Mobile Tablet-Based Stroke Rehabilitation in the Acute Care Setting

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Abstract

Introduction: The number of stroke survivors living with post-stroke deficits is increasing worldwide. Although stroke rehabilitation can improve these deficits and promote the recovery of function when initiated early post-stroke, many survivors are not able to access rehabilitation because of a lack of resources. Early mobile tablet-based stroke rehabilitation may be a feasible means of improving access to recovery promoting therapies.

Objective: To summarize and advance the knowledge of early mobile tablet-based therapies (MTBTs) for stroke survivors with regards to feasibility and barriers to care.

Methods: This thesis is comprised of two major studies. (1) A scoping review summarizing the literature for MTBTs following stroke. (2) A cohort study testing the feasibility of a MTBT for post-stroke communication, cognitive, and fine-motor deficits.

Results: (1) Twenty-three studies of MTBTs following stroke were identified. Most of these therapies targeted communication or fine-motor deficits, and involved patients in the chronic stages of stroke. Barriers to care were summarized. (2) A 48% recruitment rate was achieved and therapy was administered a median of four days post-stroke. However, therapy adherence was very low because of frequently encountered barriers to care.

Conclusions: Stroke survivors are interested in using tablet technology to assist with their post-stroke recovery. However, early MTBT post-stroke may be challenging for some survivors because of encountered barriers to care. Regular patient-therapist communication using a convenient method of interaction appears necessary to minimize barriers and to help patients overcome barriers when they occur.

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Chapter 1. An Introduction to Stroke Rehabilitation

The Growing Burden of Stroke

Trends in Stroke and Stroke Survival

The 2010 Global Burden of Disease Study indicated an important trend in stroke epidemiology based on 119 studies; individuals are increasingly suffering from and surviving strokes. Between 1990 and 2010, mortality rates decreased in high, middle and low income countries, while the absolute number of individuals suffering their first stroke (16.9 million) and stroke survivors (33 million) increased by 68% and 84% respectively.[1] The burden of disability as measured by disability-adjusted life-years lost, also increased by 12%, reaching 102 million. Notably, the greatest increase in survival (113%) and daily-adjusted life-years lost (31%) occurred among individuals aged 75 or older. The authors concluded that if the observed global trends continue, by 2030 there would be 70 million stroke survivors and 200 million daily-adjusted life-years lost. This same trend appears in Canada where the percentage of admitted stroke patients dying in hospital has dropped since 2003 to 17% in 2013,[2] and the number of individuals experiencing their first stroke has continued to increase (by 31% or 95,000 strokes) between 2001 and 2013, despite the near stable prevalence of stroke, due to population growth and ageing.[3] Additionally, it is estimated 62,000 Canadians each year suffer a stroke (approximately one stroke every nine minutes)[2] and that there are currently 405,000 survivors in Canada living with the effects of stroke.[3] It has been predicted that this number will increase to between 654,000 – 726,000 by 2038.

Post-Stroke Consequences and Functional Independence

As the absolute number of strokes and stroke survivors continues to increase, it follows the number of individuals experiencing lasting post-stroke disabilities or complications will also increase. Strokes can occur in different areas of the brain and thus its affect on survivors depends on which tissue is damaged from lack of blood flow. Among survivors, approximately one-third experience

communication deficits (aphasia),[4] up to two-thirds experience some other form of vascular cognitive impairment (executive function, memory, visual neglect),[5] one-third suffer from post-stroke depression (PSD),[6] 69% experience upper-limb paralysis,[7] and 63% are initially unable to walk.[8] These impairments can significantly impact stroke survivors' ability to perform routine tasks common to independent life, also known as activities of daily living, such as cleaning and feeding themselves. Therefore, they are said to impact the survivor's ability to function independently or limit their functional independence. The impact may be so severe that survivors can no longer live independently and require institutionalization or some other form of continuous care.

Stroke Rehabilitation

What is Stroke Rehabilitation?

Stroke recovery is often classified into three phases based on time post-stroke; the acute phase (<1 month), the sub-acute phase (1-6 months), and the chronic phase (>6 months).[9] The conditions appearing post-stroke are not necessarily permanent and can improve spontaneously during the acute and sub-acute phases with the most recovery being seen within the first 3 months post-stroke.[10] However, many patients do not experience a complete spontaneous recovery from their deficits and a growing number of survivors are not achieving their pre-stroke level of function.[1-3] Comprehensive specialized stroke rehabilitation attempts to maximize recovery of functional abilities through recurrent stroke prevention and individualized, multi-disciplinary therapeutic exercises to improve stroke-induced impairments.[11] The type, difficulty and intensity of therapy is tailored to each patient and depends on the type of deficits present and their severity. Stroke rehabilitation may be managed by an individual healthcare professional or a team consisting of a speech-language pathologist, occupational therapist, physiotherapist, physiatrist, and psychiatrist as necessary. Therapy may be delivered in various settings including while in hospital after receiving acute care (initial stroke care and management), after transfer

to an inpatient rehabilitation, or in an outpatient setting (another hospital/clinic/home.) after initial acute care or inpatient care has ended.

Evidence Supporting Stroke Rehabilitation

The Evidence-Based Review of Stoke Rehabilitation has compiled strong evidence in favor of the effectiveness of stroke rehabilitation in improving functional independence based on multiple randomized controlled trials. The included randomized controlled trials compared specialized, multidisciplinary stroke care and/or rehabilitation to alternate care often consisting of treatment on a general medical ward. Results from the meta-analysis indicated that combined acute/rehabilitation units were associated with reduced odds of combined death/dependency (OR = 0.56, 95%CI = 0.44, 0.71) and need for institutionalization (OR = 0.55, 95%CI = 0.38, 0.80).[12] Taken together, the authors concluded that these results suggested that combined stroke units were associated with improvements in functional independence. A significant reduction in the odds of combined death/dependency was also observed for subacute rehabilitation (defined in this case as therapy occurring in a facility separate from acute care: stroke rehabilitation/stroke unit or inpatient rehabilitation) compared to alternate care (OR = 0.63, 95%CI = 0.43, 0.83) although only a trend towards the reduction of need for institutionalization was observed.

The Importance of Early Initiation and Intensity

Stroke rehabilitation has been found to be most beneficial when initiated early post-stroke. Two reviews of the stroke rehabilitation literature have concluded that earlier initiation of therapy is associated with greater improvements in functional ability.[13,14] Ottenbacher and Jannell (1993) found an inverse correlation between effect sizes (173 in total) and time of rehabilitation initiation ($r = -.32$, $p < .05$).[13] The effect sizes included measures of activities of daily living, specific deficits, and length of hospital stay and were collected from 36 clinical trials. A later review further supported this trend reporting that rehabilitation begun between three and 30 days post-stroke was strongly associated with

improved functional outcomes compared to later initiations.[14] However, the ideal window for initiating rehabilitation has still not been identified with a trial of very early mobilization post-stroke (within 24 hours of onset) showing fewer favorable outcome compared to usual care (adj. OR = 0.73, 95%CI = 0.59, 0.90).[15] There is also a dose-response relationship between rehabilitation and functional recovery with greater improvements being seen at higher intensity levels.[10] This trend is true for various therapies, including physiotherapy,[16,17] occupational therapy,[17,18] and speech-language therapy,[17,19] although as recovery continues, there is a pattern of diminishing returns.[10]

Stroke Rehabilitation for Chronic Stroke

Until recently, common beliefs were that chronic stroke rehabilitation was not beneficial[20] as functional recovery was not possible after 6 months following stroke[8,21] and there was no evidence suggesting beneficial effects of chronic stroke rehabilitation.[22] Although the majority of recovery following stroke does occur during the first three months, evidence suggests functional gains are possible after 6 months and well into the chronic phase of stroke recovery, albeit at a much slower pace.[10] Furthermore, 339 randomized controlled trials comprising 24,873 participants evaluating chronic stroke therapies were identified by a review searching six databases.[22] Most of the trials were related to motor recovery of upper extremities and mobility, however trials of interventions for cognitive deficits, aphasia and psychosocial difficulties were also numerous. The authors noted the majority of these trials indicated a positive benefit and argued the evidence base was robust.

The Individual Domains of Stroke Impairments and Therapies

Understanding the evidence of stroke rehabilitation requires more than the results of studies evaluating the holistic model of care, the organized stroke unit, versus other more general models of care. Stroke rehabilitation is complex and inter-disciplinary typically involving a combination of speech-language therapy, cognitive therapy, occupational therapy, physiotherapy, and depression management and treatment depending on the survivor. Therefore, it is important to understand the evidence of these

elements individually to separate therapies research has concluded to contribute to the therapeutic benefit of stroke rehabilitation and those therapies appearing to offer no improvement of functional recovery.

Cognitive Deficits

Condition and Impact

Evidence gathered by the Evidence-Based Review of Stroke Rehabilitation suggests that vascular cognitive impairment is estimated to affect up to two-thirds of patients post-stroke.[5] Vascular cognitive impairment is broad term that acknowledges and captures the difference causes and presentation of cognitive decline experienced by stroke survivors.[23] Notably, the presence of vascular cognitive impairment does not necessarily mean the presence of dementia and the nature of the experienced cognitive decline in stroke patients differs depending on the presence or absence of vascular dementia. Survivors with vascular cognitive impairment and no dementia tend to have impairments in attention, processing speed and executive dysfunction, while memory and orientation tend to be unaffected compared to those with vascular dementia.[5] However, stroke survivors may have up to a ten times increased risk of developing vascular dementia compared to those without stroke. A systematic review of 30 cohorts gathered between 1950 and 2009 found that approximately 10% of survivors develop dementia post-stroke in addition to 10% whom already have dementia at the time of their stroke, and that one-third experienced dementia after a recurrent stroke.[24]

Decreased cognitive function is associated with greater likelihood of mortality and decreased functional independence. An age/sex matched cohort found that stroke patients with cognitive impairments (and no dementia) had an almost three times greater mortality risk (RR = 2.9, 95%CI = 0.8, 10.9) compared to controls[25] and a 2005 review by Leys et al. found that survivors who do develop dementia have a two to six times increased mortality rate.[26] The Evidence-Based Review of Stroke Rehabilitation concluded that cognitive impairments were associated with reduced ability to perform

not only activities of daily living but also instrumental activities of daily living[5] which are more complex and required for independent living; activities including housekeeping, shopping and meal preparation.[27] In particular, Zinn et al. (2004) found that at 6 months post-stroke, survivors with cognitive impairments had significantly lower instrumental activity of daily living scores than those without (mean = 18.2 vs. 21.0, $p < .0002$) despite similar rehabilitation procedures.[28] Evidence suggests that only up to 20% of survivors with cognitive impairments experience recovery of their cognitive functions within 1 year post-stroke.[5]

Cognitive Rehabilitation

Cognitive Rehabilitation is focused on restoring the brain-behavior processes that contribute to knowing.[29] These processes are diverse including but not limited to various types of attention, memory, executive functions, and visuospatial perceptual abilities. Generally, therapy consists of repeated practice to relearn and strengthen previously intact abilities and the use of internal/external compensatory methods or adaptive strategies to help improve functional abilities. The underlying rationale behind therapies that seek to restore cognitive abilities is that repetitive practice can help return patients to their pre-stroke abilities. External compensatory methods may include alarms or notifications for memory impairments, and internal methods include imagery techniques for memory and multi-step tasks. Ultimately, the goal is to improve the stroke survivor's ability to perform tasks of daily living requiring cognitive processes.

