 000 and 12 499 steps, and above 12 500 reports moderately active, physically active, and very active adults (Bassett et al., 2017). Averages between 6500 and 8500 steps per day for people with a disability reported describing moderate to vigorous physical activity (Tudor-locke et al., 2011). Studies of individuals with disabilities documented an average daily step count between 4695 and 6126 steps per day (Cavanaugh, Coleman, Gaines, Laing, & Morey, 2007; Kilmer, Wright, & Aitkens, 2005; Tudor-Locke, Washington, & Hart, 2009; Xanthopoulos et al., 2008). These findings show that moderate to vigorous physical activity target is not always met with PwD. Similarly, one study documented the average daily steps specific to people living with a moderate or severe TBI and reported an average of 5834 steps per day (Williams, Weragoda, Paterson, & Clark, 2013). This study suggests that people living with a moderate or severe TBI are not achieving the recommended moderate to intense physical activity level (Bull et al., 2020; Kumahara & Ayabe, 2019; O’Connell et al., 2016) and that exercise programs should be developed to increase the daily step count and overall physical activity for this population.

In general, exercise programs targeting an increase in physical activity levels should be multifaceted (Fletcher et al., 2018), and this is also true for people living with a TBI (Hamilton, Khan, Clark, Williams, & Bryant, 2016). Implementing exercise programs that consider the type of physical activity, behaviour change strategies, social support and environmental settings could improve daily participation and activity engagement.

Social support

A partnership and collaborative approach between the person living with a disability, their family, and their friends can help tailor an exercise program to the specific needs of a person. As an example, understanding the level of caregiver support required to assist the person living with a disability could help the implementation and sustainability of an exercise program. A recent systematic review on the adherence to non-condition specific home-based exercise programs revealed the importance of a family member or a friend being present to provide support during the exercise session and has demonstrated that this presence can positively impact adherence (Bachmann, Oesch, & Bachmann, 2018). Khalil et al. (2013) also reported that the presence of a caregiver contributes to both adherence and motivation factors in people with a neurological condition (Khalil et al., 2013; Lorenz, Charrette, O’Neil-Pirozzi, Doucett, & Fong, 2017). Specific to people living with a moderate or severe TBI, research shows that the presence of caregivers or family partners can enhance the social aspect of the intervention leading to an increase in adherence and engagement (Hassett, Tate, Moseley, & Gillett, 2011; Winter, Moriarty, Robinson, Piersol, Vause-Earland, et al., 2016).

Environmental context

A recent study with people living with a severe TBI revealed that when targeting an improvement in physical activity, the concept of physical activity needs to be broadened (Analytis et al., 2018). In addition to social support, the home environment can have important impacts on any exercise program targeting an improvement in physical activity and mobility.

Traditionally, physiotherapy practice is provided face-to-face either in a hospital, in a community-based clinic or the person's home. Often organized in silos, the hospital setting situates the rehabilitation environment within a medical context leading to a focus on the health condition rather than accounting for the home environment of the person living with a disability. The clinic setting offers a medical space to complete a variety of rehabilitation treatments from conventional therapeutic exercise to electrotherapy and manual therapy approaches. The home-based setting provides an alternative to the traditional medical setting and could increase the considerations given to how a person functions in their home environment, thus being a key factor of rehabilitation success.

The home-base environment could facilitate the inclusion of functional assessment and meaningful tasks within therapeutic sessions, and lead to an improvement in balance, mobility and satisfaction with the rehabilitation services post-neurological conditions (Junior et al., 2019; Siemonsma et al., 2014). Specifically, evidence has demonstrated the effectiveness of home-based exercise programs on balance, gait speed and function for people living with a moderate or severe TBI (Tefertiller et al., 2019; Tiwari, Daly, & Alsalaheen, 2018). A study on community reintegration for veterans who have experienced a severe TBI has also described the importance of home-based programs and reported that the natural environment can create a more "holistic approach" to health services (Winter et al., 2016). Research clearly demonstrates that a home-based environment can influence the intervention effectiveness by offering a familiar environment facilitating function and comfort of each individual. This setting being specific to each dyad can positively influence the implementation of home-based telerehabilitation exercise programs by facilitating the transfers of skills to daily life environment. Other factors must also be considered in the development of a high-intensity home-based exercise program.

1.3 A high-intensity home-based exercise program

People-Centered Approach

An overarching people-centered approach was used to frame the key components of the exercise program. Healthcare providers are traditionally trained to organize their clinical care using a patient-centered approach with the patient at the center of care and the health care provider providing a solution or an intervention for a specific health condition or illness (Håkansson Eklund et al., 2019; Starfield, 2011; Zhao, Gao, Wang, Liu, & Hao, 2016). When used in a physiotherapy context, the term *patient*-centered places patients at the center of their care but may situate them as passive agents in their care relationship, while the therapist remains the active agent. Failing to actively engage the patient in the therapeutic relationship can pose a barrier to a patient's autonomy. For example, care may be negatively impacted when a therapy is mostly organized by a physiotherapist in a position of power and privilege (Andress et al., 2020; A. J. Hall, Burrows, Lang, Endacott, & Goodwin, 2018; Mudge, Kayes, & McPherson, 2015). When using the *patient*-centered approach, a physiotherapist may unconsciously see a person as a patient first rather than as an individual who is as an active participant in their care.

An alternative model, *people*-centered care is defined as an "approach to care that consciously adopts individuals', carers', families' and communities' perspectives. It includes attention to the health of people in their communities" (Organisation, 2019; World Health Organization (WHO), 2016). The people-centered approach focuses on fostering partnerships, decision-making, and active engagement in the therapeutic process to empower the person living with a disability (PwD) (Håkansson Eklund et al., 2019; Zhao et al., 2016). It values a bidirectional authentic approach to clinical encounters (Campbell & Heather thiessen, 2020; World Health Organization (WHO), 2007).

Other factors capable of influencing the effectiveness of an exercise program include the intensity of the exercise program, behavioural strategies and the method of delivery.

High-Intensity Home-Based Exercise Programs Components

We used the following three key interacting components to inform the development of the home-based exercise programs for people living with a moderate or severe TBI:

A) *A motor learning approach* including exercise dosage and high-intensity practice helped tailor the exercise program to specific body impairments and activity-participation limitations present in people with moderate or severe TBI.

B) *Self-Determination Theory (SDT)* which introduced how supportive behaviours can lead to autonomous motivation and influence intervention adherence as well as activity engagement.

C) *The use of telerehabilitation* as a method of delivery expanding on frequencies of supervision.

Motor Learning

Motor learning is the current and leading evidence-based approach in neurorehabilitation. It is described as “ processes leading to a permanent change in motor actions” (Kitago & Krakauer, 2013) and as “processes that strengthen the relationship between perception and action consistent with task and environmental constraints” (Levin & Demers, 2020). A clinical approach to motor learning is the use of task-oriented exercises targeting specific movements linked to an activity (van Dijk, van der Sluis, & Bongers, 2016). Rehabilitation clinicians traditionally use task-oriented exercises in a program to ease the transition to real-life situations.

Fitts and Posner have characterized motor learning in three succinct but evolving stages: cognitive stage, associative stage, and autonomous stage (Fitts & Posner, 2000). In the cognitive phase, the task must be explained in great detail for the individual to have the necessary tools to anticipate the movement and adapt to the task (Shishov, Melzer, & Bar-Haim, 2017). In the associative phase, informative feedback and movement repetition are required to support learning leading to task acquisition (Bierman, Franjoine, Hazzard, Howle, & Stamer, 2016; Shishov et al., 2017). Finally, the autonomous stage leads to skills transfer from one setting to the next. In that stage, the task is acquired, and the focus is on the efficiency of movement.

As explained in the associative phase of motor learning, movement repetition is key to task acquisition. Rehabilitation studies have demonstrated that high movement repetitions in exercise programs for both people post-stroke or TBI are critical for cortical reorganisation and therapeutic effectiveness (Kimberley, Samargia, Moore, Shakya, & Lang, 2010; Moore et al., 2020). Although not specific to people living with a moderate or severe TBI, a recent clinical practice guideline on the improvement of locomotor function also supports the use of high-intensity training to improve ambulation in people post-neurological injuries (Hornby et al., 2020). Charette et al. (2016)

investigated the impact of high-intensity exercise training targeting adults with chronic severe brain injury and documented an improvement in gait speed after a 6 week, 3 days per week program (Charrette et al., 2016).

Studies on high intensity of practice specific to people living with deficits following a TBI are still emerging. One study investigated the impact of training intensity on mental health in people with all severities of TBI and found a relationship between an increase in the number of daily steps and a decline in stress and depression (Bellon et al., 2015). Another study showed that completing twenty intensive exercise sessions totalling 50 hours of exercise could improve gait speed and mobility in people with chronic deficits from a TBI (Peters et al., 2014). Specific to moderate or severe TBI, a systematic review documented the effects of high-intensity training on patient function and revealed that the high-intensity training had more impact than usual in-patient rehabilitation care (Königs, Beurskens, Snoep, Scherder, & Oosterlaan, 2018). A case study of a woman with a severe TBI who completed a 4-week home-based circuit training also demonstrated that an intensive exercise program could be beneficial for gait speed (Tiwari et al., 2018). Though these studies show potential, there is a lack of evidence around high-intensity exercise programs post-hospital discharge for people living with a moderate or severe TBI.

Defining high-intensity parameters

Parameters frequently used to define high-intensity in physiotherapy are dose (i.e., number of repetitions during the session), frequency (i.e., the total number of sessions), and duration/timing (i.e., length of the session or program) (Jette, 2017). The optimal parameters are yet to be standardised or defined for the recovery of motor deficits in people living with a moderate or severe TBI. Current evidence guided the parameter choices for this doctoral research.

Based on the number of repetitions used in animal studies to influence neuroplasticity and brain modulation, Birkenmeier, Orager and Lang (2010) demonstrated that it was feasible for people post-stroke to complete 300 to 800 repetitions per session (Birkenmeier, Prager, & Lang, 2010). A range between 160 and 800 repetitions per sessions was drawn from studies on high exercise intensity and their effectiveness on motor outcomes. These studies include the use of constraint-induced movement therapy to improve upper limb function for people living with a stroke (Kwakkel, Veerbeek, Wegen, & Wolf, 2016; Liu, Huai, Gao, Zhang, & Yue, 2017), the use of intensive mobility training including 150 minutes of exercises per session to improve balance and mobility for people living with a TBI (Peters et al., 2014), and intensive task-oriented practice targeting the number of repetitions rather than the hours of practice to improve upper and lower extremity function in both post stroke and TBI recovery (Abdullahi, 2017; Birkenmeier et al., 2010; Canning et al., 2003).

A systematic review on home-based exercise programs documented that the optimal number of exercises to include in a home-based exercise program to improve adherence should range between 2 and 4 (Bachmann et al., 2018). Preliminary trends in exercise programs targeting balance, functional mobility and physical activity improvement suggest that the length of a program should last between 4 and 6 weeks and consist of a least 16 to 20 sessions (Canning et al. 2003; Ustinova et al. 2015; Charette et al. 2016; Tiwari et al. 2018; Lorenz et al. 2018). Therefore, at a minimum, the duration of an exercise program should include 4 weeks of 4 exercise sessions per week, for a total of 16 sessions. As for optimal exercise duration, the WHO recently recommended 150 to 300 minutes of moderate intensity physical activity per week for individuals living with a disability (WHO, 2019). In the spirit of combining both recommendations, each program included in this thesis were carried out 5 days a week, for a total of 20 sessions per program.

A summary of evidence on high-intensity exercise programs for people living with a moderate or severe TBI informing the design of our high-intensity exercise programs is documented in Table 1.1.

Table 1.1 Summary of existing high-intensity exercise program supporting the development of our home-based high-intensity telerehabilitation exercise programs.

Current evidence		Parameters for exercise programs
Intensity and dose	• 160 to 800 repetitions • 2 to 4 exercises per home-based programs	Minimum of 300 repetitions per session Choices of 2, 3, or 4 exercises
Duration	• 150 to 300 minutes per week	Minimum of 4 weeks per program Maximum of 300 minutes per week
Frequency of exercise sessions	• 16 to 20 sessions	Two programs of 20 exercise sessions 5 sessions per week
Frequency of remote supervision	• 3 to 18 face-to-face visits	Two frequencies were be piloted: High frequency: 20 remote visits Low frequency: 4 remote visits

Behaviour Change and Self-Determination Theory

In addition to motor learning and high-intensity exercise, the application of behavioural strategies in the delivery of exercise programs can influence behaviour change and facilitate the uptake of physical activity (Brett, Sykes, & Pires-Yfantouda, 2015; Dlugonski et al., 2012; INESS-ONF, Guideline, & INESS-ONF, 2016; Sara, 2020; Tate, Perdices, McDonald, Togher, & Rosenkoetter, 2014). A number of behaviour change theories including the Trans-theoretical model (Prochaska, DiClemente, & Norcross, 1993), the Theory of Planned Behaviour (Ajzen, 2011), the Social Cognitive Theory or Self-Efficacy Theory (Bandura, 2001), and the Self-Determination Theory (SDT) (Deci & Ryan, 2000) have been used to explain the use of these behavioural strategies. The Self-Determination Theory is used as the framework for this thesis.

Self-Determination Theory

Self-Determination Theory views each person as an active source experiencing the world as opposed to the world being experienced through the person. It explains autonomous motivation, patient engagement, and ultimately how to adopt behaviours supporting lasting intervention effects (Deci & Ryan, 2000; Ryan & Deci, 2017). Engagement is: *" co-constructed, occurring through a relationship with the clinician "* (Bright, Kayes, Worrall, & McPherson, 2015). Autonomous motivation is defined as: *" people's inherent growth tendencies, innate psychological needs, and personality integration that are the basis for their autonomous motivation "* (Ryan & Deci, 2000). Finally, adherence is defined as: " *the extent to which a person's autonomous behaviour – taking medication, following a diet, and/or executing lifestyle changes, corresponds with agreed recommendations from a health care provider "* (Sabaté, 2003). Programs based on SDT could improve the well-being of people who were affected by a moderate or severe TBI by enhancing the effectiveness of the exercise program programs (Figure 1.1. Panel A).

Self-Determination Theory is composed of six mini-theories. One of these theories is the Basic Psychological Needs Theory (BPNT) targeting the fulfillment of the three innate psychological needs. This SDT mini theory posits that three basic innate psychological needs must be fulfilled for an individual to function at its optimum state. These needs are autonomy, competence and relatedness (Ryan & Deci, 2000) (Figure 1.1, Panel A). Autonomy refers to the individual experiencing ownership of actions. Competence refers to the individuals feeling knowledgeable and skilled to interact with the situation at hand. Relatedness refers to the individual feeling cared for and being able to connect with another person (Ryan & Deci, 2017).

A meta-analysis by Gillison et al. (2019) reviewed a variety of SDT-based strategies used to facilitate patient engagement and autonomous motivation and concluded that the use of multiple strategies is better than using a particular one (Gillison, Rouse, Standage, Sebire, & Ryan, 2019). Examples of behavioural strategies used in healthcare targeting the fulfilment of autonomy, competence and relatedness to increase engagement, autonomous motivation and adherence were: 1) providing the patient with choices and information, acknowledging different perspectives, providing structure, and emphasizing responsibility; 2) providing informative feedback and identifying barriers; and 3) expressing interest in developing a rapport as well as encouraging social support (Gillison et al., 2019). Since these specific behavioural techniques have proven to improve autonomous motivation, it is fitting to incorporate them in the telerehabilitation exercise programs.

As explained from SDT, individuals are constantly seeking information from others to define their own behaviours. This process is referred to interpersonal behaviours (Rodrigues et al., 2018). The following three interpersonal behaviours can either be supportive or thwarting towards fulfilling the three basic psychological needs. These behaviours are autonomy supportive/thwarting, competence supportive/thwarting, and relatedness supportive/thwarting (Rocchi, Pelletier, Cheung, Baxter, & Beaudry, 2017)(Figure 1.1, Panel B).

Autonomy supportive behaviours have been studied extensively in the sport, education and healthcare fields and documented a positive relationship between high autonomy support and motivation (Chan, Lonsdale, Ho, Yung, & Chan, 2009; Dannapfel, Peolsson, Ståhl, Öberg, & Nilsen, 2014; Gillison et al., 2019; Murray et al., 2015; Pelletier, Guertin, & Rocchi, 2017; Rocchi, Pelletier, Cheung, et al., 2017). Competence supportive behaviours were reported to be influential in self-management and decision making (Camden et al., 2020; Kors et al., 2020; Ntoumanis et al., 2020; Ryan & Deci, 2017). Lastly, interpersonal behaviours supporting relatedness could facilitate the internalization of feedback (the transition from extrinsic to intrinsic to self-regulation) (Deci & Ryan, 2000; Gillison et al., 2019) (Figure 1.1, Panel A).

Some researchers would say that for needs supportive behaviours to be at their most effective, the receiver's perception of supportive/thwarting interpersonal behaviours must align or be perceived as more supportive than the behaviours self-reported by the provider (Chia et al., 2016; Rocchi & Pelletier, 2018; Rodrigues et al., 2020). Consequently, it is important to document how supportive or thwarting interpersonal behaviours are being reported by the care provider (i.e. a physiotherapist) and perceived by the care receiver (i.e., a person with the disability) because they are two independent constructs capable of influencing autonomous motivation (Rocchi, Meredith, Pelletier, 2017; Rocchi & Pelletier, 2018) (Figure 1.1, Panel B). Rocchi, Pelletier, Chueng et al. (2017) validated two questionnaires, the Interpersonal Behaviour Questionnaire (IBQ) and the Interpersonal Behaviour Questionnaire-Self (IBQ-Self) (Rocchi, Pelletier, Cheung, et al., 2017), which document the extent to which interpersonal behaviours are self-reported by a provider and perceived by a receiver. These questionnaires can also be used to explore the levels of agreement between what is reported by the care provider and what is perceived by the care receiver.

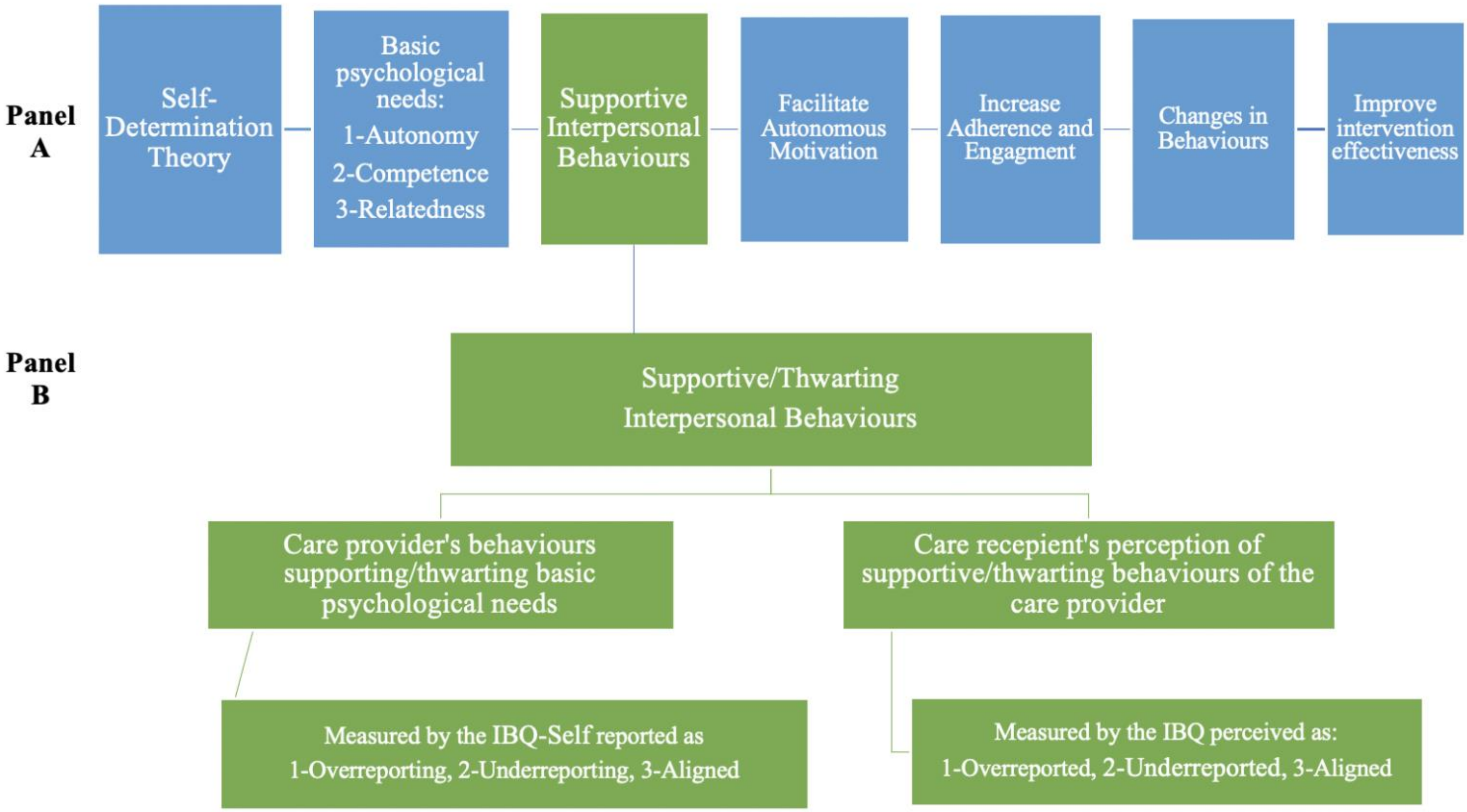

Figure 1.1 Panel A illustrates the relationship between Self-Determination Theory, and how supporting the three basic psychological needs of autonomy, competence and relatedness can lead to autonomous motivation, increase engagement and changes in behaviours. Panel B illustrates the relationship between the interpersonal behaviours and the Self-Determination Theory and expands on the documentation of a care provider's (physiotherapist) self-reported interpersonal behaviours and a care receiver's (PwD) perception of these interpersonal behaviours.

Delivery Method

Telerehabilitation

Telerehabilitation is the last key component to the design of the high-intensity exercise program investigated in this doctoral research. As described earlier, barriers including geographical locations, transportation cost including income lost for accompanying family members (Driver, Ede, Dodd, Stevens, & Warren, 2012), and the recent IPAC restrictions due to the global pandemic have influenced the clinical implementation of alternative methods of healthcare delivery such as telerehabilitation.

Telerehabilitation is a subdiscipline of telehealth, co-existing alongside telemedicine which can be broken down into four main functions: teletherapy, telemonitoring, teleconsultation and telehomecare (Parmanto & Saptono, 2009) (Figure 1.2). Individuals can be monitored, assessed and re-assessed, treated, provided with education and self-management tools via synchronous or asynchronous delivery.

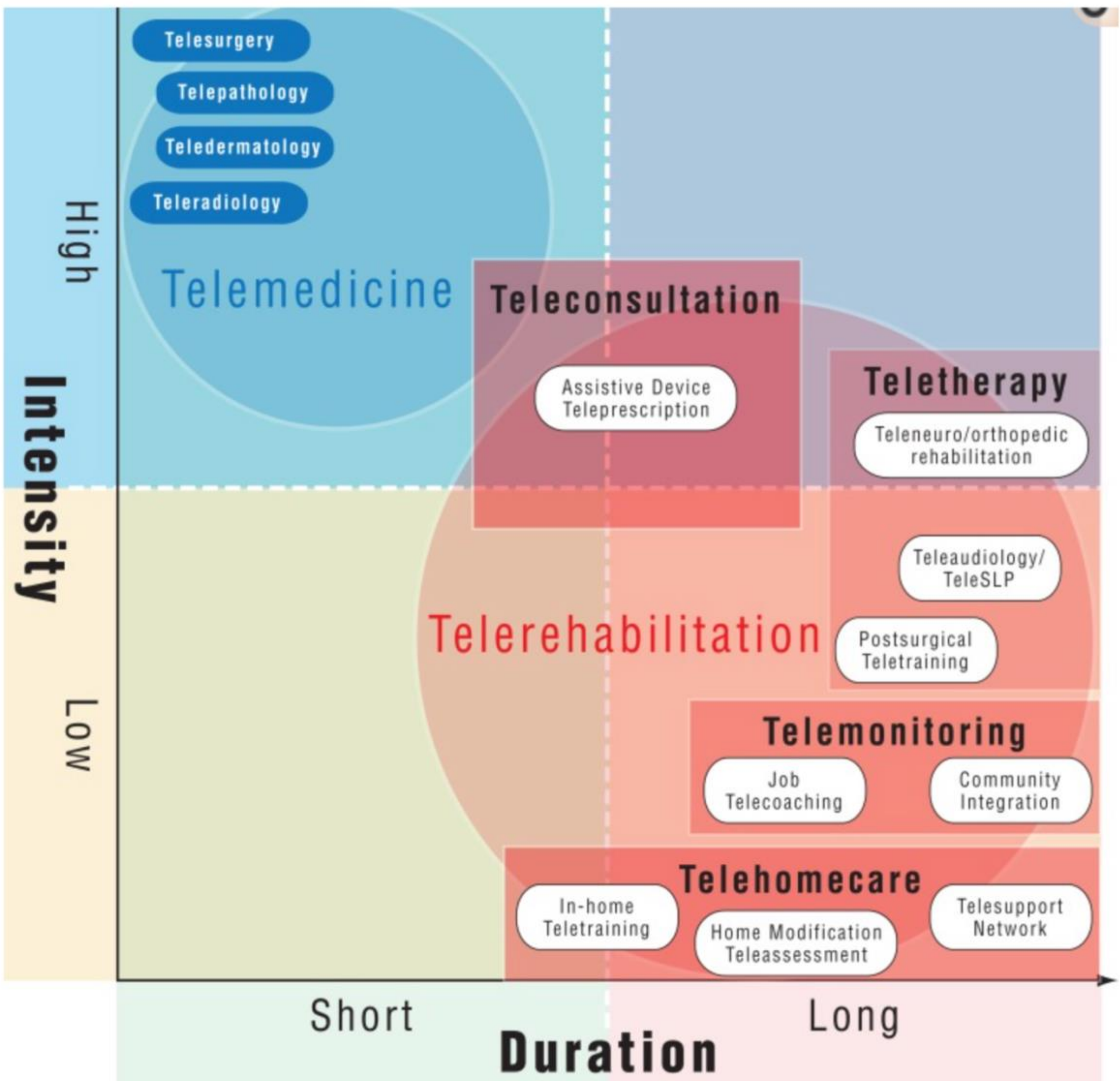

Figure 1.2 This intensity-duration telemedicine map illustrates how various use (i.e., teleconsultation, teletherapy, telemonitoring, telehomecare) of telerehabilitation co-exist with telemedicine. This work is licensed by the author(s) under a Creative Commons Attribution 4.0 United States License. Int J Telerehabil. 2009 Fall; 1(1): 73–84. Published online 2009 Sep 4.

Synchronous telerehabilitation

Synchronous telerehabilitation refers to the timing of supervision of a therapist. With synchronous telerehabilitation the feedback and interpersonal communication is received in real-time (Cherney, Kaye, Hitch., 2011). Technologies used synchronously in neurorehabilitation to remotely assess (telemonitoring) or provide therapy (teletherapy, teleconsultation) include phone calls, videoconference, and text messaging.

The use of videoconferencing in pediatric movement assessment (Nicola, Waugh, Charles, & Russell, 2018), or traditional musculoskeletal knee assessments including the range of motion, pain and gait biomechanics (Richardson, Truter, Blumke, & Russell, 2017) are examples of telemonitoring or teleassessment. Systematic reviews on the use of teletherapy provided good evidence for feasibility and efficacy of using of telerehabilitation for rehabilitation post-stroke (Appleby et al., 2019; Laver et al., 2020; Sarfo, Ulasavets, Opare-Sem, & Ovbiagele, 2018; Tchero, Teguo, Lannuzel, & Rusch, 2018), rehabilitation and self-management for individuals with degenerative neurological conditions (Di Tella et al., 2020), rehabilitation for cardiovascular conditions (Cristo, Nascimento, Dias, & Sachetti, 2018; Hwang, Bruning, Morris, Mandrusiak, & Russell, 2015), rehabilitation with people with cognitive deficits (Cotelli et al., 2019), and rehabilitation following orthopaedic surgery (van Egmond et al., 2018; Wang, Lee, Hunter, & Chan, 2021).

Asynchronous telerehabilitation

Asynchronous telerehabilitation is a mode of delivery where the therapist accesses the health records and patient information after it has been completed. With asynchronous telerehabilitation, the analysis of health information or the provision of feedback occurs after the exercises were completed (Cherney, Kaye, & Hitch., 2011). Asynchronous telerehabilitation is used to monitor change over time (telemonitoring), provide behaviour change strategies, or share knowledge on various health conditions or rehabilitation interventions (teletherapy) (Archer et al., 2015; Claes, Buys, Smart, & Budts, 2017; Hwang et al., 2015; Tate, Jackvony, & Wing, 2003).

Examples of asynchronous telerehabilitation are email follow-ups with a patient, the use of motivational smart applications (APPs) and pre-recorded videos (Tallner, Pfeifer, & Maurer, 2016). Supportive feedback and assistance with problem-solving leading to an increase in motivation can be provided via text messaging or email communications. Alternatively, sensor technology can offer a cost-effective method to monitor how a patient is progressing while supporting patient autonomy (Burridge et al., 2017) or to assess the fall risks for individuals post-stroke (Williams et al., 2017).

Sensor technology such as activity tracking devices can provide immediate feedback to the patient and save the physical activity information for a physiotherapist to review offline. For example, commercial devices such as a Fitbit® have been validated to accurately track steps in the community setting for people living with neurological conditions (Giggins, Clay, & Walsh, 2017; Singh et al., 2016). Similarly, the use of a Fitbit ® has also been validated with people with slower gait speed (Klassen et al., 2016), with different shoes or different grounds being walked on (O'Connell et al., 2016) as long as the position of the device is worn at the foot or ankle (Singh et al. 2016).

Telerehabilitation and TBI

There is a growing body of evidence showing that it is feasible, accepted by patients and clinicians, and effective to use telerehabilitation for people living with a TBI. Three reviews have revealed that the most common technology used for telerehabilitation with this population was the telephone. One review (n=6) found that telerehabilitation was as effective as usual in-person care to improve cognition and quality of life (Betts et al., 2018). The other review (n=13) exploring the use of telerehabilitation to improve access to community-based rehabilitation revealed that internet-based intervention was feasible and telephone-based sessions were effective for sleep quality and mental health (Ownsworth et al., 2020). Our review (n=26)(Chapter 2) supported these findings and documented that the use of the telephone was the most popular and that cognitive and education intervention were most common for this population (O'Neil et al., 2019).

Two studies focusing on the delivery of cognitive therapy found the use of videoconferencing to be feasible and effective in hospital and community settings (De Luca et al., 2020; Ng, Polatajko, Marziali, Hunt, & Dawson, 2013). Videoconferencing was also reported to facilitate transfer of care and care coordination between in-patient and out-patient rehabilitation services for people living with a TBI (Hernandez, Scholten, & Moore, 2015; Slomic, Soberg, Sveen, & Christiansen, 2017). The use of activity tracking devices to monitor physical activity was also reported to be feasible and accepted by people living with a moderate or severe TBI (Block et al., 2016; Leanne Hassett, Moseley, Harmer, & Van Der Ploeg, 2015; Jones, Dear, Hush, Titov, & Dean, 2016).

Gaps remain for physiotherapy-specific telerehabilitation programs for this population. Few studies have investigated the use of telerehabilitation to improve upper extremity motor recovery and found that a remotely supervised technology intervention was feasible and as effective as usual care (Hermens, Huijgen, Giacomozzi, & Ilsbroukx, 2007; Huijgen et al., 2008). To our knowledge, no studies have investigated the feasibility and effectiveness of telerehabilitation programs to improve balance, mobility and physical activity deficits.

Physiotherapist Remote Supervision

Evidence from two systematic reviews targeting the impact of adherence to a home-based program suggests that guidance from a therapist as opposed to self-guided home-based programs positively impacts adherence (Bachmann et al., 2018; Essery, Geraghty, Kirby, & Yardley, 2017). Interestingly, these reviews also highlighted self-determination and autonomous motivation as significant contributing elements to increased program adherence.

The frequency of remote supervision, meaning how often a physiotherapist is present to supervise a high-intensity home-based physiotherapy session, is a parameter to consider because it has an important impact on cost-effectiveness. In the musculoskeletal field, a recent study on knee osteoarthritis reported that a minimum of three and a maximum of eighteen face-to-face visits are required for the intervention to be clinically significant (Lieberz, Regal, & Conway, 2020). In people who have experienced a severe TBI, no differences in effectiveness in cardiovascular fitness were documented in a study investigating the differences between an in-person supervised program and an unsupervised home-based program (Hassett et al., 2009). These findings suggest that a minimum of three face-to-face physiotherapy visits would beneficial but that unsupervised home-based exercise intervention for this population is feasible. To date, the optimal frequency of remote supervision has yet to be properly understood.

1.4 Philosophical views, Theoretical lens and Methodological overview

World views and theoretical lens

Based on an overarching ideology of seeing perspectives from all standpoints, a mixed-method methodology oriented this doctoral research. This methodology has yet to be clearly defined in the mixed-method community. It is described as either a multifaceted way to see the world (Greene, 2007), a pure methodology combining quantitative and qualitative methods (Hesse-Biber, 2015), or as a study intending to combine specific elements (Creswell & Plano Clark, 2018). The latter definition is used in this body of research.

From a pragmatic philosophical worldview with an underlying transformative paradigm, this doctoral research is practice-oriented with an underlying inclination towards social justice for people living with disabilities. These two-paradigm approaches have been described as “best suited” for mixed-methods and can often be combined allowing for pluralistic views of the world (Creswell & Plano Clark, 2018). The Self-Determination Theory offers a clear lens to conduct this doctoral research within a mixed-method methodology (figure 1.3).

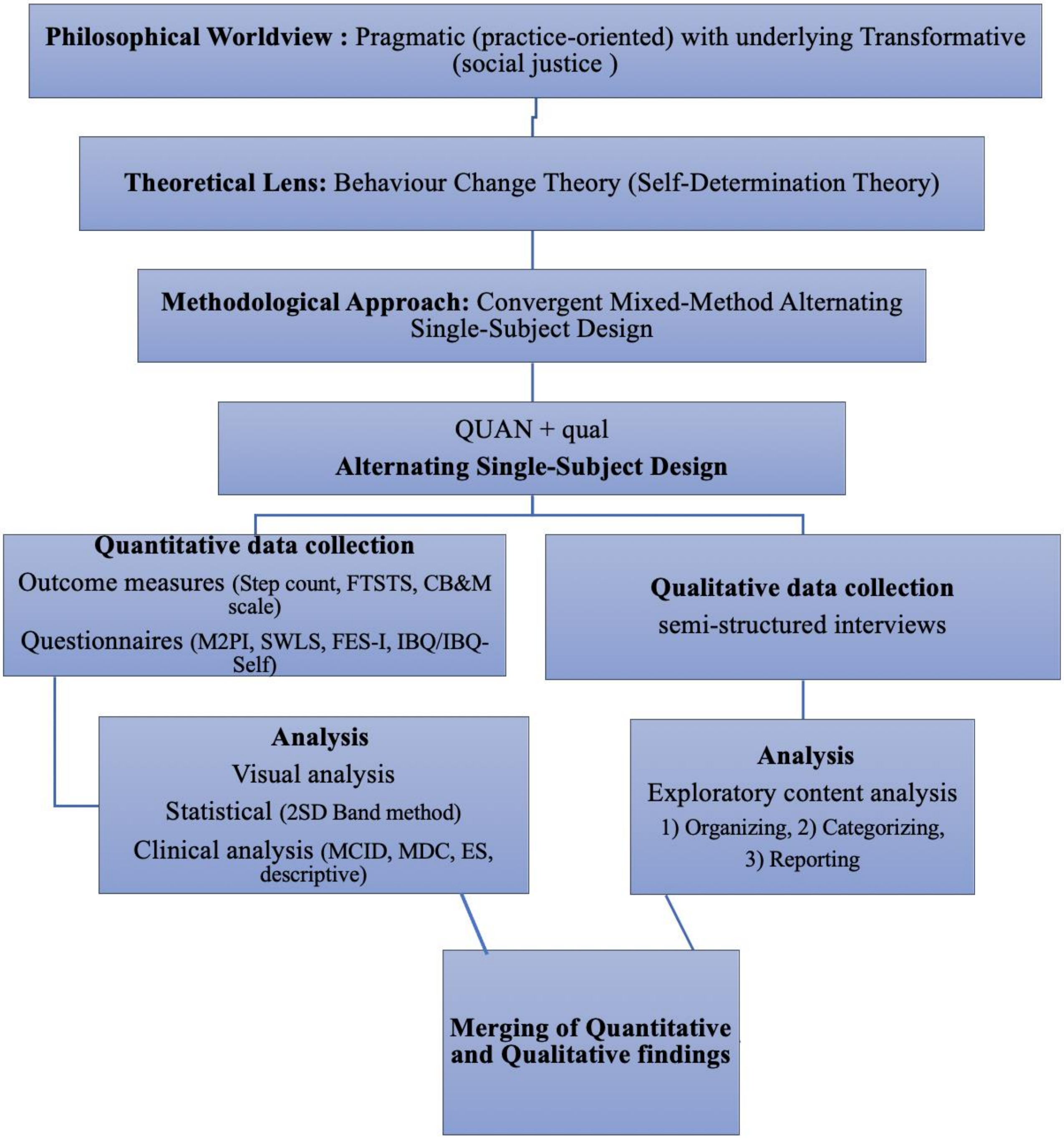

Figure 1.3 Methodology overview including philosophical paradigm, theoretical lens and methodological designs. Note: the Quantitative design (QUAN) is in capital letter to illustrate the emphasis on quantitative data compared to qualitative data. Mayo-Portland Participation Index (M2PI), Satisfaction with Life Scale (SWLS), Fall-Efficacy Scale-International (FES-I), Interpersonal Behaviours Questionnaire/Self (IBQ/IBQ-Self), Standard Deviation (2SD), Minimal Clinical Important Difference (MCID), Minimal Detectable Change (MDC), Effect Size (ES).

Methodological Approaches: Convergent Mixed-Methods Alternating Single-Subject Design

A convergent mixed-method alternating single-subject design was used. The collection of quantitative and qualitative data from each dyad provided an opportunity for all stakeholders to actively engage in the process. It allowed us to gather perspectives from the researcher/therapist, people living with a TBI, and the family partners of those living with a TBI to identify lived experiences beyond the exercise programs.

The rationale behind the use of a single subject design (SSD) over a randomized controlled trial stems from the well-known complexity and heterogeneous clinical presentation of an individual following a moderate or severe TBI (Ottenbacher, 1986; Rvachew & Matthews, 2017). From an ethical standpoint, the use of SSD allowed for the intervention to be accessible to all potential participants which followed the social justice orientation of this dissertation. Moreover, other intervention studies targeting balance and mobility in face-to-face exercise interventions with the same population reported a sample size ranging between 1 and 16 (Charrette et al., 2016; Kaski, Buttell, & Greenwood, 2018; Tiwari et al., 2018) which informed the realistic sample size for this Ph.D. research and confirmed the design choice.

While the Single-Case Reporting Guideline In Behavioural Intervention (SCRIBE) Checklist (Tate et al., 2016) was used to report the findings of each study included in this dissertation, the Risk-of-Bias in N-of-1 Trials (RoBiNT) scale was used to verify the scientific rigour of our design by considering internal and external validity (Tate et al., 2013)(Table 1.2).

Table 1.2 Steps used to increase internal and external validity documented using the RoBiNT scale

Steps taken to increase internal validity	**Steps taken to increase external validity**
1. *Design:* we used a level one evidence complex alternating single subject design to investigate the effectiveness of the intervention at three points time while allowing the comparison of two frequencies of remote supervision: daily or weekly 2.*Randomisation:* we counterbalanced the intervention phases between daily supervision or weekly supervision. 3. *Sampling behaviour:* each person living with a moderate or severe TBI (PwD) completed the following 5 phases: baseline, program 1, washout, program 2 and 1-month follow-up. 4. *Blinding of patient/therapist:* blinding was not possible in this study. 5. *Blinding of assessor:* outcome measures and interviews were completed by a research assistant independent from the therapist and blinded to the exercise program. 6. *Inter-rater reliability:* all assessments were completed by the same research assistant reducing internal validity bias across PwD. 7. *Treatment adherence:* to account for treatment fidelity, we assessed adherence using daily logbooks and activity tracking devices.	8. *Baseline:* The weeklong baseline started with a series of outcome measures to better understand the clinical presentation of each PwD. 9. *Therapeutic setting:* the home-based setting was considered and tailored for each PwD during a pre-intervention information session. 10. *Dependent variables:* This is well described in the following section. 11. *Independent variable:* we used the Template for Intervention Description and Replication (TiDieR) checklist for a complete intervention reporting (Hoffmann et al., 2014)(Chapter 5). 12/13. *Raw data record and analysis:* the data collection and analysis are well described in the following section. 14. *Replication:* we replicated the entire experiment 5 times with the participation of 5 dyads (5PwD/5family partners). 15. *Generalization:* Although findings cannot be generalized using single-subject design, consistency and multiple replications of the results across PwD were acknowledge.

The convergent mixed-method combined with the alternating single-subject design provides a methodological approach naturally fitting to understand each individual's experiences of completing a complex telerehabilitation intervention. Based on the procedures proposed by Creswell and Plano Clark (2018), a brief overview of the three steps used in this mixed-method doctoral thesis are summarized (Figure 1.4). A detailed description of the methodology can be found in the published protocol in Chapter 3, followed by protocol modifications due to COVID-19.

Step 1: Data collection

We used quantitative and qualitative methods of data collection in parallel to capture information from different standpoints. Details and psychometric data for each quantitative outcome measure and questionnaire (Step Count, Five time Sit to Stand, Community Balance and Mobility Scale, Mayo-Portland Participation Index, Fall-Efficacy Scale International, Satisfaction with Life Scale, and the Interpersonal Behaviours Questionnaire and Interpersonal Behaviours Questionnaire Self) are reported in Chapter 3 (section 3.3), Chapter 5 (section 5.3), and in Table 1.3. Qualitative data was collected using two semi-structured interviews.

Step 2: Analysis

The quantitative and qualitative data were analysed separately (Table 1.3). We analysed the repeated measures (Daily Step Count and Weekly Five Time Sit to Stand) following the SSD traditional method of analysis including visual analysis as well as the semi-statistical two standard deviation band method (2SDband) (Backman et al., 1997; Nourbakhsh & Ottenbacher, 1994). The questionnaires were evaluated descriptively. The qualitative data was analysed using an exploratory content analysis using inductive and deductive approaches using the three-phase process (preparing, categorizing, and reporting) (Elo et al., 2014; Elo & Kyngäs, 2008).

Table 1.3 Parallel data collection and analysis procedures including a rationale for statistical and clinical important difference.

Description of outcome measures used for data collection	Statistical Significance 2SD Band method Minimal Detectable Change (MDC) Minimal Clinical Important Difference (MCID) Effect Size (ES) or Cut-Off scores or categories	Rationale for this Doctoral Thesis
Quantitative Data Analysis		
Step Count Repeated measure using Fitbit® to collect information on physical activity level.	Statistical: 2SD band method on repeated measures MDC: 45 Steps in healthy adults MCID: 1000 steps per day were self-reported as an improvement in PA for adults with fibromyalgia ES: 2000 Steps Healthy people (from children to older adults)	TBI: no available evidence with TBI population, therefore we decided to use 2000 steps as the most conservative measure of clinical meaningful change
FTSTS Repeated outcome measure used to measure functional mobility	Statistical: 2SD band method on repeated measures MDC: 2.5 seconds in women 60 years old and older. MCID: 2.3 seconds in people with vestibular issues ES: 13 seconds for people with vestibular issues	The more conservative data of 2.5 seconds was used to determine improvement in mobility on the FTSTS
CB&M scale Pre-post outcome measures used to document dynamic balance	MDC: 7.5 points in TBI	Clinical improvement was noted when a change in score of 7.5 was documented
M2PI Pre-post questionnaire used to collect information on participation	60=severe limitation 50-60 =moderate to severe 40-50 =mild to moderate 30-40 = mild limitations Below 30= good participation	Use T-Scores to descriptively analyse
FES-I Pre-post questionnaire used to collect information on concerns with falling	MDC: 8.2 points in people with vestibular issues Concern with fear of falling scores: 16–19 = low 20–27 =moderate 28– 64 = high	Use T-Scores to descriptively analyse
SWLS Pre-post questionnaire used to collect information on satisfaction with life	Scores: 5-9 = extremely dissatisfied 10-14= dissatisfied 15-19= below average 20-24= average satisfaction 25-29= satisfied 30-35= highly satisfied	Use T-Scores to descriptively analyse
IBQ/IBQ-Self Pre-post questionnaire used to collect information on interpersonal behaviours	N/A	Descriptive explorative study on interpersonal behaviours using telerehabilitation.
Qualitative Data Analysis		
Semi-structured interviews	Exploratory content analysis: 1. transcription and data organization into categories, 2. experiences were compared, and categories were merged or further divided, 3. reporting of categories and example of descriptive narrative quotes	

Step 3: Integration and merging of data

Once both sets of data were analyzed in parallel, we integrated the quantitative and qualitative findings. The joint displays of findings were illustrated using either tables, graphs, narratives or topic areas (Creswell & Plano Clark, 2018). These integration approaches allow for observation of similarities and differences between the two data sets.

To display the findings, we combined the quantitative and qualitative findings when possible. Common topics were compared, and similar findings were illustrated by a narrative display of quotes and similar results from outcome measures. Contradictory quantitative and qualitative data were presented in separate areas allowing for an interesting discussion.

1.5 Hypothesis, Aim and Thesis Synopsis

Hypothesis

We hypothesized that high-intensity home-based exercise programs, combining both synchronous and asynchronous methods of delivery are feasible and effective for people living with a moderate of severe TBI and their families.

Aim of Dissertation

This doctoral research contributes to the telerehabilitation literature by understanding the implementation of telerehabilitation to improve access to home-based exercise programs targeting balance, mobility and physical activity for people living with a moderate or severe TBI. The specific purpose of this work was to investigate:

1) the feasibility of remotely delivering high-intensity home-based exercise programs supervised remotely either daily or weekly with people living with a moderate or severe TBI;

2) the effectiveness of two remote supervision schedules (daily or weekly) for high-intensity home-based telerehabilitation exercise programs on physical activity, functional mobility and balance for people living with a moderate or severe TBI;

3) the lived experiences faced by people with TBI and their family partners when completing a remotely delivered home-based exercise program, supervised daily or weekly; and

4) how interpersonal behaviours are self-reported by the treating physiotherapist and perceived by people who have experienced a moderate or severe TBI in a telerehabilitation setting.

Thesis synopsis

This dissertation contains five manuscripts (Chapter 2 to 6) documenting various findings linked to the previously stated overarching objectives (Figure 1.5). A discussion chapter (Chapter 7) follows the manuscripts, summarizes the findings and explains the impact on clinical practice, influences organisations and informs policymakers.

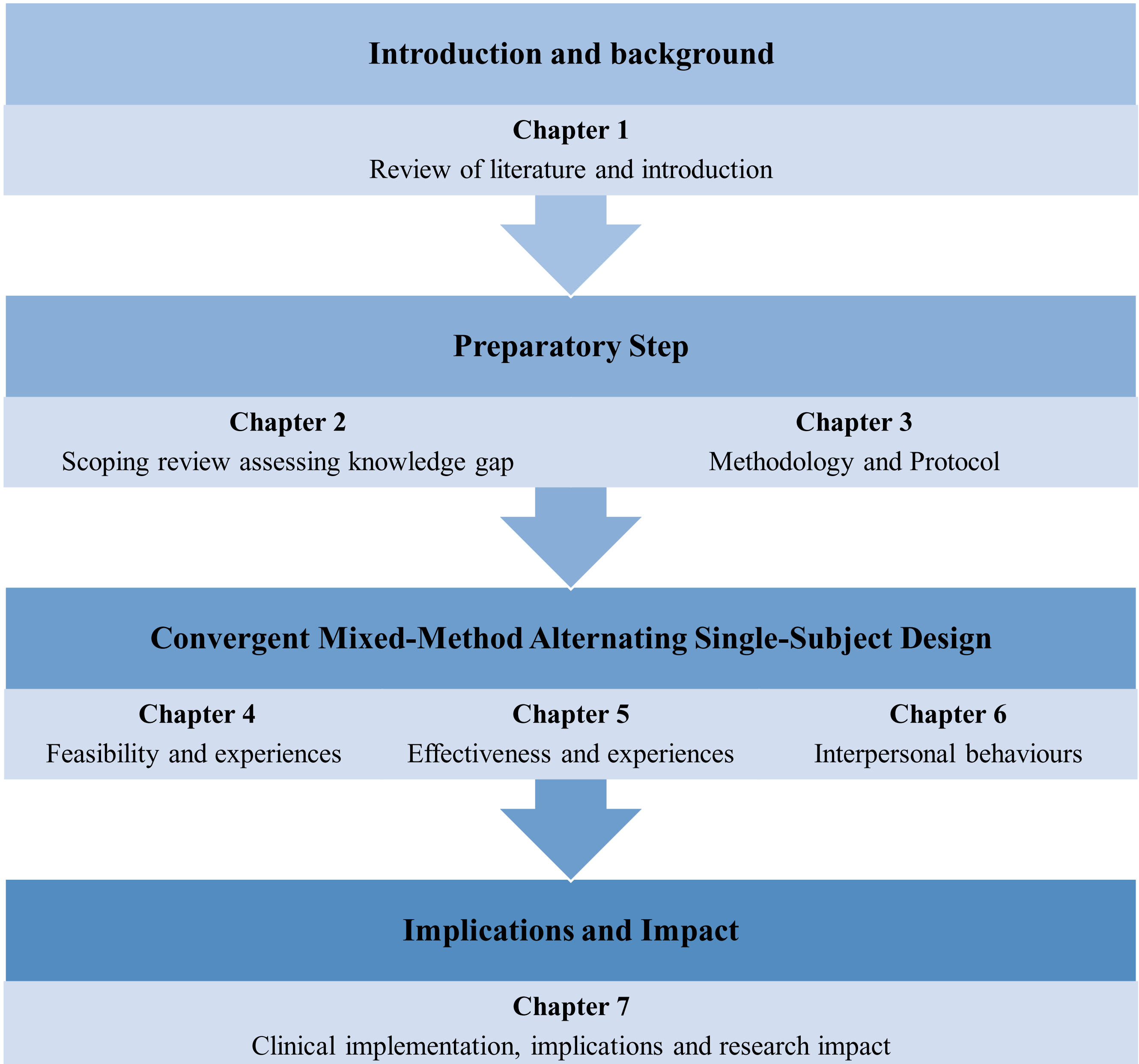

Figure 1.4 Doctoral thesis outline

Preparatory work

Chapter 2: Remote supervision of rehabilitation interventions for survivors of moderate or severe traumatic brain injury: A scoping review

Chapter two contains the published scoping review documenting the gaps in the literature around remote supervision of rehabilitation interventions for survivors of moderate or severe traumatic brain injury. The specific objectives for this study were to review:

1) The types of supervision used between synchronous, asynchronous or mixed;
2) The remote supervision parameters (frequency, duration, intensity);
3) The types of implementation and clinical outcome used to document feasibility and effectiveness of interventions for the population living a with moderate or severe TBI.

This scoping review was based on the Arksey and O'Malley (2005) and Colquhoun et al. (2014) methodology (Arksey and O'Malley, 2005; Colquhoun et al., 2014). The full article was published in the Journal of Telemedicine and Telecare (2019). Ethic approval was not required for this study.

Chapter 3: Remotely Supervised Home-Based Intensive Exercise Intervention to Improve Balance, Functional Mobility, and Physical Activity in Survivors of Moderate or Severe Traumatic Brain Injury: Protocol for a Mixed Methods Study

A published methodology used to conduct this Ph.D. thesis is presented in Chapter three. The protocol provides the methodological details used for the complex telerehabilitation home-based exercise programs.

This protocol was published in the Journal Medical Internet Research-research protocol (2019) (International Registered Report Identifier (IRRID): PRR1-10.2196/14867). Ethics approval was granted by the Bruyère Research Institute Ethic Board (M16-18-038) as well as the University of Ottawa REB (H-12-18-771).

Chapter 3 supplement: Modifications to published protocol due to COVID-19

A chapter supplement was added to describe the modifications to the published protocol that occurred as a result of COVID-19.

Mixed-Method Single-Subject Design

Chapter 4: Remotely Supervised Exercise Programs to Improve Balance, Mobility and Activity Among People with Moderate to Severe Traumatic Brain Injury: Description and Feasibility.

In chapter four, the feasibility of implementing remotely supervised high-intensity home-based exercise programs for people living with a moderate or severe TBI is presented.

We hypothesized that high-intensity home-based remotely supervised exercise programs were feasible for this population. Two main objectives were targeted in this study:

1) Investigate if a high-intensity home-based exercise program delivered remotely was feasible for people with a moderate or severe TBI and their family partners;
2) Better understand the lived experience of people with a moderate or severe TBI and their family partners with this telerehabilitation program.

Feasibility was measured using the following outcome measures: Process (adherence and retention), resources (usability of the technology), intervention aspects (engagement and dosage, adverse events), and lived experience (semi-structured interviews).

The feasibility study was submitted for publication to Physiotherapy Canada Journal on March 25, 2021 and is now under review. This study was approved by the Bruyère Research Institute Ethic Board (M16-18-038) as well as the University of Ottawa REB (H-12-18-771).

Chapter 5: The Impact of two Telerehabilitation Supervision Schedules on Physical Activity, Mobility, and Balance Among People with a Moderate or Severe Traumatic Brain Injury: a mixed-method approach.

Chapter five reports on the effectiveness of this telerehabilitation program on various outcomes. We hypothesized that the two teletherapy supervision schedules for high-intensity home-based exercise programs would be effective for this population.

The main study objectives were to understand the impact of two supervision schedules for a high-intensity home-based telerehabilitation exercise program on:

1) Physical activity levels (step count using an activity tracking device), functional mobility (Five Times Sit-to-Stand), and dynamic balance (Community Balance and Mobility scale); and
2) Participation (Mayo-Portland Participation Index, M2PI), concerns with falling (Fall-efficacy Scale International), and satisfaction with life (Satisfaction with Life Scale).

The effectiveness study was submitted for publication to Physiotherapy Canada Journal on March 25, 2021 and is now under review. Ethics approval was received by the Bruyère Research Institute Ethic Board (M16-18-038) as well as the University of Ottawa REB (H-12-18-771).

Chapter 6: How do People Living with a Disability Perceive the Physiotherapist Interpersonal Behaviours? Implications for home-based telerehabilitation

Chapter six introduces the Self-Determination Theory and explains concepts around interpersonal behaviours as well as how to assess interpersonal behaviours in a telerehabilitation setting. This descriptive sub-analysis study explored how interpersonal behaviours can support or frustrate (thwart) basic psychological needs necessary to motivation and adherence. The main objectives of this study were to document:

1) How the physiotherapist self-reports supportive/thwarting interpersonal behaviours;
2) How therapist behaviours were perceived by the people with a moderate or severe TBI; and
3) If the perception of these interpersonal behaviours aligned between the therapist and the exercisers.

Explained by the Self-Determination Theory, we wanted to introduce the concepts of supporting / thwarting autonomy, competence, and relatedness in a telerehabilitation context.

This study on interpersonal behaviours was submitted to Physiotherapy Theory and Practice on April 23rd, 2021 and is under review. This study was approved by the Bruyère Research Institute Ethic Board (M16-18-038) as well as the University of Ottawa REB (H-12-18-771).

Integration and Impact

Chapter 7

In the final chapter of this dissertation, the findings from all the studies are integrated. I present how this doctoral research could impact future clinical, and research implementation, inform policymakers and influence how organisations are structuring their telerehabilitation programs.

Of most importance, in this chapter, I discuss how telerehabilitation programs could potentially impact the daily lives of people who have experienced a moderate or severe TBI, who are currently living with motor or cognitive deficits and who are ageing at home following a traumatic brain injury.

Note

The studies found in Chapter 2, 3, 4, 5 and 6 are formatted as per each peer-reviewed journal where the manuscripts were published or are currently under-review. Tables and figures were renumbered to fit the formatting of this dissertation. Copyright and permissions are found in the appendix D.

Chapter 2. A Scoping Review on Remotely Supervised Interventions

Remote supervision of rehabilitation interventions for survivors of moderate or severe traumatic brain injury: A scoping review

Citation:

O'Neil J, van Ierssel J, Sveistrup H. **Remote supervision of rehabilitation interventions for survivors of moderate or severe traumatic brain injury: A scoping review.** J Telemed Telecare. 2020 Oct;26(9):520-535. Doi: 10.1177/1357633X19845466. Epub 2019 May 31. PMID: 31148489. Link: https://pubmed.ncbi.nlm.nih.gov/31148489/

The review presented in this chapter was published in the *Journal of Telemedicine and Telecare* on May 31, 2019. An integral copy of this publication can be found in Appendix D. Financial support was received from the University of Ottawa Admission Scholarship and Graduate Studentship Program at the Bruyère Research Institute 2018-2019.

2.1 Abstract

Introduction: Individuals with moderate or severe traumatic brain injury (TBI) often have persistent impairments upon discharge home. In rural communities, specialized rehabilitation services to address impairments can be difficult to access. The purpose of this scoping review is to examine how remote supervision is currently being used in TBI rehabilitation to identify gaps in knowledge that need to be addressed to facilitate access to and implementation of these services.

Methods: The main objective for this review is to identify the methods being used to deliver remote supervision for rehabilitation in a moderate or severe TBI population. The aim of this review was to document the implementation characteristics of remote supervision used including: (1) type of supervision such as synchronous, asynchronous supervision or mixed; (2) frequency and intensity of remote supervision; and (3) outcomes used to measure intervention delivery as well as effectiveness within this population. This scoping review follows EQUATOR Network recommendations for screening and extracting data.

Results: Twenty-six studies using a variety of remote supervision technology and outcome measures were included. Supervision frequency and intensity are poorly reported with no standardization. One hundred and six outcome measures were reported in this review showing large diversity in the areas being explored.

Discussion: Different types of remote supervision have been used with this population; however, there are no clear guidelines on clinical implementation. Future studies must better define implementation parameters of remote supervision. Benefit on physical activity, balance and mobility outcomes also need to be further explored.

Keywords: TBI, remote supervision, rehabilitation, technology, telerehabilitation

2.2 Introduction

Survivors of moderate or severe traumatic brain injury (TBI)

In Canada, 65% of patients diagnosed with a TBI are discharged home, often without planned follow-up from rehabilitation service provider.[1] Survivors of TBI living in the community without management for chronic functional impairments may have activity and participation deficits for years and in some cases decades after the initial trauma.[2] Such deficits significantly impact their quality of life.[3] In a disability and rehabilitation report from the World Health Organization (WHO) (2011), rehabilitation is defined as "a set of measures that assist individuals who experience, or are likely to experience, disability to achieve and maintain optimal functioning in interaction with their environments". The main intent of this scoping review was to identify what has been done remotely in terms of rehabilitation for this specific population. Rehabilitation intervention and increased physical activity can provide a means to reduce these deficits. Traumatic brain injury survivors are living longer, resulting in an increasing number of older individuals needing rehabilitation for chronic impairments.[4] Improved access to rehabilitation services and activity supervision is essential as TBI survivors have to deal with the impairments from both the TBI as well as the normal ageing processes.[5] Decreasing associated cost and burden of transportation for rehabilitation may result in improved access. Remotely supervising specialized rehabilitation programmes for individuals closer to where they live is one way to reduce cost while providing access to rehabilitation services needed to manage lifelong impairments.

Remote supervision

Telerehabilitation is an umbrella term that includes a variety of technology used in the rehabilitation context allowing it to be completed without face-to-face support. Remote supervision (RS) is one method of delivery within the telerehabilitation sphere, and it is defined as the use of communication technology to provide supervised rehabilitation from a remote location.[6] In this review the term RS will be used to identify a clinician who is either administering an assessment or an intervention with a patient remotely. For example, RS by physiotherapists facilitates the delivery of physical interventions as well as supervision of exercise, which can reduce the long-term cost of rehabilitation.[7] Supervising from another location using technology has been used effectively as an alternative to face-to-face guidance for physical therapy interventions for orthopaedic populations such as post-total knee arthroplasty,[8–10] with individuals who have cardiorespiratory impairments such as asthma[11] in the management of chronic obstructive pulmonary disease,[12] and in neurological conditions such as post-stroke.[13–15] However, evidence supporting the use of RS with the whole spectrum of the TBI population is sparse.[16,17] The complexity and heterogeneity of a moderate or severe TBI population makes it difficult to infer results from studies on other health conditions. Studies that target the RS of TBI patients are essential to meet the urgent need for comprehensive and intensive rehabilitation.

Remote supervision may be described as either synchronous or asynchronous. Synchronous supervision refers to the provision of feedback or supervision in real-time.[18] Videoconferencing is a commonly used example of synchronous supervision in which the therapist can see and provide both audio and visual feedback to the patient at the exact time the patient is performing the activity. This feedback combination promotes a therapeutic relationship between the therapist and the patient. Tsaousides et al. (2014)[19] demonstrated the feasibility of using this form of technology for group occupational therapy focusing on emotional regulation post TBI. Asynchronous supervision is defined as the provision of supervision and feedback after the intervention has been completed. Subtypes of asynchronous supervision include, but are not limited to, the use of emails and messaging.[20]

Purpose

The purpose of this scoping review is to examine the evidence of RS in the rehabilitation of individuals with moderate or severe TBI in order to identify gaps in knowledge that need to be addressed in order to better facilitate access to and implementation of these services.

Objectives

The main objective for this review is to document the RS methods being used to deliver therapy or assess clinical outcomes in a moderate or severe TBI population. The specific aims of the study are to document implementation characteristics including: (1) The type of RS method used (i.e., synchronous, asynchronous, mixed); (2) the frequency of RS delivery of any therapeutic intervention; and (3) the outcomes measures used to assess the delivery model of RS (i.e., feasibility) and the clinical outcomes assessing intervention. Results from this study will provide guidance for future feasibility studies and clinical trials with RS.

2.3 Methods

A scoping review was considered the best design to highlight large variations in application of interventions, outcomes assessed, and clinical outcome measures given that the use of remote technology in specialized rehabilitation of individuals with moderate or severe TBI is novel and knowledge still sparse. Following the PRISMA checklist proposed by the EQUATOR Network[21] and supported by Colquhoun, Levac and O'Brien et al. (2014),[22] this scoping review followed five methodological steps. The research question was defined according to the Patient

Intervention Comparison Outcome principle and specific inclusion and exclusion criteria (Table 2.1) were identified a priori. Emphasis was placed on the method of supervision included in the study, in order to have a comprehensive picture of the current state of knowledge of RS. Search terms were developed with the assistance of an experienced librarian by searching the indexed terms related to RS and telerehabilitation, and then extrapolated to a moderate or severe TBI population. To better inform subsequent studies, the term physical rehabilitation was included in the search terms to narrow the rehabilitation to a subtype while still keeping it broader than only physiotherapy intervention (Supplemental files).

Table 2.1 Major concepts defining search terms as well as inclusion and exclusion criteria.

Major concepts and related search terms	Concept 1. Moderate or severe traumatic brain injury
	Traumatic brain injury.mp.) or Brain Injuries, Traumatic/
	Concept 2. Remote supervision (synchronous and asynchronous)
	Telerehabilitation.mp. or Telemedicine/ or Telerehabilitation/ or Videoconferencing/ or Remote Consultation/)
	accelerometry.mp. or Accelerometry, mobile health.mp. or Telemedicine
	Concept 3. Rehabilitation
	Exercise/ or Physical Fitness/ or physical therapy or physiotherapy or physical interventions
Inclusion criteria	Adults aged 18–64 years
	Inclusion of individuals with moderate or severe TBI
	Remote supervision as an intervention, assessment or feasibility study
Exclusion criteria	Face-to-face supervision only

Four electronic databases were searched, including Medline-OVID, PsychINFO, CINAHL and Cochrane Library. Grey literature and references lists were also searched; however, no additional articles were selected. The last search was conducted on 7 May 2018 (Appendix A). The search was made without limitations on dates given that RS is still an emerging concept in healthcare literature. Language was limited to French and English studies only. The absence of RS as an intervention delivery method or assessment mode was the only limitation placed on study methodology.

Studies were identified by a single researcher (JO) and duplicates were eliminated. Titles and abstracts were screened by two independent researchers, both Ph.D. candidates and physiotherapists (JV and JO). When the population was only described as TBI without specifying the severity, the authors were contacted to ensure that moderate or severe TBI was included. Studies were retained if they met the eligibility criteria and were included for independent full text review by both researchers. Discrepancies were resolved through discussion until consensus was reached. A third reviewer (HS) was available for discussion in case of any unresolved conflict; however, this was unnecessary.

A standardized data extraction form initially guided by the Cochrane Collaboration (from Supplemental file Appendix B) was used to facilitate data selection for each study retained. This extraction form was developed and tested a priori to systematically extract data from studies included in the final selection. As recommended by Colquhoun et al. (2014),[22] the reviewers piloted the extraction form on one study[23] and adjusted the form accordingly. Changes included deleting duplicate concepts, defining the sample and adding geographical location of participant recruitment (i.e., rural vs. urban setting). As per Colquhoun et al. (2017),[24] the independent researchers reached a minimum of 80% agreement when piloting the data extraction form prior to reviewing all studies. Once adjustments were made to the extraction form, this agreement quota was reached without needing mediation from a third reviewer.

Following the same methodological framework, data were interpreted to better identify the gaps by: Grouping data by themes according to the objectives, analysing each theme descriptively using frequency distributions and reporting the outcome under each theme discussing the implication for future research and clinical practice.

A quality assessment of intervention reporting was completed to support our objective of documenting the implementation characteristics of RS. The TIDieR checklist[25] was chosen for this analysis as it allowed for a structured assessment of complex rehabilitation intervention description.[26] Each included intervention study was assessed by two separate reviewers (JO, JV).

2.4 Results

Of the 166 studies that met the inclusion criteria, 140 studies were excluded, leaving 26 studies eligible for full data extraction (see Figure 2.1). All included studies were conducted in upper or upper-middle income countries between 1996 and 2017. Eight studies evaluated the use of RS as a means of clinical assessment[27–34] and 18 as a means to deliver clinical intervention.[30,35–46] Of the 18 intervention studies, six were feasibility studies focusing on either feasibility of using RS as an intervention delivery or the feasibility of a RS clinical intervention.[19,34,47–51] Of the 26 included studies, less than half reported the number of days per week or duration of each remotely supervised sessions.