The effectiveness of post-stroke cognitive rehabilitation is unknown, with insufficient evidence available to neither refute nor support cognitive therapy's ability to restore cognitive abilities. The lack of conclusions partially stems from much of the literature being focused on patients recovering from traumatic brain injury.[30] Studies that do include stroke patients have not been of high enough methodological quality to make firm conclusions, with four separate Cochrane reviews of cognitive therapy for attention,[31] spatial neglect,[32] executive dysfunction,[33] and memory[34] post-stroke concluding

insufficient evidence due to the lack of high-quality trials. Although effectiveness remains unclear, cognitive therapy principles are still used by occupational therapists to help patients perform activities of daily living to improve functional independence and there is some evidence supporting specific strategies.

Attention

Attention is a broad term including but not limited to selective attention, divided attention, sustained attention, and spatial attention. Deficits in attention have been treated in stroke patients using attention training where patients respond to a target auditory or visual stimuli while ignoring distractor stimuli, often within some sort of timed task.[29] The 2013 Cochrane review on the cognitive rehabilitation of attention following stroke found a significant effect of therapy on divided attention compared to usual care (standardized mean difference = 0.67, 95%CI = 0.35 - 0.98), while effects on global attention and other attention sub-types were non-significant.[31] The authors stated a need for more high-quality trials. The Evidence-Based Review of Stroke Rehabilitation concluded that cognitive training for attention may improve performance on certain tasks but was unable to conclude the types of attention responsive to therapy.[5]

Visual Neglect

Definitions of visual neglect vary but this perceptual impairment may be generally defined as a problem with responding to or locating stimuli within the field of vision. Patients with unilateral visual neglect, or unilateral spatial neglect have deficits confined to either their left or right visual field. As a result, these patients may only eat half of their food, shave half their face or bump into walls if they are located in the impaired visual field. Cognitive rehabilitation approaches have included, visual scanning training, cue-response paradigms, and the use of prisms mounted to eye glasses to shift images into the neglected field.[32] The effectiveness of cognitive therapy for neglect is generally better supported than

for other deficits with two systematic reviews concluding that visual scanning training is beneficial[5,35] and another acknowledging measureable benefits immediately post-therapy.[32]

Memory Impairments

Cognitive rehabilitation has sought to improve broad memory deficits (general memory problems), specific deficits (memory for specific tasks or objects), and those memory problems identified by patients as being problematic by patients themselves.[36] Attempted therapeutic techniques have included errorless learning, compensatory strategy training, and external assistive devices.[35] Compensatory strategy training in particular has been supported as an effective method for the remediation of memory deficits.[5] Effective strategies have included imagery training[37] as well as external assistive devices such as pagers.[36] However, these studies included only a minority of stroke patients.

Executive Dysfunction

Executive function refers to the integrative cognitive abilities responsible for the planning, organization, and execution of context appropriate, purposeful and goal-oriented behavior.[29] Due to their broad nature, deficits falling underneath the umbrella of executive dysfunction are not rigidly defined and include emotional, behavioral, and cognitive disturbances. Disturbances may result in a poor ability to anticipate consequences of actions, perform multi-step processes, and initiate behaviors. Therapies used to treat executive dysfunction have included problem-solving training, self-instructed behavioral monitoring, and external aids.[29] Studies of self-awareness training have also been performed as many individuals with executive dysfunctions are unaware of their deficits.[35] Although there is evidence supporting problem-solving training for improving performance of everyday activities, much of the literature is based on TBI patients.[29,35] For stroke patients, there is some evidence suggesting that executive function impairments can be treated using computer therapies for improving working memory,[38] mental imagery to rehearse tasks,[39] and analogical problem solving.[40]

Upper and Lower Extremity Motor Impairments

Condition and Impact

Impaired lower and upper extremity functions are common post-stroke with 63% of survivors being initially unable to walk independently[8] and 69% experiencing at least some amount of upper limb impairments ranging from just below full functioning to complete paralysis.[7] These motor impairments can severely impact a survivor's ability to function independently as walking is dependent on leg impairment[8] and performance of activities of daily living are strongly related to arm function.[41] Rehabilitation of extremity function is usually provided by a physiotherapist (also called physical therapist or rehabilitation specialist) with the main goal of regaining function in order to independently perform activities of daily living.[42]

Rehabilitation of Lower Extremity Function

Lower extremity motor function and independence in performance of activities of daily living can be improved post-stroke through physical therapy.[43] Improvements in activities of daily living performance also appear to persist long-term and are not only present immediately after therapy. There are different approaches to physical rehabilitation including more passive neurophysiological approaches where the therapist guides patients through movements (the popular Bobath technique is one such approach),[44] and active interventions focused on relearning specific motor skills needed for daily activities.[45] Most therapists do not adhere to a single approach when treating patients but rather prefer to combine different treatment components.[43] Thus, although no single technique has distinguished itself as the best for improving recovery, the approach of combining therapy techniques has been found to be more effective than no treatment.

Rehabilitation of Upper Extremity Function

The effectiveness of interventions for arm and hand recovery post-stroke remains unclear at this time. Although evidence suggests a variety of therapies improve upper limb function, the body of

evidence is of moderate or low quality and does not allow for adequate comparisons of therapies.[46] Promising interventions include the mental practice of specific tasks,[47,48] mirror therapy for visual stimulation of the affected limb,[49,50] repetitive task training,[51,52] and virtual simulations of real-life tasks.[53,54] Cochrane reviews of constraint induced movement therapy,[55] and electromechanical and robotic-assistive technology[56] also found evidence supporting treatment effectiveness but the poor quality of the included studies was once again noted as a limitation.

Post-Stroke Aphasia

Condition and Impact

Post-stroke aphasia is a multi-modal communication deficit marked by an impaired ability to produce or understand written, verbal or non-verbal forms of communication including body language.[57] Post-stroke aphasia impacts approximately one third of stroke patients,[4,58] is linked with reduced ability to perform activities of daily living and associated with increased risk for both short and long-term mortality.[59,60] Aphasic patients with communication deficits were identified as being at a five-fold greater risk for poor rehabilitation response compared to patients without these deficits.[59] Screening tools are available for identifying patients with various types of aphasia, however appropriate treatment is not always available. Nearly one half of aphasic patients still experience deficits at discharge.[61]

Speech and Language Therapy

Speech-language therapies **are** typically provided by speech and language therapists or speech-language pathologists. The goal of speech-language therapy is to improve communicative abilities needed for daily tasks (known as functional communication) by improving language production, understanding, and participation.[62] Although it is unclear which procedures are most effective, speech-language therapy does improve functional communication and evidence suggests more intensive therapy results in larger treatment gains.[19,62] More recent research has focused on exploring constraint-induced language therapy (alternately called constraint induced aphasia therapy) in which non-verbal,

compensatory forms of communication are restricted in favor of developing verbal skills.[63] Constrained induced language therapy appears to be as effective as conventional speech-language therapy in sub-acute patients,[64] and better than no therapy in patients with chronic post-stroke aphasia,[65] however comparative trials are too few and too small to make strong conclusion regarding effectiveness.[62]

Post-Stroke Depression

Condition and Impact

Post-stroke depression affects approximately one-third of stroke patients at some point during the first five-years post-stroke with 23% of stroke survivors experiencing symptoms at five years post-stroke.[66] Patients with post-stroke depression are at a 22% increased risk for mortality compared to patients without depression.[67] Furthermore, stroke patients with persistent mental health symptoms (including depression) during the first months post-stroke are at risk for poorer long-term functional outcomes even after controlling for other risk factors including age and initial impairment.[68] Despite recommendations by Canadian and International stroke best practice guidelines, depression screening is not routinely performed.[69] This is thought to be due to factors related to the screening tool (lack of awareness of comfort with the tool), the practice environment (staffing and training limitations), and the screen adopters (lack of awareness by patients or no desire to discuss mental health because of stigma).

Post-Stroke Depression Management

Treatment guidelines currently recommend screening patients at risk of developing depression and treating persistent symptoms with an appropriate anti-depressant medication with close monitoring.[70] Although guidelines suggest patients be offered psychological therapy, no specific therapy is recommended, likely due to the lack of strong evidence in favor of any particular treatment.[71] However, some evidence suggests treating patients early with both psychosocial-behavioral therapy and medication reduces depression more than standard medical care alone.[72] There has also been growing

interest in mindfulness-based Interventions, which originate from Buddhism and attenuate distress by drawing attention to an individual's own stream of internal and external sensations through meditation exercises.[73] A systematic review of mindfulness-based therapies given post-transient ischemic attack or stroke demonstrated evidence in favor of positive treatment effects for anxiety and depression.[74]

Access to Early Stroke Rehabilitation

Accessing Stroke Rehabilitation

Evidence suggests the vast majority of stroke survivors are not engaging in therapeutic activities in the acute setting early post-stroke. Within the first 14 days post-stroke, patients were observed to have spent more than 50% of their time confined to their bed (despite most being allowed/able to move about) with only 13% of their time spent engaged in activities that could improve their functioning.[75] Despite their deficits, many survivors are not referred for inpatient stroke rehabilitation. In Canada, only 16% of stroke patients are transferred to inpatient rehabilitation facilities when the number survivors who would benefit is estimated to be 40%.[76] Among those who are transferred, only 50% begin rehabilitation within 12 days post-stroke when the ideal time for maximum recovery is thought to be five to seven days. On average, patients spend 8 days waiting to be transferred to inpatient facilities once acute therapy has been completed.[77] These problems are not unique to Canada with similar trends being seen in the United States where only 24% of stroke survivors are transferred to inpatient rehabilitation after waiting an average of 27 days post-stroke.[78,79] Patients not referred to inpatient services may attempt to seek outpatient therapy. However, accessing these services is also challenging,[80] with less than one-third of survivors receiving outpatient stroke rehabilitation when the amount expected to benefit from such therapy is above 50%.[81]

The lack of timely treatment in the acute, inpatient, and outpatient settings is thought to be cause by a lack of a therapists with specialization in stroke rehabilitation.[80] A survey of Ontario rehabilitation centers also suggests current therapists are already overburdened with the number of

patients under their care with some therapist having as many as 56 beds under their care.[82] Furthermore, the survey also revealed that rehabilitation centers have a limited number of beds dedicated to stroke victims. Despite the existence of beneficial care, many stroke survivors will be left with cognitive and physical impairments preventing them from returning to their pre-stroke activities and will need to acquire personal care. As the number of stroke survivors continues to rise, there is an increasing need to deliver stroke rehabilitation services in a resource efficient manner and prevent more individuals from losing their independence.