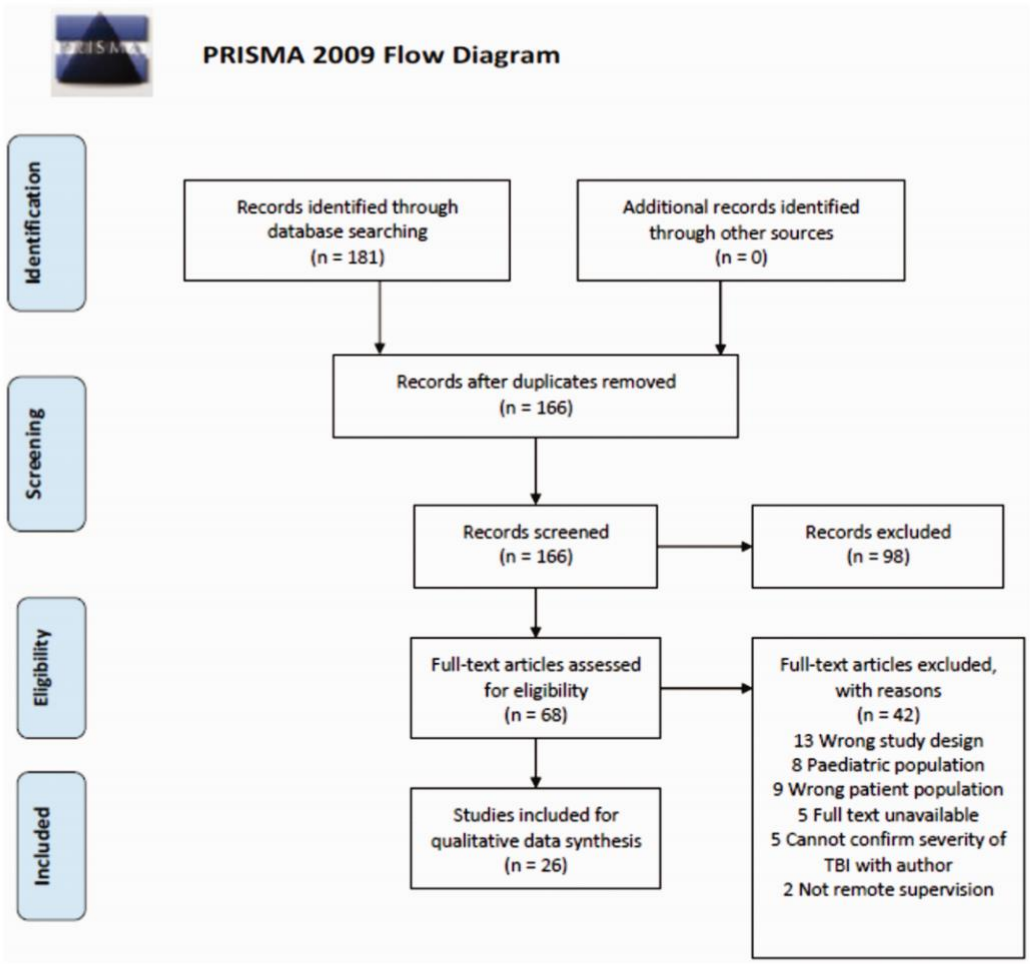

Figure 2.1 PRISMA flow diagram for scoping review process demonstrating included studies, recommended by Moher et al. (2009).21

Assessment studies

Amongst the eight studies focusing on clinical assessment, synchronous delivery was overwhelmingly the preferred means of RS ($n = 6$), with only two employing the use of a mixed type ($n = 2$). The type of technology used in the application of a synchronous RS assessment was split between telephone calls ($n = 2$)[31,32] and videoconferencing ($n = 4$).[27–30] Preliminary evidence demonstrated that telephone-based assessment can reduce time and effectively assess residual impairments while videoconference can be a valid method of assessment while maintaining patient satisfaction when compared with face-to-face. Interestingly, the only two studies using a mixed method to evaluate clinical outcomes incorporated newer modes of technology such as smart technology and recording. One pilot study examined the use of phone and digital recording to assess communication asynchronously[33] whereas the combination of a smart phone application and phone system was found in the other prospective study to track and clinically assess mental health.[34]

These studies using RS as a mode of clinical assessment varied in frequencies as well as differences in rehabilitation objectives. Two studies described parameters related to duration of the assessment which ranged between 15 and 30 minutes,[31,33] whereas in the majority of the studies, outcomes were assessed at a frequency of one or two sessions. Uniquely, Juengst et al. (2015) assessed outcomes at eight different follow-ups points and showed good compliance with the 2 minutes of daily assessment, providing preliminary evidence of high adherence rate when using the smart phone application in such a manner (Table 2.2).

Table 2.2 Studies including remotely supervised clinical assessment only. Type of Remote Supervision (RS), clinical assessment as well as frequency parameters are included.

Included studies	Study objectives	Type of remote supervision	Type of outcome measures	# of sessions	Rehab professional
Dombovy et al., 1996	Assess functional, neuropsychological and social via telephone at 3–6 months post injury	Phone	FIM, Telephone Interview for Cognitive Status (TICS), Neurobehavioural Rating Scale (NRS), Questions regarding employment, performance of household activities, personal, financial management, travel and social activities	1 session of 15–30 minutes	Nurse practitioner
Schopp et al., 2000	1) Assess the use of videoconference 2) Assess experience of psychotherapy via videoconference	Videoconference	Patients rated the following on Likert-type scales (from 1, lowest, to 7, highest): 1) global satisfaction with the interview	2 sessions	Neuropsychologist
Theodoros et al., 2003	Assess online protocol versus face-to-face assessment of dysarthria	Videoconference	An overall rating of the severity of dysarthria, the Assessment of Intelligibility of Dysarthric Speech (ASSIDS)	2 sessions	Speech–language pathologist
Guo et al., 2008	Compare communication during phone interaction	Digital recording, phone	Assessment of Intelligibility of Dysarthric Speech (ASSIDS), Rating comfort, frequency of exchange structure moves	1 assessment of 15 minutes	Speech–language pathologist
Theodoros et al., 2008	Assessing aphasia using standardized language assessment via an Internet-based videoconferencing system	Videoconference	The Boston Naming Test (BNT) (2nd edition), the short forms of the Boston Diagnostic Aphasia Examination, 3rd edition (BDAE-3),	1 assessment	Speech–language pathologist
Hutson et al., 2009	Assess the impact of impairment on self-ratings of community integration and life satisfaction	Phone	CIQ, SWLS	1 assessment	Not reported
Turkstra et al., 2012	Compare in-person vs. telehealth assessment of discourse	Videoconference	The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS), total number of words, total number of c-units, type-token ratio, number of mazes (revisions and repetitions)	1 assessment	Speech–language pathologist
Juengst et al., 2015	Assess feasibility and validity of a mobile health system to track mood	Email, Smart phone application, Phone	Post-concussion symptoms checklist (PSC), background of Smartphone experience, Compliance, Satisfaction, Telehealth Usability Questionnaire (TUQ), processing speed (Trail Making Test A and B, California Verbal Learning Test II (CVLT-II), Delis-Kaplan Executive Function System (DKEFS), verbal fluency sub-test, the Stroop Interference test, Patient Health Questionnaire (PHQ) 2, Generalized Anxiety Disorder (GAD) 2, Fatigue, Positive and Negative Affect Schedule (PANAS), Patient Health Questionnaire (PHQ) 9, Generalized Anxiety Disorder (GAD) 7)	8 sessions	Not reported

Intervention studies

Eighteen out of the 26 included studies focused on intervention. Of these, 12 were clinical trials investigating intervention effectiveness,[23,36–39,41–46] 4 investigated the feasibility of using RS as an intervention delivery method[19,47,48,50] and 2 focused on the feasibility of the RS intervention itself.[34,49,51] Rehabilitation interventions focused mostly on cognitive training and education, whereas the feasibility studies presented an introduction to targeting different impairments such as physical activity and upper-extremity deficit. Overall, poor reporting was found relating to the specific rehabilitation provider, with 10 out of 18 studies either not reporting at all who was providing the intervention or describing it with the general term "therapist".

Clinical trial

The choice of technology for RS in the intervention studies was wide-ranging, but consisted of three main types: Phone, videoconference and digital recording. However, two new RS modalities were introduced in the intervention studies: Virtual reality and instant messaging, which respectively demonstrated the efficacy of RS delivery for rehabilitation intervention to improve upper-extremity impairments and automaticity of speech (Table 2.3). None of the 12 included intervention-based studies were trials focusing on improving lower-extremity impairments or balance deficits.

The longest intervention protocol supervised patients remotely by telephone over a 21-month period, averaging a total intervention time between 300 and 495 minutes.[23] Of the studies which described the length of each session, most studies ranged between 30 minutes and 60 minutes, with the exception of one study that averaged 8.5 hours per session.[36] Two studies totalled the highest number of sessions at 30.[40,41] In contrast, the shortest amount was six sessions.[42,44,45] The weekly number of sessions and duration of each session was not described in all studies (Table 2.3).

Table 2.3 Studies including remotely supervised rehabilitation intervention only. Type of Remote Supervision (RS) and clinical intervention as well as frequency parameters are included.

Included studies	Study objectives	Type of remote supervision	Type of outcome measures	Implementation parameters	Rehab professional
Clinical trial: synchronous remote supervision intervention studies					
Warden et al., 2000	Report the results of a prospective RCT comparing home versus inpatient cognitive rehabilitation for patients with moderate to severe head injury	Videoconference, Phone	Number of hours spent on various activities Military fitness for duty Military fitness for duty and perception of treatment	8 sessions in total 1 day per week 2 months	Master's-level psychiatric nurse
Tam et al., 2003	Evaluate the effectiveness and perceived efficacy of the newly developed customized tele-cognitive rehabilitation programme for three subjects with traumatic brain injury	Videoconference	Impact of daily life Efficacy of telehealth treatment Neurobehavioural Cognitive Status Examination (NCSE) or Cognistat Rivermead Behavioural Memory Test (RBMT) Rivermead Perceptual Assessment Battery (RPAB), Recall items x2 (subjective)	6 sessions in total	Occupational therapy
Bell et al., 2005	Measure the effectiveness of a scheduled telephone intervention offering counselling and education to people with traumatic brain injury (TBI) on behavioural outcomes compared with standard follow-up at 1 year postinjury	Phone	FIM, DRS Functional Status Examination (FSE) Neurobehavioural Functioning Inventory (NFI), Glasgow Outcome Scale–Extended (GOSE) The Brief Symptom Inventory (BSI), CIQ, SF-36 EuroQol, Modified Perceived Quality of Life (PQOL)	7 sessions in total	Not reported
McGrath et al., 2008	Determine whether the client, mentor and clinical case coordinator find VTC as effective as face-to-face supervision and if this results in cost savings	Videoconference, Phone	Survey – effectiveness of medium used that week Effects on working relationship Overall satisfaction of medium $ spent on travel vs equipment	16 sessions in total	Not reported
Bergquist et al., 2009	Examine whether cognitive rehabilitation delivered over the Internet was associated with improvements in functioning	Instant Messaging	The Compensation Techniques Questionnaire, CIQ, Neurobehavioural Functioning Inventory (NFI)	30 sessions in total 2–3 days per week	Therapist: specialty not reported
Bombardier et al., 2009	Determine whether an intervention designed to improve functioning after traumatic brain injury also ameliorates depressive symptoms	Phone	Brief Symptom Inventory-Depression (BSI-D) subscale The Short-Form-36 Mental Health Index (MHI-5) The Neurobehavioral Functioning Inventory-Depression (NFI-D) subscale	6 sessions in total 30–45 minutes per sessions 9 months	Neurobehavioural examiner
Bergquist et al., 2010	Report patient satisfaction with an Internet-based cognitive rehabilitation programme	Instant Messaging	The Compensation Techniques Questionnaire Study Satisfaction Questionnaire	2–3 sessions in total	Therapist: specialty not reported
Bell et al., 2011	Evaluate the effect of a Scheduled Telephone Intervention (STI) compared with usual care (UC) on function, health/emotional status, community/work activities, and wellbeing	Phone	FIM, DRS, Participation with Recombined Tools-Objective, GOSE, the Brief Symptom Inventory-18	11 sessions in total	Clinicians with master's degrees: specialty not reported
Henry et al., 2012	Explore the feasibility of adapting progressive tinnitus management needs of Veterans and military personnel with TBI by providing the educational counselling via home-based telehealth	Phone	Tinnitus Handicap Inventory (THI), Epworth Sleepiness Scale (ESS), Hospital Anxiety and Depression Scale (HADS) Primary Care PTSD screening tool (PCPTSD), Tinnitus and Hearing Survey (TAHS), Tinnitus questionnaire	6 sessions in total 6 months	Audiologist and psychologist
Fann et al., 2015	Test the efficacy of a 12-session manualized cognitive behavioural therapy programme to treat major depressive disorder	Phone	Hamilton Depression Rating Scale (HAMD-17), Patient-reported Symptom Checklist-20 (SCL-20), SCID, the Working Alliance Inventory-Short Form, quality of life (SF-36), Sheehan Disability Scale, Patient Global Impression (PGI), post- concussive symptoms Symptom Checklist	12 sessions in total	Therapist: specialty not reported
Clinical Trial – Mixed (Synchronous and Asynchronous) remote supervision intervention studies					
Goldberg et al., 2012	Examine the effects and generalization of a modified script training intervention, delivered partly via videoconferencing, on dialogue scripts	Digital recording, Videoconference	Rate of speech % percent script-related, percent words with grammatical Morphemes, # disfluencies per word	9 sessions in total 3 week, 3 times per week	Speech–language pathologist
Kizony et al., 2017	Document the service delivery implemented by the CogniMotion System for people with ABI over a 2-year span	Virtual Reality, Videoconference	System Usability Scale, National Institutes of Health Stroke Scale (NIHSS), The Mini-Mental State Exam (MMSE), MOCA, The Trail Making Test (TMT, parts A and B), The Fugl-Meyer Assessment (FMA), The Motor Activity Log (MAL)	16–20 sessions in total 2 days per week 2 months	Physiotherapist or occupational therapist
Feasibility of using remote supervision as a delivery method					
Diamond et al., 2003	Build an internet-based, "Virtual Rehabilitation Centre" that provides rehabilitation, education and support services to individuals with TBI and, determine the relationships between nature and severity of cognitive impairments and the ability to use the VRC	Virtual Reality	The Virtual System-Instructional and Assessment Scales (VS-IAS), VRC Performance, Neurobehavioural cognitive status examination (NBCSE)	No clear, but assume 1	Not reported
Bergquist et al., 2008	Investigate the feasibility of learning how to use the IM system for cognitive intervention	Instant Messaging	% missed sessions for the first 10 sessions	Ranging between 12 and 62 sessions, average 32 intervention sessions in total	Cognitive rehabilitation therapist
Tsaousides et al., 2014	Assess the feasibility ofdelivering a manualized CBT-based group treatment of emotional regulation to a group of individuals with TBI simultaneously via a web-based videoconference	Email, Videoconference	The Therapist Checklist (TCL) assessing participants' subjective experience satisfaction with treatment delivery, duration and frequency of session group size content presentation format Difficulties in Emotion Regulation Scale (DERS); The Brain Injury Rehabilitation Trust Regulation of Emotions Questionnaire (BREQ); Satisfaction with Therapy and Therapist Scale (STTS); The Problem-Solving Inventory (PSI); The Social Problem-Solving Inventory–Revised: Short Form (SPSI-R-S)	16 sessions in total 60 min per session 2 days per week 2 months	Therapist: specialty not reported
Jones et al., 2016	Evaluate the acceptability and feasibility of a remotely delivered self-management programme aimed at increasing physical activity among adults who dwell in the community and have ABI.	Email, Phone	Participation in the intervention, examined via participant-reported feedback as to which lessons were completed during the 8-week programme, attrition from the study, clinician time spent per participant, accessibility, adverse events, Programme Satisfaction Questionnaire, average daily step count (ACTIVPAL3), average daily time spent sitting or lying down, average daily time spent in moderate to vigorous physical activity, 10 item scale adapted from the Spinal Cord Injury Exercise Self-Efficacy Scale, K-10 a brief self-report measure of nonspecific psychological distress, modified Reintegration to Normal Living Index (mRNLI)	6 sessions synchronous and 6 asynchronous in total 30–60 min asynchronous sessions 1 synchronous day per week 2 months in total	Physiotherapist
Feasibility of a remotely supervised clinical intervention					
Huijgen et al., 2008	Investigate the feasibility of the HCAD system in clinic compared to usual care on Upper-extremity clinical outcomes	Videoconference	Action Research Arm Test (ARAT), the Nine Hole Peg Test (NHPT), User satisfaction was asked with a Visual Analogue Scale (VAS), Compliance (time and amount)	20 sessions in total 30 min asynchronous session 1 synchronous day and 5 asynchronous day per week 1 month	Therapist: specialty not reported

Feasibility studies

Interestingly the technology in the feasibility studies differed from the technology used in the clinical intervention studies. The feasibility of using stand-alone virtual reality, instant messenger as RS method of delivery was addressed in two studies[43,44] and showed that the learn ability of the technology can be achieved in the cognitively impaired TBI survivors. The mixed RS method of delivery using videoconferencing with email proved to be a satisfying and feasible method to deliver group intervention.[19] Likewise, phone combined with email[50] demonstrated significant satisfaction among participants. The feasibility of RS intervention was also investigated in all types of RS technology. Stand-alone asynchronous RS was introduced with the Home Care Activity Desk (HCAD) virtual system where the effectiveness on upper-extremity outcome was comparable to conventional care;[49] mixed synchronous RS intervention of telephone combined with the videoconference was shown comparable to face-to-face delivery;[51] and the mixed phone, email and first introduction of smart phone application demonstrated that survivors of TBI can improve adherence rate with the use of smart technology.[34]

Thirty-two sessions represented the highest frequency of RS interaction.[47] In contrast, six sessions was the least frequent reported number of sessions[50] (Table 2.3).

Outcomes

Remote supervision feasibility outcome

Twenty feasibility measures were identified that evaluated the feasibility of using RS as an intervention delivery. Following the classification proposed by Thabane et al. (2010), the process was measured by the following: User satisfaction with a Visual Analogue Scale; compliance (time and amount); percentage of missed sessions for the first 10 sessions; feedback interviews (experiences and use of approach); adherence (session recordings); The Therapist Checklist assessing participants' subjective experience satisfaction and background of smartphone experience; the Programme Satisfaction Questionnaire; attrition from the study; Satisfaction with Therapy and Therapist Scale; resources by duration and frequency of session; group size; content presentation format; the Telehealth Usability Questionnaire; accessibility; the Virtual System-Instructional and Assessment Scale; management by clinician time spent per participant; and the scientific aspect by adverse events.[51] Of these four classifications (process, resources, management and scientific aspect), we identified 11 out of 20 measuring the process, 7 out of 20 assessing the resources, and 1 out of 20 each for the management and scientific aspect.

Nine different outcomes were discovered in studies investigating the feasibility of remote intervention delivery. However, the majority of studies targeted effects of intervention on cognitive performance and memory ($N = 4$) as measured by the Neurobehavioural Cognitive Status Examination (NBCSE), The Dysexecutive Questionnaire (DEX), The Problem-Solving Inventory (PSI), The Social Problem-Solving Inventory–Revised: Short Form (SPSI-R-S) and Oral Trail Making Test (TMT)-B. Again, this demonstrates a lack in consistency of outcome measures as well as poor variety of outcomes in feasibility studies of RS rehabilitation intervention.

Clinical outcome

Thirty-six outcome measures were found in the assessment studies, averaging five measures per clinical outcome. Speech–language pathology rehabilitation was represented most often in terms of intervention ($N = 5$), with remotely supervised assessment measuring clinical changes in speech outcome with outcome measures such as: Assessment of Intelligibility of Dysarthric Speech (ASSIDS), an overall rating of the severity of dysarthria, The Boston Naming Test (BNT) (2nd edition), short forms of the Boston Diagnostic Aphasia Examination, total number of words, total number of c-units, type-token ratio, number of mazes (revisions and repetitions) and verbal fluency sub-test.

Fifty-two outcome measures were used to objectively demonstrate the effects of remotely supervised interventions. Aside from feasibility outcomes, community integration and participation ($N = 6$) and general health ($N = 6$) outcomes were identified the most frequently in studies. Respectively, these outcomes were clinically measured by the Military fitness for duty, CIQ, the Working Alliance Inventory-Short Form, The Motor Activity Log (MAL), Participation with Recombined Tools-Objective, Sheehan Disability Scale and the Brief Symptom Inventory (BSI), the Brief Symptom Inventory-18, Patient-reported Symptom Checklist-20 (SCL-20), Post-concussion Symptom Checklist, National Institutes of Health Stroke Scale (NIHSS) and Patient Global Impression (PGI). No physical activity outcome measures were identified in any of the included intervention studies. However, when compared to the included RS clinical assessment studies, impairment-based clinical outcomes such as vestibular and upper-extremity deficits were identified.

Gap analysis

The gap analysis was first completed by grouping the data into four themes reflecting the overall objectives: Type of remote supervision, frequency of remote supervision, type of outcome and outcome measures, and types of RS intervention. Each theme was analysed descriptively, and gaps were reported to highlight the main findings.

Type of remote supervision

The oldest form of remote supervision, telephone-based RS intervention, was most often used, which demonstrates a gap in the implementation of newer types of technology for RS in a clinical setting. Newer forms of stand-alone synchronous technology such as videoconferencing and virtual reality were also shown to be sparse in intervention studies ($N = 7$). In addition, only one study discussed the use of current technology such as smart phone application.

Frequency of remote supervision

Reporting of implementation parameters of RS such as duration of sessions, frequency per week or length of intervention was poor in all study subtypes, including assessment, intervention and feasibility, leading to an incomplete picture of the use of RS for this population. There was also a lack of consistency in reporting RS parameters such as intensity of intervention, length of assessment or intervention and frequency of supervision.

Type of outcome and outcomes measures

A large variety of outcome measures were identified ($n = 106$) demonstrating a broad assessment of the use of RS; however, a gap was shown in the standardization of outcome measures for this specific population for this intervention delivery method. Clinical outcomes and clinical outcome measures identifying the impact of RS delivery on lower-extremity, balance, mobility and physical activity are limited. As for feasibility measures, most assessed the same construct; however, a gap was demonstrated in the data management and scientific aspect measures.

Type of RS intervention

Cognitive training and education were the two most common interventions (12 out of 20 intervention studies), which reflects inadequately on the inclusion of physical intervention. Interventions targeting lower-extremity deficits, balance, mobility and physical activity were poorly represented in this review.

Quality of reporting in intervention studies

Of the 18 included intervention studies, only half of the studies[23,47,51] were over a 70% cut-off of quality reporting when using the TIDieR checklist (Figure 2.2 and 2.3). This quality assessment suggests a lack of implementation information related to types of providers, locations and the specificities of how the intervention is being tailored. The items that were most frequently not reported pertained to the type of rehabilitation providers or how the intervention was tailored.

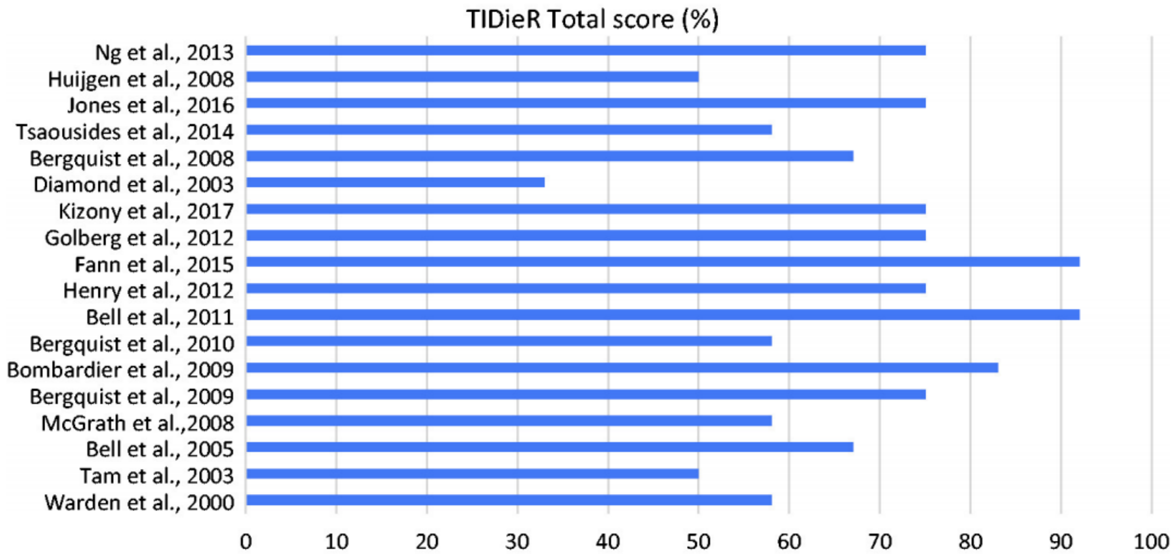

Figure 2.2 Quality reporting using the TIDieR checklist (Hoffman et al., 2014).25 Percentage of items being properly reported (%) for all included intervention studies.

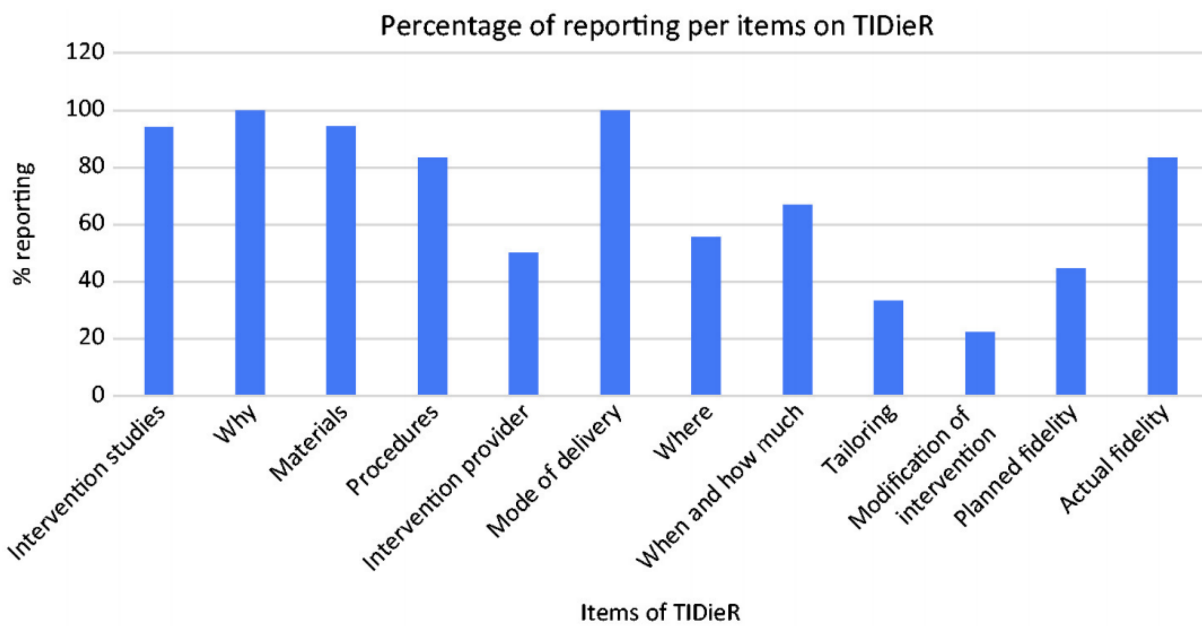

Figure 2.3 Percentage (%) of reporting per items on the TIDieR checklist demonstrating where the gaps in reporting are mostly found.

2.5 Discussion

This scoping review demonstrated the lack of studies and evidence on RS and rehabilitation intervention in adults who sustained a TBI. To our knowledge, this is the first scoping review combining the two concepts while exploring specific implementation parameters such as synchronous or asynchronous mode of delivery and frequency of RS, as well as clinical outcomes measures used to demonstrate effectiveness of intervention or intervention delivery.

A small sample of RS technology was used in this review. Telephone interventions were frequently used, which could potentially present as challenging for survivors of moderate and severe TBI. Telephone technology relies solely on auditory information to deliver therapeutic interventions, which may be too complex to deliver interventions for individuals with residual cognitive impairments.[52] However, telephone-based assessment has been shown to reduce assessment time compared with in-person while being an effective method to identify residual impairment in this population.[31] An alternative form of technology that was identified was text-based communication, such instant messaging (IM). When compared with other types of RS, it demonstrated a higher frequency of sessions. This could be beneficial when aiming to increase frequency of supervision, potentially leading to an increase in intervention frequency. Despite preliminary evidence of modern technology such as synchronous videoconferencing, virtual reality and smart technology, additional studies must be completed to better understand their impact and future clinical implementation.

This review also demonstrated poor reporting of clinical implementation parameters related to frequency, intensity, duration and number of sessions of remotely supervised interventions. Without this specific information, clinical replication of the intervention can be difficult.[25,26] Complete and detailed reporting of such parameters are needed to better understand the impact certain frequencies could have on different outcomes and provide evidence for clinical implementation of RS.

Studies exploring the impact of RS on common motor deficits found in adults post moderate or severe TBI such as balance, mobility and physical activity were lacking. Of the 18 included studies (intervention and feasibility), physical activity outcomes measures were only found in one study and none were found for balance or mobility. The inclusion of such outcome measures should be considered in future trials to better understand the impact RS has on motor deficits. In addition, a large variety of outcome measures assessing the same construct were identified demonstrating minimal standardization of outcome measures for this population. The choice of which outcome measure to incorporate in a study protocol is key to enable efficacy studies to be compared.

Our systematic review complements two recent systematic reviews by Ownsworth et al. (2018) and Betts et al. (2018),[16,17] which targeted the efficacy of telerehabilitation intervention in individuals with all severities of TBI. The objectives of the present scoping review were to better understand the breadth rather than depth of knowledge on the implementation characteristics such as frequency of remote delivery or assessment or the type of outcome measures currently being used. The present scoping review targeted the population post moderate or severe TBI excluding studies where only a mild TBI sample was present, whereas the systematic reviews by Ownsworth et al. (2018) and Betts et al. (2018) included all levels of TBI severity. While Ownsworth et al. (2018) also explain the high usage of telephone-based intervention in this population, the exclusion of a smaller sample (<10) might have resulted in a poor exploration of the efficacy of other types of technology found in the current scoping review such as virtual reality or smart phone application. The systematic review conducted by Betts et al. (2018) discusses the inclusion of outcome measures and intervention parameters targeting cognition and quality of life but does not reflect on the breadth of other outcome measures or types of intervention used for this population and telerehabilitation. This review contributes and adds to the literature in the areas of intervention parameters, outcome measures, types of technology and types of interventions.

2.6 Conclusion

Preliminary evidence exists for the clinical implementation of RS in a moderate or severe TBI population. However, evidence shows that limitations in the implementation of remote technology and brain injury rehabilitation still remain. Standardized frequency parameters for effective intervention have not yet been identified. Authors must consider reporting these parameters carefully in future studies to allow for comparison between parameters. The effects of RS intervention on physical activity, balance or mobility still remain unclear. Further studies targeting these specific clinical outcomes with consistent and standardized measures throughout design must be completed. The small number of studies included in this review show that well-established modes of telecommunication such as phone calls are still the intervention delivery methods of choice for synchronous RS. Therefore, the inclusion of novel technology in rehabilitation intervention should continue to grow. Additional clinical trials, reviews and meta-analyses must be completed to better understand this area.

Limitations

Since the last database search was conducted in May 2018, and the manuscript was completed shortly after, recently published reviews[16,17] are not included. To mitigate this issue, a complete comparison of these two newly published systematic reviews with this current scoping review was completed. The main differences are highlighted in the present discussion section. The inclusion of English and French language only may also have resulted in key articles being missed. Articles not describing the severity of the TBI were also excluded, narrowing the breath of this review.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: An Admission Scholarship at University of Ottawa 2016-2020 and a Graduate Studentship Programme at the Bruyère Research Institute 2018-2019.

Supplemental material

Supplemental material is available for this article online.

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Supplemental published document (Scoping Review)

Example of Search Strategy from OVID-Medline

1. ((telerehabilitation.mp. or Telemedicine/ or Telerehabilitation/ or Videoconferencing/ or Remote Consultation/) adj3 Traumatic brain injury.mp.) or Brain Injuries, Traumatic/
2. ((Exercise/ or accelerometry.mp. or Accelerometry/ or Physical Fitness/) adj3 Traumatic brain injury.mp.) or Brain Injuries, Traumatic/
3. (Synchronous supervision and Traumatic brain injury).mp. or Brain Injuries, Traumatic/ [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
4. (Asynchronous supervision and Traumatic brain injury).mp. or Brain Injuries, Traumatic/ [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
5. (mobile health.mp. or Telemedicine/) adj3 (Traumatic brain injury.mp. or Brain Injuries, Traumatic/)
6. Computer-Assisted Instruction/ or Telemedicine/ or asynchronous delivery.mp.
7. 5 and 6
8. 1 or 2 or 3 or 4 or 5 or 6
9. (physical therapy or physiotherapy or physical interventions).mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
10. 8 and 9

Example of Search Strategy from CINAHL

#1 telerehabilitation.mp. or Telemedicine/ or Telerehabilitation/ or Videoconferencing/ or Remote Consultation/
#2 Traumatic brain injury.mp. or Brain Injuries, Traumatic/
#3 #1 and #2
#4 Exercise/ or accelerometry.mp. or Accelerometry/ or Physical Fitness/
#5 #2 and #4
#6 #3 and #4
#7 Electronic Mail/ or Telecommunications/ or Computer Communication Networks/
#8 #3 and #7
#9 Synchronous delivery
#10 #2 and #9
#11 #1 and #9
#12 mobile health.mp. or Telemedicine/
#13 #2 and #12
#14 #3 and #12
#15 Computer-Assisted Instruction/ or Telemedicine/ or asynchronous delivery.mp.
#16 #2 and #15

Scoping Review Remote supervision extraction form
(initially guided by Cochrane Collaboration)

1. Date form completed *(dd/mm/yyyy)*	
2. Name/ID of person extracting data	
3. Study title	
4. Contact details of corresponding author	
5. Study ID *(e.g. 01 plus surname of first author and year first full report of study was published e.g. Smith 2001)*	
6. Country in which the study conducted	
7. Economic level of the country in which the study conducted *(e.g. low income, lower-middle income or upper-* *Rural or Urban if available*	
8. Funding sources and possible conflict of interest	

Inclusion criteria for eligibility

	Inclusion criteria	Comments	Page in Article
Study type (levels of evidence)	1, 2, 3a,b * RCT, Systematic reviews, Cohort studies, Case-control studies		
Participants	Adult Moderate and Severe TBI (18-64years old)		

Methods

	Description	Page in Article
Study objectives		
Sampling		

Objective 1 and 2: Type of Remote supervision and Frequency of Remote Supervision

Description Type	Frequency of remote supervision	Comments	Page in Article

Objective 3: Types of outcome measures and rehabilitation

Outcomes	Outcome measures	Comments (Time points measured)	Page in Article

Chapter 3. Protocol and Detailed Methodology

Remotely Supervised Home-Based Intensive Exercise Intervention to Improve Balance, Functional Mobility and Physical Activity in Survivors of Moderate or Severe Traumatic Brain Injury: Protocol for a Mixed-Method Study

Citation:

O'Neil J, Egan M, Marshall S, Bilodeau M, Pelletier L, Sveistrup H. **Remotely Supervised Home-Based Intensive Exercise Intervention to Improve Balance, Functional Mobility, and Physical Activity in Survivors of Moderate or Severe Traumatic Brain Injury: Protocol for a Mixed Methods Study.** JMIR Res Protoc 2019;8(10):e14867 doi: 10.2196/14867
URL: https://www.researchprotocols.org/2019/10/e14867.