Mobile Tablet-Based Stroke Rehabilitation: The mHealth Opportunity.

The ubiquity of smartphones, mobile application (apps), and mobile-tablet computers has brought along with it a revolution in how we live and also the rise of the mobile health (mHealth field). These mobile devices (cellphones, tablets, handheld gaming devices, etc.) are affordable, portable, computers with a vast selection of available software and apps. There are many health-focused apps available for mobile devices offering therapies, clinical scales, and health-tracking features, and many more offering simple games that are analogous to many exercises used by cognitive therapists (word puzzles, memory games, motor/attention/timing scenarios, etc.). Mobile tablets (Apple iPads, Samsung Galaxy Tablets, etc.) intuitively appear to be an excellent device for stroke patients to access these apps as tablet computers are larger and thus easier to manipulate than other smaller devices like smartphones.

There has been an interest in offering therapy to stroke patients using mobile devices reflected by case studies,[83,84] stakeholder perspective pieces on integrating mobile technology,[85,86] and small experimental studies.[87] There is evidence suggesting cognitive deficits and aphasia can be treated using computerized therapies,[4,5] and that tablet-based interventions are well received by patients with chronic conditions.[85,87,88] However, this information has not been formally summarized using systematic methods leaving the current accumulated knowledge base of the field unknown, specifically:

1. The characteristics of the MTBTs that have been attempted with stroke survivors in terms of deficits targeted and method of administration.
2. The barriers or adverse events related to the administration of MTBTs that have been encountered by participants.

We decided that this information would help advance our understanding of post-stroke, tablet-based therapy feasibility by providing a summary of which interventions could be successfully performed, and the barriers to care associated with successful and unsuccessful therapies. Furthermore, it was thought that attempting to summarize the field would identify research gaps in our understanding of treatment feasibility.

Until recently, the feasibility and acceptability of offering early tablet-based rehabilitation to stroke survivors in the acute stages of recovery were completely unknown. Without any research to suggest otherwise, it is understandable why tablet-based therapy may be thought of as unfeasible in this population. Even if the newly acquired post-stroke deficits were mild, patients may find manipulating the tablets to be frustrating as they struggle to cope with their new physical and mental deficits. While it is tempting to test the functional outcomes of patients treated with tablet-based therapy in the acute setting, questions regarding feasibility and acceptability need to be answered before a methodologically sound evaluation early tablet-based stroke rehabilitation can be conducted.

RecoverNow: A Mobile Tablet-Based Stroke Therapy Platform for the Acute Care Setting.

RecoverNow is a mobile tablet-based stroke therapy platform designed for use in the acute care setting. It was initially conceived as an iPad tablet computer loaded with speech language therapy apps to test the feasibility of tablet-based therapy in the acute setting with a restricted population of users with mild speech deficits.[89] The initial RecoverNow pilot study demonstrated feasibility and acceptability with 30 acute stroke patients averaging approximately 150 minutes of daily usage during their acute stay. Furthermore, nearly all of the participants scored the device as being moderately convenient or

greater. An engagement survey was administered to a new, expanded cohort of 30 acute stroke patients including individuals with fine-motor, cognitive and perceptual deficits in addition to communication needs.[90] Patients found receiving the device early in their acute stay to be acceptable and that RecoverNow offered the type of therapy they were interested in performing. Furthermore, many patients expressed an interest in continuing to use the device upon discharge from acute care.

Based on the first two phases of RecoverNow, it is clear many patients are interested in using tablet devices in acute care and beyond to engage in therapeutic activities, and that an ideal population of patients with mild deficits are able to use the devices successfully. However, the first two phases of RecoverNow raised further questions about offering mobile tablet-based stroke rehabilitation:

1. What is the feasibility of offering a comprehensive mobile tablet-based stroke rehabilitation platform (addressing cognitive, fine-motor, and mood deficits in addition to communication deficits)?
2. What is the feasibility of offering mobile tablet-based rehabilitation to stroke patients with more severe deficits?
3. What is the feasibility of offering patients the opportunity to continue engaging in mobile tablet-based stroke rehabilitation outside of acute care?

These questions encouraged the development of RecoverNow into a comprehensive mobile tablet-based stroke rehabilitation platform for use across the entire acute phase of stroke regardless of setting. A number of new features were added for patients and therapists to improve the usability of RecoverNow tablets and make the device appropriate for use outside acute care. It was decided that a new cohort study was needed to establish the feasibility of the new platform with an expanded group of patients who were allowed to take the device outside of acute care.

The Advancement of Mobile Tablet-Based Stroke Rehabilitation

The objective of this thesis was to summarize and advance the knowledge of mobile tablet-based therapies for stroke survivors. There were two specific research questions which guided the main research content of this thesis. (1.) What mobile tablet-based therapies have been attempted with stroke survivors in terms of deficits targeted and method of administration? Answering this question will help to inform the implementation of successful mobile tablet-based therapies for stroke survivors, summarize the barriers related to unsuccessful therapy administration, and also identify research gaps. (2.) What is the feasibility of a comprehensive mobile tablet-based therapy platform for mild to moderately impaired stroke survivors across the acute continuum of care? Answering this question will help to advance our understanding of treatment feasibility by offering a wide range of therapies to patients with a wide range of deficits (in terms of both type and severity), across multiple care settings (acute care, inpatient rehabilitation, home). This thesis is split into four further sections:

1) A systematic scoping review on MTBTs for patients with stroke to summarize the current evidence and help inform the administration of MTBTs and identify research gaps.
2) A detailed description of a MTBT for the early stroke recovery (RecoverNow) covering development and functionality.
3) A prospective cohort study to determine the feasibility of offering a comprehensive mobile tablet-based stroke rehabilitation platform (RecoverNow) in the acute care setting.
4) A discussion integrating study results, acknowledging limitations, and providing suggestions for future research.

A brief summary and linking statement is provided at the end of each thesis chapter to preserve a sense of continuity and highlight the relationship between the thesis chapters.

Chapter 2. Mobile Tablet-Based Therapies Following Stroke: A Systematic Scoping Review of Administrative Methods and Patient Experience

Chapter Preface

Authors and their Contributions

- Michael Pugliese: preliminary searches, study protocol, search strategy, database and all other search methods, article screening, data extraction, and final manuscript.
- Dylan Johnson: study protocol, article screening, and data extraction.
- Dr. Dar Dowlatshahi: study protocol, final manuscript.
- Dr. Tim Ramsay: study protocol, final manuscript.

Appendices

- Appendix 2.1: Clinical Trials of Mobile Tablet-Based Therapies Following Stroke

Abbreviations

- MTBT: mobile tablet-based therapy
- PRISMA(-P): Preferred Reporting Items for Systematic Reviews and Meta-Analyses (-Protocol)
- RCT: randomized controlled trial

Publication Status

- This work was submitted to and is currently under review by PLOS ONE (confirmation email submitted with thesis).
- This work was submitted as shown here with the exception of some minor changes needed to adhere to PLOS ONE submission guidelines.

Abstract

Background and Purpose: Stroke survivors are often left with deficits requiring rehabilitation to recover function and yet, many are unable to access rehabilitative therapies. Mobile tablet-based therapies (MTBTs) may be a resource-efficient means of improving access to timely rehabilitation. It is unclear what MTBTs have been attempted following stroke, how they were administered, and how patients experienced the therapies. The review summarizes studies of MTBTs following stroke in terms of administrative methods and patient experiences to inform treatment feasibility.

Methods: Articles were eligible if they reported the results of an MTBT attempted with stroke participants. Six research databases were searched along with grey literature sources, trial registries, and article references. Intervention administration details and patient experiences were summarized.

Results: The search returned 903 articles of which 23 were eligible for inclusion. Most studies were small, observational, and enrolled chronic stroke patients. Interventions commonly targeted communication, cognition, or fine-motor skills. Therapies tended to be personalized based on patient deficits using commercially available applications. The complexity of therapy instructions, fine-motor requirements, and unreliability of internet or cellular connections were identified as common barriers to tablet-based care.

Conclusions: Stroke patients responded positively to MTBTs in both the inpatient and home settings. However, some support from therapists or caregivers may be required for patients to overcome barriers to care. Feasibility studies should continue to identify the administrative methods that minimize barriers to care and maximize patient adherence to prescribed therapy regiments.

Background

Rationale

Stroke survivors experience many post-stroke complications limiting their ability to function independently, including limitations to mobility,[8] upper-limb function,[7] communication,[5] and cognition.[4] Specialized stroke rehabilitation has been shown to improve functional independence better than non-specialized care,[12] and is most effective when performed early[13,14] and intensely post-stroke.[10] However, due to the growing number of stroke survivors[1] and lack of rehabilitation resources[75,81,91,92], many patients are not able to begin rehabilitative therapies early in order to maximize functional recovery. Easily accessible and resource-efficient stroke rehabilitation is needed to provide all stroke survivors with the opportunity to recover their functional abilities and improve their independence.

Mobile tablet computers with therapeutic applications could potentially offer a means of providing early and resource-efficient stroke rehabilitation. Tablet computers can be easily purchased and there exist many inexpensive or free applications with scenarios analogous to those used in stroke rehabilitation. These devices are portable with fairly large, touch-responsive screens, which could be manipulated by stroke survivors depending on their post-stroke disabilities. Rehabilitation therapists can prescribe applications to patients based on their post-stroke difficulties.

Mobile tablet-based therapies (MTBTs) following stroke are an exciting new paradigm with many possibilities. However, the suitable population, timing and setting, the necessary patient-support structure, and general therapy adherence are unclear. To better understand the feasibility of this intervention, it is critical to understand previous approaches to MTBT administration and the resulting patient experience, including treatment barriers and therapy adherence. A thorough review of the literature may provide important information for the successful conduct of large and potentially costly randomized controlled studies designed to demonstrate treatment efficacy.

Objective

The objective of this study was to summarize the administration of mobile tablet-based therapy (MTBTs) following stroke and the subsequent patient experience to inform treatment feasibility. In particular, we sought to accomplish this objective by answering three research questions:

1. What post-stroke deficits or complications have been targeted by MTBTs and how were the therapies administered?
2. What barriers to care did patients experience while engaging in MTBTs following stroke?
3. Were patients adherent to MTBTs following stroke?

Methods

Protocol and Registration

The design of this scoping review was guided by the most current and widely known guide for scoping reviews,[93] and by PRISMA-P[94] and PRISMA where applicable.[95] PROSPERO currently does not accept scoping review protocols for registration and therefore the study protocol was hosted on the University of Ottawa research depository and can be accessed here: http://hdl.handle.net/10393/35696.

Eligibility Criteria

All included articles were required to meet the following criteria: (1) the study population includes adult stroke survivors (18 years or older) of any type (ischemic/hemorrhagic) or stage (acute/chronic) in any setting, and (2) the study intervention involves stroke survivors interacting with a mobile tablet in response to a post-stroke deficit or complication. Articles were excluded if they met one or more of the following criteria: (1) the mobile tablet is primarily used by someone other than the stroke survivor, (2) the mobile tablet is more correctly described as an E-reader, and (3) the manuscript is a study protocol or conference abstract containing data otherwise available from a full study manuscript.

We defined MTBTs as patient-driven interactions with mobile tablets via various modalities for therapeutic purposes in response to a deficit, complication, or in order to prevent further health deterioration. There were no restrictions with regards to comparators, outcomes, study design and context, or settings, and conference abstracts were included if no full study manuscript could be found. However, only articles written in English were included and the search was limited to articles written from 2010 onwards as mobile tablets did not become widely popular until this time.

Information Sources

Six databases were searched: MEDLINE (OVID interface), EMBASE (OVID interface), PsycINFO (OVID interface), CINAHL, Cochrane Database, and Web of Science. Additional sources were used to augment the database search for academic material: (1) a snowball search of relevant articles and reviews identified by the database search, (2) stroke research-related organizational websites, and (3) clinical trial databases were searched for completed and ongoing studies. A grey literature search was performed to find unpublished material using Google Scholar, the ProQuest Dissertation and Theses Database (Global and UK & Ireland), and the OpenGrey European grey literature database.

Search: Medline (Ovid Interface) Search Strategy

1. exp Stroke/
2. exp cerebrovascular disorders/
3. (stroke* or cerebrovascular* or cerebral vascular or CVA*).tw.
4. ((cerebr* or brain) adj3 infarct*).tw.
5. 1 or 2 or 3 or 4
6. (mobile device* or mobile computer* or handheld computer* or tablet*).tw.
7. (ipad* or galaxy tab* or surface pro*).tw.
8. 6 or 7
9. 5 and 8

10. Restrictions: published in English between 2010-Present.

Study Selection

A two-stage screening process performed by two independent reviewers was used to select included studies. In stage one, two authors (MP, DJ) screened abstracts and titles for potentially relevant articles, and in stage two, two authors (MP, DJ) read potentially relevant articles to confirm they met the inclusion criteria.

Data Collection Process

Two authors (MP, DJ) independently extracted data with the assistance of a data extraction form. During the analysis period it became apparent that certain important characteristics important for completed the review objectives were not collected during the initial data collection process (items described below). A single reviewer (MP) collected these additional study details and entered them into the Excel spreadsheet for analysis.

Data Items

Data items were selected based on the research objective and questions stated above. Items included general study information, participant characteristics, intervention details, comparator description, study outcome description and results, study setting and other contextual information.

Risk of Bias in Individual Studies

As per current guidelines, no risk of bias assessment was performed for individual studies.[93]

Analyses

The review goals and content were not appropriate for quantitative synthesis techniques commonly used in meta-analyses of systematic reviews. However, general study characteristics, participants, interventions, comparators, and patient-reported experiences were summarized narratively and using descriptive statistics where appropriate.

Results

Study Selection

The search returned 868 articles from database searches, 8 potentially relevant articles from grey literature searches, 11 unique clinical trials from registry searches, and 16 potentially relevant articles through snowball reference searches of included studies for a total of 903 articles (Figure 2.1). Title and abstract screening narrowed the search down to 60 articles of which 37 were excluded leaving 23 articles for inclusion[83,85-90,96-111]. The eligible articles came from various search sources; 19 from database searches, 2 from grey literature, 2 from snowball searches, and included both full-texts and abstracts. Seven of the included articles were abstracts, the remaining articles were full manuscripts. None of the clinical trials identified by registry searches provided preliminary data or were completed, and therefore were not formally included. However, a table summarizing trial status and intervention targets are provided as supplementary material (Appendix 2.1).

Study Characteristics

Most of the included studies were observational; 10 cohort studies, 3 case studies, 2 cross-sectional studies, and 1 qualitative interview (Table 2.1). Of the 7 experimental studies, 3 were randomized controlled trials, 2 were randomized experiments, 1 was a non-randomized experiment, and 1 used a cross-over design. Sample sizes were small ranging from 1 to 63 with an average of 18 participants. Three articles (Salaris et al. 2016 (1), Salaris et al. 2016 (2), and Janssen et al. 2016) were conference abstracts based off the same "TnT" study, although they reported different results. The majority of studies recruited participants in the chronic or subacute stages of stroke (14 studies), and only 2 studies included acute stroke patients. Participant stroke stage was either not reported or unclear in the remaining 7 studies. Only 8 studies explicitly reported the number of participants who had previous experience with tablets. On average, nearly half of the participants in these studies had previously used a mobile tablet.

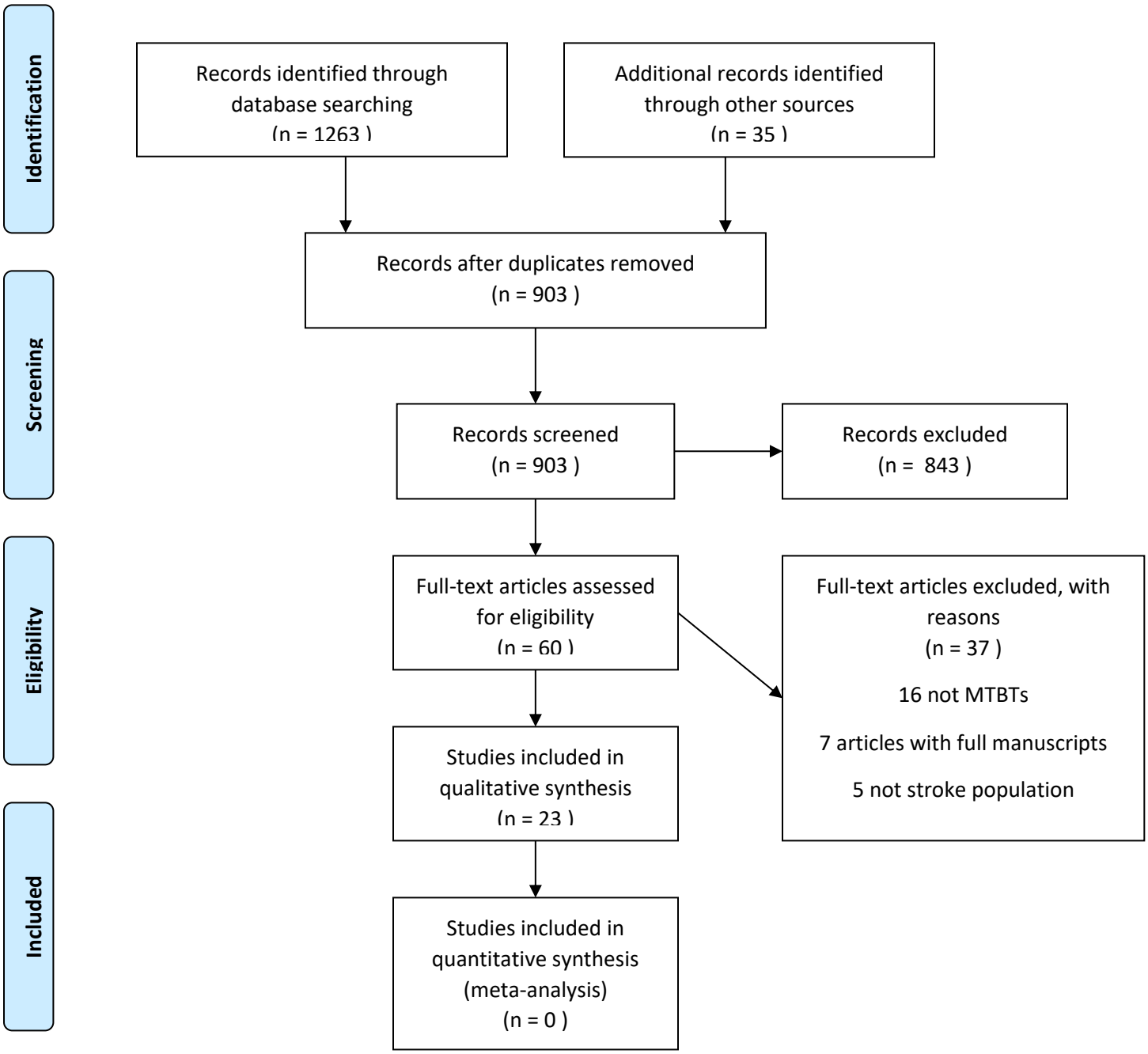


Figure 2.1 PRISMA flow diagram.

Targets of Mobile Tablet-Based Therapy and Methods of Administration

Study interventions targeted a range of post-stroke deficits and complications: 11 MTBTs were described as including an intervention for communication, 4 for fine-motor skills, 4 for quality of life (although 3 of these were from the same "TnT" study), 3 for cognitive deficits, 2 for deficits targeted by physiotherapy, and 1 each for balance and upper extremity function. Therapies tended to be administered using iPad tablets to provide personalized therapy using a unique assortment of commercially available apps for individual participants (Table 2.2).