The research protocol presented in this chapter was published in the *Journal of Medical Internet Research-Research Protocol* on October 9th, 2019. A copy of this publication is attached in Appendix D. Financial support was received from the University of Ottawa Admission Scholarship, a Graduate Studentship Program at the Bruyère Research Institute 2018-2019, and a project research grant from the Canadian Institute for Military and Veteran Health Research and True Patriot Love.

3.1 Abstract

Background: Traumatic brain injury (TBI) may impact an individual physically, cognitively, socially, and emotionally. Poor balance, reduced mobility, and low daily physical activity often will require ongoing physical rehabilitation intervention. However, face-to-face specialized physiotherapy is not always accessible for individuals living in rural settings.

Objective: We will answer four questions: (1) What is the feasibility of a remotely supervised, home-based, intensive exercise intervention with survivors of moderate and severe TBI? (2) Does the frequency of remote supervision have an impact on the feasibility of completing a home-based intensive exercise program? (3) Does the frequency of remote supervision impact balance, functional mobility, and physical activity? (4) What is the lived experience of remote supervision for both survivors and caregivers?

Methods: Four participants will complete two intensive, 4-week (five days per week) home-based exercise interventions remotely supervised via synchronous videoconference. Each exercise intervention will have a goal of 160 to 300 repetitions or 60 minutes of tailored exercises to promote neuroplasticity and be defined as an intensive home-based exercise intervention. An alternating single-subject design will allow for the comparison between two frequencies of remote supervision, once weekly and five times weekly. Daily repeated outcome measures, pre- and postintervention outcome measures, and 1-month follow-up outcome measures will be collected to explore the effect on feasibility and physical variables. Daily outcome measures include step count and Five Times Sit-to-Stand test. Pre-post measures include assessment of quiet stance and the Community Balance and Mobility Scale. A semi-structured interview will be completed at the end of each intervention segment to document the lived experience of both survivors and their study partners. Finally, five questionnaires will be used to understand the overall experience: the Mayo-Portland Adaptability Inventory-4 Participation Index, Satisfaction With Life Scale, Fall Efficacy Scale-International, Interpersonal Behavior Questionnaire, and System Usability Scale. Data will be analyzed following traditional single-subject methods of analysis.

Results: Ethics approval was received from both the Bruyère Research Institute and University of Ottawa review boards in March 2019. Recruitment is underway.

Conclusions: The proposed intervention is multi-factorial in nature due to the involvement of multiple technology sources and the inclusion of a complex dyad (survivors and caregivers) in a community setting. This type of research is timely given that alternative methods of physical intervention delivery are needed to facilitate gains in balance, mobility, physical activity among TBI survivors with limited access to clinical care, and the quality of the patients' experience.

International Registered Report Identifier (IRRID): PRR1-10.2196/14867

Keywords: telerehabilitation; physical activity; traumatic brain injury; home-based exercises; accessibility

3.2 Introduction

Background

A traumatic brain injury (TBI) can impact an individual physically, cognitively, socially, and emotionally, as described by the Ontario Neurotrauma Foundation [1]. These impairments can become chronic, influencing the quality of life of an individual throughout their life span. One-third of military personnel who survived a moderate or severe TBI have continued issues with activities of daily living even up to 14 years postinjury [2,3]. Physical deficits can present as poor balance [4], reduced mobility, and low daily physical activity [5]. These impairments may lead to decreased social participation [6], increased fear of falling [7], and may invoke social isolation [8].

Physical rehabilitation professionals, such as physiotherapists, can influence the recovery of these deficits [9,10], which may positively influence daily function [7]. Traditional face-to-face outpatient physiotherapy sessions are usually completed in-clinic, in-person with a therapist; however, this option is not always accessible to the affected individual. Inequities can be associated with geography, financial barriers, or acceptability [11]. A lack of available knowledgeable professionals in rural communities, increased travel cost and travel time to urban centers, and injury characteristics are examples of barriers for survivors of moderate or severe TBI living in rural communities [7,12,13].

For these reasons, it is crucial to investigate alternative methods of treatment delivery that could impact the accessibility of specialized physiotherapy services. Synchronous remote supervision refers to a form of remote supervision, such as videoconferencing, which allows patient information to be received and recorded in real time by the supervising therapist, and for the therapist to provide immediate feedback [14,15]. Previous studies have assessed the usability of telerehabilitation for the neurologically impaired population and found it to be "as feasible as usual care for upper extremity function in stroke, TBI, and MS [multiple sclerosis]" [16]. Balance interventions delivered remotely by telerehabilitation were also shown to be effective for people with neurological diagnoses [17,18].

To facilitate neuroplasticity, increasing patients' daily physical activity participation and the number of exercise repetitions they perform are key factors [19], and must be included in any home-based exercise program. Most effective exercise programs for balance, functional mobility, and physical activity for TBI survivors' range between 16 and 20 sessions completed in 4 to 6 weeks [10,20-23]. These exercise programs were delivered face-to-face or as a home program without remote supervision. Therefore, we are still uncertain of the effect of frequency for remotely delivered programs.

Exploring the effect frequency of supervision has on different outcomes is needed to develop accessible and effective interventions for this population. A recent study by Lacroix et al. [24] explored the dose-response relationship between static balance outcomes and supervision in older adults. They found increased effects with supervision compared with no supervision. They also showed that a low number of supervised sessions (mean 6.7 sessions) was enough to have a positive effect on outcomes, but not as much as full supervision (mean 30 sessions). This indicates that having supervised sessions is important for improving motor skills. However, we are still uncertain of the specific amount of supervision needed to have an impact on physical impairments while remaining feasible for survivors. Minimal research has been done in this area for TBI survivors. It is feasible for this population to independently complete a community exercise program [25]; however, the optimal frequency of remote supervision that will positively impact physical outcome measures is unclear.

Objectives

This study will determine the feasibility and effectiveness of two frequencies of remote supervision for a home-based intensive exercise intervention (daily and weekly supervision) for military or veteran survivors of moderate or severe TBI. Four main questions will be investigated: 1. What is the feasibility of a remotely supervised home-based intensive exercise intervention with survivors of moderate and severe TBI? 2. Does the frequency of remote supervision have an impact on the feasibility of completing a home-based intensive exercise program? 3. Does the frequency of remote supervision impact balance, functional mobility, and physical activity? 4. What is the lived experience of remote supervision for both survivors and caregivers?

We hypothesize that a remotely delivered exercise program targeting balance, mobility, and increased physical activity will be feasible and that frequency of supervision will have an impact on the effectiveness of the intervention. We also hypothesize that the dyad (survivor and caregiver) will report a satisfactory experience.

3.3 Methods

This study will follow a sequential explanatory mixed methods intervention approach (Figure 3.1) [26]. Qualitative observations collected via semi-structured interviews will help interpret and better qualify information stemming from the quantitative data.

A single-subject design is often used to compare different interventions in clinical settings [27-29] and provides a way to explore the feasibility and potential effectiveness in the early stages of investigating a new intervention. An alternating single-subject design will allow for comparison between the two frequencies of remote supervision. The phase sequence determined a priori will include baseline (6 data points), intervention 1 for 4 weeks (20 data points), a 4-week washout period, intervention 2 for 4 weeks (20 data points), a postintervention phase (3 data points), and a

1-month follow-up phase (1 data point). A 4-week washout period will be added to mitigate the effects of the first intervention on the second intervention. During this period, the participants will be asked not to perform any of the specific exercises from the intervention program. Replication across four participants will help establish if there is a causal relationship.

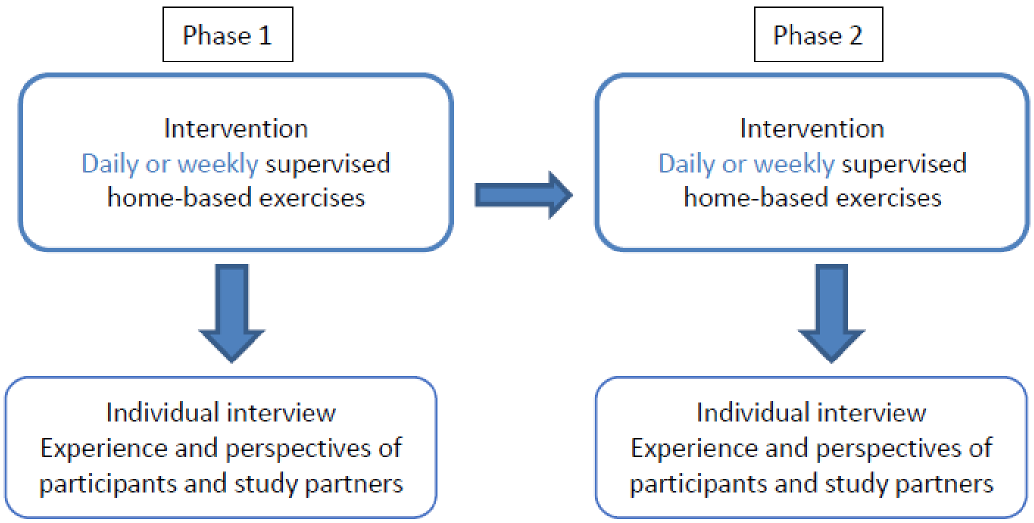

Figure 3.1 Sequential explanatory approach demonstrating the phases of the remotely supervised home-based interventions differing in supervision frequencies. A crossover design will be used; two participants will begin with daily supervision and two participants will begin with weekly supervision

Participants

Four survivors of moderate to severe TBI aged 18 to 64 years and their respective study partners will be recruited from the community via recruitment posters and videos. Participants will be eligible if they report a diagnosis of a moderate or severe TBI a year or more ago. This diagnostic can be defined as a score of 12 or less on the Glasgow Coma Scale [30], time spent in an in-patient unit, loss of consciousness with trauma, or presence of posttraumatic amnesia. To be included, participants must speak English or French and live in the community (not in the hospital or long-term care facilities). The ability to stand independently for a minimum of 2 minutes will be required. Participants will be asked to confirm this on the screening call and will be assessed for 2 minutes stance at the first assessment session. In addition, the TBI survivors will need a consenting study partner. The relationship between study partner and participant can be of a personal nature, such as caregiver, family member, personal support worker, or friend willing to participate with the survivor for the entire study.

Potential participants will be excluded if they report symptoms of vertigo, measured by questions from the Dizziness Handicap Inventory [31], or are unable to use the videoconferencing system.

Exercise Intervention

Interventions will take place in the participants' homes. Five face-to-face visits at the Bruyère Research Institute in Ottawa, Canada, will take place for assessment purposes. All exercise interventions will be completed remotely. A familiarization session during the first face-to-face visit at the Bruyère Research Institute will mark the first day of the baseline phase. The participant and study partner will be trained on the use of the activity tracking device and the videoconference platform. Education on safety precautions during the home-based exercise intervention session will be provided (i.e., wearing proper shoes, removing clutter, having enough space to move, having a chair near to take breaks when required, instructions in case of presence of dizziness, injuries, or falls). The exercise intervention objectives will be discussed with the dyad, such as "the goal of this exercise intervention is to increase your physical activity levels, improve your balance and mobility by spending 30 to 60 minutes per day exercising. The goal is to reach a minimum amount of repetitions per session ranging between 160 and 300 repetitions." Questions related to individual abilities, goals, motivation, and adherence strategies will be asked to tailor the intervention to each participant. Collaboration with the study partner will take place to tailor the daily diary log and facilitate its completion. A participant manual, including daily exercises, safety precautions, and technology information, will be provided to each study dyad.

TBI survivors assisted by the study partner will be asked to complete a daily log including step count and the Five Times Sit-to-Stand (FTSTS) test [32,33].

The four participants will complete two intensive, 4-week (five days per week), home-based exercise interventions remotely supervised via synchronous videoconference. Participants will be supervised via videoconferencing daily or weekly for the entire proposed intervention period. During the weekly remote supervision intervention, remote supervision will be provided on Mondays; for the remaining days of the week, participants will complete the intervention aided by their study partner, but unsupervised by the researcher. Each participant will be emailed a link to start the videoconference intervention 15 minutes before starting the intervention, and the study partner will facilitate connection with the therapist. The therapist in charge will collaborate with the dyad to ensure proper positioning of the camera and safe environment.

A trained and registered physiotherapist with over 10 years of experience in rehabilitation of TBI will provide all remote supervision sessions via the Ontario Telemedicine Network. Each participant will be asked to complete the exercise intervention at the same time of the day. Individual exercise sessions will be structured and tailored to each participant as defined in the familiarization session. The exercise intervention will consist of two to four exercises targeting essential components of dynamic balance, weight shifting, reaction time, and postural control (Table 3.1). As an example, sit-to-stand, side stepping, lunges, squats, tandem walking, and single-leg stance could be included in the exercise intervention (Multimedia Appendix 1). These specific exercises were chosen because they were included in previous programs targeting dynamic balance in TBI survivors [5,10,20-23]. Exercises will be completed 1 minute at a time, for a total of 10 minutes per specific exercise. When possible (i.e., with the sit-to-stand exercise), the number of repetitions of the exercises will be recorded by the therapist or study partner at the end of each minute and entered in the daily log. If a participant cannot complete the exercises as planned, the physiotherapist will provide options ahead of time to modify the exercises to enable the participant to be successful and reach the desired intensity; for example, modifying the height of a stepping block.

Table 3.1 Tailoring of intervention in collaboration with each dyad

Table 1. Tailoring of intervention in collaboration with each dyad (participant and study partner).

Intervention parameters	Tailoring options
Numbers of sessions	20 sessions, 5 days per week, for 4 weeks
Length of each exercise session	Options for each participant: (1) 60 minutes maximum and a minimum of 160 repetitions; (2) reaching 160-300 repetitions
Number of exercises	Tailored for each participant: 2 to 4
Goal of exercises	Targeting balance, mobility, and gait components
Exercise options	(1) Sit-to-stand from a chair, stool, couch; (2) step-up, side steps, high knees, squats, short lunges; (3) standing still, feet together, with arm movements; (4) walking between parallel lines 14-inches apart, walking forward placing foot on lines, walking sideways

Technology

Participants will be provided with a computer for the duration of the study to have access to the remote supervision. The Ontario Telemedicine Network will allow for secure and confidential remote supervision to be completed via videoconference. This platform adheres to all personal health information policies. A link will be emailed to the participant before each session, and a one-click process will facilitate access to the remote supervision. Audio and video will be recorded using screen capture software (Bandicam software), eliminating the use of cloud-based storage.

An individual activity tracking device dashboard will be set up for each participant on the computer. The activity tracking device information collected daily will be synchronized, and the research team will be able to access the dashboard remotely.

Feasibility Measures

Measures of feasibility will be recorded throughout the study. As per Thabane et al [34], four different feasibility factors will be measured: (1) process (adherence rate, retention rate, recruitment rate), (2) resources (length of the intervention, equipment, capacity of transportation for assessments), (3) management (data management), and (4) scientific aspects (safety, dose; Table 3.2).

Table 3.2 Measures of feasibility

Table 2. Measures of feasibility.

Feasibility factors	Measurements
Process	
Adherence rate	Number sessions completed
Retention	Number of participants recruited, number of participants completing study
Recruitment	Severity, transportation issues, availability of study partner, time
Resources	
Length of intervention	Minutes of interventions
Equipment	Reported issues, cost
Transportation capacity	For five face-to-face visits
Management	
Data management	Time spent on data collection and analysis, therapist time on remote supervision
Scientific	
Safety	Adverse events
Dose	Number of repetitions, number of sessions

Outcomes Measures

Daily repeated measures, pre-post intervention measures, and 1-month follow-up measures will be recorded (Table 3.3).

Table 3.3 Outcome measures and data collection protocol

Table 3. Outcome measures and data collection protocol.

Outcome measures	Baseline	Daily remote supervision[a]		Weekly remote supervision[a]			1-month follow-up
		During exercise program	Posttest	Pretest	During exercise program	Posttest	
Feasibility							
Adherence	x	x	x	x	x	x	x
Adverse events	x	x	x	x	x	x	x
Retention	x						x
Recruitment	x						
Equipment	x	x	x	x	x	x	x
Transportation	x		x	x		x	x
Length of intervention		x			x		
Data management	x	x	x	x	x	x	x
Dosage		x			x		
Repeated measures							
Step count	x	x	x	x	x	x	x
Five Times Sit-to-Stand test	x	x[b]	x	x	x[b]	x	x
Pre-post measures							
Quiet stance (two conditions)	x		x	x		x	x
Community Balance & Mobility Scale	x		x	x		x	x
Pre-post self-reported							
Mayo-Portland Participation Index	x		x	x		x	
Fall Efficacy Scale-International	x		x	x		x	
Satisfaction with Life Scale	x		x	x		x	
IBQ[c] and IBQ-Self	x		x			x	
System Usability Scale			x				

[a]These two interventions will be alternating for participants 1 and 2 and participants 3 and 4.
[b]On Mondays with a therapist.
[c]IBQ: Interpersonal Behavior Questionnaire.

Primary Measures: Daily Repeated Measures

Physical activity will be measured by recording step count with an activity tracking device placed at the ankle throughout the entire study [35]. Step count will be recorded every day between intervention sessions to document the effect of the intervention on the amount of physical activity, and during the activity sessions to monitor the number of stepping repetitions.

Functional mobility will be recorded daily with the completion of the FTSTS test. The FTSTS test measures lower extremity muscle strength and transitional movements [33], which contribute to poor balance when decreased [36]. For both supervision frequencies, the FTSTS test will be assessed by the therapist and study partner remotely on Mondays and by the study partner alone during the remaining weekdays.

Secondary Measures: Pre-Post Intervention Measures

As part of the five in-person visits, pre-post intervention measurements will be collected within 5 days of intervention completion. Standing balance will be measured pre-and-post intervention for each intervention using the Balance Tracking System Inc (BTracks) [37]. Participants will be asked to stand as still as possible with their feet hip-width apart on the balance board and hands placed on their hips. Two conditions of quiet stance will be measured—eyes open and eyes closed—for three trials of 30 seconds for each condition [38]. Mean velocity (cm/s), root mean square in the anteroposterior and mediolateral planes, and center of pressure (COP) area (95% confidence interval ellipse) will be computed from the balance data.

Functional balance will be measured with the Community Balance and Mobility Scale (CB&M) [39,40]. This clinical test will be administered by an experienced physiotherapist blinded to the intervention study phase (e.g., daily or weekly supervision) for each frequency of remote supervision.

Three self-reported questionnaires will be collected pre-and-post intervention for both frequencies of remote supervision: the Mayo-Portland Participation Index (M2PI) [41], the Satisfaction With Life Scale [42], and the Fall Efficacy Scale-International. The Mayo-Portland Adaptability Inventory-4, which includes the M2PI Participation Index, is increasingly used in TBI research and allows for a comprehensive picture of ability, adjustment, and participation. The

M2PI [41] is a participation index in which eight domains assess a person's issues within different situations on a Likert scale ranging from 1 to 4. This index will be completed to capture data on participation and explore the impact that remotely supervised physical interventions can have on these three physical domains.

The Satisfaction with Life Scale [42] will be added as a measure of intervention effectiveness. This scale has been widely used with individuals who have survived a moderate or severe TBI and will provide insight into the impact of the remote supervision interventions on overall life satisfaction [43].

The Fall Efficacy Scale-International will allow for a subjective assessment of the fear of falling pre- and postintervention [44]. Fear of falling influences the ability to perform rehabilitation programs independently [45] and is directly correlated with balance deficits [7]. A cut-off score of greater than 23 can be defined as presenting with a fear of falling [46].

One novel questionnaire will be administered at three points in time—baseline session, postintervention 1, and postintervention 2—to assess the quality of the interaction between the therapist and patient. The Interpersonal Behavior Questionnaire (IBQ) [47,48] will assess the patient's perceptions of their therapist's interpersonal behaviors, and the IBQ-Self will assess the therapists' perceptions of their own interpersonal behaviors toward their patients. Each participant will complete their respective part of the questionnaire. The IBQ will be coded in six different categories: autonomy support, autonomy thwarting, competence support, competence thwarting, relatedness support, and relatedness thwarting [47,48] to determine if the therapist interpersonal behaviors are need supportive or need thwarting.

Finally, the System Usability Scale will be collected at post-intervention 1 to identify the usability of the Ontario Telemedicine Network system to assess whether it is a good fit for this population [49].

One-Month Follow-Up Measures

A 1-month follow-up will be scheduled to reassess standing balance, functional mobility, and physical activity. Participants will be contacted and asked to wear the activity tracking device on their ankle for the 3 days before the final face-to-face visit. During the final face-to-face visit, the FTSTS [33] and the CB&M scale assessment [39] will be completed. Postural sway via quiet stance will also be reassessed by completing the same COP measures as in pre-post testing. Finally, step count will be gathered by the dyad over 3 days.

Semi-structured Interview

As part of the mixed methods design, interviews will be administered with TBI survivors and their study partners separately either face-to-face or via videoconferencing technology at the end of each intervention period (week 4 and week 12). At the beginning of each interview, a brief introduction, confidentiality statement, and description of the research objective will be given to the survivor or the study partner. Each 60-minute independently completed interview will take place in a private, neutral location [50]. An interview guide will facilitate the probing of topics related to the participant's overall experience, physical activity, safety, experience with remote supervision, and adherence. All interviews will be audio-recorded and saved, password-protected, and encrypted for confidentiality. Field notes will be used to describe the participants' behavior, therapist-perceived comfort levels, and nonverbal demeanor, which will help contextualize the interview and situate the experiences within that context.

Data Analysis

Daily repeated measures data will be analyzed following the four-step single-subject design method of analysis, and pre-post measures for each participant will be descriptively analyzed (Table 3.4).

Table 3.4 Outcome measures, analysis, and expected changes

Table 4. Outcome measures, analysis, and expected changes.

Outcome measures and method of analysis	Expected changes
Step count	
SSD[a] traditional methods	Increase in step count number
Five Times Sit-to-Stand	
SSD traditional methods	Decrease in time (seconds)
Quiet stance (center of pressure>)	
Descriptive	Velocity: decrease showing an increase in postural stability; root mean square: decrease displacement showing an increase in postural stability; 95% ellipse: decrease displacement showing an increase in postural stability
Community Balance & Mobility Scale	
Descriptive and MDC (7.5)	Increase in total points by a minimum of 7.5
Questionnaires pre-post	
Descriptive	Fall Efficacy Scale-International: decrease number showing decrease concern or fear of falling (score >23 indicates high concern of falling); Mayo-Portland Participation Index: increased index of participation; Satisfaction With Life Scale: increased satisfaction
Questionnaires	
Descriptive	IBQ[b]/IBQ-Self: enhanced communication and self-efficacy between all groups
Feasibility	
Descriptive, feasibility, and process	Adherence: increase in completion of session 80%; retention rate: 100% retention rate; recruitment rate: 80% recruitment rate
Descriptive, feasibility, and resources	Length of the intervention, dose, and intensity by interview; equipment using the System Usability Scale: high score showing usability; capacity of transportation for assessments
Descriptive, feasibility, and management	Data management by therapist field note
Descriptive, feasibility, and scientific aspects	Safety by adverse events: decrease in adverse events

[a]SSD: single-subject design.
[b]IBQ: Interpersonal Behavior Questionnaire.

Analysis for Daily Repeated Measures (Step Count and FTSTS)

In step 1, a visual analysis will be completed by analyzing the trend and identifying stability [51]. A visual comparison of the direction and rate of change as well as variability between all phases (baseline, intervention 1, postintervention 1, washout period, intervention 2, and postintervention 2) [51,52] will be completed.

In step 2, serial dependency will be calculated on all raw data using the lag-1 autocorrelation (r) [46]. The baseline phase for all participants will be more than 5 points; therefore, serial dependency will be assessed on baseline data only [53]. In the case of a statistically significant presence of serial dependency confirmed by the Bartlett test, a first-difference transformation will be calculated before visual and statistical analysis. Once serial dependency is eliminated, a single line graph will be constructed for each participant and daily outcome measure [52].

In step 3, the overall changes between baseline and the first intervention phase and the washout phase and the second intervention phase will be analyzed with the two-standard deviation band method [53,54].

In step 4, an effect size analysis will be completed to supplement visual analysis. The effect size will be calculated by the standardized mean difference of all points proposed by Gage and Lewis [55] and Olive and Smith [56].

Analysis for Pre-Post Measures

All feasibility measures, CB&M scale, COP measures, and self-reported questionnaires will be analyzed descriptively. Mean and standard deviation will allow for the interpretation of intervention effects on outcome measures (Table 3). Clinical significance will also be considered using the CB&M scale, which is 7.5 points for minimal detectable change [39]. To quantify feasibility, a priori cut-offs were defined based on a similar study [57]. The process factors will be quantified as feasible if 80% of the sessions are completed and 100% retention is achieved; dosage factor will be feasible if 80% of sessions achieve 160 to 300 repetitions.

Analysis of Semi-structured Interview

A thematic analysis will be used to organize the data [58]. All semi-structured interviews will be fully transcribed to text by the main researcher to allow familiarization with the data. Field notes and audio transcription of each interview will be amalgamated, and the main researcher will become deeply involved with the data before disassembling it into codes. A preestablished framework, the theoretical domain framework [59], will be used to facilitate coding of themes into domains often used in behavioral change and implementation research [52]. If the theoretical domain framework is not suitable for all codes, modifications will be made. As such, general thematic codes will be identified for each transcript and will be collated into a matrix. The matrix will provide a visual representation of all the data to facilitate interpretation. This matrix will be reviewed by a second reviewer, and then interpreted in relation to each question. Patterns between the different participants, within their dyad and between interview one and two, will then be analyzed. This deductive-inductive analysis will provide evidence-based information which could enable a deeper comprehension of the lived experience of remotely supervised home-based interventions.

Ethics

Ethics approval was obtained after a full review process by the Bruyère Research Institute in January 2019, followed by the University of Ottawa board of ethics in March 2019. As per ethics approval, a four-step process will be followed for recruitment and consenting of each participant and caregiver (dyad): recruitment sites will be contacted and recruitment material (poster and video) will be provided, a verbal consent before screening potential participants will be completed on initial contact with primary investigator (J O'Neil, a physiotherapist and Ph.D. candidate), screening of potential participants will be conducted by the primary investigator, and for eligible participants, consent forms will be signed, and participants will be given a code to secure confidentiality.

3.4 Results

Recruitment is currently underway. Community physiotherapy clinics, military-associated health care professionals, and brain injury associations have received a recruitment site letter, poster, and video. This study is expected to be completed by December 2020.

3.5 Discussion

The proposed intervention is multi-factorial because of the involvement of multiple technology sources and the inclusion of a dyad. Furthermore, the community setting will add another dimension of complexity. However, this type of research is timely because alternative methods of physical intervention delivery are needed to facilitate gains in balance, mobility, and physical activity. Patients who are discharged home and entering the chronic phase of their rehabilitation could benefit from completing an intensive home-based exercise intervention delivered remotely to improve their overall independence. A better understanding of remote supervision and its implementation will allow us to inform future studies around the same constructs.

Acknowledgments

Financial support was received from an Admission Scholarship at University of Ottawa for 2016-2020, a Graduate Studentship Program at the Bruyère Research Institute and a project research Grant from the Canadian Institute for Military and Veteran Health Research and True Patriot Love.

Conflicts of Interest

None declared.

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Supplemental published document (Protocol)

Exercise choices

Step-up, High knees,

Standing still feet together with arm movements,

Sit to stand from chair or stool or couch,

Walk backwards-sideways,

✓ Side steps,

Standing on one leg,

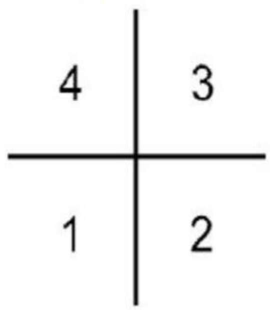
Short lunges,

Walk on toes,

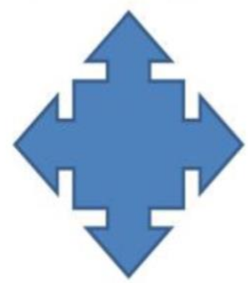
✓ Squats,

Walking between parallel lines 14 inch apart,

Four square stepping



Stepping on star pattern or cross,



Chapter 3. Protocol revisions

The following modifications were made to the published protocol. Due to the COVID-19 pandemic all in-person sessions were restricted leading to having the completely pivot the protocol to being entirely remotely delivered.

1) Methodology

The explanatory mixed-method methodology presented in the published protocol was revised to a convergent mixed-method single-subject design to better fit the Ph.D. research alternating single-subject design methodology. As described in the protocol, the use of theoretical domain framework was modified and qualitative data was analysed using content analysis.

2) Remote measurements

All clinical assessment and questionnaires were complete remotely for dyad 3, 4 and 5. Completing the assessments remotely allowed us to continue during COVID-19 and extend our recruitment Canadian wide. Training on remote assessments was provided for the research assistant.

3) Standing balance assessment

As documented in the published protocol (Chapter 3), the static standing balance was planned to be measured in-person five times (baseline, post-program 1, post-washout, post-program 2and 1 month-post) by the BTracks. This lab-based measure was dropped due to the COVID-19 restrictions, and the pivot to all assessments being remotely.

4) Increased sample size

I had proposed to recruit 4 dyads (8 participants) as a minimum for this Ph.D. research, but I was able to recruit and complete the protocol with 5 dyads (10 participants).

Chapter 4. The Feasibility of High-Intensity Telerehabilitation Exercise Programs

Remotely Supervised Exercise Programs to Improve Balance, Mobility and Activity Among People with Moderate to Severe Traumatic Brain Injury: Description and Feasibility.

(under review - Physiotherapy Canada Journal on March 25th, 2021)

Citation:

O'Neil J, Egan M, Marshall S, Bilodeau M, Pelletier L, Sveistrup H. **Effectivenss** Physiotherapy Canada (under review – submitted March 25th, 2021)

This chapter contains findings from the feasibility study which was submitted to *Physiotherapy Canada* on March 25th, 2021 and is currently under review. This study was supported by two project grants, the Canadian Institute for Military and Veteran Health Research and True Patriot Love and the Spark program grant from the Centre for Aging and Brain Health Innovation (CABHI); and graduate scholarships from the Ontario Graduate Scholarship, University of Ottawa and the Bruyère Research Institute. This study was approved by the Bruyère Research Institute Ethic Board (M16-18-038) as well as the University of Ottawa REB (H-12-18-771).

4.1 Abstract

Introduction: Further investigation into the feasibility of using videoconferencing and activity tracking devices in providing high-intensity home-based exercise programs for people with a moderate or severe traumatic brain injury (TBI) is needed in order to facilitate clinical implementation and patient adoption.

Objective: This study aimed to 1) determine if home-based telerehabilitation exercise programs were feasible for people with a moderate or severe TBI, and 2) improve the understanding of the lived experience of people with a TBI and their family partners with this program.

Methods: A mixed-methods approach including measures of feasibility and semi-structured interviews was used. Five people with a moderate or severe TBI and their family partners (dyads) completed two high-intensity home-based exercise programs delivered remotely by a physiotherapist daily and weekly.

Results: Telerehabilitation services in home-based settings were feasible for this population. Adherence and engagement were high. Dyads were satisfied with the use of technology to deliver physiotherapy sessions. A pre-intervention program that provided training on key components such as use of technology, safety precautions, and communication methods improved the overall feasibility. Frequency of remote supervision may impact adherence and intensity of therapy and should be considered when tailoring interventions.

Conclusion: Telerehabilitation provides a feasible delivery option allowing people with a TBI to spend energy on therapy rather than travelling. Further research is needed to further understand the effectiveness of such programs on balance, mobility and physical activity levels.

Keywords: Telerehabilitation; Home-Based Exercises; Feasibility; Traumatic Brain Injury

4.2 Introduction

People with a moderate or severe traumatic brain injury (TBI) have ongoing issues including balance deficits [1], decreased physical activity levels [2] and poor mobility [3]. Residual cognitive deficits may impede the ability to engage in therapy. Difficulties with activity engagement can be mitigated by the presence of a physiotherapist and the use of behaviour change strategies. Following a self-determination theory approach could facilitate the active engagement [4,5] and consequently positively impact feasibility and effectiveness of an intervention. when compared to physiotherapist-supervised programs, self-supervised therapeutic exercises are known to be equally as effective at improving motor function, however there is some evidence reporting that the presence of a therapist can positively impact pain outcome and quality of life in patients [6]. In Canada, this therapist presence is not always accessible due to geographical location or lack of transportation options [7]. Thus, delivery methods such as telerehabilitation can provide an alternative way for people with a disability resulting from a moderate or severe TBI to access supervision from a physiotherapist.