Table 2.1. Studies of mobile tablet-based therapies following stroke.

Article	Format	Design	Stroke Stage	Sample	Tablet Experience
Carabeo et al. 2014	manuscript	cohort	chronic	3	1
Choi et al. 2016 (1)	manuscript	cohort	chronic	8	7
Choi et al. 2016 (2)	manuscript	experiment	subacute	24	not reported
Crotty et al. 2014	manuscript	cohort	not reported	32	not reported
Davis & Holzbach 2014	abstract	case study	not reported	1	not reported
Des Roches et al. 2015	manuscript	experiment	subacute/chronic	51	22
Hiyamizu et al. 2013	abstract	experiment	unclear	10	not reported
Hoover & Carney 2014	manuscript	cohort	chronic	20	5
Jang & Jang 2016	manuscript	experiment	chronic	21	not reported
Janssen et al. 2016	abstract	experiment	not reported	15	not reported
Katalinic et al. 2013	manuscript	cohort	not reported	39	not reported
Kizony et al. 2016	manuscript	experiment	subacute/chronic	20	not reported
Kurland et al. 2014	manuscript	cohort	chronic	5	1
Lavoie et al. 2016	manuscript	case study	chronic	1	not reported
Mallet et al. 2016 (1)	manuscript	cohort	acute	30	21
Mallet et al. 2016 (2)	abstract	cohort	acute	12	not reported
McCormick & Holmes 2016	abstract	cohort	subacute/chronic	13	not reported
Rand et al. 2013	manuscript	cohort	subacute/chronic	11	not reported
Routhier et al. 2016	manuscript	case study (2)	chronic	2	not reported
Salaris et al. 2016 (1)	abstract	cross-sectional	not reported	63	not reported
Salaris et al. 2016 (2)	abstract	cross-sectional	not reported	15	not reported
Stark & Warburton 2016	manuscript	experiment	chronic	10	3
White et al. 2015	manuscript	qualitative	subacute/chronic	11	0

Therapies were performed in home or inpatient settings and mostly performed independently with no reported assistance from caregivers or clinicians. However, even when therapies were independent, regular contact was often kept with patients through video-conferencing (Katalinic et al. 2013; Kurland et al. 2014), in-person visits (Lavoie et al. 2016; Routhier et al. 2016), or both (White et al.

2016). Certain MTBTs were only performed independently part of the time, with some therapist-assisted use occurring during tele-rehab sessions (Crotty et al. 2014), in-person meetings (Davis & Holzbach 2014; Des Roches et al. 2015; Janssen et al. 2016), and group therapy sessions (Hoover & Carney 2014).

Table 2.2. Characteristics of attempted mobile tablet-based therapies following stroke.

Study	Target	Independent	Setting	Personalized	App(s)
Carabeo et al. 2014	fine-motor skills	Yes	inpatient	No	FINDEX
Choi et al. 2016 (1)	communication	Yes	home	Yes	iAphasia
Choi et al. 2016 (2)	upper extremity	Yes	inpatient	Yes	Mou-Rehab
Crotty et al. 2014	communication/physiotherapy	partially	home	Yes	commercial
Davis & Holzbach 2014	communication	partially	inpatient	unclear	not reported
Des Roches et al. 2015	communication/cognition	partially	clinic/home	Yes	commercial
Hiyamizu et al. 2013	balance	unclear	not reported	unclear	not reported
Hoover & Carney 2014	communication	partially	inpatient	Yes	commercial
Jang & Jang 2016	fine-motor skills	unclear	not reported	No	unnamed
Janssen et al. 2016	quality of life	partially	inpatient/home	unclear	unclear
Katalinic et al. 2013	comprehensive	yes	home	yes	commercial
Kizony et al. 2016	fine-motor skills	yes	in/outpatient	No	commercial
Kurland et al. 2014	communication	yes	home	yes	commercial
Lavoie et al. 2016	communication	yes	home	yes	commercial
Mallet et al. 2016 (1)	communication	yes	acute care	yes	commercial
Mallet et al. 2016 (2)	communication/cognition	unclear	acute care	yes	not reported
McCormick & Holmes 2016	physiotherapy	yes	not reported	unclear	SIMULATe
Rand et al. 2013	fine-motor skills	yes	not reported	No	commercial
Routhier et al. 2016	communication	yes	home	yes	commercial
Salaris et al. 2016 (1)	quality of life	partially	inpatient	Unclear	unclear
Salaris et al. 2016 (2)	quality of life	partially	inpatient/home	unclear	unclear
Stark & Warburton 2016	communication	yes	home	yes	commercial
White et al. 2015	quality of life	yes	home	yes	commercial

Studies often personalized their MTBTs to individual patients by assigning different commercial applications based on assessments (Mallet et al. 2016 (1); Mallet et al. 2016 (2)) or perceived needs (Katalinic et al. 2013; White et al. 2015). Therapies using a single commercially available app (Des Roches et al. 2015) or single app developed by the study team (Choi et al. 2016 (1), Choi et al. 2016 (2), Jang & Jang 2016, McCormick & Holmes 2016), personalized therapies by assigning different modules based on assessments. The most frequently used commercially available apps were Tactus Language Therapy (Hoover & Carney 2014, Katalinic et al. 2013, Mallet et al. 2016 (1); Stark & Warburton 2016; White et al.

2015), Constant Therapy (Des Roches et al. 2015; Hoover & Carney 2014; Mallet et al. 2016 (1)), and Dexteria (Katalinic et al. 2013; Kizony et al. 2016; Rand et al. 2013). Studies of communication MTBTs presented personalized visual stimuli using a variety of apps including Keynote, iBooks, and PowerPoint.

Barriers to Tablet-Based Care Following Stroke

Barriers to care, methodological challenges, and patient experience were defined as separate outcomes at the protocol stage but were found to be intertwined during data collection (i.e. barriers to care are often patient reported experiences that lead to methodological challenges). Eight studies reported barriers to MTBT care, which were categorized as device, patient and system barriers (Table 2.3). The difficulty of the assigned tasks were identified as a device barrier in 3 studies (Carabeo et al. 2014; Choi et al. 2016 (1); Kurland et al. 2014). In each case, participants found the assigned tasks too easy to perform. Bugs in videoconferencing software (Katalinic et al. 2013) and the high speed of task prompts and requests (White et al. 2015) were also identified as device barriers. However, the software bug was later resolved.

Table 2 3. Barriers to mobile tablet-based therapy following stroke

Device Barriers	**Patient Barriers**	**System Barriers**
Task difficulty	Difficulty following complex instructions	Unreliable connections
Task bugs	Finger dexterity	Hospital infection control standards
Task speed	Accidently changing crucial settings	Hospital protocol
	Comfort	Network security
	Post stroke depression	
	Strain	
	Patient's home bandwidth	
	Distractibility	

The most commonly reported patient barrier was difficulty in following complex instructions (Kurland et al. 2014; Mallet et al. 2016 (1); Routhier et al. 2016; White et al. 2015). Specifically, some participants had difficulty understanding how to use the device (Mallet et al. 2016 (1); White et al. 2015) although it was noted in both cases that participants were able to overcome their difficulties with additional familial support. In other cases, participants had difficulty navigating the device to access the

therapy materials (Kurland et al. 2014; Routhier et al. 2016). The second most commonly identified patient barrier was finger dexterity (Kizony et al. 2016; Mallet et al. 2016 (1); Routhier et al. 2016). It was reported that some participant had difficulty isolating their fingers so that only one would touch the screen at a time in order for the device to respond (Kurland et al. 2014), some had difficulty manipulating the device in general, and some had difficulty opening the device case (Mallet et al. 2016 (1)). This final barrier was overcome by using a different tablet case.

Two studies reported patients feeling uncomfortable about specific aspects of their assigned MTBT (Mallet et al. 2016 (1), White et al. 2015). A participant in a MTBT for communication initially felt embarrassed speaking to their device in the hospital, however this was overcome by providing a headset (Mallet et al. 2016 (1)). In another instance, patients felt apprehensive about learning new technology and were particularly anxious about making mistakes in front of study staff (White et al. 2015). These participants felt more comfortable exploring the device at home. Various other patient barriers were reported by single studies. One participant did not use their tablet due to post-stroke depression and feelings of overwhelming post-stroke change (White et al. 2015). Participants taking part in a fine-motor intervention reported the MTBT as being strenuous when performed continually (Carabeo et al. 2014). Particular complaints included muscle strain and numbness, hand numbness and jitters, and eye fatigue. Finally, one study reported that the patient's internet bandwidth made videoconferencing software unusable (Katalinic et al. 2013) and another reported that a participant was particularly excited to use their device for non-therapeutic purposes (Kurland et al. 2014). In the latter case however, this did not appear to interfere with therapy progress.

System barriers were mostly limited to a study conducted in the acute setting (Mallet et al. 2016 (1)), however two studies of home-based MTBTs also noted barriers in this domain (Katalinic et al. 2013; White et al. 2015). All three of these studies reported connection issues as interfering with care. Some participants lived in areas with poor 3G coverage, resulting in subpar videoconferencing quality

(Katalinic et al. 2013). This was resolved by calling participants to help them connect the devices to their home internet connection. However, some participants in another home study reported finding their home internet connections to be unreliable (White et al. 2015). In addition to connection problems, Mallet et al. 2016 (1) also reported barriers from Hospital Infection Control, Hospital IT Security and Hospital Staff. Infection control required tablets be cleaned with disinfecting wipes before being transferred to another patient. There were concerns about Hospital network security requiring an independent security assessment before the study could continue. Finally, five eligible patients were missed because standard of care speech-language pathology assessments were not completed.

Despite these barriers the overall reported patient response was very positive with many studies reporting high satisfaction and usability through either surveys (Choi et al. 2016 (2); Crotty et al. 2014; Kizony et al. 2016; Mallet et al. 2016 (1); Mallet et al. 2016 (2); McCormick & Holmes 2016; Rand et al. 2013) or qualitative interviews (Carabeo et al. 2014; Choi et al. 2016 (1); Hoover & Carney 2014; Kurland et al. 2014; Routhier et al. 2016; White et al. 2015). Specific patient-reported positive aspects were the self-directed and independent aspects of tablet-based therapies (Carabeo et al. 2014; Kurland et al. 2014; Routhier et al. 2016; White et al. 2015) and the convenience of home therapy (Crotty et al. 2014; Kurland et al. 2014; Routhier et al. 2016). Patients from three studies indicated that tablet devices were useful rehab tools (Kizony et al. 2016, Rand et al. 2013) and patients from two other studies felt the device contributed to rehabilitation improvements (Carabeo et al. 2014, White et al. 2015). Three studies also reported positive responses from caregivers (Hoover & Carney 2014; Kurland et al. 2014; White et al. 2015) with Kurland et al. (2014) noting that families reported observing improvements and White et al. (2015) indicated that the device gave family and friends an opportunity to engage in therapy with the participants.