Telerehabilitation can increase access to and may reduce costs of post-stroke rehabilitation [8]. Telephone-based rehabilitation interventions targeting cognitive training, education and upper-extremity deficits have been shown to be feasible and effective for people with a moderate to severe TBI [7]. The feasibility of using videoconferencing and activity tracking devices to support remote physiotherapist supervision of high-intensity home-based balance and mobility exercise programs specifically for people with a moderate or severe TBI is still unknown. Due to the complexity of the proposed intervention and heterogeneity of deficits resulting from moderate or severe TBI, an alternative single-subject design was used to investigate the feasibility of telerehabilitation as a method of delivery to supervise a home-based exercise program targeting balance, mobility and physical activity. The first objective of this study was to document whether people with a moderate/severe TBI could participate in and complete a remotely delivered high-intensity home-based exercise program. A sub-objective was to examine potential differences in feasibility between high (daily) and low (weekly) remote supervision frequency programs. The second objective was to better understand the experience of people with a disability resulting from a moderate or severe TBI (PwD) and their family partners with this home-based program.

4.3 Methods

Design

Full methodology of the larger study as well as detailed information about the exercise program appears in O'Neil et al. (2019) [11]. Briefly, a mixed-methods alternating single-subject design (SSD) was used. Quantitative data regarding process (adherence, retention), resources (usability of the technology), and intervention aspects (engagement, dosage, adverse events) were collected [12]. In parallel, qualitative data were extracted from multiple semi-structured interviews conducted with PwD post TBI and family partners. This study was approved by two Research Ethic Boards.

Participants

Dyads, each composed of a PwD resulting from a TBI and a family partner, were recruited via social media and community physiotherapy clinics. Inclusion criteria were: i) age between 18-64 years old; ii) report of moderate or severe TBI by the dyads defined by either a Glasgow Coma Scale score of ≤ 12 or presence of post-traumatic amnesia greater than 24 hours or in-patient hospital stay; iii) at least one year post-injury; iv) ongoing mobility and balance issues but still able to stand without physical help for two minutes demonstrating the ability to complete a standing exercises program; v) access to high-speed internet at home; and vi) commitment from a study partner to be present in the house during exercise sessions, for safety reasons. Individuals with persistent vertigo were excluded. Potential participants verbally consented to being screened for eligibility on the phone. If eligible, they signed the consent to participate in the study prior to attending the first assessment session.

Intervention

All program components were provided and delivered by a registered physiotherapist with over 11 years of experience in neurological rehabilitation, 20 years as an elite level athlete and over 7 years of experience with synchronous telerehabilitation. A 30- to 90-minute pre-intervention education session was completed remotely with each dyad focusing on videoconferencing system use and camera positioning for each exercise, home safety assessment, education, and exercise review.

Individualized exercise programs were co-designed by the physiotherapist and dyad following the first assessment. The dyad selected between 2 and 4 exercises designed to promote balance and mobility from a list of 12 pre-identified exercises (e.g., squats, side steps, sit to stand, lunges, single leg balance). Each PwD post TBI was to complete a minimum of 300 repetitions of task-oriented exercises within a maximum of 60 minutes per session. Sessions were stopped before reaching 60 minutes if the PwD demonstrated or expressed fatigue, or for safety reasons as determined by the therapist or family partner. If 300 repetitions were reached in less than 60 minutes, the PwD was given the choice to stop or keep going. Exercise choices and difficulty levels were based on previous studies demonstrating the effectiveness of high-intensity exercises for people with TBI [13–17]. Family partners were instructed to be present in the home for all exercise sessions and assisted with technology when necessary.

Each program consisted of two phases of 20 sessions (5 days per week for 4 weeks) separated by a 4-week washout period. The phases differed only in the frequency of remote physiotherapist supervision that was provided; either daily (20/20 sessions supervised) or weekly (4/20 sessions supervised). The order of supervision delivery was counterbalanced across dyads. Investigating the feasibility of a lower frequency of supervision (weekly) may inform future exercise program designs targeting people with higher physiotherapy needs and lower physiotherapy access by limiting cost associated with physiotherapy supervision.

Remote exercise programs were delivered using the Ontario Telemedicine Network, a secure videoconferencing platform. A confidential videoconference link was emailed to the dyad prior to each session. Each dyad had a laptop or tablet and an activity tracking device (Fitbit. Charge ®) [18]. Technology was personally owned (laptop or tablet: 3 dyads; Fitbit: 2 dyads) or borrowed from the study team (laptop or tablet: 2 dyads; Fitbit®: 3 dyads). Asynchronous monitoring using the activity tracking device positioned on the ankle allowed each PwD post TBI to record their daily steps and captured data regarding daily physical activity levels.

Measurement and Analysis

Feasibility of the intervention considered: i) the process, including adherence and retention; ii) resources related to the usability of the technology; iii) intervention aspects including engagement and dosage, adverse events; and iv) lived experience. Adherence, documented as the number of sessions attended, was measured through a daily logbook, field notes and as the overall activity level reported on the Fitbit®. A Fitbit® was placed at the ankle, a validated measure of physical activity in the neurological population [18–21]. Retention was reported as the number of PwD who completed both intervention phases. Technical issues such as poor internet connectivity with the OTN platform and video quality were recorded by the physiotherapist for each remotely supervised session. The ease of using OTN to deliver exercise programs was measured using the System Usability Scale (SUS)[22]. Each dyad completed the SUS following the first intervention phase. The dyad's independent scores were analyzed as "above average usability" (score > 68), "below average usability" (score < 68) or "average" (score 68) following the SUS normalization to percentile rule [22]. Physical and technical issues related to the use of the activity tracking device [18,19,23] were documented via the physiotherapist's field notes and the research assistant interviews with the dyad. Engagement and dosage were documented in the dyad's daily logbook and physiotherapist's field notes as average session length, active minutes and repetition numbers for each session. Safety was documented by the physiotherapist during each remotely supervised session as the number and type of adverse events. Program adherence, retention and engagement, usability of technology, and exercise dosage data were analyzed descriptively.

Qualitative data on the lived experience of the exercise intervention was extracted from field notes and semi-structured interviews held with each PwD and family partner independently. Interviews were conducted following each intervention phase by a research assistant who followed an interview guide (appendix). Interview transcripts were analyzed by gathering common topics using qualitative content analysis [24]. Common topics were assembled and integrated with the quantitative data when possible. Meaningful experiences were exemplified by the use of direct quotes from participants. Some quotes were translated from original French and reviewed by a francophone research team member. Strategies such as participant validation, the use of field notes to capture multiple data source over time, and a thorough description of participants ensure trustworthiness of reported qualitative data by considering credibility, dependability, and transferability respectively [25].

4.4 Results

Six dyads consented to the study and five dyads completed the program. One dyad dropped out before starting the study. The PwD post TBI were composed of 1 woman and 4 men (PwD 1 to PwD5) which follows the expected ratio with this type of injury of 20% women to 80% men [26]. The family partners were represented by 3 women (spouses or mother) and 2 men (father or son) (FP1 to FP5). The time post-injury ranged between 3 and 12 years. Two military with TBI reported having experienced a moderate injury and three civilians were considered to have had a severe injury.

Process

Adherence and Retention

Each PwD demonstrated high adherence and retention. Specifically, PwD1, PwD2 and PwD5 completed 90% (36/40), 92.5% (37/40), and 87.5% (35/40) of the exercise sessions, respectively, while PwD3 and PwD4 had 100% (40/40) adherence. Overall, twelve sessions were missed during the program. Two missed sessions occurred during the daily supervision phase while the remaining ten missed sessions occurred during the weekly supervision phase, (1 session during a scheduled remotely supervised session and 9 of the self-supervised sessions). Family partners were not always actively engaged during every session. However, they were always present in the house to ensure safety.

Some PwD preferred to complete sessions in the morning. This either helped them start their day or they found they had more energy for the exercises:

> "I always try to start my day off with exercises so like [I] turn on." (PwD1)
>
> "I found that I am more fresh in the morning and then my mental fatigue affects my physical" (PwD2)

Family partners experienced scheduling challenges posed by obligations such as caring for children, working, or going to school but were able to adapt their schedule for the program:

> "The biggest challenge is that the kids are at home and so we don't have access to babysitters very much, so it is just trying to do it, making sure that the kids are not in the way and they yell, and they cry and they're still very little" (FP1)
>
> "It has not been difficult. It is just re-arranging my schedule" (FP3)
>
> "We have to adapt, we were not able to do it [the exercises] at the same time every day because of work but we always found the time, even if it was late at night" (FP4)

Resources

Usability of the technology

The system usability of the videoconferencing technology (OTN) to deliver the program ranged from 58 (below average) to 100 (above average) for PwD and 78 to 100 (above average) for family partners. Many participants identified similar factors influencing the successful use of the technology including pre-existing comfort with technology, the simplicity of the OTN platform as well as the family partner's ability to learn the technology quickly:

> "Also, the video I don't have a problem. I did computer engineering so that helps a lot." (FP3)
>
> "The computer program is super easy to log into" (FP2)
>
> "Join the conference, you just click on the email and follow the instructions in there. Like so from day 2, I did all that by myself" (PwD1)
>
> "At the beginning of the program, I wasn't sure because I am like a dinosaur with technology, I am not technical, it scared me. But now, it is going well, very well" (FP4)

Periods of poor connectivity and low internet speed resulting in video latency impeding audio-visual communication occurred across dyads during 13 out of 117 attended remotely supervised sessions. On two occasions, a speaker phone was used to compensate for the audio lag through the videoconferencing system. Overall, only 3 out of 117 sessions could not be fully completed because internet connectivity issues limited the ability to safely see the dyad (PwD2, PwD3, PwD4).

Although internet speeds and WiFi reliability for dyads in remote locations posed occasional challenges, the technical challenges did not negatively impact their views of the telerehabilitation program:

> "Aside from one day where it was storming, we really haven't had any issues." (FP1)

> "The only thing that I can think of, is a, like sometimes WiFi can be a little laggy" (PwD2)

The use of the Fitbit Charge® was well received despite technical issues. These issues were mostly related to difficulty synchronizing the Fitbit Charge® to the iPad (PwD4, PwD5). All PwD were able to wear the device on their ankle all day for a total of 14 weeks. Issues related to the low-quality ankle strap holding the activity tracking device was reported by two PwD (PwD2, PwD4), however these issues did not restrict its use:

> "I had my Fitbit on the entire time, and it did work" (PwD2)

> "The Fitbit does become addictive" (PwD5)

> "We had an issue with the strap holding the Fitbit. The Velcro didn't hold after the first week." (FP4)

Intervention Aspects

Engagement and Dosage

The average active time per session was higher during the daily supervision than the weekly supervision phase for all PwD post TBI. During the daily supervision phase, average session lengths ranged between 32 and 53 minutes and each PwD was active between 11 and 25 minutes on average. During the weekly phase, the average session lengths ranged between 28 and 59 minutes with each PwD active between 10 to 18 minutes on average (Table 4.1). With the exception of one person with a TBI (PwD4), the average number of repetitions per session were all higher in the daily supervision sessions. The metrics captured by the Fitbit ® will be presented in the effectiveness manuscript.

Table 4.1 Dosage and Intensity during the daily versus weekly remote supervision phases for each survivor.

Daily versus Weekly	**PwD 1 (severe TBI) ***	**PwD 2 (moderate TBI)**	**PwD 3 (severe TBI)**	**PwD 4 (severe TBI) ***	**PwD 5 (moderate TBI) ***
Range of session lengths in minutes	28 to 60 Vs 30 to 45	27 to 40 Vs 20 to 33	24 to 50 Vs 33 to 55	40 to 60 Vs 54 to 60	17 to 52 Vs 31 to 44
Average session length in minutes (SD)	47 (±8.4) Vs 37(±6.9)	32 (± 4.8) Vs 28 (±7.2)	39 (± 7.3) Vs 47 (±9.5)	53 (± 5.2) Vs 59(±3)	40 (± 8.1) Vs 39 (± 5.7)
Average minutes of active time per session (SD)	25 (±6) Vs 15 (±3)	17 (± 3.6) Vs 15 (±7.5)	11 (±1.5) Vs 10 (±2.7)	20 (± 2.5) Vs 18 (±1.7)	12 (± 2.5) Vs 11 (± 1.9)
Average number of repetitions per session (SD)	644 (±148) Vs 364 (±88)	500 (±156) Vs 387(±82)	479 (±81) Vs 419 (±160)	567 (± 102) Vs 624 (±50)	685 (± 159) Vs 683 (± 123)

When the dyads were asked about their preference between daily or weekly supervision, reviews were mixed. Feedback, instructions around quality of movement and progression, accountability and social interactions were reported as being reasons in favour of daily supervision. However, when asked about other options, some dyads reported an interest in mid-range supervision, such as three times a week:

> "I think every day is better. She [physiotherapist] corrects me, like when I am not doing the exercises like the right way" (PwD3)
>
> "With supervision every day, the pro for that was that it very much kept him accountable and he for some reason was excited to see that face [physiotherapist]. He doesn't get a lot of social interaction" (FP1)
>
> "Three times a week would be very good, because P4 already does exercises on his own every day" (FP4)
>
> "In an actual clinical physiotherapy setting that is basically what you have. You start off with the daily then you work to the weekly. I wouldn't start with weekly right off the bat" (FP5)

Adverse events

Extreme fatigue, pain including knee or hip pain and dizziness were occasionally reported by PwD post TBI during the supervised sessions (Figure 4.1). Out of 117 attended remotely supervised sessions, one person with a TBI (PwD1) sustained a low impact fall when he tripped over the family cat.

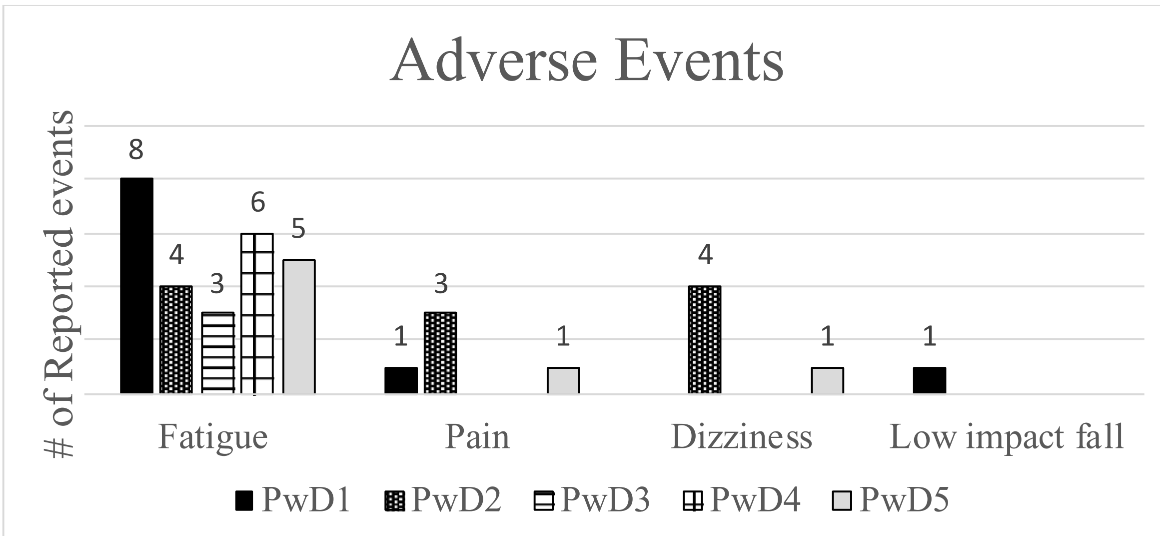


Figure 4.1 Number of adverse events reported by each person with a disability resulting from a TBI (PwD) with a during remotely supervised sessions (daily and weekly phases).

Dyads spoke about the importance of their preparation before each session to ensure that the exercise area was clear of hazards:

> "Well, I got to make sure that the exercise area is always clear cause, I have kids and it is almost never clear, so I have to clean up beforehand." (PwD1)

> "We remove any obstacles around and make sure he doesn't hit his leg anywhere" (FP3)

> "Um, well I make sure that everywhere is clear, if I am doing the exercises just on the sheet, I make sure there is enough room, and make sure, um, my Dad has to be paying attention also cause he is the one that kind of watches me" (PwD3)

Lived experiences with home-based exercises

Each dyad appreciated the ability to exercise at home with remote supervision. They spoke about increased comfort, reduced wait time, lower expenses, and avoidance of fatigue related to travel to a clinic:

> “Sometimes I don’t like going to gyms. Like there is always the “A” type, and so the home is comfortable.” (PwD2)

> “He is in the comfort of his house and then he is with familiar people” (FP3)

> “In clinic, you always have to wait. At the beginning of the appointment and then when you are actually in a room and you have done your exercises you have got to wait again because they have to come back because they are treating like 4 or 5 other people. Whereas the remote you get it done and you’re done. It is always under 45 minutes and it’s great.” (PwD5)

> “One of my challenges is fatigue and I like that I don’t have to leave the house. I only have to worry about the exercises, I have full concentration on the exercise.” (PwD1)

> “Since we have a lot of travel to do, it really tires out P4 when we have to travel 40 minutes there and 40 minutes back, it is nice to have video” (FP4)

4.5 Discussion

This study demonstrated that it is feasible to remotely deliver high intensity home-based exercise programs for people with a moderate and severe TBI under conditions of daily or weekly supervision with limited adverse events. While adherence was acceptable for both supervision schedules, only three sessions were missed during the scheduled remotely supervised (daily or weekly) compared to nine in the self-supervised sessions. Findings from our study support current literature on the presence of physiotherapists in addition to family partners to increase adherence [27,28] and contribute by documenting similar findings for home-base programs delivered via videoconference.

Activity engagement appeared similar under the two conditions. Most PwD post TBI participating in this study preferred daily supervision over weekly supervision, placing importance on the ability to receive feedback right away from the physiotherapist. However, when presented with choices in supervision schedule, family partners preferred two to three times a week. With emerging physiotherapy delivery models, rapid uptake of telerehabilitation due to COVID-19 [29] and the expansion of integrated care models in Canada [30], exploring optimal frequency of remote delivery will be important not only to benefit PwD and FP but also for policy development and funding around rehabilitation services.

The therapist providing the intervention had over 11 years of clinical experience as a physiotherapist with individuals with neurological conditions as well as a significant background in self-determination and autonomous motivation as an elite athlete. Kimberly et al., 2010 observed that in-person sessions conducted by a therapist with 5 to 15 years of experience was linked to patients performing higher repetitions, indicating higher patient engagement in physical activity [31]. In addition, when comparing in-person supervision vs no-supervision, a study on balance training targeting people with Parkinson's disease reported higher patient motivation and in the supervised group [32], which is often linked to higher engagement. Higher repetitions in the daily remote supervision schedule were recorded in our study which supports the concept of greater engagement in therapy when a therapist is present.

Patient education and behaviour change strategies have shown to impact short-term adherence and engagement in home exercise programs which is often challenging [33,34]. Our data suggest that a remote intervention with scheduling flexibility, elimination of travel to physiotherapy sessions, and behaviour change strategies based on targeting both the person with the TBI and family partners (e.g., education session, tailored exercise material, informative feedback from both the supervising physiotherapist as well as the activity tracking device) could produce high adherence and satisfaction for our telerehabilitation program. While each dyad included a family partner, only family members of the individuals with severe TBI deficits were actively involved in all exercise sessions. However, it is important to note that all family partners provided important support to the PwD and therapist by helping organize a safe space and scheduling the exercise program around family activities.

Therapists may feel that the use of multiple sources of technology such as videoconference, tablets and activity tracking devices over a four-month period will be daunting for the family partners and the people who are experiencing severe motor and cognitive deficits. However, PwD post moderate or severe TBI participating in our study and their family partners reported limited difficulty using technology for videoconferencing or documenting daily activity. The pre-intervention education session allowing them to practice using the technology while being supported by the therapist for any technical issues may have been critical with this high technology usability. Similarly to previously reported findings [35], connectivity issues did not impact usability or satisfaction with the remote delivery aspect of the exercise program. The simplicity of a "click and go" format of the OTN videoconferencing platform was valued by all dyads.

The dyads reported benefits of a home-based program. This is consistent with other studies where participants preferred the use of telehealth in home settings to in-person clinic sessions [36]. Multiple PwD in our study also reported poor outcomes linked to transportation such as increased fatigue and time wasted travelling to a clinic or waiting for face-to-face therapy. This supports previous findings where a relationship between the distance travelled and poor health outcome was expressed [37]. The convenience of having access to a physiotherapist from home strengthens patient satisfaction and maximize the energy spent on the therapy. This trend was also reported by patients undergoing telerehabilitation post burn injury [38].

While telerehabilitation can improve access to rehabilitation services, health inequities linked to technology such as digital literacy, access to technology and connectivity must also be considered [39]. In this study, education on technology use was offered and technology was provided when necessary to help bridge equity gaps. However, many rural communities continue to lack reliable, high speed internet required for this kind of videoconferencing. Solutions to improve internet access must be considered in the design of future telerehabilitation programs to ensure equal access.

Limitations

A single-subject design was used which limited our ability to generalize our findings due to low sample size. All remote supervision was provided by the same physiotherapist whose specific skills, knowledge and clinical experience with telerehabilitation may have impacted patient engagement. Further research using larger samples and therapists from different backgrounds are recommended and will clearly be needed as service delivery trends towards online modalities.

4.6 Conclusion

A remotely delivered home-based physiotherapy program targeting balance, mobility and physical activity for people with moderate or severe TBI with a partner in the home was feasible to implement. Each dyad who completed two phases of twenty daily exercise sessions was satisfied with the technology and enjoyed being at home for the program. A subsequent paper will report the effectiveness of this program on balance, mobility and physical activity levels.

Clinical Recommendations and Implications for Rehabilitation

- Tailoring exercise programs for each PwD as well as family partners is critical to facilitate active engagement. Therapists should consider optimal scheduling, user-friendly platforms, fatigue levels, behaviour change as well as education for technology use in their design of an intervention.

- The use of activity tracking devices to monitor step count was feasible and enjoyed by participants. Therapists may consider using sensor-based devices to objectively monitor patient outcomes remotely.

- Knowing that the weekly remote supervision was as feasible as daily remote supervision to deliver this program, therapists should consider the PwD and FP's scheduling preferences when pondering the optimal frequency of remote physiotherapy supervision.

- Safety hazard policies must be put in place to reduce fall risks. For example, dyads stressed the importance of preparing a safe home-environment prior to starting each session.

Acknowledgements

We would like to acknowledge the exceptional work of Anne Hobson-Taillon, our research assistant and assessor for this project. Thank you to all families for your amazing collaboration with this project. This work was supported by the Canadian Institute for Military and Veteran Health Research-True Patriot Love initiative, and by a Spark program grant from the Centre for Aging and Brain Health Innovation (CABHI). Graduate scholarships from the Ontario Graduate Scholarship, University of Ottawa and the Bruyère Research Institute also supported this work.

Declaration of conflicting interests

The Author(s) acknowledge (s) that there is no conflict of interest to declare.

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Chapter 5. The Effectiveness of High-Intensity Telerehabilitation Exercise Programs

The Impact of two Telerehabilitation Supervision Schedules on Physical Activity, Mobility, and Balance Among People with a Moderate or Severe Traumatic Brain Injury: a mixed-method approach.

(Under review, Physiotherapy Canada Journal on March 25th, 2021)

Citation:
O'Neil J, Egan M, Marshall S, Bilodeau M, Pelletier L, Sveistrup H. **The Impact of two Telerehabilitation Supervision Schedules on Physical Activity, Mobility, and Balance Among People with a Moderate or Severe Traumatic Brain Injury: a mixed-method approach.** Physiotherapy Canada (under review – submitted March 25th, 2021)

This study was submitted to *Physiotherapy Canada Journal* on March 25th, 2021 and is currently under review. We acknowledge the financial support received from the Canadian Institute for Military and Veteran Health Research (CIMVHR) and True Patriot Love (TPL) and the Spark program grant from the Centre for Aging and Brain Health Innovation (CABHI); and graduate scholarships from the Ontario Graduate Scholarship, University of Ottawa and the Bruyère Research Institute. This study was approved by the Bruyère Research Institute Ethic Board (M16-18-038) as well as the University of Ottawa REB (H-12-18-771).

5.1 Abstract

Background: Many individuals who experience a moderate or severe traumatic brain injury have long term deficits in physical activity, balance and mobility. With limited access to specialized rehabilitation due to living in remote communities, difficulties with transportation or physical distancing requirements, new delivery models are being investigated. Determining the effectiveness of telerehabilitation is critical given the current movement towards remote healthcare delivery.

Objective: This study investigated the impact of two teletherapy supervision schedules used to deliver a home-based intensive exercise program on physical activity, mobility, balance, participation, concerns with falling and satisfaction with life.

Methods: A mixed-method approach with alternating single subject design (SSD) and interviews was used. Five individuals who experienced a moderate or severe TBI completed two intensive home-based telerehabilitation programs. Programs differed only on supervision schedule: daily or weekly. Impacts on dynamic balance, functional mobility, physical activity levels, fear of falling, satisfaction with life, and participation were measured.

Results: Four individuals demonstrated clinically significant improvements in physical activity level, and clinically improved balance and mobility. A trend towards decreased concerns with falling for three individuals was observed during the weekly telerehabilitation schedule compared to the daily schedule. Important functional gains (e.g., improved balance, decreased fatigue) were also perceived and reported by the family partners regardless of supervision schedule.

Conclusions: Exercise programs delivered via telerehabilitation can effectively improve balance and mobility, as well as impact concerns with falling and physical activity levels for this population. No clear differences were seen between the two telerehabilitation supervision schedules.

Keywords: Telerehabilitation, Traumatic Brain Injury (TBI), Teletherapy, Exercises, Physiotherapy

5.2 Introduction

Individuals with chronic impairments and activity limitations including poor balance, restricted mobility, and lower physical activity levels secondary to a moderate or severe traumatic brain injury (TBI), can benefit from access to community rehabilitation services throughout their lifespan [1]. Programs targeting balance improvement could reduce fall risk while the promotion of daily physical activity could positively impact fatigue levels and overall mood [2,3]. In the years following a moderate or severe TBI, these improvements could reduce hospital readmission rates [4,5]. Thus, the promotion of daily physical activity, balance, life satisfaction and participation in the years post-TBI is crucial.

Intensive physiotherapy programs promoting neuroplasticity [6] and physical activity can support healthy aging in the community [7] and reduce fall risk [8] following a neurological condition. High numbers of repetitions, between 300-800 per day of a specific task, should be included in high intensity exercise programs to promote motor learning and neuroplasticity [9]. However, specialized services such as high-intensity rehabilitation services might be limited for individuals who live in remote or rural areas, in cities where publicly funded intensive programs are limited, and for individuals with transportation or financial barriers linked to travel. More recently, barriers to in-person therapy such as COVID-19 have emerged making face-to-face rehabilitation challenging and potentially risky. Physical distancing requirements, the cost of personal protective equipment and patient fear of exposure risk associated with face-to-face care have become further impediments to rehabilitation. Telerehabilitation is well situated to mitigate some of these barriers.

Telerehabilitation, the use of telecommunication to deliver rehabilitation, is increasingly used as a supplement or as an alternative to face-to-face rehabilitation [10]. In this study, telerehabilitation is defined as teletherapy using videoconferencing to deliver care and telemonitoring using activity tracking devices to monitor activity [11]. The main objectives of this study were to demonstrate the effectiveness of telerehabilitation to improve physical activity, functional mobility and dynamic balance, and to understand the impact of two supervision schedules for a high-intensity home-based telerehabilitation exercise program on people living with a disability resulting from a moderate or severe TBI (PwD). A sub-objective was to document the impact of an intensive home-based telerehabilitation exercise program on participation, any concerns regarding falling, and satisfaction with life.

5.3 Methods

Design

This study combines a convergent mixed-method approach with an alternating single-subject design (SSD)[12,13]. Within the SSD, quantitative and qualitative data were collected in parallel to investigate the impact of two supervision schedules of a high-intensity home-based telerehabilitation exercise program. The SSD consisted of five phases: baseline, intervention with supervision schedule 1, washout period, intervention with supervision schedule 2 and, 1-month follow-up. The order of daily or weekly remote supervision of the exercise program was counterbalanced across individuals. To understand the impact of each supervision schedule, quantitative data were recorded with the use of daily repeated measures and pre-post intervention measures. Independent semi-structured interviews helped explore the lived experiences of PwD from TBI and their family partner after each intervention. Methods are described below and detailed in O'Neil et al (2019)[14].

Participants

People with a TBI living with disabilities such as balance and mobility deficits were recruited and screened. The following inclusion criteria were used for screening: i) reporting of moderate or severe TBI diagnostic by either knowledge of the Glasgow Coma Scale (GCS) at time of injury scoring 12 or less, loss of consciousness, or hospital admission due to the injury; ii) minimum 1 year post injury; iii) ability to stand without physical assistance for a minimum of 2 minutes; iv) consenting study partner (family partner); v) available internet; and vi) able to participate in videoconferencing. Individuals with persistent vertigo were excluded for safety reasons.

Intervention

To facilitate clinical replication, a full description of the intervention using the Consensus on Exercise Reporting Template (CERT) proposed by Slade and colleagues (2016)[15] is provided in Table 1.

Table 5.1 Detailed description of the intervention as per CERT

Item Category	Abbreviated Item Description	Study Intervention
WHAT: materials	1.Type of exercise equipment	Chair, line on floor, weights for progression or household objects (e.g., cans, boxes)
WHO: provider	2.Qualifications, teaching/supervising expertise, and/or training of the exercise instructor	Registered physiotherapist with over 11 years of clinical experience; over 7 years of telerehabilitation experience, currently completing her PhD; and exercise experience as an elite level athlete.
HOW: delivery	3.Whether exercises are performed individually or in a group	Individually
	4.Whether exercises are supervised or unsupervised	Home-based exercise program supervised via videoconference daily or weekly by the physiotherapist. Daily supervision: the physiotherapist provided remote supervision 5 days per week for 4 weeks. Weekly supervision: remote supervision was provided once a week for 4 weeks. During the weekly supervision, PwD from TBI and family partners were responsible for completing 4 additional unsupervised sessions per week.
	5. Measurement and reporting of adherence to exercise	Family partners and the physiotherapist used a daily log to document the number of repetitions, length of exercise sessions, daily step count recorded through the use of a Fitbit Charge ™, adverse events, technology difficulties and adherence. Questions about adherence were also asked during the semi-structured interview.
	6. Details of motivation strategies	Participants were asked to discuss goals, priorities and motivations prior to study initiation. Dyads were provided with a selection of recommended exercises targeting essential components of dynamic

		balance, weight shifting, reaction time, and postural control and actively engaged in designing their exercise program.
	7. a) Decision rules for progressing the exercise program and, b) How the exercise program was progressed	a) Modifications were provided if a PwD had difficulty completing the exercises or made progress to ensure the level of difficulty was appropriate. b) Exercises were modified by in/decreasing the height of a squat or length of steps, adding/removing weights, in/decreasing speed, or adding/removing a cognitive task.
	8. Each exercise is described so that it can be replicated (eg, illustrations, photographs)	Sit to stand, side stepping, lunges, squats, tandem walking, single leg stance. These exercises were adopted from previous programs targeting dynamic balance in individuals with moderate or severe TBI (Canning et al., 2003; Charrette et al., 2016; Lorenz et al., 2017; Tiwari et al., 2018; Ustinova et al., 2015; Wise et al., 2012)
	9. Content of any home program component	Prior to starting the home-based intervention, a pre-program remote session was completed to assess safety of the environment in the home, provide education on how to set-up the technology and environment, and test the technology.
	10. Non-exercise components	Each PwD wore a Fitbit Charge ™attached at the ankle to monitor their daily steps.
	11. How adverse events that occur during exercise are documented and managed	Adverse events were documented in field notes, physiotherapist and the family partner's daily log.
WHERE: location	12. Setting in which exercises are performed	Participant's home
WHEN, HOW MUCH: dosage	13. Detailed description of the exercises (eg, sets, repetitions, duration, intensity)	Two intensive 4 week, five days per week exercise programs were completed by each PwD. Each program had between 2 and 4 exercises. During each session, exercises were completed for one minute at a time and repeated in order to achieve a minimal goal of 300 repetitions of task-oriented exercises or a maximum of 60 minutes per session. If 300 repetitions were reached in less than 60 minutes, PwD were given the choice to stop or keep going. When needed, they were encouraged to take short breaks.
TAILORING: what, how	14.Whether exercises are generic ("one size fits all") or tailored to the individual	Programs were tailored and co-designed by the PwD, and family partner (dyad). Two to four individual exercises were selected by each dyad from a set of twelve exercises. All proposed exercises focused on improving dynamic balance and mobility.
	15. Decision rule that determines the starting level for exercise	We used the ability to stand for a minimum of 2 minutes without physical assistance as a decision rule to determine starting level and safety to participate in the program.
HOW WELL: planned, actual	16. a) How adherence was assessed and b) Whether the exercise intervention is delivered and performed as planned	a) Adherence was documented by number of completed sessions reported in daily logs, field notes and interviews b) All PwD were able to complete between 2-4 exercises. On average 94% of the sessions were completed.

Outcome measures

Our primary outcome measures, physical activity level and functional mobility, were measured and recorded repeatedly throughout each intervention period. An activity tracking device (Fitbit Charge ™) was used to record step count on a daily basis and the Five Time Sit to Stand test (FTSTS) documented functional mobility on a weekly basis (Figure 1). Dynamic balance was documented before and after each intervention with the Community Balance and Mobility Scale (CB&M) [22,23]. Our secondary outcome measures were collected by administering three questionnaires to PwD and family partners before and after each intervention. The participation index a subscale of the Mayo-Portland Adaptability Inventory (M2PI) was used to document participation [24]. The Fall-Efficacy Scale International (FES-I) [35] and the Satisfaction with Life Scale (SWLS) [37] were used to document concerns related to falling and the level of satisfaction with life, respectively. We also explored perspectives from each PwD and their family partner using semi-structured interviews completed after each intervention.