Patient Adherence to Tablet-Based Care Following Stroke

The majority of studies (17/23) prescribed a MTBT dose with only 6 studies not assigning specific MTBT regiments or not reporting this information (Table 2.4). Prescribed therapy dosages varied although most assigned regiments lasted between 2-6 weeks and assigned 3-6 MTBT sessions a week. Two studies were experiments in which participants only engaged with the MTBT for a single session (Kizony et al. 2016; Rand et al. 2013).

Table 2.4. Assigned mobile tablet-based therapy dosages.

Study	Assigned Mobile Tablet-Based Therapy Dosage	Clinician-Led Sessions
Carabeo et al. 2014	9 sessions of 30 minutes over 1.5 months	standard rehab program
Choi et al. 2016 (1)	4 weeks, as often/long as possible	None
Choi et al. 2016 (2)	10 sessions of 30 mins over 2 weeks	30 minutes of occupational therapy
Crotty et al. 2014	8 weeks	videoconference sessions
Davis & Holzbach 2014	not reported	structured therapy sessions
Des Roches et al. 2015	6 hours a week for 10 weeks plus clinician sessions	10 MTBT sessions (1 per week) over 10 weeks
Hiyamizu et al. 2013	9 sessions (3 per week) over 3 weeks	not reported
Hoover & Carney 2014	20 sessions (5 per week) over 4 weeks	intensive full rehab program
Jang & Jang 2016	24 sessions (6 per week) over 4 weeks	not reported
Janssen et al. 2016	None, could use how they please	standard rehab program
Katalinic et al. 2013	lent device for 3 months	videoconference sessions
Kizony et al. 2016	single use experiment	None
Kurland et al. 2014	120-144 sessions (5-6 per week) over 6 months	24 sessions (1 per week) over 6 months
Lavoie et al. 2016	12 sessions (4 per week) over 3 weeks	weekly non-therapeutic home meetings
Mallet et al. 2016 (1)	1 hour/day during acute stay	standard acute care
Mallet et al. 2016 (2)	1 hour/day during acute stay	standard acute care
McCormick & Holmes 2016	18 sessions over 18 days	not reported
Rand et al. 2013	single use experiment	None
Routhier et al. 2016	20 sessions (4 per week) over 5 weeks	weekly non-therapeutic home meetings
Salaris et al. 2016 (1)	none, could use how they pleased	standard rehab program
Salaris et al. 2016 (2)	none, could use how they pleased	standard rehab program
Stark & Warburton 2016	28 sessions (everyday) for 4 weeks	not reported
White et al. 2015	none, could use how they pleased	Unclear

Tablet-based therapy usage habits were reported by a minority of studies (Table 2.5). Tablet usage ranged from little daily usage (Kurland et al. 2015) to daily use equal to or exceeding 1 hour (Choi et al. 2016 (1); Mallet et al. 2016 (1); Mallet et al. 2016 (2)). Specific tablet usage was not reported by a handful of studies. In particular, Stark & Warburton could not confirm usage habits using information transmitted from the tablets and relied on patient self-reported usage. White et al. qualitatively

reported the usage habits of a handful of participants using quotes to communicate the variety of usage habits they observed in their participants.

Table 2.5. Participant mobile tablet-based therapy usage habits.

Study	Mobile Tablet-Based Therapy Usage
Choi et al. 2016 (1)	Mean usage: 60 minutes/day
Des Roches et al. 2015	Mean usage: 40 minutes/day
Kurland et al. 2014	Mean usage: 18 minutes/day
Mallet et al. 2016 (1)	Mean usage: 150 minutes/day
Mallet et al. 2016 (2)	Mean usage: 85 minutes/day
McCormick & Holmes 2016	Participants completed at least 30 minutes of scheduled 90 minute sessions
Salaris et al. 2016 (2)	Used 2-3 times/week during inpatient stay and up to 1-2 hours/days after discharge
Stark & Warburton 2016	Patients reported using table at least 20 minutes every day for 4 weeks
White et al. 2015	Patients reported variable tablet-usage habits

Discussion

This systematic scoping review yielded 23 eligible articles pertaining to mobile tablet-based therapies for a variety of post-stroke deficits and complications. The majority of the identified articles reported the results of observational studies with small samples of chronic or subacute stroke patients. The goals of most of the studies were exploratory, with only a few articles reporting the results of experimental studies attempting to demonstrate treatment effectiveness. The collected body of literature suggests MTBTs following stroke may be feasible and acceptable, with many studies expressing positive experiences. However, common barriers to care were identified that may prevent certain patients from successfully engaging in therapy.

Mobile Tablet-Based Communication, Cognitive, and Fine-Motor Therapy Following Stroke

The majority of the attempted MTBTs targeted communication, cognitive, and fine-motor deficits. Considering interventions for these deficits are arguably the most intuitive to implement on a tablet device, it is not entirely surprising that research has focused mainly on these interventions. Furthermore, there is already research supporting the effectiveness of computer-based speech-language therapy.[4] This research-base, coupled with the emergence of popular therapeutic apps like

Constant Therapy, Tactus Therapy, and Dexteria may explain why many researchers are more interested in attempting MTBTs for these deficits over other post-stroke complications. Although the methods of administration varied among MTBTs for communication and fine-motor deficits, some trends emerged.

Most MTBTs were performed independently without clinician guidance, although in some cases caregivers or family members participated in therapy with patients. Regular contact with clinicians through videoconferencing and in-person visits were common even among independently performed therapies. The involvement of others in therapy may be beneficial for patient barriers related to therapy and device complexity could be overcome with assistance. Contact with clinicians offers an opportunity for patients to voice issues regarding tablet complexity and for therapists to re-explain complex therapy tasks or features to participants and their caregivers. However, therapists should try not to infringe upon patient independence as this was indicated as one of the aspects of tablet-based therapy that patients enjoyed. Similarly, patients would likely prefer for physicians to keep contact in a manner that does not require them to leave their home as the home-based aspect of therapy was also frequently noted as a positive attribute. Videoconferencing was successfully used to contact patients, although some technical difficulties were noted and it is possible that not all patients will have access to reliable cellular or wireless internet connections.

Mobile tablet-based therapies tended to use personalized tasks tailored to patient deficits. Personalization may prevent patients from encountering therapies with inappropriate difficulty levels and encourage extended therapy engagement. However, this relationship between personalization and therapy engagement was not made clear from the collected usage data. It should be noted that even studies with personalized therapy tasks reported barriers to care involving task difficulty suggesting personalization alone is not enough. Rather, therapies should both be personalized and then adjusted as patients engage in therapy. The result is an iterative process whereby patients are assigned tasks based upon their deficits, engage in therapy, express difficulty or make progress, and then the process begins

again as new tasks are assigned. This also further highlights the importance of maintaining regular contact with clinicians who are needed to make informed therapy adjustments.

Mobile Tablet-Based Physiotherapy

Mobility and upper extremity deficits are very common post-stroke,[7,8] and yet there were only four studies involving tablet-based physiotherapy activities, two of which were reported as short conference abstracts. Perhaps, the lack of physiotherapy interventions reflects the difficulty of translating traditional physiotherapy to tablets or perhaps due to interests in other promising technology such as robotics.[56,112] Although the few studies reported heterogeneous administrative methods, interesting ideas for tablet-based physiotherapy were described. One intervention for upper extremity therapy used a combination of tablet sensors with a smartphone attached to the patient upper limb to track movement in response to tablet therapy activities which was well-received by patients (Choi et al. 2016 (2)). Other studies used video capabilities to provide visual feedback on movements or provide visual demonstrations (Hiyamizu et al. 2013), and assigned patients a Fitbit to track activity levels (Crotty et al. 2014).

The ability of tablets to host video conferences with therapists could be particularly useful for providing tablet-based physiotherapy. Crotty et al. 2013 reported using a combination of video conferences to deliver therapy, and video recording to save sessions for later viewing, however the details of this administrative method with regards to physiotherapy were not made clear. Further detailed studied of similar administrative approaches and barriers to care would be helpful for determining the feasibility of tablet-based physiotherapy in the home setting. Although patients would likely enjoy the convenience of home physiotherapy instead of travelling to or staying in a rehabilitation center, the safety of home-based physiotherapy is unknown.

Mobile Tablet-Based Depression Treatment

There were no tablet-based mood interventions published, despite depression being common following stroke.[6] However, three abstracts from one study and one further study reported on interventions targeting quality of life, a construct related to depression. Although the results provide some promise that simply providing patients with a tablet computer could improvement quality of life, and perhaps therefore mood, it remains unknown if a more structured approach to tablet-based mood therapy is feasible. Interestingly, another study reported improvements in mood and arm function after a physiotherapy intervention. This suggests that providing tablet-based interventions to improve physical deficits could indirectly lead to improvements in post-stroke depression. Logically some patients would feel depressed following the sudden loss of their physical abilities and independence following stroke, and it follows that improvements in physical function could be coupled with an improvement in mood. Future studies of tablet-based intervention targeting physical abilities should consider measuring mood as a secondary outcome to further explore this hypothesis.

Designing and administering tablet-based interventions directly targeting mood is difficult, as no intervention has distinguished itself as particularly effective with stroke patients using a traditional face-to-face administrative approach. For example, although there has been considerable research on internet-based cognitive behavioral therapy in other populations,[113,114] it remains unclear if this approach is effective for individuals post-stroke.[71] However, there has been promising evidence for the effectiveness of mindfulness-based therapies for improving mood post-stroke[74] and there exists the possibility of translating these interventions to tablet devices in the future.

Mobile Tablet-Based Therapy for Acute Stroke Patients

Early rehabilitation initiation is important to maximize recovery of function,[13,14] and MTBTs could be used to provide early therapy during the significant amount of downtime experienced by patients in acute care.[75] Despite this, the only two studies attempting MTBTs in the acute stroke setting to provide early stroke rehabilitation services (Mallet et al. 2016 (1); Mallet et al. 2016 (2)) were

performed by our own Ottawa Stroke Program Research Team. The technology, need, and available time exist to administer tablet-based therapy in the acute stroke setting. Further investigation into this area is warranted.