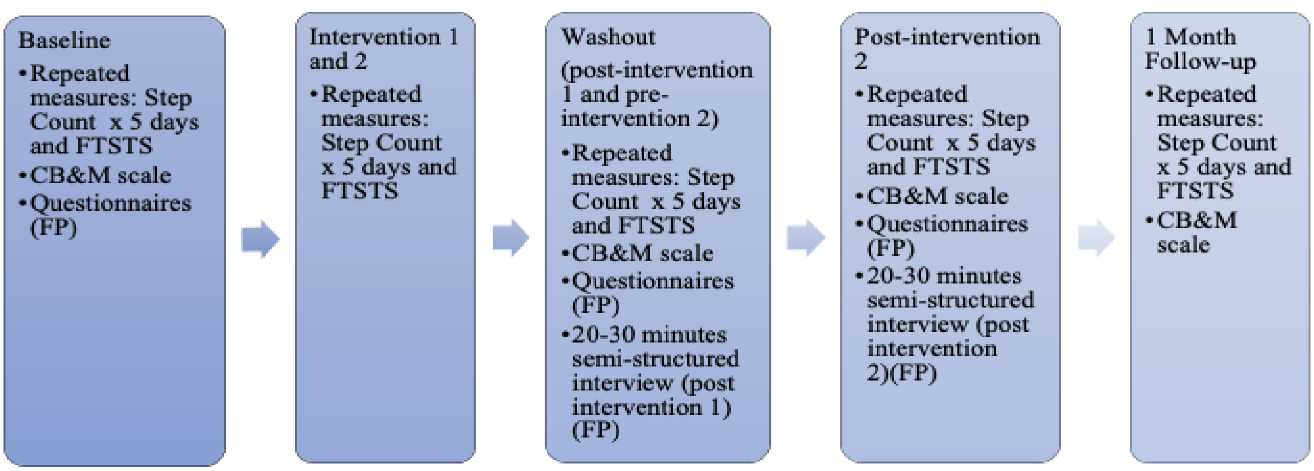

Figure 5.1 Schedule of outcome measures for all person with disability post TBI (PwD) and family partners (FP). The presence of FP indicated the family partners completing the measure. Note: Community Balance and Mobility scale (CB&M scale), Five Time Sit to Stand (FTSTS). Questionnaires are: Fall Efficacy Scale-International (FES-I), Mayo-Portland Participation Index (M2PI), and Satisfaction with Life Scale (SWLS).

Due to the COVID-19 pandemic, a subset of assessments was conducted remotely rather than the planned in-person pre and post assessments.

Analysis

Visual analysis and traditional SSD analysis methods were used to compare measures of physical activity and mobility at baseline, during and post interventions for each PwD. Serial dependency using the Bartlett's test was assessed prior to visually interpreting the data [25,26]. The two-standard deviation band (2SDBand) method [27], a quasi-statistical method, allowed for the documentation of statistically significant changes when two consecutive points fell outside the 2SDBand. The 3 standard deviation rule (3SD) proposed by Portney and Watkins was applied to identify outliers in order to discuss their meaning [28]. When outliers were identified, we reviewed field notes and participant logs for potential explanations. Outliers were included in the quantitative analysis.

For each dependent variable and where appropriate, the minimal detectable change (MDC), minimal clinical important difference (MCID), effect size (ES), mean, standard deviation (SD), and range were reported. Since normative data for people with TBI is limited, it was important to recognize the variability in the available data. While some studies report a MDC of 45 steps [29], or a self-report of 1000 steps [30] as numbers indicating an improvement in physical activity; the conservative effect size of 2000 steps per day was used to depict meaningful improvement in physical activity level [31]. Since no data are available for the FTSTS in people with TBI, we informed our decision with the following available data. A MCID of 2.3s and a 13s cut-off are used to document balance improvements in individuals with vestibular deficits while a MDC of 2.5s has been used to document improvement in an older female population [32,33]. Following a more conservative approach, we used 2.5 seconds to indicate improvement in mobility on the FTSTS [34].

Finally, the CB&M scale has been validated for people with TBI with a MDC of 7.5 used to identify change in dynamic balance and mobility [22].

Data related to participation, fear of falling and life satisfaction were reported descriptively. The M2PI scores were documented through a T-score, representing a given score compared to a reference value for individuals with acquired brain injury, including moderate or severe TBI. T-scores above 60, between 50-60, between 40-50, between 30-40 or below 30 represent severe limitations, moderate to severe limitations, mild to moderate limitations, mild limitations or good participation, respectively [24]. FES-I scores between 16–19, 20–27 and 28– 64 represented low, moderate and high concern with fear of falling, respectively [35]. Moveover, a MDC of 8.2, based on people with vestibular deficits was used to determine a trend in FES-I scores [36]. The level of satisfaction with life was documented using the SWLS as extremely dissatisfied (scores 5-9), dissatisfied (score 10-14), below average satisfaction (15-19), average satisfaction (20-24), satisfied (25-29, and highly satisfied (30-35) [37].

Following a three-step process, qualitative data was analyzed using an exploratory content analysis method [38]. After transcribing each semi-structured interview, the experiences of each PwD post TBI and their family partner were first organized into broad categories. Within these categories, experiences of the dyads were compared, merged or separated into new categories in a second phase. Finally, categories were illustrated using descriptive narrative quotes.

Ethics approval was received by the Bruyère Research Institute Ethics Board (M16-18-038) and the University of Ottawa REB (H-12-18-771).

5.4 Results

Participants

Five dyads (five PwD resulting from a moderate or severe TBI and five family partners) participated in this study. Three individuals with moderate or severe TBI (PwD 1, 4 and 5) started with the daily intervention, while two individuals (PwD 2 and 3) started with the weekly intervention. Demographic information is outlined in Table 5.2.

Table 5.2 Demographic of dyads

PwD resulting from TBI	Location	Ethnicity and Language	Civilian/ Military	Sex	Age Range	Mechanism of Injury	Year of injury
1	Rural, Ontario	White, English	Civilian	M	20-30	MVA Severe TBI	2014
2	Urban, Ontario	White, English	Military	M	30-40	Blast injury Mild-Moderate TBI	2008
3	Urban, Ontario	Black, English,	Civilian	M	30-40	Violence-Trauma Severe TBI	2013
4	Rural, Quebec	White, French	Civilian	M	20-30	MVA Severe TBI	2017
5	Rural, BC	White, English	Military	F	50-60	Violence-Trauma Mild-Moderate TBI	2014
Family Partner	**Location**	**Ethnicity and Language**	**Civilian/ Military**	**Sex**	**Age Range**	**Occupation**	**Relationship with PwD**
1	Rural, Ontario	White, English	Civilian	F	20-30	Caregiver and self-employed	Wife
2	Urban, Ontario	Indigenous, English	Military	F	20-30	Caregiver, Student	Wife
3	Urban, Ontario	Black, English	Civilian	M	70-80	Caregiver, Retired	Father
4	Rural, Quebec	White, French	Civilian	F	50-60	Business owner, caregiver	Mother
5	Rural, BC	White, English	Civilian	M	18-20	Student	Son

Note: Person with a disability resulting from the moderate or severe TBI (PwD), Motor Vehicle Accident (MVA), Traumatic Brain Injury (TBI).

Serial Dependency

Serial dependency was found in the FTSTS data for PwD 2 ($r=0.48 > 0.35$) as well as step count data for PwD 3 ($r=0.4 > 0.2$). Both serially dependent data sets were transformed once using first difference transformation to remove serial dependency before continuing with the analysis.

Primary outcomes: Physical activity, functional mobility and dynamic balance

Physical activity level (Daily step count)

Statistically significant changes, circled points in Figure 5.2, were observed with PwD 3 during the weekly intervention, and PwD 4 during the daily intervention and the follow-up. All

PwD demonstrated meaningful clinical change at some point in the interventions, however changes were more noticeable in the weekly supervised intervention. Of note, an outlier on day 52 for PwD 5 was identified. This remarkably high daily step count was recorded as a result of an unusual double hike that day.

Mobility (Weekly Five Time Sit-to-Stand)

For the FTSTS, statistically significant and clinical improvements were observed in 4 out of the 5 PwD (Figure 5.3; circled points and dotted line). Statistical significance was observed for PwD 1, 3, 4 with at least two consecutive points out of the 2SD band regardless of supervision schedule. The PwD 5 made statistically significant changes during her first intervention (daily supervision). The PwD 1, 4 and 5 demonstrated clinical improvement during the first supervision period (daily) while PwD 3 also demonstrated clinical improvements during the first supervision period (weekly).

Dynamic Balance- CB&M scale

The PwD 2, 3, and 4 demonstrated clinical improvements after the second intervention (daily supervision) which were maintained or improved 1-month after the program was completed. The PwD 5 showed clinically improvement after both interventions (Table 5.3A).

Daily Step Count

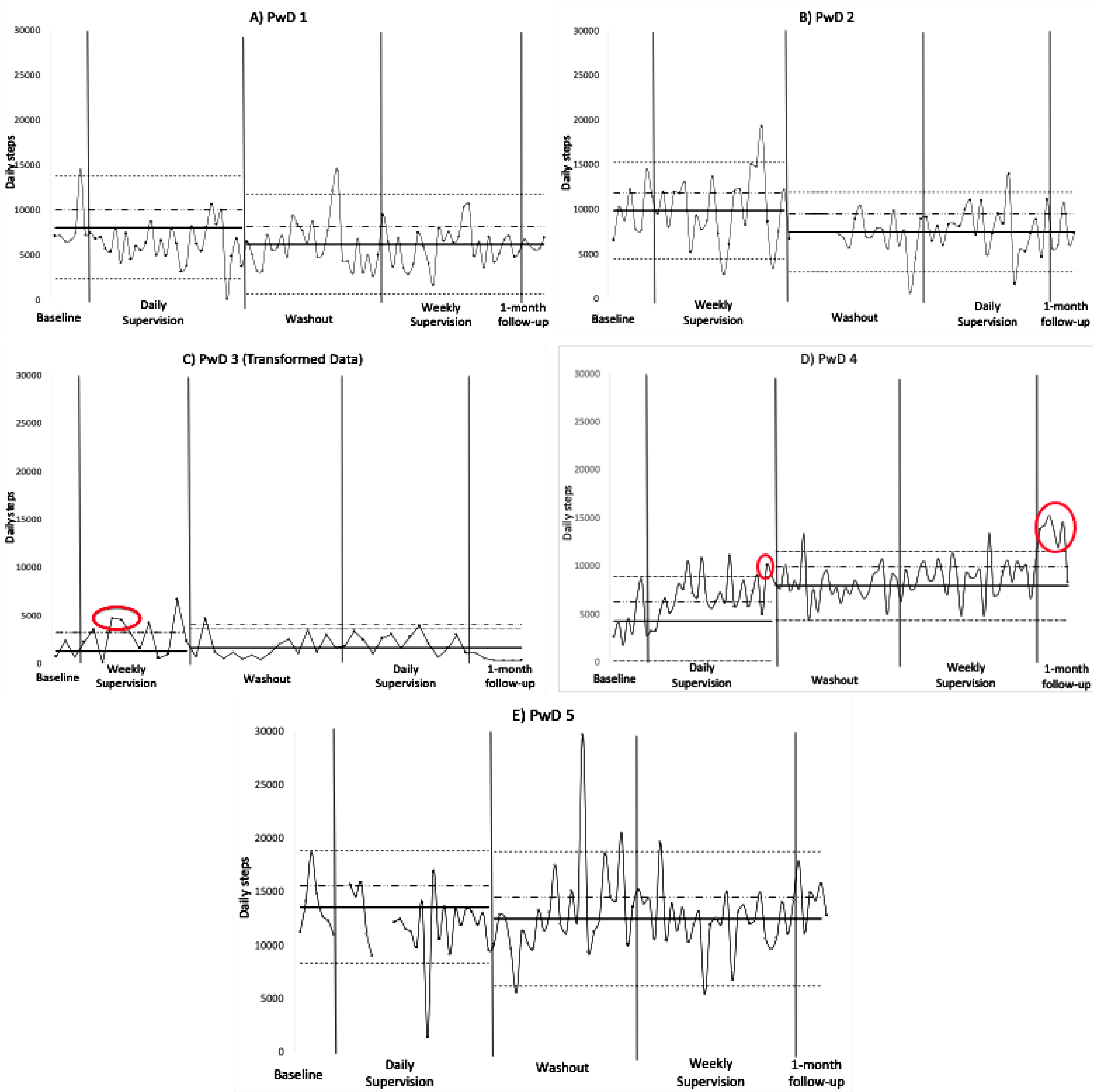

Figure 5.2 Statistically significant changes in daily step counts (2 points outside 2 SDband) are circled in red. Horizontal lines (solid) represent means and corresponding +/-2SD (dotted for the baseline or washout periods used to determine change in the respective intervention phases. Meaningful clinical improvement defined by an effect size of 2000 steps is represented by the dashed line above the mean at baseline and washout.

Five Time Sit-to-Stand

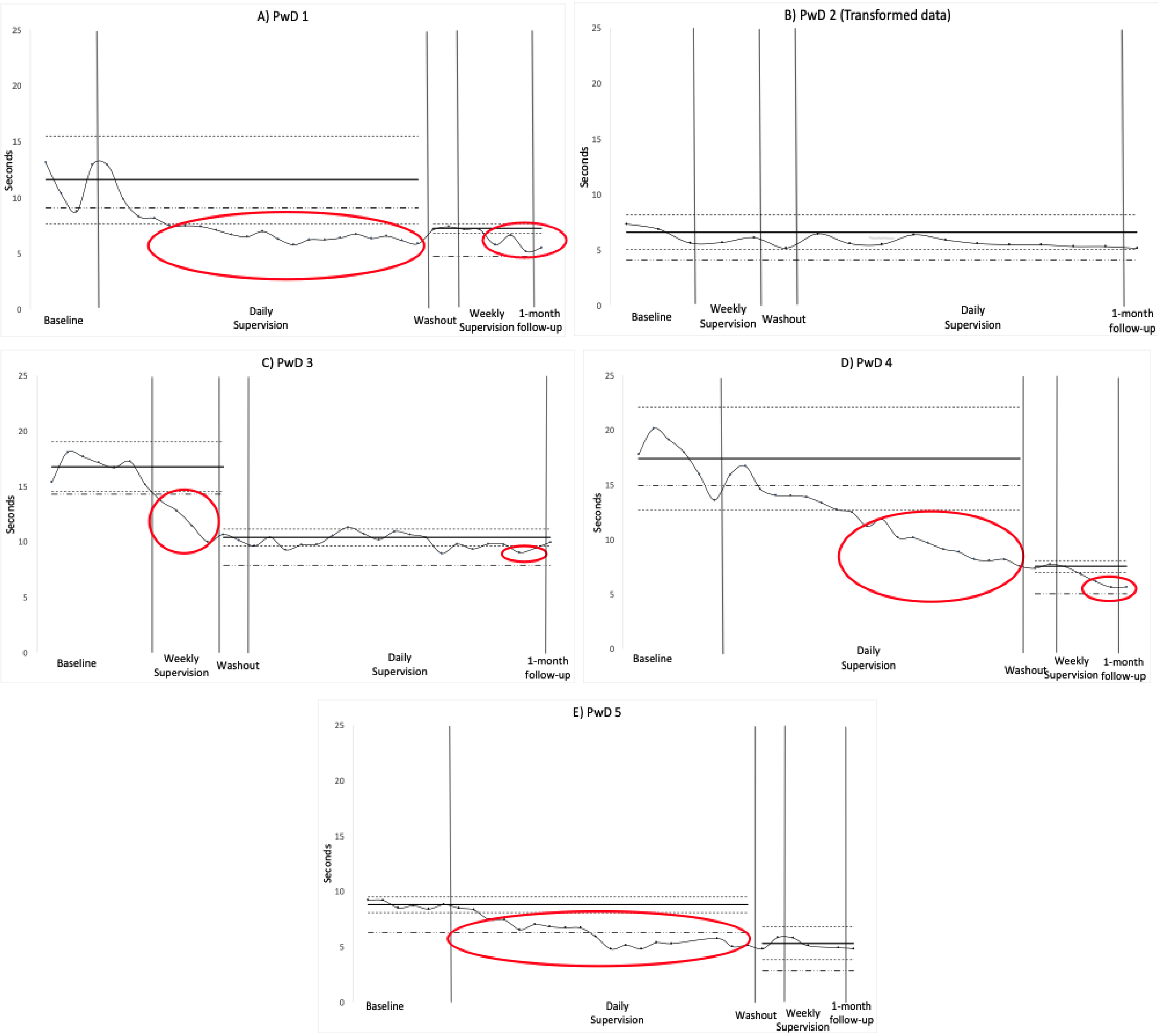

Figure 5.3 Statistically significant changes in FTSTS (mobility) are demonstrated by 2 or more consecutive points outside the 2SDBand (red circles). Solid black lines represent means (baseline or washout), dotted lines represent +/- 2SD (baseline or washout). Clinical improvements are represented by the dashed line defined as a MDC of 2.5 seconds from baseline or washout mean.

Secondary outcomes: participation, concerns with falling, and satisfaction with life

Level of Participation

Overall T-scores on the Mayo-Portland Participation Index ranged from 51 to 55, 51 to 54, 48 to 61, and 48 to 54 at baseline, post-intervention 1, pre-intervention 2, and post-intervention 2 respectively. This indicates that the T-scores remained stable in the moderate or severe limitation of participation category for all PwD.

Concerns with falling

With the exception of PwD1, all PwD returned to their baseline levels of concerns with fear of falling at the end of the second intervention (Table 5.3B). Clinical improvements after both interventions moving from high concerns with falling to moderate concerns was documented for PwD1. Although PwD 2 and 3 showed similar tendencies following weekly remote supervision, this was not sustained.

Satisfaction with Life Scale: Person with Disability resulting from TBI

Satisfaction with life changed minimally for each person post moderate or severe TBI (Table 5.3C). Positive changes in life satisfaction were reported after the weekly intervention by PwD 2, and after daily supervision schedule by PwD 5.

Table 5.3 Scores on the A) Community Balance and Mobility Scale, B) Concerns with falling, C) Satisfaction of Life Scale for each PwD.

PwD resulting from TBI	Baseline	Post-intervention 1	Washout	Post-intervention 2	1-Month Follow-up
A) Community Balance and Mobility Scale (out of 96)					
1	45	46	**67**	**65**	n/a
2	83	78	80	**93**	**93**
3	17	15	22	21	**30**
4	24	30	31	**39**	**42**
5	62	**77**	61	**75**	**84**
B) Fall Efficacy Scale (out of 64)					
1	33	**24 (daily)**	34	**22**	
2	30	25 (weekly)	28	31	
3	25	22 (weekly)	21	25	
4	35	36 (daily)	36	33	
5	30	28 (daily)	36	31	
C) Satisfaction of Life Scale (out of 35)					
1	28 (satisfied)	23 (average satisfaction)	26 (satisfied)	29 (satisfied)	
2	20 (average satisfaction)	28 (satisfied)	23 (average satisfaction)	30 (highly satisfied)	
3	22 (average satisfaction)	22 (average satisfaction)	24 (average satisfaction)	23 (average satisfaction)	
4	21 (average satisfaction)	22 (average satisfaction)	19 (slightly dissatisfied)	19 (slightly dissatisfied)	
5	19 (slightly dissatisfied)	27 (satisfied)	13 (dissatisfied)	18 (slightly dissatisfied)	

Note: In the CB&M scale scores, the numbers in bold indicate a clinical improvement defined by an MDC of 7.5. In the FES-I scores, numbers in bold indicate clinical improvement by MDC of 8.2.

Satisfaction with Life Scale: Family Partner

Overall, family partners 2 and 5 reported improvements in satisfaction with life compared to baseline and voiced being highly satisfied after the weekly supervised intervention. Family partner 3 also reported a positive change in satisfaction with life after the weekly intervention, while family partner 4 improved after the washout period (Table 5.4).

Table 5.4 Satisfaction of Life Scale scores for each family partners.

Family Partners	Baseline	Post-intervention 1	Washout	Post-intervention 2
1	28 (satisfied)	26 (satisfied)	29 (satisfied)	29 (satisfied)
2	17 (Slightly dissatisfied)	31 (highly satisfied)	30 (highly satisfied)	29 (satisfied)
3	27 (satisfied)	30 (highly satisfied)	21 (average satisfaction)	29 (satisfied)
4	25 (satisfied)	27 (satisfied)	31 (highly satisfied)	29 (satisfied)
5	27 (satisfied)	28 (satisfied)	29 (satisfied)	32 (highly satisfied)

Experiences of participants

The objective of the semi-structured interview was to document the lived experiences of the PwD resulting from a moderate or severe TBI and their family partners. Through our analysis, we discovered that participants would report on the benefits of the program in various areas as part of how they experienced the program.

The PwD reported positive benefits of program participation related to balance, functional mobility and overall activity. Following the exercise programs, family partners (FP) observed and reported improvements in daily function, strength and endurance leading to increased activity engagement:

> "It seemed to have improved everything too, my balance overall, I think. Like single leg, because before like I couldn't do a second and now it is like 10 seconds. And walking, looks less ataxic. I can run too." (PwD1)

"My balance improved a lot in the week" (PwD2)

"I feel physically he has become a bit stronger, he can handle a little more activity, before becoming overwhelmed with fatigue" (FP1)

"He is a lot faster. He is stronger, more steady on the right side" (FP4)[1]

5.5 Discussion

We investigated the impact of two telerehabilitation supervision schedules of a high intensity home-based exercise program for people with moderate or severe TBI on mobility and life experience outcomes. First, individuals in this study presenting with chronic motor deficits post moderate or severe TBI showed statistically significant positive changes for physical activity levels, functional mobility, and dynamic balance. Although daily and weekly remote supervision schedules may have impacted outcomes differently, no consistent differences between the two schedules were seen across our participants.

Impact on primary outcomes

The severity of injury as well as the PwD functional activity levels ranged substantially at study onset. For example, a higher functioning individual with moderate TBI (PwD 2) averaged 7 seconds on the FTSTS and 10 000 steps per day at baseline while an individual with severe TBI deficits (PwD 4) clinically presented with an average of 18 seconds on the FTSTS and 4000 steps per day at baseline. Results from our SSD suggests that the high-intensity exercise program delivered via videoconferencing was effective in improving physical activity levels, functional mobility, and dynamic balance in PwD with a higher severity of TBI (PwD 3, and 4) and lower levels of physical activity, limited mobility, and poor dynamic balance. Improving opportunities for physical activity could be beneficial for people with severe motor deficits [39]. This high intensity

[1] Quote translated from French to English

telerehabilitation program was effective for lower functioning participants which could provide a clinical opportunity and a viable option for exercise program delivery.

Interestingly, positive impacts on physical activity levels (i.e., step count) were observed more frequently following the weekly supervision intervention and 1-month follow-up than the daily supervision intervention. It is possible that the use of an activity tracking device provided access to a form of informative feedback enticing the individual with the TBI to increase their daily physical activity. Studies involving older adults suggest that the use of an activity tracking devices could promote physical activity and can be as effective as telephone consultations [40–42]. In addition, we know that supporting competence can improve autonomous motivation [43]. Perhaps the daily supervision intervention supported competence but also fatigued the participants while the activity tracking device offered informative feedback throughout the day supporting competence and also autonomy during the unsupervised sessions. Our findings suggest that including an activity tracking device as part of an exercise program may positively support autonomy and promote an increase in physical activity for people with moderate or severe TBI.

We documented clinical improvements in functional mobility (i.e., FTSTS) and dynamic balance (i.e., CB&M) in four PwD post TBI following the initial intervention, regardless of supervision schedule. For a task to improve, three stages of motor learning needs to be acquired: in the cognitive stage, the attention is focused of how to perform the task; in the associative stage, the connections between performance and results are initiated; and in the autonomous stage, the ability to use the skill in other contexts [44]. Informative feedback from the physiotherapist and the addition of intensive practice to daily activity during the first intervention period may have allowed the individuals to consciously increase their mobility, balance, awareness and knowledge. This intensive four-week intervention could have provided an opportunity to “prime” the body to learn and improve, thus illustrating the cognitive stage of motor learning.

In addition, daily repetitions of the FTSTS could have increased learning effects and facilitated skill acquisition. Moreover, mobility gains were sustained through the four-week washout as well as 1-month follow-up, which in itself demonstrates autonomy, skill acquisition and retention. The effectiveness of this exercise program may not have been influenced by the remote supervision schedule but rather the delivery of feedback based on motor learning principles.

Impact on secondary outcomes

Mixed perceptions around the levels of participation between the questionnaire and the interviews were observed in this study. Specifically, none of the PwD post TBI reported an improvement in participation from the beginning to the end of the program on the M2PI questionnaire. However, qualitative reports from these same individuals and their family partners suggested an increase in activity participation and motor function. Unfortunately, this was not captured by the M2PI. Perhaps gross measures of participation are not representative of this chronic population. The M2PI was repeated four times by the PwD which may have provided them the opportunity to self-reflect on current social participation limitations. With known cognitive and self-awareness deficits following moderate or severe TBI [45], the decrease in reported participation on the M2PI may suggest an improvement in deficit awareness and self-perception. Assessing changes in self-awareness in addition to participation should be considered in future studies in order to dissociate the impact of an interventions on participation from self-awareness [46–48].

Specific trends were documented between the weekly frequency of remote supervision and positive changes in satisfaction with life for family partners. Three family partners (FP 2, FP3 and FP5) tended to rate their satisfaction with life higher following the weekly intervention. Life satisfaction and overall caregiver health are essential to provide support for veterans [49]. Perceived social support can also positively impact the quality of life of the caregiver [50]. Our study suggests that once per week supervision from the physiotherapist may have been enough for the family partners to feel supported and consequently improve life satisfaction. The family partners also reported a positive relationship between the program and mental health. Family partners reported external accountability stemming from the physiotherapist's support as a key factor in the increased satisfaction and personal relief.

Limitations

The use of alternating SSD replicated across multiple individuals, though not generalizable, can still influence future studies and clinical practice with this specific population [51]. Introducing the activity tracker during the baseline phase could have inflated the "typical" step count number for the individual. To mitigate this in future studies, the activity tracking device should be introduced ahead of time and a longer baseline phase should be planned. Future studies should carefully choose participation measures including concepts of autonomy, activity performance, and self-awareness. Validating questionnaires with constructs specific to functional status such as the CORE-Q [52] or assessments that tailor the activities to each person such as the Ghent Participation Scale [53] might better reflect participation in this population. The pandemic and requirements of social distancing may also have negatively influenced the levels of daily activity for the PwD enrolled in the trial during this period (PwD3, PwD4 and PwD5). As suggested by

O'Neil et al. (personal communication) [2], the therapist's clinical experience with telerehabilitation may have influenced the effectiveness of the intervention. Further studies on the role of providers (e.g., therapist, family partner, rehabilitation specialist), ease and comfort with telerehabilitation, may demonstrate which skills are needed for effective remote supervision and could influence continuing education curriculums.

5.6 Conclusion

The use of telerehabilitation to deliver intensive home-based exercise programs was effective to improve physical activity, functional mobility, dynamic balance in five people with moderate/severe traumatic brain injury. We documented trends in reducing concerns with falling or improving satisfaction with life for three people who survived a moderate or severe TBI. We also found that weekly supervision had similar benefit to daily supervision. Physiotherapists must consider the influence of remote supervision, dosage, motor control principles, and people-specific therapeutic goals when tailoring their interventions. One individual (PwD 2) demonstrated that a high level of physical activity did not directly translate to high dynamic balance. It is important to specifically include task targeting dynamic balance for this population. Telerehabilitation may be feasible, effective, and may positively impact the life of people who experienced a moderate or severe TBI, and their family partners. Future research should examine if telerehabilitation is effective for people with TBI on a larger scale within different context.

O'Neil et al. **Remotely supervised exercise programs to improve balance, mobility and activity among people with moderate to severe TBI: Description and feasibility.** (manuscript submitted to Physiotherapy Canada, March 25th, 2021)

KEY MESSAGES

What is already known on this topic

- Key motor learning principles such as feedback, distributed practice, bouts of intensive practice and specificity have been shown to be key to recovery and motor re-learning[54].
- Targeting high-intensity exercise can improve chronic motor deficits.

What this study adds

- Planning to include motor learning strategies by tailoring the intervention to environmental context, social support, physical and cognitive capacities, behaviour, and method of delivery should be considered by physiotherapists.
- Including an extended 4-week remotely supervised practice period could help prime the individual's motor learning and therefore the effectiveness of the intervention.
- Increasing daily step count and high-intensity home-based balance exercise improved the effectiveness of the telerehabilitation program on dynamic balance, mobility and physical activity in this population.

Acknowledgements

Funding supporting this work was received from the Canadian Institute for Military and Veteran Health Research-True Patriot Love initiative and from a Spark program grant from the Centre for Aging and Brain Health Innovation (CABHI). The first author also received scholarships from the Ontario Graduate Scholarship, the University of Ottawa and the Bruyère Research Institute. Lastly, thank you to all participants and Anne Hobson-Taillon, our research assistant for her remarkable collaboration with this project.

Declaration of conflicting interests

The Author(s) acknowledge (s) that there is no conflict of interest to declare.

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Chapter 6. The assessment of interpersonal behaviours in a telerehabilitation setting

How do People Living with a Disability Perceive the Physiotherapist Interpersonal Behaviours? Implications for home-based telerehabilitation

(Under Review Physiotherapy Theory and Practice Journal on April 23rd, 2021)

Citation:
O'Neil J, Pelletier L, Bilodeau M, Egan M, Marshall S, Sveistrup H. **How do People Living with a Disability Perceive the Physiotherapist Interpersonal Behaviours? Implications for home-based telerehabilitation.** Physiotherapy Theory and Practice, Taylor and Francis. Under review April 23rd, 2021

The interpersonal behaviour and the use of interpersonal behaviours questionnaires were explored in this chapter. This manuscript was submitted to the *Physiotherapy Theory and Practice Journal* on April 20th, 2021. We acknowledge the financial support received from the Canadian Institute for Military and Veteran Health Research (CIMVHR) and True Patriot Love (TPL) and the Spark program grant from the Centre for Aging and Brain Health Innovation (CABHI); and graduate scholarships from the Ontario Graduate Scholarship, University of Ottawa and the Bruyère Research Institute. Ethic approval was received by the Bruyère Research Institute Ethic Board (M16-18-038) as well as the University of Ottawa REB (H-12-18-771).

6.1 Abstract

Background According to Self-Determination Theory, the fulfillment of basic psychological needs of autonomy, competence, and relatedness plays an important role in one's motivation, engagement and well-being. How a therapist is perceived to support or thwart these needs can impact adherence to treatment, thus influencing the effectiveness of therapeutic interventions.

Objectives This study explores how the physiotherapist self-report interpersonal behaviours, how the person living with a disability (PwD) perceives the physiotherapist supportive/thwarting interpersonal behaviours, and how the two aligns in the context of telerehabilitation.

Methods Five PwD and their physiotherapist completed two telerehabilitation exercise programs. The PwD completed the Interpersonal Behaviour Questionnaire (IBQ) to examine how they perceived the physiotherapist interpersonal behaviours. The physiotherapist completed the Interpersonal Behaviour Questionnaire-Self (IBQ-Self) to document how they self-reported these same behaviours. Descriptive statistics were used to document self-reports and perceptions of behaviours.

Results Each PwD perceived the physiotherapist as being more supportive than thwarting. The supportive/thwarting behaviours varied across relationships.

Conclusion Assessing how therapist support/thwart psychological needs and how these behaviours are perceived by PwD is recommended as it may influence the therapist's behaviour and the PwD's adherence to future telerehabilitation exercise programs.

Keywords: Interpersonal behaviour, Self-Determination Theory, Physiotherapy, Telerehabilitation

6.2 Introduction

Interpersonal approaches have evolved from the biomedical approach where the care provider focuses on the disease and is seen as the main source of a patient's rehabilitation success (George Engel, 1977), to a *patient*-centred approach where each patient is at the center of their care and a partner within each episode of care (Starfield, 2011). Pushing the boundaries further than a single episode of care is the emerging *people*-centered approach where there is an intentional partnership between a care provider and a care recipient to engage and empower individuals (Josefsson, 2016; Sjöberg & Forsner, 2020; World Health Organization (WHO), 2016). In other words, in the people-centred approach, the care recipient is seen as a person within a social and environmental context capable of making their own decisions and actively engaging in the rehabilitation process. Since an overarching goal for physiotherapists is to support the autonomy of individuals leading to taking more responsibilities towards self-management of their health conditions, examining how to implement an approach that is centered on active engagement and active partnership is important.

The Self-Determination Theory (SDT) is a theoretical framework used to explain active engagement and motivation to change behaviour. Central to SDT is the concept of a human's innate psychological need for autonomy, competence and relatedness to others (Deci & Ryan, 2000). For example, in healthcare, autonomy could be viewed as the ability of a person living with a disability (PwD) to self-empower and self-manage. Competence could be defined as the PwD's ownership of knowledge leading to self-efficacy and decision-making. Finally, relatedness could be described as a PwD's need to feel close or connected to others. The fulfillment of these three basic psychological needs can ultimately lead to an increase in autonomous motivation and engagement (Ng et al., 2012; Rodrigues et al., 2018).

According to SDT (Ryan & Deci, 2017), interpersonal behaviours can either be supportive and promote the fulfilment of autonomy, competence and relatedness or be thwarting and frustrate the fulfilment of these needs. During rehabilitation, interpersonal behaviours between a care provider (e.g., physiotherapist) and a care receiver (e.g., PwD) can positively or negatively impact a person's motivation leading to increased or decreased engagement in the exercise program (Ginis, Ma, Latimer-Cheung, & Rimmer, 2016; Ryan & Deci, 2000). In a therapeutic relationship, the therapist can demonstrate supportive and/or thwarting interpersonal behaviours that could have an impact on the PwD's motivation and engagement. In the rehabilitation context, understanding interpersonal behaviours from the physiotherapist's perspective but also, and equally importantly, from the PwD's perspective, makes SDT an appropriate framework to use under the people-centred approach.

Needs-supportive interpersonal behaviours have been shown to have a positive influence on the motivation of an individual leading to active engagement in many fields including health, sports, education, work, and parenting (Camiré, Rathwell, Turgeon, & Kendellen, 2019; Chia et al., 2016; Fleenor, Smither, Atwater, Braddy, & Sturm, 2010; Rocchi & Pelletier, 2017; Rocchi & Pelletier, 2018; Slemp, Lee, & Mossman, 2021). Research in the healthcare field, including physiotherapy, has shown that supportive behaviours towards autonomy, competence, and relatedness lead to better patient outcomes (Gillison et al., 2019; Hall et al., 2020; Murray et al., 2015, 2019; Ntoumanis et al., 2020). Examples of these positive outcomes include weight loss, smoking cessation and physical activity adherence (Ng et al., 2012; Ntoumanis et al., 2020; Rodrigues et al., 2018). Studies on physical activity adherence have also documented a link between the perceived supportive behaviours from a physiotherapist and the promotion of a PwD's autonomy and competence (Chan, Lonsdale, Ho, Yung, & Chan, 2009; Dannapfel, Peolsson, Ståhl, Öberg, & Nilsen, 2014). Therefore, identifying the extent to which a PwD perceives how a physiotherapist supports their basic psychological needs is critical.

The level of congruence or alignment between the PwD's perception of a physiotherapist's behaviours and the physiotherapist's self-report of those behaviours is also an important element of SDT. For instance, a physiotherapist self-reporting as being supportive of a PwD's needs does not directly translate to a PwD perceiving the physiotherapist's behaviours as supportive. For a physiotherapist to be more supportive and less thwarting of basic psychological needs, it is important to assess how their self-reported interpersonal behaviours align with the behaviours perceived by the PwD.

For example, recent research suggests that alignment between the athlete's and the coach's perception of the coach's behaviour (if supportive), leads to an increase in the effectiveness of the coaching intervention (Rocchi & Pelletier, 2018; Rodrigues et al., 2020). Therefore, for a physiotherapist, understanding how their behaviours are perceived by the PwD could help optimize their behavioural strategies and maximize the effectiveness of their intervention.

Documenting Interpersonal Behaviours

Approaches to documenting interpersonal behaviours may include i) direct observation of each individual's behaviour (Haerens et al., 2013), ii) care provider self-report of one's own supportive or thwarting interpersonal behaviour (e.g., how the physiotherapists might perceive his/her behaviour towards a PwD) (Murray et al., 2019); and iii) the care recipient's perception of the care provider's behaviour (e.g., how a PwD perceives the physiotherapist's behaviours). Documenting the combination of provider self-report and recipient perception of interpersonal behaviours allows us to explore the alignment between what is perceived by the PwD and what is reported by the physiotherapist (Rocchi et al., 2017). Two validated questionnaires documenting interpersonal behaviours from the care provider-recipient relationship are the Interpersonal Behaviour Questionnaire-Self (IBQ-Self) and the Interpersonal Behaviour Questionnaire (IBQ) (Rocchi et al., 2017).

Findings support the relative importance of the PwD's perception and the alignment between the perspectives of the PwD and the self-report of the therapist. For instance, literature on education and autonomous learners suggests that how the recipient perceives supportive and/or thwarting interpersonal behaviours is crucial for their autonomous motivation (Chia et al., 2016). The alignment between how people in a role of authority (e.g., fitness trainers, coaches) self-report their behaviours with what is perceived by the recipients (e.g., exercisers, athletes) is also important, as the congruence between the two would show an authentic relationship leading to better support of the recipient's needs (Rocchi & Pelletier, 2018; Rodrigues et al., 2020; Ryan & Deci, 2017). Understanding both the PwD's perception of supportive or thwarting interpersonal behaviours and the alignment between what is perceived and what is self-reported is necessary to the effectiveness of a telerehabilitation exercise program.

Telerehabilitation

A systematic review by O'Keeffe et al. (2016) documents strategies used by physiotherapists to facilitate the provision of supportive and bidirectional therapeutic exchanges. These strategies include education and active listening which lead to an improvement in intervention adherence (O'Keeffe et al., 2016). When used during in-person physiotherapy services, these strategies can support competence needs by improving the PwD's knowledge and providing the necessary information to facilitate decision-making (Hall et al., 2020; Kors et al., 2020; O'Keeffe et al., 2016). A recent systematic review of telerehabilitation interventions for a pediatric population reported that physiotherapists who used a "coaching approach" with parents by providing education to support self-management and autonomy improved the effectiveness of the intervention (Camden et al., 2020). This reinforces the idea that behavioural strategies aimed at supporting autonomy and competence can impact program effectiveness in both in-person and telerehabilitation settings. Yet, little attention has focused on how these strategies are delivered in a telerehabilitation context for the adult population with a TBI. To our knowledge, one study has focused on measuring autonomy-supportive behaviours within a telerehabilitation session, however, this was targeting web-based interventions without the input from a care provider (Smit, Dima, Immerzeel, Van Den Putte, & Williams, 2017).

Objectives

In this study, we were interested in documenting 1) the therapist's self-reported interpersonal behaviours, 2) the PwD's perception of the therapist interpersonal behaviours, 3) the alignment between the PwD's perception of the therapist's behaviours and the therapist's self-report of the behaviours, and 4) the changes in alignment over time. Specifically, two questionnaires were used to address our objectives: the IBQ-Self to document how the physiotherapist was self-reporting their supportive and/or thwarting interpersonal behaviour and the IBQ to document how the physiotherapist's interpersonal behaviour was perceived by each PwD.

6.3 Methodology

This exploratory sub-study is part of a larger mixed-method alternating single-subject study investigating the feasibility and effectiveness of remotely supervised high-intensity home-based exercise programs for individuals who experienced moderate or severe TBI. The full protocol appears in O'Neil et al., 2019. This study was approved by the Bruyère Research Institute REB (M16-18-038) and the University of Ottawa REB (H-12-18-771).

Participants: Persons living with a Disability

Study participants were recruited via social media, posters, and recruitment videos sent to various military associations and physiotherapy clinics treating people with neurological conditions. Individuals were screened and consented to be included in the study if they: 1) self-reported having sustained a moderate or severe TBI a year or more ago causing balance or mobility issues, 2) were able to participate in an exercise program remotely using the internet and a videoconferencing system, 3) could stand for 2 minutes without physical assistance to safely be challenged with balance exercises. The presence of a family partner was required in the house during all exercise sessions in case of emergency and to help record the exercise intensity. Individuals experiencing constant vertigo were excluded for safety reasons.

Five individuals living with a moderate or severe TBI aged between 20- and 60-years old presenting with chronic cognitive, motor impairments, and participation limitations completed the study (Table 6.1). Participants ranged between 3- and 12-years post-injury.

Table 6.1 Characteristics of study participants.

PwD, reported severity of TBI, supported by functional measure	**Reported ethnicity, language, occupation**	**Presence of aphasia validated by clinical judgment**	**Sex**	**Age Category**	**Mechanism and severity of Injury**	**Years post injury**
1 Severe TBI FTSTS: 11.6 sec.	White, English Civilian,	No aphasia	M	20-29	MVA, Severe TBI	6
2 Mild-Moderate TBI FTSTS: 6.6sec.	White, English, Military	No aphasia	M	30-39	Blast injury, Mild-Moderate TBI	12
3 Severe TBI FTSTS: 16.8 sec.	Black, English, Civilian	Presence of expressive aphasia	M	30-39	Violence-Trauma, Severe TBI	7
4 Severe TBI FTSTS: 17.4 sec.	White, French, Civilian	Presence of expressive aphasia	M	20-29	MVA, Severe TBI	3
5 Mild-Moderate TBI FTSTS: 8.8 sec.	White, English, Military	No aphasia	F	50-59	Violence-Trauma, Mild-Moderate TBI	6

Note: Motor Vehicle Accident (MVA), Traumatic Brain Injury (TBI), Five Time Sit to Stand (FTSTS), Male (M), Female (F)

Participant: Physiotherapist

All exercise programs were delivered by a single physiotherapist (JO). The physiotherapist was a white woman with 11 years of clinical experience with individuals post moderate or severe TBI, 7 years of telerehabilitation experience, 5 years of research experience as a Ph.D. candidate, and exposure to motivational strategies as an elite-level athlete. Through these various experiences, the physiotherapist acquired significant knowledge in behaviour change strategies.

Exercise Program

Briefly, each PwD completed two 4-week high-intensity telerehabilitation exercise programs separated by a one-month washout period. During each exercise program, the PwD exercised 5 days per week for a total of twenty sessions. Exercise sessions consisted of as many repetitions as possible of the chosen two to four exercises (e.g., squats, sit-to-stand, high knees, side steps) completed in one-minute bouts. A goal was set to achieve a minimum of 300 repetitions per session. The exercise programs differed only in the frequency of physiotherapist remote supervision. One program involved daily remotely supervised sessions (20 sessions in total ranging from 32 to 53 minutes) and the other program, included weekly remotely supervised sessions (4 sessions in total ranging from 28 to 59 minutes) (Table 6.2). The initial supervision frequency, daily or weekly, was counterbalanced across PwDs.

Before the first exercise program, the physiotherapist spent an average of two hours with each PwD and their family partners. In this session, baseline measures were collected to document pre-intervention mobility, balance and physical activity status. As an example, the Five Time Sit to Stand (FTSTS) was used to document functional mobility. This baseline information allowed the PwD, family partner and physiotherapist to co-design and tailor the exercise programs targeting balance and mobility to the abilities and interests of each individual. This session also provided education on how to use the technology and how to prepare a safe environment at home for the telerehabilitation sessions. Due to COVID-19, the education sessions were delivered either in-person with an online component for PwD 1, 2, 3 and 4, or entirely remotely for PwD 5.

Table 6.2 Time spent remotely during each program by the PwD and the physiotherapist.

PwD	**Exercise Program 1**		**Exercise Program 2**	
	# of sessions with physiotherapist remotely	Average interaction time (min) (SD) per session	# of days with physiotherapist remotely	Average interaction time (min) (SD) per session
1 *	20 days	47 (±8.4) minutes	4 days	37 (±6.9) minutes
2	4 days	28 (±7.2) minutes	20 days	32 (± 4.8) minutes
3	3 days	47 (±9.5) minutes	20 days	39 (± 7.3) minutes
4 *	20 days	53 (± 5.2) minutes	4 days	59 (±3) minutes
5 *	18 days	40 (± 8.1) minutes	4 days	39 (± 5.7) minutes

Note: Person with disability resulting from a moderate or severe TBI (PwD), standard deviation (SD). PwD starting with daily supervision are identified by * beside number.

Measures of Interpersonal Behaviour

The physiotherapist's self-report of interpersonal behaviours with each PwD was documented using the IBQ-Self, a validated questionnaire measuring how a person in a supervising role (e.g., physiotherapist) perceives and reports their own interpersonal behaviours (Rocchi et al., 2017). The PwD's perception of the physiotherapist's behaviour was documented using the IBQ, a validated questionnaire documenting how the interpersonal behaviour of a person in a supervising role (e.g., physiotherapist) is perceived by the recipient of an interaction or exercise program (e.g., a person living with a disability) (Rocchi et al., 2017).

Both questionnaires include 24 items documenting six sub-types of interpersonal behaviours: autonomy-supportive, autonomy-thwarting, competence-supportive, competence-thwarting, relatedness-supportive and relatedness-thwarting. For example, questions about autonomy ask whether the physiotherapist encourages decision-making (supportive) or limits choice (thwarting). Competence supportive or thwarting questions focus on feedback, encouragement and messages of incompetence. Lastly, relatedness supportive and thwarting behaviour questions address the physiotherapist's legitimate interest in the person and the lack of caring, respectively. Each subtype is measured on a Likert scale ranging from 1 (do not agree at all) to 7 (completely agree). Documenting both supportive and thwarting behaviours is essential because they are two independent constructs influencing motivation (Rocchi & Pelletier, 2018).

A research assistant facilitated the completion of the IBQ by the PwD ensuring that the physiotherapist remained blinded to the answers of each PwD. The IBQ was completed either in English or French[3] at three-time points: baseline (after the initial completion of program baseline measures), post-program 1 and post-program 2. The physiotherapist completed the English version of the IBQ-Self for each PwD at baseline and at the end of each exercise program. The physiotherapist's responses were recorded without the knowledge of the PwD perception.

Analysis

The initial analysis consisted of documenting perceived supportive and thwarting interpersonal behaviours of the physiotherapist as reported by the physiotherapist (IBQ-Self) and PwD (IBQ). The six subtypes were combined and averaged to provide a score for supportive behaviours and a score for thwarting behaviours. The level of congruence of the interpersonal behaviours of the physiotherapist as perceived by the physiotherapist and PwD is described by comparing the averages of behaviour subtypes for supportive and thwarting behaviours, separately. The qualitative description of alignment between the physiotherapist self-report and each PwD's

[3] Rocchi, M., & Pelletier, L.G. (2021) Validation de la version française du « Interpersonal Behaviour Questionnaire ». submitted manuscript, University of Ottawa.

perception at three-time points (baseline, post-program 1, post-program 2) is documented as either misaligned (i.e., overreported, underreported) or aligned (i.e., in agreement).

6.4 Results

The results will highlight i) the extent to which the physiotherapist was perceived to be needs-supportive versus needs-thwarting and how this changed over time, and ii) the extent of alignment between the PwD's perceptions of the physiotherapist interpersonal behaviours and the physiotherapist's self-report.

<u>Perceived supportive versus thwarting interpersonal behaviours and changes across time.</u>

All PwDs perceived the physiotherapist's interpersonal behaviours as being more needs-supportive than needs-thwarting at all time points (Figure 6.1). Similarly, the physiotherapist self-reported being more needs-supportive than needs-thwarting for each PwD.

Over time, the perceived supportive behaviours varied for PwD 1 and 2, stabilized at the highest score after baseline for PwD 3 and 5, and remained consistent at the highest supportive behaviour score throughout baseline and after the two programs for PwD 4.

The perception of the physiotherapist's thwarting interpersonal behaviours decreased overtime for PwD 1 and 2 and stayed consistent across time at the lowest score for PwD 3, 4 and 5. The physiotherapist self-reported becoming more needs-supportive overtime across all PwD, and less needs-thwarting overtime for four PwD (PwD 2, 3, 4, 5).

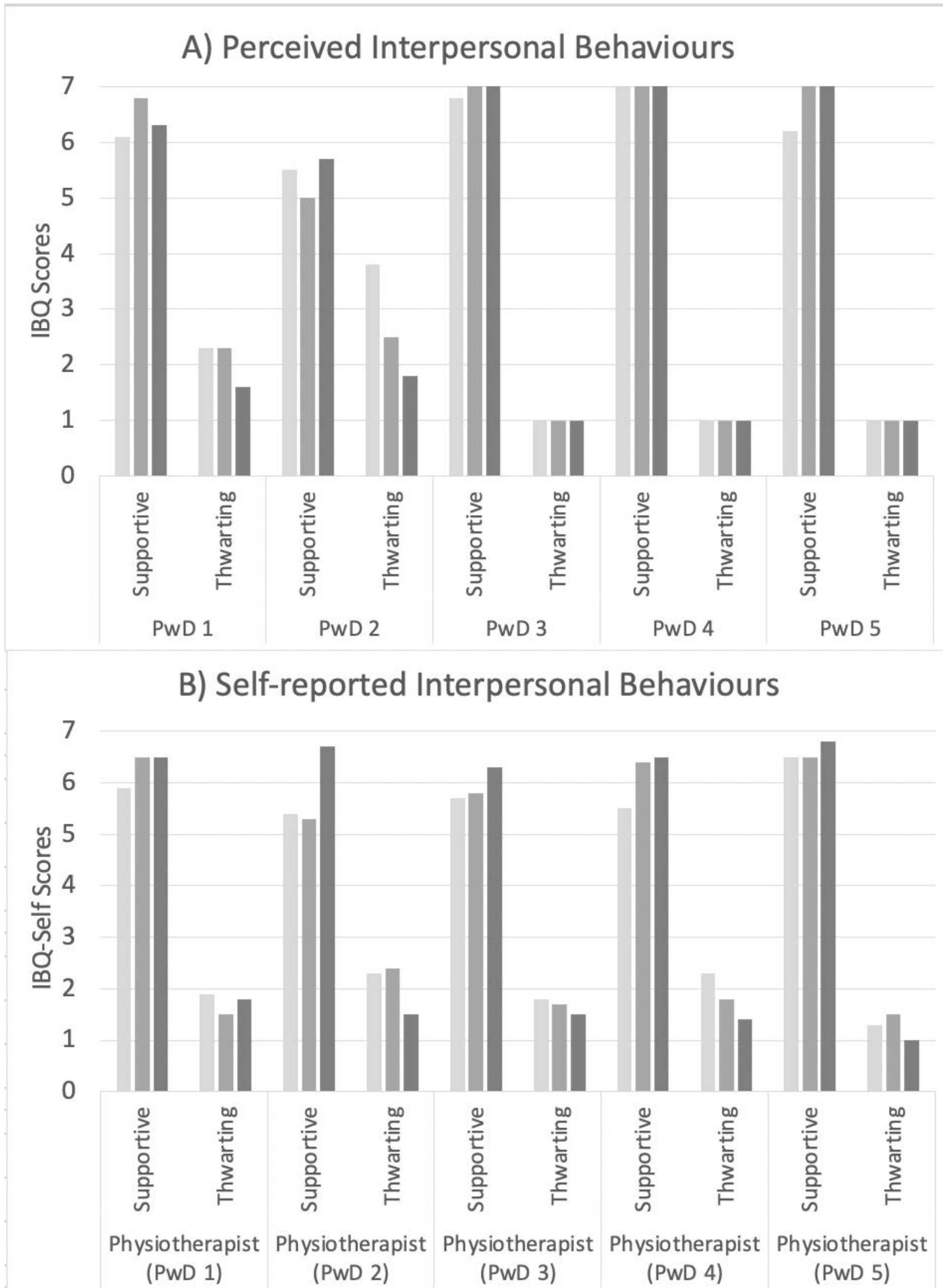
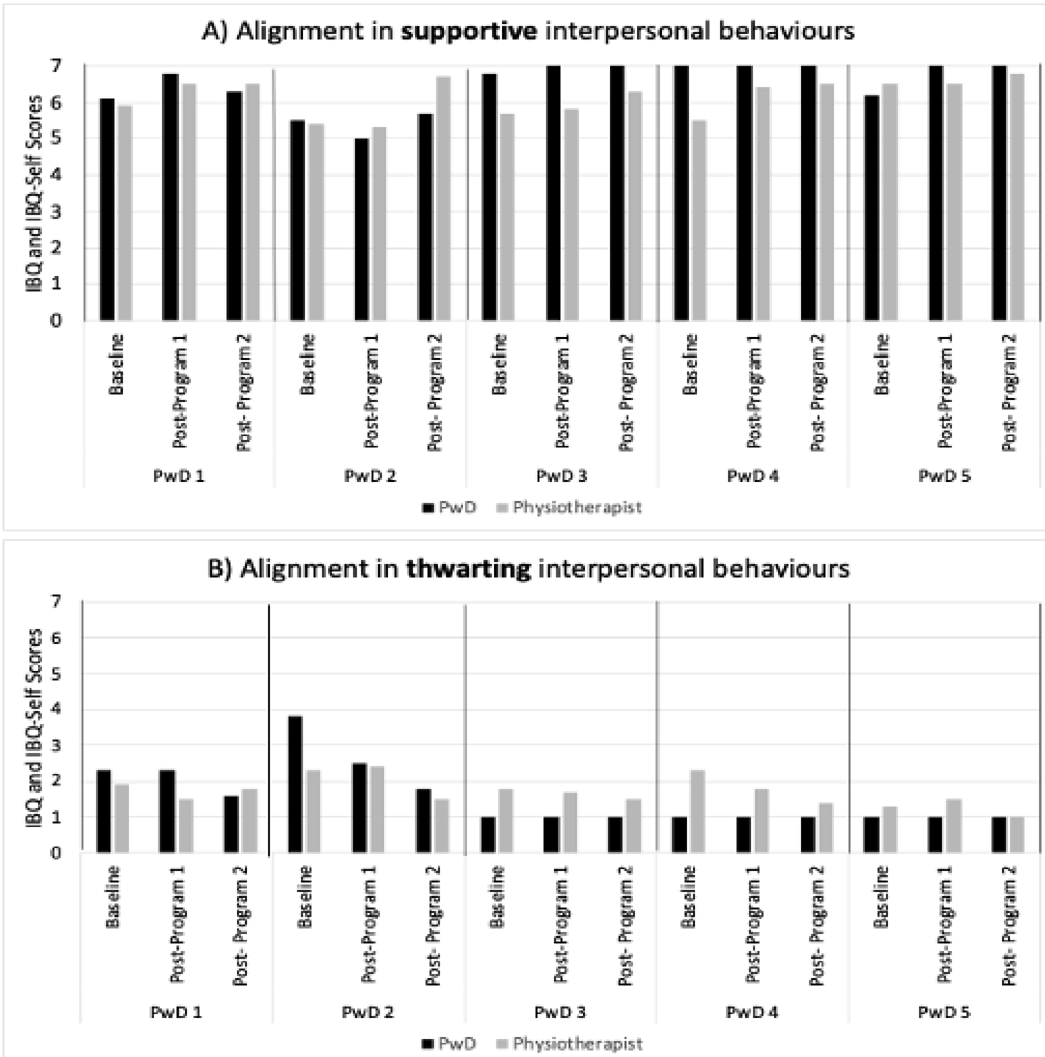


Figure 6.1 IBQ scores representing the PwD's perception of therapist supportive/thwarting interpersonal behaviours (Panel A: top) and IBQ-Self scores representing the physiotherapist self-reported supportive/thwarting interpersonal behaviours with PwD 1 through 5 (Panel B: bottom) at baseline (light grey), post-program 1 (medium grey) and post-program 2 (dark grey). Note: person with disability resulting from traumatic brain injury (PwD), Interpersonal Behavioural Questionnaire (IBQ), Interpersonal Behavioural Questionnaire-Self (IBQ-Self).

Alignment between perceived and self-reported supportive and thwarting behaviours

Over time, greater alignment occurred between the perceived and self-reported needs-supportive behaviours for four PwD (PwD 1, 3, 4, 5) and the physiotherapist (Figure 6.2). The perceived interpersonal behaviour reported by all PwD increasingly aligned with the physiotherapist's self-report of needs-thwarting behaviours.



C) Differences between scores on the IBQ -Self and IBQ for supportive and thwarting behaviours			
Supportive/Thwarting	**Baseline**	**Post-Program 1**	**Post-Program 2**
PwD 1	**-0.2 /-0.4**	**0.3** / -0.8	**0.2/0.2**
PwD 2	**-0.1** /-1.5	**0.3 /-0.1**	**1 /-0.3**
PwD 3	-1.1 /0.8	-1.2 /0.7	-0.7 **/0.5**
PwD 4	-1.5 /1.3	**-0.6** / 0.8	**-0.5 /0.4**
PwD 5	**0.3 /0.3**	**-0.5 /0.5**	**-0.2 /0**

Figure 6.2 Alignment between the PwD's perception and the physiotherapist's self-report at three points time for the supportive interpersonal behaviours (Panel A) and Thwarting interpersonal behaviours (Panel B) supported by a 10% difference between IBQ-Self and IBQ scores (Table C). Note: person with disability resulting from traumatic brain injury (PwD), Interpersonal Behavioural Questionnaire (IBQ), Interpersonal Behavioural Questionnaire-Self (IBQ-Self). The IBQ-Self scores were subtracted from the IBQ scores (physio-PwD). The bolded text indicates a difference of less than 10% of the total possible score of 7.

6.5 Discussion

In this study, valuable information on how the physiotherapist's interpersonal behaviours were self-reported and perceived by each person living with a moderate or severe TBI (PwD) in a physiotherapy context was documented using two validated questionnaires, the IBQ-Self and IBQ (Rocchi et al., 2017). Setting time aside from the exercise programs to complete the IBQ-Self or IBQ allowed the physiotherapist and each PwD to reflect on how needs-supportive and needs-thwarting interpersonal behaviours were conveyed and perceived.

Key behavioural strategies such as empathic listening, collaborative decision-making, understanding of a person's frame of reference, and goal setting can improve patient engagement in neurorehabilitation (Cameron et al., 2018; Kors et al., 2020; Medley & Powell, 2010). For these strategies to work optimally, behaviours must be perceived by a PwD as being needs-supportive within the therapeutic relationship. Documenting the alignment between a physiotherapist's self-report (IBQ-Self) and a PwD's perception (IBQ) would allow a physiotherapist to adjust their behaviours to support basic psychological needs. This is critical for the development of effective therapeutic relationships and the optimal use of behavioural strategies (Gillison et al., 2019; Markland & Tobin, 2004; Ryan & Deci, 2017).

As shown in the literature, the fulfillment of autonomy, competence and relatedness is even higher if the interpersonal behaviours reported by the provider aligns with what is perceived from a recipient (Camiré, Rathwell, Turgeon, & Kendellen, 2019; Fleenor et al., 2010; Rocchi & Pelletier, 2018; Rodrigues et al., 2020). A study of 53 coaches and 250 athletes by Rocchi & Pelletier (2018), documented that 30% of the coaches may be overly positive about their behaviours (Rocchi & Pelletier, 2018). Our results showed that the alignment between the physiotherapist's self-reported behaviours and the PwD's perception of these supportive behaviours were underreported by the physiotherapist across all relationships. Therefore, by not being overly positive about oneself, the physiotherapist showed more authentic behaviours.

Previous studies have also documented that "coaches" who underreport their supportive behaviours while "athletes" overreport their perception of the "coaches" supportive behaviours tend to have positive outcomes on the "athlete" engagement (Rocchi & Pelletier, 2018; Rodrigues et al., 2019). Findings from our feasibility[4] study showed that adherence to the program ranged between 87.5 and 100% and that active engagement was high by recording an average of 470 to 685 repetitions per session in the daily program and 364 to 683 repetitions per session in the weekly program. Our effectiveness[5] study demonstrated clinically significant improvement in physical activity level and clinical improvement in balance and mobility in four out of five PwD. Our current study posits that the supportive interpersonal behaviours underreported by the physiotherapist and perceived as highly supportive behaviours by the PwD led to this high adherence, active engagement, and effectiveness of the telerehabilitation exercise programs.

Low support for and thwarting of an individual's needs for autonomy, competence and relatedness is a reason for poor therapeutic engagement (Deci & Ryan, 2000; Ng et al., 2012; Pelletier et al., 2017; Rocchi, Pelletier, Cheung, et al., 2017; Ryan & Deci, 2017). Literature on the use of thwarting behaviour in sports report that athletes sometimes expect their coaches to use thwarting behaviours in situations including poor concentration or when a decision on their readiness to compete is required (Rocchi & Pelletier, 2018). This could be due to the nature of their sport or for safety reasons. The same might be true for physiotherapists and a PwD. The PwD

[4] O'Neil et al. (2021). Remotely Supervised Exercise Programs to Improve Balance, Mobility and Activity Among People with Moderate to Severe Traumatic Brain Injury: Description and Feasibility. Submitted to Physiotherapy Canada on March 25, 2021

[5] O'Neil et al. (2021). The Impact of two Telerehabilitation Supervision Schedules on Physical Activity, Mobility, and Balance Among People with a Moderate or Severe Traumatic Brain Injury: a mixed-method approach. Submitted to Physiotherapy Canada on March 25, 2021

in our study could have indeed expected the physiotherapist to be more controlling (thwarting) due to their brain injury severity, however, as demonstrated in our results this hypothesis was rejected. The PwD with aphasia and severe TBI perceived the physiotherapist's thwarting behaviours as being low throughout the telerehabilitation exercise programs. Perhaps the lower perception of thwarting behaviours could have resulted from the initial co-design of the exercise programs.

As presented earlier, supportive and thwarting interpersonal behaviours are two different constructs. There is some evidence showing that a provider using supportive behaviours toward the fulfillment of the three basic psychological needs, even when thwarting behaviours are expected to be higher or required, is important (Camiré, Rathwell, Turgeon, et al., 2019; M. S. Hall et al., 2020). In our study, each PwD was initially provided with options related to the exercise program. They were asked to choose between two to four exercises, and collaboratively to identify the optimal level of challenge for these exercises. Perhaps the initial PwD's perception of the physiotherapist's supportive behaviours towards the fulfillment of autonomy, competence and relatedness had an impact on the overall perceived interpersonal behaviours and the effectiveness of the telerehabilitation program. Even when a thwarting behaviour is required, for example for safety reasons, a physiotherapist can still be perceived as supportive.

The change in alignment over time between the physiotherapist self-report and the PwD's perception of the physiotherapist interpersonal behaviours was explored in this study and demonstrated that the self-report and the perception tended to get closer to alignment as the PwD and the physiotherapist became familiar. Previous studies have documented the alignment by calculating the differences between the average scores on the IBQ-Self and the average score of the IBQ and reporting the differences falling within a ±10% range (Fleenor et al., 2010; Rocchi & Pelletier, 2018; Rodrigues et al., 2020). Following this method, scores aligning in our study were documented to fall within that 10% range at the end of the second program. Time was emphasized as a key process to support motivation in people with diabetes (Fisher, Polonsky, Hessler, & Potter, 2017), to establish therapeutic connections with people with musculoskeletal impairments (Babatunde, MacDermid, & MacIntyre, 2017; Miciak, Mayan, Brown, Joyce, & Gross, 2019), and to craft therapeutic alliance in the physiotherapy profession (Brun-Cottan, McMillian, & Hastings, 2020). Therefore, time may be an essential component for the self-reported interpersonal behaviours of a physiotherapist and a PwD's perception of these behaviours to align.

Clinical implications

Based on the SDT literature, findings from this study have important clinical implications. First, physiotherapists should be aware of how each individual perceives supportive and thwarting behaviours. The use of the IBQ, a validated questionnaire documenting if a physiotherapist is being perceived as supportive or thwarting can provide the physiotherapists with key information around how their behaviours are being perceived (Rocchi, Pelletier, Cheung, et al., 2017). This information will bring the therapist to self-reflect on ways to change their behaviour, so they become more needs supportive and less needs thwarting during therapeutic exercise sessions. This supports the findings from a recent review on needs-supportive interventions revealing that one-on-one consultations and self-reflection can be effective approaches to support each individual (Slemp et al., 2021).

Physiotherapists who are underreporting supportive behaviours may be humble and more concerned with their patient's welfare. The association between humility and authenticity, and the perception of needs-supportive behaviours have been documented in different research areas. In the management field, the process of humble knowledge offering was documented to be a prerequisite for knowledge sharing (Anand, Walsh, & Moffett, 2019). In the psychology field, authenticity and transparency in the therapeutic approach were reported to support relatedness (Ryan & Deci, 2017). Using the IBQ-Self and the IBQ (Rocchi, Pelletier, Cheung, et al., 2017) as a self-reflection tool could document the presence of humility or authenticity within interpersonal behaviours. Since authenticity has been reported to improve the PwD's trust in a therapist (Morera-Balaguer et al., 2021), physiotherapists self-assessing how they support/thwart interpersonal behaviours using the IBQ-Self relative to how they are being perceived by a PwD may help improve the humility and authenticity to enhance the therapeutic relationship.

Findings from our study demonstrated that it was feasible to use the IBQ with most people living with a moderate or severe TBI to document how a physiotherapist's interpersonal behaviours were perceived. The use of interpersonal behaviour questionnaires with each PwD receiving physiotherapy services could help physiotherapists understand how interpersonal behaviours may differ across relationships. Providers should not assume their interpersonal behaviour always aligns with the receivers' perceptions (Lawford, Bennell, Campbell, Kasza, & Hinman, 2020; Rocchi & Pelletier, 2018). Results from our study showed that perceptions of interpersonal behaviours varied across relationships. One possible reason could be that the overall objective of the IBQ may have been cognitively challenging for some PwD who presented with aphasia, severe TBI and possibly awareness deficits. A deficit in self-awareness is common post-TBI (Bayley, Swaine, Lamontagne, Marshall, Allaire, Kua, Marier-Deschênes, 2016; Hurst, Ownsworth, Beadle, Shum, & Fleming, 2020; Nagele, Vo, Kolessar, Neaves, & Juengst, 2020) and could have influenced the ability of the PwD to perceive the therapist's supportive or thwarting behaviours. The assistance of a research assistant made it feasible to complete the IBQ but adapting interpersonal behaviour questionnaires to be more inclusive of individuals with severe TBI, aphasia, or self-awareness deficits is necessary.

Limitations

Previous studies on interpersonal behaviours and the use of the IBQ-Self and IBQ were completed with larger sample sizes (Rocchi & Pelletier, 2018; Rocchi, Pelletier, Cheung, et al., 2017; Rodrigues et al., 2020). The smaller sample size of this study limited the generalization of the findings, the use of statistical analysis including subtypes analysis, the average across participants and across all time points. It is important to note that all remote sessions were supervised by the same physiotherapist, a white female, lead investigator in the study with training in SDT. It is critical to be aware of this positionality, and how it could have influenced the way supportive or thwarting behaviours were reported by the physiotherapist.