The Next Steps for Mobile Tablet-Based Therapies Following Stroke

This review provides a summary of MTBT administration methods, barriers to care, and therapy adherence following stroke. The accumulated studies suggest many stroke patients are able to successfully engage in tablet-based therapies for communication, cognitive and fine-motor deficits with minimal assistance and enjoy the independence and convenience of tablet-based therapy despite barriers to care. Attempting randomized controlled trials for therapies targeting communication, cognitive, and fine-motor deficits may not yet be appropriate despite seemingly strong support for treatment feasibility. Further studies should track therapy adherence and experiment with methods for encouraging patient adherence to therapy regiments. Successful methods for promoting therapy engagement may be simple as sending text notifications to the tablet device, setting weekly therapy goals, regular videoconferences, or perhaps a combination of strategies individually tailored to patient preferences.

Limitations

The large breadth of outcome information eligible for extraction from articles by the two independent reviewers means some relevant outcomes could have been missed. However, the data extraction process used assistive documents to help reviewers identify relevant outcomes. No risk of bias assessment was performed on the included studies as is common for scoping reviews. However, this was done in accordance with current scoping review guidelines and considering the goals of the review were to collect information on administrative methods and barriers to care, a risk of bias assessment would be unlikely to impact our findings.

Conclusions

The majority of MTBTs following stroke targeted communication, cognitive, and fine-motor deficits, and were positively received by patients despite barriers to care. The findings suggest tablet-based therapy may be feasible for certain stroke deficits although little is known about therapy adherence. Feasibility studies should continue to refine the administrative methods for frequently targeted post-stroke deficits to minimize barriers to care and maximize treatment adherence.

Acknowledgements

The authors would like to thank Michael Boutet from the University of Ottawa Health Sciences Library for advising on the database search strategy.

Appendix 2.1 - Clinical Trials of Mobile Tablet-Based Therapies Following Stroke

Table 2.6. Status and basic characteristics of incomplete clinical trials of mobile tablet-based therapies following stroke

Registry	ID	Status	Target	Setting	Stroke Stage
ICTRP	ACTRN12613000779774	Not yet recruiting	Mobility	Inpatient/Home	Acute/Subacute
ICTRP	ACTRN12613001182785	Not yet recruiting	Communication	Inpatient/Home	Chronic
ICTRP	ACTRN12614000081617	Not yet recruiting	Quality of Life	Home	Acute/Subacute
ICTRP	ACTRN12614000564651	Not yet recruiting	Dementia	Home	Any
ICTRP	ACTRN12616000051448	Not yet recruiting	Mobility	Home	Acute/Subacute
ICTRP	ACTRN12616001733460	Not yet recruiting	Mobility	Home	Any
ICTRP	ISRCTN16023965	Recruiting	Cognition	Home	Subacute/Chronic
ICTRP	NCT01836159	Recruiting	Fine motor/Cognition	Home	Acute/Chronic
ICTRP	NCT02136433	Recruiting	Upper extremity	Unclear	Any
ICTRP	NCT02615132	Recruiting	Communication	Home	Acute
CTG	NCT01928602	Unknown	Communication	Home	Chronic

CTG: ClinicalTrials.Gov; ICTRP: International Clinical Trials Registry.

Chapter Summary

This chapter reported the results of a systematic scoping review to summarize MTBTs following stroke in terms of therapy targets, method of administration, and the barriers encountered to inform treatment feasibility. The final included articles described a new and heterogeneous field of research primarily concerned with conducting observational studies exploring patient experience and providing preliminary evidence of treatment efficacy. While therapies were generally well-received by patients, few studies reported treatment adherence or tablet usage habits and barriers to care were identified. There were few studies that attempted tablet-based physiotherapy and no studies attempted tablet-based depression interventions. The only two studies that attempted MTBTs with stroke patients in the acute care setting described the feasibility of RecoverNow, a tablet-based platform for early stroke rehabilitation developed by our own research team. The next two chapters of this thesis will cover the development of the most recent iteration of RecoverNow and the results of the third RecoverNow feasibility study.

Chapter 3. The RecoverNow Stroke Rehabilitation Platform

Chapter Preface

Objectives

The purpose of this chapter is to explain the development and functionality of the RecoverNow platform used in the study reported in the following chapter. Understanding the newly developed features of RecoverNow will help contextualize the results of the cohort study to be reported in the following chapter without the need to refer to the literature.

The RecoverNow Stroke Rehabilitation Platform

The RecoverNow Concept

The idea for RecoverNow precipitated from the difficulty patients experience accessing timely stroke rehabilitation as mentioned in the literature and observed by clinicians at The Ottawa Hospital. It was thought that tablet computers would be an ideal device for offering independent, patient-driven rehabilitation in the acute setting due to its portability, large number of apps, and relatively larger screen size compared to other mobile devices. However, to the best of our knowledge at the time, and now further supported by the scoping review reported in the previous chapter, there had been no research supporting the feasibility of mobile tablet-based stroke rehabilitation in the acute care setting. The lack of previous research and the opportunity to provide early stroke rehabilitation in a cost-efficient manner led to the initial iteration of the RecoverNow platform and the first two study phases.

Previous RecoverNow Platform Design

The initial RecoverNow tablet and study has been described in detail in the literature.[89] For the purposes of this thesis, it is important to understand the initial RecoverNow design consisted of an Apple iPad Air tablet with a variety of commercially available apps for speech language therapy. Tablet features not used for therapeutic purposes were locked out using the iOS “restrictions” features except for basic applications which could not be blocked. The initial RecoverNow was successful with mildly aphasic acute stroke patients using the device for an average of more than 1 hour a day while in acute care. An engagement survey followed and included patients with occupational therapy needs in addition to speech-language therapy needs. There was a clear patient interest in continuing tablet therapy outside of acute care.[90]

Development Goals

A new phase of RecoverNow development was initiated to expand the RecoverNow platform into a more comprehensive mobile tablet-based stroke rehabilitation platform for use across the acute

care-path; whether it be from acute care to inpatient rehabilitation, home, or some other combination of discharge destinations. RecoverNow was improved to create a secure tablet-based platform through which therapists could remotely alter assigned applications as recovery progresses, communicate with patients, and track therapy progress. The Ottawa Hospital mHealth division developed RecoverNow as an android-based "launcher" to house commercially available applications, transmit encrypted data usage to a webpage administration portal and restrict non-therapy tablet features. The major features added and technical challenges encountered during the development process are listed below in Table 3.1 and explained in subsequent paragraphs.

Table 3.1. RecoverNow platform development

Developed Features	**Technical Challenges**
User friendly tablet interface	No major issues
Administrative hub	Admin/tablet synching
Tablet-patient pairing	Admin/tablet synching
Remote app installation	Admin/tablet synching
Patient app usage tracking	Admin/tablet synching, user/tablet synching
Security	Platform crashes, locking out non-therapy features

The Current RecoverNow Platform

Android Operating System Launcher

Previous iterations of RecoverNow had used Apple iPad tablets (Apple, Cupertino, California, United States) which use the iOS operating system. Although the iOS platform was used successfully and there exist a huge library of applications, the RecoverNow platform was developed for the Android operating system as it offered the programming flexibility needed to create a platform capable of remote modification. Unlike iOS, Android is an open-source operating systems that allows developers to access and modify the system's source code, and allows for easier blocking of native, non-therapeutic tablet features.

The RecoverNow platform is itself not an application nor an operating system. Rather, it is an alternate "launcher" which replaces the tablet computer's default interface (Figure 3.1). By replacing the

default launcher with RecoverNow, patients are immediately directed to the RecoverNow home screen upon turning on the tablet device. This made it difficult (but not impossible) for users to inappropriately access non therapy-related tablet features. Further measures were taken to disable these features: the taskbar at the top of the screen was locked, certain therapist-only areas of the platform were blocked by passwords, an application (Package Disabler Pro) was used to block internet usage for certain applications, and programming was used to disable internet-ad links.

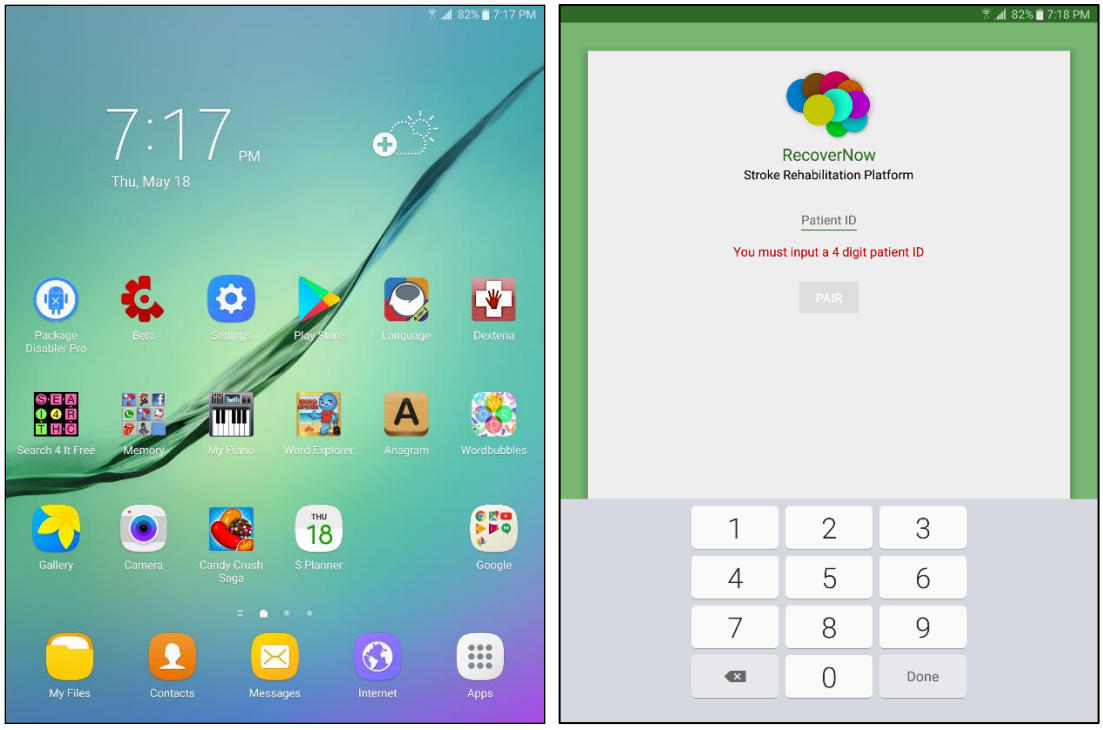


Figure 3.1. Comparison of default tablet launcher (left) and RecoverNow tablet launcher (right).