6.6 Conclusion

The use of the IBQ-Self and IBQ was feasible in a telerehabilitation context and should be used in future clinical and research settings. The questionnaires provided an objective assessment of both physiotherapist and the PwD perception of the physiotherapist's supportive or thwarting behaviours. When tailoring telerehabilitation programs to each PwD, therapists should include needs supportive interpersonal behaviours to facilitate sustained behaviour change.

Equally important is how these behaviours are being perceived by a PwD. Allowing enough time to develop meaningful and supportive relationships can impact the effectiveness of exercise programs by facilitating a closer alignment between what is reported by a therapist and what is perceived by each PwD. Within each rehabilitation session, behaviours supporting the fulfillment of basic psychological needs of autonomy, competence and relatedness are critical to the PwD's motivation and therapeutic engagement.

Acknowledgments

The first author (JO) was supported by an Ontario Graduate Scholarship, an excellence scholarship from the University of Ottawa, and a Bruyère Research Institute Graduate Scholarship. Project support was provided through a Canadian Institute for Military and Veteran Health Research-True Patriot Love grant as well as a Spark grant from the Center for Aging and Brain Health Innovation. We would like to acknowledge the contribution to the study by Anne Taillon as well as the incredible collaboration of the PwD and family partners who participated in this project.

Disclosure The authors declare no conflict of interest.

Clinical recommendations

- Physiotherapists should ground their therapeutic approach using Self-Determination Theory (Ryan & Deci, 2000), and integrate tailored supportive interpersonal behaviours into the delivery of the telerehabilitation exercise programs.

- Physiotherapists should self-assess how they perceive their interpersonal behaviours with each PwD using the IBQ-Self (Rocchi, Pelletier, Cheung, et al., 2017) to improve their effectiveness with using behavioural strategies.

- Physiotherapists should assess how their interpersonal behaviours are being perceived by the PwD using the IBQ (Rocchi, Pelletier, Cheung, et al., 2017) to document how their behaviours are being perceived within telerehabilitation exercise programs.

- Physiotherapists should consider using both questionnaires to assess how their behaviours align with the PwD's perception to better tailor their own behaviours. This could lead to more authentic relationships, empowerment of PwD, and increase the effectiveness of exercise programs.

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Chapter 7. General Discussion and Conclusion

7.1 Findings Summary and Implications

The COVID-19 Pandemic has expanded the use of telemedicine in the healthcare system beyond traditional medical consultations in remote regions to everyday use (Bettger & Resnik, 2020; Froilan, 2020; Omboni, 2021). Rapid clinical uptake of telemedicine seen across the world has led to substantial changes in delivery modalities across various healthcare sectors. This quick pivot also expanded the adoption of telerehabilitation within the physiotherapy space (Lee, 2020; Middleton, Simpson, Bettger, & Bowden, 2020; Quinn, MacPherson, Long, & Shah, 2020; Signal, Martin, Leys, Maloney, & Bright, 2020). Telerehabilitation can help reach more people in need of rehabilitation services while allowing them to remain at home. Healthcare leaders, clinicians and PwD now see telerehabilitation as a viable delivery option to lower hospital expenses while still improving health outcomes (Jachak et al., 2020).

There are still many unanswered questions in the current literature on the use of telerehabilitation for people living with a moderate or severe TBI (O'Neil, van Ierssel, & Sveistrup, 2020; Ownsworth et al., 2020). With this shift towards digital practice in physiotherapy (Lee, 2020), it is necessary for clinicians, researchers, healthcare leaders, and people living with a disability (PwD) to understand how telerehabilitation can be successfully implemented and optimally adopted.

This dissertation contributes to the telerehabilitation field by 1) investigating the feasibility of using videoconferencing for remote supervision as well as using an activity tracking device for remote monitoring; 2) documenting the effectiveness of telerehabilitation exercise programs on various clinical outcomes including physical activity levels, functional mobility, dynamic balance, participation and satisfaction with life, and concerns with falling; 3) exploring the lived experience of people living with a TBI and their family partners when using telerehabilitation delivered in their home daily or weekly; and 4) applying the theoretical concepts of Self-Determination Theory to assess how interpersonal behaviours are self-reported by physiotherapists and perceived by PwD within a telerehabilitation setting. Findings from this doctoral thesis provide a road map to optimal implementation of telerehabilitation home-based exercise programs.

In this chapter, I will summarize the literature supporting the methodology used in this dissertation and explain how various components of the telerehabilitation programs led to the feasibility and effectiveness of both home-based telerehabilitation programs with this population. I will introduce a new method of inquiry allowing physiotherapists to identify how their interpersonal behaviours are perceived by the PwD and how their self-reported behaviours can support or frustrate basic psychological needs in a telerehabilitation context. I will also highlight implementation elements capable of optimizing telerehabilitation implementation in clinical practice, in the rehabilitation organizations and policies. Finally, I will present the influence of this doctoral thesis on future research.

Summary of Findings and Implications

Early in the pandemic, the Canadian Physiotherapy Association asked me to provide expert guidance around rapid telerehabilitation clinical implementation. In doing so, I cautioned:

> *"Speeding up the implementation of this new model of care and cutting corners due to urgency is not recommended. We must research, be diligent, and acquire the proper training and skills prior to launching such services. Overlooking these important steps could lead to poor quality of care, poor sustainability, increase fear of use from clients, and poor confidence from therapists overall, reducing the quality of physiotherapy in Canada"* (Canadian Physiotherapy Association, O'Neil., 2020).

In my opinion, this quote summarizes my passion and motivation for my dissertation research and highlights potential implications for the profession.

Feasibility, Effectiveness and Interpersonal behaviours

In chapter 2, a review of twenty-six articles is presented, revealing valuable information on the types of technology used for remote assessments and remote interventions, the frequency of remote assessments, and the frequency of remote delivery of interventions for individuals who experienced a moderate or severe TBI. From this review, I identified the preferred technologies used to remotely deliver interventions which included videoconferencing (Golberg, Haley, Jacks, & Goldberg, 2012; Huijgen et al., 2008; Kizony et al., 2015; McGrath, Dowds, & Goldstein, 2008; Tam et al., 2003; Tsaousides, D'Antonio, Varbanova, & Spielman, 2014; Warden et al., 2000), phone calls (Bell et al., 2011, 2005; Bombardier et al., 2009; Fann et al., 2015; Henry et al., 2012), digital recordings (Golberg et al., 2012), and emails (Jones et al., 2016; Tsaousides et al., 2014). Two new approaches were also discovered which are the use of virtual reality (Diamond et al., 2003; Kizony et al., 2015) and instant messaging (Bergquist et al., 2010; Bergquist, Gehl, Lepore, Holzworth, & Beaulieu, 2008; Bergquist et al., 2009). In this scoping review (Chapter 2), I documented the technologies used to conduct remote assessments and revealed that the use of videoconferencing or telephone calls was predominant (Guo & Togher, 2008; Hutson, Loughlin, Sullivan, Kelley, & Poole, 2009; Schopp, Johnstone, & Merveille, 2000; Theodoros, Hill, Russell, Ward, & Wootton, 2008; Theodoros et al., 2003; Turkstra, Quinn-Padron, Johnson M.S. Workinger, & Antoniotti, 2012). The assessments ranged between 15 and 30 minutes and were only repeated once or twice during a program. I also found that interventions were mostly focusing on cognitive deficits rather than motor deficits.

In Chapter 3, I detail the mixed-method alternating single-subject design used to fill some of the gaps found in Chapter 2. To my knowledge, the use of videoconferencing to remotely deliver high-intensity exercise programs targeting motor deficits and ongoing remote monitoring is novel and understudied for this population. Collecting quantitative and qualitative data allowed me to capture complex information from all perspectives painting a more realistic portrait of telerehabilitation implementation for this population (Creswell & Plano Clark, 2018).

In chapter 4, the use of videoconferencing to assess mobility and deliver intensive exercise programs was demonstrated to be feasible. Conducting physiotherapy assessment via telerehabilitation has been frequently described as a challenge for clinicians working with a population with neurological impairments (Block et al., 2016; Laver et al., 2020). Two key outcomes from this feasibility study related to remote assessment are worth sharing. Findings showed that it was feasible to repeatedly document daily physical activity using a Fitbit® attached to the ankle for the duration of 14 weeks. Following the initial COVID-19 breakout, I pivoted my data collection to an entirely remote format. Participants completed the Five-Time Sit to Stand test, the M2PI, FES-I, and IBQ/IBQ-Self questionnaires, and the Community Balance and Mobility Scale remotely allowing me to gather initial information on safety measures, education of family partners, and material requirements to conduct remote assessments. These findings provide initial information for the validation of remote clinical outcome measures.

High adherence to the home-based telerehabilitation exercise programs was also documented in the feasibility study. A recent systematic review on the adherence to home-based physiotherapy programs reported that non-adherence could reach up to 70% (Essery et al., 2017). My results show otherwise by documenting that all five dyads completed the two exercise programs with adherence ranging between 87.5% and 100%. Thus, it is possible to achieve high adherence in a remotely supervised exercise program with this population.

In Chapter 5, I demonstrated that intensive exercise programs delivered using videoconferencing were effective for clinically improving physical activity, dynamic balance and functional mobility in people living with a moderate or severe TBI. Current evidence shows that people living with chronic deficits years after a TBI have chronic balance issues (Habib Perez et al., 2020; McKechnie et al., 2016; Ponsford et al., 2014). Results from the effectiveness study reported that two PwD statistically significantly increased their physical activity levels, four PwD statistically significantly improved their functional mobility, and all PwD clinically improved their dynamic balance. My results suggest that with optimal telerehabilitation programs, people in the chronic phase of recovery from a severe TBI suffered between 3 and 12 years ago can still improve.

In chapter 6, results from my explorative study on interpersonal behaviours demonstrated that it was feasible to use two validated questionnaires, the IBQ and IBQ-Self (Rocchi, Pelletier, Cheung, et al., 2017) to assess how needs-supportive and needs-thwarting interpersonal behaviours are self-reported by the physiotherapist and perceived by the PwD. Adopting needs-supportive behaviours (e.g., autonomy-supportive, competence-supportive, relatedness-supportive) can support the PwD's autonomous motivation and lead to greater engagement in exercise programs (Bright, Kayes, Worrall, & McPherson, 2015; Murray et al., 2015; Ryan & Deci, 2000). Findings from my study documented the PwD perceiving the physiotherapist as being more supportive and less thwarting of basic psychological needs. This has interesting clinical implications for the implementation of telerehabilitation.

Implications for telerehabilitation

Current literature suggests that the aging population with residual deficits from a moderate or severe TBI is growing (Gardner et al., 2017; Liew et al., 2019). We also know that an increase in the risk of falls is associated with aging following a moderate or severe TBI (Klima et al., 2019). Remaining mindful of the small sample size of this Ph.D. research, my overall findings showed that telerehabilitation programs targeting balance and overall fitness are feasible and are effective at supporting motor function improvement and reducing concerns with falls. Clinical implementation of telerehabilitation programs in the community could reduce potential health deterioration associated with ageing following a moderate or severe TBI (Forslund et al., 2019) and decrease fall risks (Liew et al., 2019; Mckechnie et al., 2015).

Second, through this doctoral research, I also confirmed that it was possible to use remote assessments with this population. Clinicians should consider using activity tracking devices as an additional objective clinical measure to remotely assess physical activity and active engagement in a program. This discovery helped identify new gaps around the use of activity tracking devices for remote assessments and suggests new directions for future research projects.

Finally, I documented the importance for physiotherapists of conveying supportive interpersonal behaviours so that they are perceived by the PwD as they were intended to, meaning to support the fulfilment of autonomy, competence and relatedness. Ensuring that clinicians' interpersonal behaviours are perceived as supportive towards a PwD's needs would foster an increase in autonomous motivation (Gillison et al., 2019; Ryan & Deci, 2017) and lead to positive outcomes within a telerehabilitation exercise program.

Three key elements that led to the feasibility and effectiveness

Co-Design

Co-designing an exercise program can facilitate adherence, engagement and motivation by ensuring that programs are individualized and tailored to each PwD (Da Silva Júnior et al., 2021; Moore, Flynn, & Price, 2021; Wentink et al., 2019). Findings from my doctoral research demonstrated the importance of collaborative partnerships and supported the use of co-designs in the development of physiotherapy exercise programs (Olafsdottir et al., 2020; Revenäs et al., 2015). The collaboration between the physiotherapist and each dyad for choosing the exercises to include in their program was an essential element contributing to the success of this home-based intensive telerehabilitation exercise program

The education around technology use and user-friendly platforms were also reported to be essential in facilitating the implementation of new technologies with the aging population, people with pulmonary conditions and people post-stroke (Bonnevie et al., 2019; Corriveau, Tousignant, Gosselin, & Boissy, 2013; Sixsmith & Gutman, 2013). In this dissertation, the co-design process started with a pre-exercise education session for both the PwD and their family partner. Within this session, we established a daily schedule, and I provided education around the safety of the home environment and the technology use. Dyads reported feeling more comfortable with the technology as a result of this session.

Having a choice in the daily schedule to complete the home-based exercise program can also impact adherence. A study examining various factors associated with medication adherence in people with osteoarthritis reported that setting a daily schedule could impact adherence (Laba, Brien, Fransen, & Jan, 2013). Dyads in our study spoke on the importance of finding the appropriate time to complete their exercises. The individuals living with a moderate or severe TBI also reported preferring the daily remote supervision from the physiotherapist while the family partners suggested trying two to three times per week instead of the weekly schedule.

Practical implications for clinicians

Results from my doctoral research showed that the collaboration in the design of the exercise program, the provision of education and trialing of the videoconferencing to receive physiotherapy and the activity tracking device to monitor daily physical activity, can be perceived as supportive of competence needs by the PwD. Going one step further, spending time on education around the use of technology can support autonomy and ultimately engagement in therapy. The lived experiences illustrated the importance of asking the family members their scheduling preferences when designing a telerehabilitation program. Perhaps clinicians should spend more time on education and asking about optimal scheduling when co-designing an exercise program to facilitate active engagement from both the PwD and their family partners.

Intensity of practice

This doctoral thesis provides further support for the documented influence of high-intensity practice and motor learning on the effectiveness of an exercise program (Crozier et al., 2018; Hornby et al., 2020; Levin & Demers, 2020). Providing evidence-based programs by achieving a dose high enough for an exercise program to be effective is crucial (Crozier et al., 2018; Moore et al., 2020). This is also true for people living with motor deficits following a moderate or severe TBI (Hoffman et al., 2010; Ko, Beurskens, Snoep, Scherder, & Oosterlaan, 2018). Findings from my dissertation confirmed that it is possible to reach high-intensity practice in a telerehabilitation setting while remaining safe. To my knowledge, targeting the intensity of exercise as a telerehabilitation implementation element was novel for this population living with chronic motor deficits. Results from my dissertation reported that it was feasible to complete an average of 575 task repetitions and an average of 958 steps per session in the daily remotely supervised program, and 495 task repetitions and an average of 788 steps per session in the weekly remotely supervised program. These numbers fall well within the current known minimal average of 300 repetitions required for neuroplasticity in the upper extremity (Birkenmeier et al., 2010). They also enabled PwD to surpass the previously documented average of 5834 steps per day for people living with a severe TBI (Williams & Schache, 2010).

Practical implications for clinical managers and policymakers

The findings of this dissertation have two implications for targeting the concept of exercise intensity for practice leaders and clinical managers who are developing telerehabilitation programs for people living with a moderate or severe TBI.

The Ontario Neurotrauma Foundation (ONF) Clinical Practical Guideline recommends monitoring the intensity of services as part of quality improvement (Bayley, Swaine, Lamontagne, Marshall, Allaire, Kua, Marier-Deschênes, 2016; INESS-ONF, 2016). Currently, rehabilitation intensity is defined as "the amount of time the patient spends in individual, goal-directed rehabilitation therapy, focused on physical, functional, cognitive, perceptual, communicative and social goals to maximize the patient's recovery, over a seven day/week period" (CorHealth Ontario, 2017). Findings from my feasibility study showed that when using time as a measure of intensity, the PwD were only active for half of the duration of each supervised session. Therefore, rehabilitation managers and policymakers should use different intensity metrics such as the active time of a session and the number of repetitions during that same session to track the intensity of their telerehabilitation sessions.

As the number of physiotherapist visits was reported to be a high cost for the healthcare system (Burgess, Hall, Bishop, Lewis, & Hill, 2020). Studies investigating the cost of telerehabilitation reported that telerehabilitation was cheaper than in-person visits when the home was further than 30 km following knee replacement surgery (Tousignant et al., 2015) and that teletherapy saved money and improved the time efficiency during rehabilitation for people with burn wounds (Liu et al., 2017). As reported in Chapter 1, there is limited literature on the optimal number of physiotherapy visits. One study recommends a range between 3 and 18 supervised in-person sessions for rehabilitation to be effective (Lieberz et al., 2020). The total number of remotely supervised sessions required to improve clinical outcomes while considering the "optimal" number of supervised sessions to reduce healthcare costs is necessary but still unknown. The frequency of supervision documented in my doctoral thesis showed that intensity of practice was higher in the daily remotely supervised program than in the weekly remotely supervised exercise program. However, in the weekly supervised program, the number of repetitions was still within the targeted range for neuroplasticity (300-800 repetitions) suggesting that four remotely supervised visits per month may be sufficient to maintain a high exercise intensity supporting positive changes in motor deficits.

Engagement and Adherence

This doctoral thesis also introduces a novel concept of documenting how interpersonal behaviours are reported and perceived as supportive or thwarting towards the basic psychological needs in an exercise context (Rocchi & Pelletier, 2018; Rodrigues et al., 2020) (Chapter 6). Considering how to facilitate adherence to, and engagement in, an intervention is crucial to its effectiveness (Ryan & Deci, 2017). The PwD's perception of high needs-supportive behaviours documented in Chapter 6 contributed to the remarkable adherence, high activity engagement, and overall satisfaction with the telerehabilitation program.

Practical implications for clinicians, organizations and policymakers.

Documenting how supportive and thwarting behaviours are perceived is innovative in rehabilitation, and even more so in a telerehabilitation space. While thwarting behaviours could be frustrating towards the PwD's basic psychological needs and cause distress and passive engagement, supportive behaviours could facilitate engagement and autonomy (Ryan & Deci, 2000, 2017). A recent study on the self-management of chronic health conditions and digital health documented that needs-satisfaction and needs-frustration vary from one individual to another (Wannheden, Stenfors, Stenling, & von Thiele Schwarz, 2021). Addressing how PwD's needs are being supported or frustrated as clinicians or rehabilitation managers could contribute to the effectiveness of high-intensity home-based telerehabilitation exercise programs. As explained by SDT, an increase in awareness from the therapist will lead to behaviour choices that are more supportive (Pelletier, Guertin, & Rocchi, 2017; Ryan & Deci, 2017). Knowledge of how interpersonal behaviours are self-reported by clinicians and perceived by PwD can influence how a physiotherapist will behave with each PwD, thus, influencing the effectiveness of rehabilitation programs. As policymakers, adding the assessment of interpersonal behaviours to program quality evaluations could lead to an improvement in program effectiveness. This is essential to the quality of care and optimal implementation and adoption of telerehabilitation.

7.2 A road map to the optimal implementation

Physiotherapists strive to improve the overall function of people living with a disability by developing and implementing effective therapeutic interventions using exercise, education, and health promotion strategies to name a few (Canadian Physiotherapy Association, 2012). This doctoral work provides insight on key elements to optimize telerehabilitation programs capable of influencing clinical practice, impact the rehabilitation industry, and inform future research and policymakers.

Optimizing implementation at the clinical practice level

Supporting relatedness with the environment and social contexts

A home-based environment coupled with social support from a physiotherapist and a family partner can positively influence clinical implementation and the effectiveness of a program. Research shows that delivering therapy in a familiar environment might enhance the provision of people-centered care (Dorsey, Okun, & Bloem, 2020) and when included in a telehealth context, the home environment can increase confidence and provide a relaxing space for therapy (Keenan, Rahman, & Hudson, 2021). Findings from my feasibility study demonstrated that the home-based environment was more convenient and easier to manage within the daily schedule of the family partner. It also removed various challenges linked to travelling to a clinic including the cost of travel, travel time and most importantly fatigue.

Social contexts such as family support and attachment can positively influence social participation (Wong et al., 2017), satisfaction with life (Gause et al., 2017) and autonomy (Kors et al., 2020). Understanding how social support is perceived by each PwD is crucial in fulfilling the basic psychological needs of autonomy, competence and relatedness. A recent study by Gause et al. (2017) concluded that understanding how social support is perceived in veterans after a TBI can impact satisfaction with life (Gause et al., 2017). As a physiotherapist, supportive behaviours that foster an emotional connection with each PwD and their family partners can lead to the fulfillment of relatedness needs. This is important in a telerehabilitation setting because it can lead to greater engagement in therapy. Taking time to understand the background, journey, goals, aspirations and needs of each PwD resulted in effective telerehabilitation exercise programs.

Supporting competence with education

Age, technology access and severity of injury are linked to low-digital literacy (Neter & Brainin, 2012). Findings from my doctoral research showed that supporting digital literacy through education allowed for a positive experience around the use of technology throughout the home-based telerehabilitation exercise program. This supports findings from previous research reporting that educational sessions can improve the use and acceptance of technology and reduce potential health inequities linked to digital competency (Jansen-Kosterink, Dekker-van Weering, & van Velsen, 2019; Neter & Brainin, 2012). In our protocol, each dyad had the opportunity to trial the videoconferencing system and synchronize the activity tracking device before the exercise program started. This supported each PwD's and their family partner's competence needs by providing training around the use of the two technologies (i.e., videoconferencing system and the activity tracking device). This session may have provided the therapist with an opportunity to use interpersonal behaviours supportive towards competence needs and potentially enhanced therapeutic alliance before starting the telerehabilitation exercise programs. Telerehabilitation being a hands-off physiotherapy service has often been accused by healthcare providers of creating a distance between the “patient” and the “therapist" making the therapeutic connection more challenging to establish (Eccleston et al., 2020; Jansen-Kosterink et al., 2019; Malliaras et al., 2021). Time spent with the PwD and their family partners outside of the therapeutic context, providing education on technology use and safety was essential in forging a therapeutic relationship leading to effective telerehabilitation programs.

Supporting autonomy with informative feedback

Informative feedback is one way to support the PwD in becoming an active agent in their rehabilitation care and facilitate a shift towards autonomous motivation. In my doctoral research, two types of supportive verbal feedback were provided during each remotely supervised session. First, the physiotherapist used motivational feedback by saying: “Well done!”, “Keep going!”, “Great work today!”. Motivational feedback can satisfy competence needs while also being needs-frustrating if delivered negatively (Ryan & Deci, 2017).

Second, the physiotherapist also provided verbal informative feedback such as: “Keep your back straight”, “Look up”, “Get your knees higher”. Literature has also demonstrated that sensor-based devices can be used to deliver feedback (Dobkin, 2017; Leanne Hassett et al., 2020; Tokucoglu, 2018). In my doctoral research, the activity tracking device was designed to remotely capture information on daily physical activity, however, the activity tracking device quickly became a source of informative feedback for the dyads. When using the activity tracking device, the PwD involved in my research reported “feeling motivated”, “enjoyed the Fitbit®”, and “getting competitive with one-self”. The device provided them with daily step counts and helped them self-monitor their daily physical activity.

Feedback can support competence and provide the right amount of challenge to support autonomy, but it must be provided in an informative and non-controlling way (Ryan & Deci, 2017). A study documenting how different types of feedback were perceived by people who suffered a stroke reported that motivational feedback was often provided more frequently (every 45 seconds) than informative feedback (every 3 minutes) (Stanton, Ada, Dean, & Preston, 2015). It is possible that having two sources of informative feedback in this doctoral research increased the frequency of informative feedback provided to each PwD and further supported the competence needs of each PwD leading to autonomy need satisfaction.

Thwarting or needs-frustrating behaviours

Strict safety guidelines were provided to each PwD to ensure safety during the program. These guidelines might have been perceived as controlling or thwarting behaviours leading to needs frustration. However, dyads reported feeling very safe with the remotely supervised exercise program and did not perceive the physiotherapist as thwarting. It is possible that this overall feeling resulted from the pre-exercise session educating dyads about the use of telerehabilitation or the ongoing informative feedback provided by physiotherapists. As a physiotherapist, it is important to know that behaviours that are sometimes perceived as thwarting, such as providing strict safety guidelines, can still be done in a way to support the fulfillment of a PwD's autonomy. Since supportive and thwarting behaviours are two independent constructs, thwarting behaviours could still be explained in a way to support the fulfilment of a PwD's autonomy (Camiré, Rathwell, Turgeon, et al., 2019; Rocchi, Pelletier, Cheung, et al., 2017; Ryan & Deci, 2017). Acknowledging the reasons behind specific needs-frustrating behaviours by using supportive behaviours could optimize the effectiveness of telerehabilitation programs.

Optimizing implementation at the organizational and policy level

Building the Infrastructure

In addition to their respective professional competencies, healthcare providers should acquire the proper knowledge and digital skills to use telerehabilitation modalities (WCPT/INPTRA, 2019). The therapist's ability to troubleshoot is necessary to support the use of telerehabilitation with a PwD. A study on the use of telemedicine and physicians' satisfaction documented that the physicians' perceived ease of use can also significantly impact the perceived usefulness of telemedicine (Kissi, Dai, Dogbe, Banahene, & Ernest, 2020). Results from our study demonstrated that each PwD's and family partner's education around the use of technology led to the dyads reporting high satisfaction and high usability of the technology. In my doctoral research, the physiotherapist providing the intervention (JO) gained experience by piloting many systems and trialing remote delivery on multiple occasions in multiple settings, allowing the physiotherapist to feel comfortable with the technology and perceive telerehabilitation as an “easy” tool to use. This suggests that before implementing telerehabilitation programs, rehabilitation managers and providers must feel competent and have the necessary skills to use technology to deliver their respective rehabilitation services. This will increase their satisfaction with the remote of delivery and provide them with the necessary skills to support the PwD with their use of the technology.

Verifying the rehabilitation providers’ knowledge around the evidence and effectiveness of telerehabilitation is also important. Without in-depth knowledge of the evidence behind telerehabilitation, the use of telerehabilitation can be compromised with the neurological population (Signal et al., 2020). Surprising results from the effectiveness study documented that some PwD with more severe TBI diagnosis at baseline, actually benefited significantly from the telerehabilitation exercise programs. Establishing inclusion criteria based on the PwD’s ability and acceptance to use technology rather than on their diagnosis could improve access to telerehabilitation services. The knowledge of current telerehabilitation evidence and education of rehabilitation providers is not only essential for the optimal use of telerehabilitation but also required to determine its suitability for each PwD.

Advocating for new policies around technology access

Access to technology is another crucial element to consider. Although poor connectivity did not impede patient engagement and satisfaction, internet connectivity issues were reported by the dyads involved in this Ph.D. thesis. The resources required to access telerehabilitation services must not be overlooked and should be considered determinants of health capable of influencing an individual's well-being (McAuley, 2014). Access to community technology and platforms were highlighted as key priorities in the development of a telemedicine program (Ochtli & Gibran, 2019; Wang, Zdaniuk, Durocher, & Wilson, 2020). As described in Chapter 3, a technology lending protocol was planned in cases where participants did not have the required technology to participate in the program. Considering technology loaning programs and internet provision as an integral component of the telerehabilitation infrastructure is necessary. Access to assistive technology has been frequently reported as contributing to inequity gaps within Canada (McAuley, 2014; Wang et al., 2020). In 2017, the Canadian Radio-television and Telecommunications Commission reported that only 37% of Canadians living in rural areas compared to 97% of the urban homes have access to the internet. Furthermore, this access is worse in indigenous communities with only 24% having access to the internet (Innovation, 2019). An overarching objective of my doctoral thesis was to increase access to rehabilitation care using remote delivery via high-speed internet. Due to the time-sensitivity of Ph.D. project, one inclusion criterion was to have high-speed internet in the home. This means that people with a TBI living in rural areas without internet were potentially excluded from participating in this doctoral research. High-speed internet should no longer be seen as a luxury when it is being used to deliver publicly funded healthcare. Findings from my dissertation further support the importance of accessing internet connectivity in rural areas, as a lack of access could exclude a large number of individuals in future research programs, could contribute to low recruitment rates, and increase health inequities.

To summarize, when integrating telerehabilitation within the health system, leaders within the rehabilitation industry must consider:

⇒ Building telerehabilitation infrastructures that includes training for providers, knowledge of the evidence behind the technology and, technology accessibility.

⇒ The use of the number of repetitions per session as an intensity parameter for the exercises.

⇒ The alignment between how interpersonal behaviours are being self-reported by the therapist and perceived by PwD.

⇒ Advocating for funded telerehabilitation excises programs as well as access to the required technology, including high-speed internet. This is necessary to facilitate aging at home after experiencing a moderate or severe TBI.

7.3 Future Research Directions

The limitations of my doctoral research suggest directions for future inquiry. First, given the small sample size of this dissertation, investigating the implementation of telerehabilitation programs on a larger scale should be undertaken. However, it is important to note that substantial recruitment challenges were experienced for this doctoral thesis, and this could limit the use of gold standard designs such as randomized controlled trials. Alternatively, implementing the proposed program using multi-site, multiple alternating single-subject designs would allow investigators to draw generalisable conclusions using meta-analysis of single-subject design (Logan et al., 2008). Evaluating the implementation of a similar program at the meso and macro level using mixed-method people-centered design would inform policies and address cost-efficiency literature gaps.

Considerations around outcome measures were also highlighted. The need to develop questionnaires that are inclusive and based on a people-centered approach was brought forward in Chapters 5 and 6. In Chapter 5, the PwD and their family partners voiced an improvement in participation during the semi-structured interviews but scores on the M2PI questionnaire (Malec, 2004) did not objectively document this. This misalignment between what is reported subjectively by the dyad and what is documented objectively on a questionnaire suggests that participation measures must better reflect the lived experience of the dyad.

The initial feasibility of using the IBQ-Self and IBQ (Rocchi, Pelletier, & Desmarais, 2017) was demonstrated in this thesis and showed that adapting the questionnaire facilitating the completion of the IBQ for people with aphasia must be considered. Validating these two questionnaires for people living with a moderate or severe TBI could solidify their use in all rehabilitation settings.

Next, the development and validation of remote outcome measures is time-sensitive due to the rapid clinical uptake of telerehabilitation (Bettger & Resnik, 2020; Lee, 2020). When my in-person data collection rapidly pivoted to remote data collection due to COVID-19, I became aware of a lack of research on remote outcome measures. Specifically, balance and mobility outcome measures should be validated for their use in a remote setting. This could be undertaken by documenting the validity and the inter/intra-rater reliability between the outcome measures completed in-person compared to the outcome measured completed remotely. This would further telerehabilitation research and would support evidence-based practice for clinicians.

Gaps in knowledge around health equity and telerehabilitation were also identified through completing this dissertation. As described in the protocol (chapter 3), tablets and activity tracking devices were made available in cases where the dyads needed them to participate in the study. The assumptions were that most dyads would have the necessary technology at home, but a contingency plan was put in place to mitigate this assumption. The contingency plan was indeed useful since two out of five dyads were provided with a tablet to complete the study. The initial assumption that everyone has the necessary equipment to receive physiotherapy using videoconferencing turned out to be false. The lack of equipment is only one example of how a person could be excluded from research on telerehabilitation. Other examples include access to the internet, knowledge around the use of technology, recruitment strategies, and language. Marginalized individuals such as those with poor socioeconomic status, recent refugees, new immigrants, indigenous people, and people who are homeless may be excluded from research because such inclusion and access needs are not addressed within the study protocol. As research on telerehabilitation supports the development and implementation of telerehabilitation services, it is important to carry out research that is consciously geared towards reducing health inequities.

Further identified research gaps are the lack of knowledge translation tools including clinical practice guidelines specific to people with severe motor and cognitive deficits; the evaluation of telerehabilitation implementation; the investigation of optimal telerehabilitation dosage; and studies around the cost-effectiveness of telerehabilitation programs.

7.4 Conclusion

My contribution to the telerehabilitation literature focused on advancing knowledge on the implementation of telerehabilitation exercise programs targeting balance and mobility for people living with a moderate or severe TBI. I identified the feasibility and effectiveness of two high-intensity home-based telerehabilitation exercise programs on physical activity, functional mobility and balance. Furthermore, I investigated the differences in remote physiotherapy supervision schedules and provided preliminary information around the optimal supervision frequency. I found no differences between the daily and the weekly remotely supervised schedule. I introduced a novel concept of assessing needs-supportive and needs-thwarting interpersonal behaviours. The alignment between how supportive or thwarting interpersonal behaviours perceived by the PwD and how these same behaviours are self-reported by the physiotherapist was demonstrated. This is another implementation element capable of influencing the feasibility and effectiveness of a telerehabilitation program.

Finally, I exposed new considerations for the clinical implementation of telerehabilitation. These include the impact of co-designing telerehabilitation exercise and the importance of practice intensity. Rehabilitation clinicians should design their telerehabilitation programs from a people-centered approach in partnerships with the PwD and their social support while being aware of how their supportive and thwarting interpersonal behaviours can support the fulfilment of autonomy, competence, and relatedness. Innovative ways such as the use of activity tracking devices to increase the amount of informative feedback provided to the PwD were introduced and found that their use was greatly enjoyed by each PwD and their family partners. I highlighted elements optimizing organizational implementation including the infrastructure, access to technology and knowledge transfer around telerehabilitation efficacy. This showed that education focusing on digital literacy, provider knowledge, therapeutic alliance, and safety impacts optimal telerehabilitation adoption. Integrating these telerehabilitation concepts within the rehabilitation models of care significantly impacts long-lasting positive health outcomes for individuals living with chronic deficits following a moderate or severe traumatic brain injury.

References for introduction (Chapter 1) and discussion (Chapter 7)

Chapter 1

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Appendix