A Case-Use Example of the RecoverNow Platform

After acute therapy, stroke survivors undergo standard of care assessments by allied health professionals. Based on speech-language and occupational therapy assessments, allied health professional can prescribe applications to patients via the RecoverNow platform. Therapists access the administration portal, create a new patient account, assign application and time goals from a desktop or

RecoverNow tablet, and then pair the patient account with RecoverNow enabled tablets. After a tablet and app training session, patients can begin recovery in acute care while waiting to be discharged. Therapists can use the administration portal to remotely track patient progress and send messages of encouragement if users are not meeting their goals. Patients can send messages from their tablets to therapists if they are not happy with the prescribed apps or if they are too difficult. Based on patient feedback and therapy progress, the prescribed apps can be continually updated as the patient moves towards recovery.

Platform Features and Layout

The Patient Interface

The RecoverNow patient interface was designed to house assigned apps, the Patient Health Questionnaire depression screen (PHQ9), messaging system, and consent form (Figure 3.2). Patients can see the assigned app schedule for the day and access apps by pressing app logos. PHQ9 depression screening is integrated into the RecoverNow platform and is accessible via the main user interface. The results are not viewable in the patient interface but are displayed in the patient profile settings menu in the administration portal upon completion (only accessible to therapists). Patients can access the messaging system from the main menu and select from four messages to be sent to therapists. These messages are collected in the messages submenu of the patient's profile found in the administration portal. A link to a brief consent form is also integrated into the patient interface. The consent form asked participants to agree to only use the device for therapeutic purposes. Despite these features being inaccessible the hospital's Internet Technology department suggested this added to measure to protect the hospital in the unlikely event that users or hackers found a way around device security measures (detailed below). The time and date of patient consent is sent to the patient profile settings menu in the administration portal.

The patient interface includes hidden, password-secured links to therapist areas of the platform that can be used to change the assigned app schedule and other tablet settings. Long-pressing the “large brain” logo in the top left and entering a password allows therapists to easily modify the assigned therapy schedule (Figure 3.3). Similarly, the “small brain” at the bottom brings therapists to the platform settings menu where platform updates can be downloaded and a link to the administration portal which stores a range of therapist-relevant features.

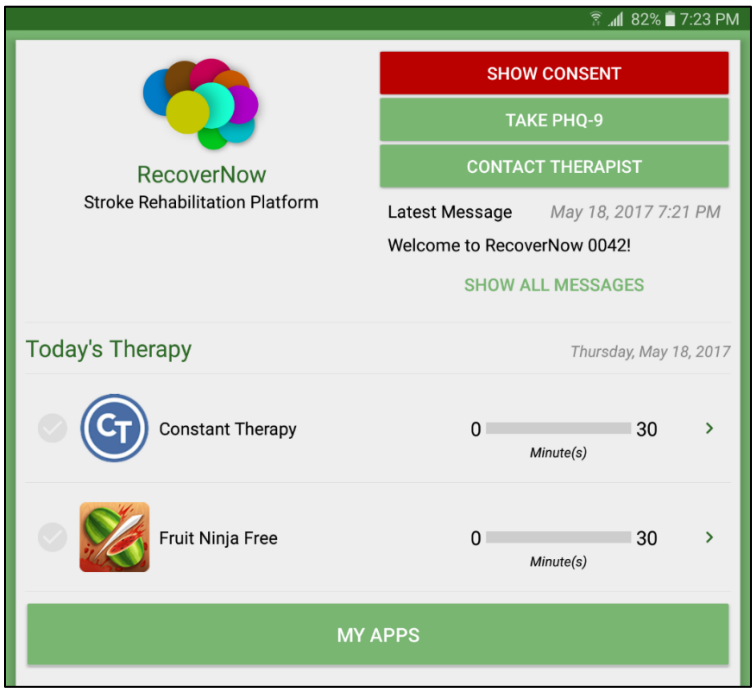


Figure 3.2. The RecoverNow patient interface showing two assigned applications, a therapist message, and links to the consent form, PHQ-9 depression screen, and messaging system.

The Administration Portal

The administration portal includes many features (Table 3.2) and was designed as a hub for therapists to track app usage for each user, collect sent/received messages, and remotely modify therapy schedules (Figure 3.4). The portal is a webpage accessible by therapist accounts assigned by the platform developers and has been optimized for mobile devices as well as desktop computers. Each

therapist signs up with an email address, is assigned an account password and is given a personal therapist code to use with the “large brain.”

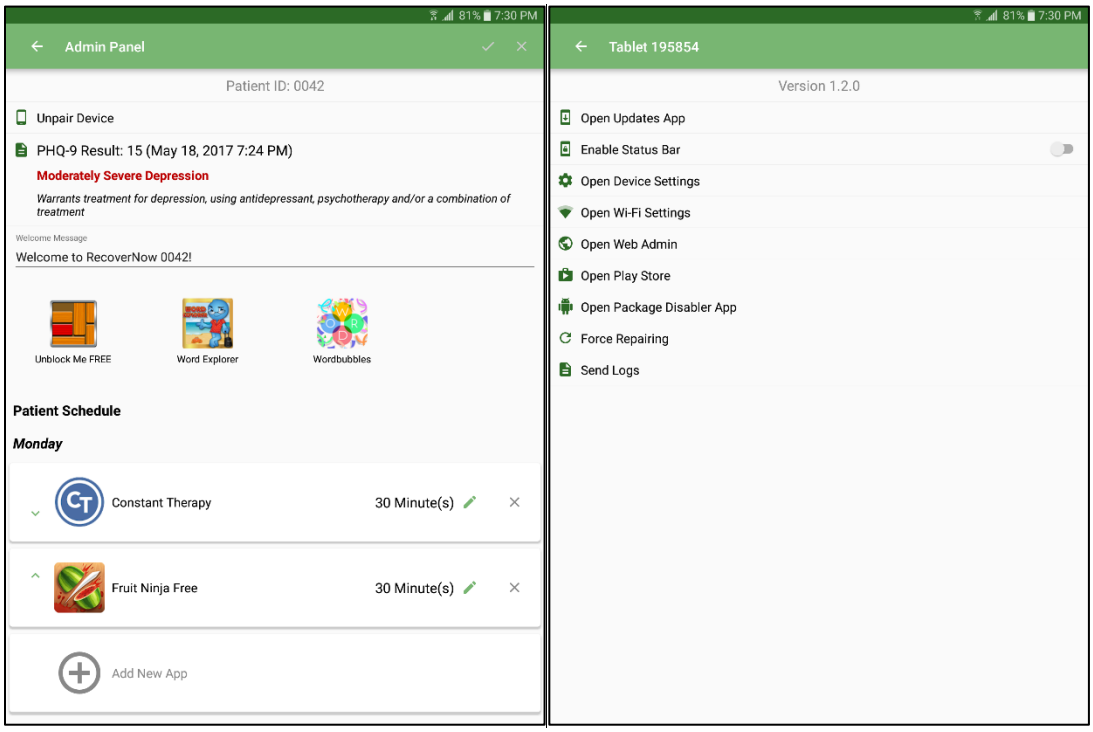


Figure 3.3. The hidden “large-brain” menu (left) and hidden “small-brain menu (right).

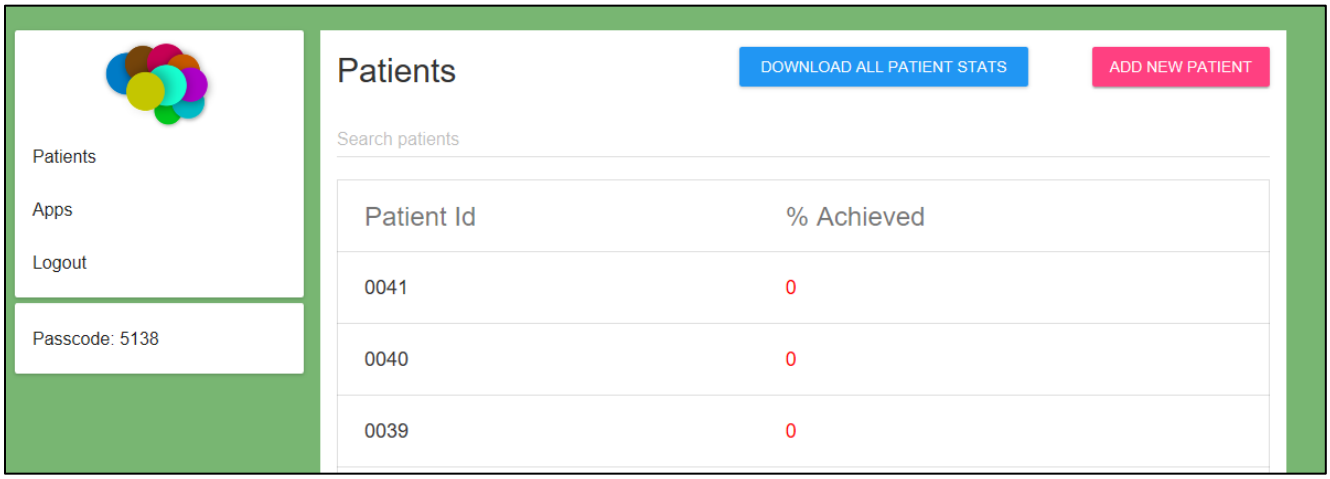


Figure 3.4. The main page of the RecoverNow administration portal.

Tablet-Patient Pairing

The “ADD NEW PATIENT” button creates a new patient ID and profile which can be paired to a RecoverNow tablet. Therapists simply input the patient ID to the RecoverNow tablet’s patient login screen (shown in Figure 3.1) and the profile is paired with the tablet. This features allows the organized synching of patient tablet actions (app usage, PHQ9, messaging, consent) with the patient profile in the administration portal. Once a patient has completed their therapy course, therapists can unpair patient profiles from the tablet via the hidden “big brain” menu. Patient profiles can be paired, unpaired, and repaired at any time from the RecoverNow tablets.

Table 3.2. Administration Portal features and interface navigational flow.

- Patients
    - Download all patient stats
    - Add new patient
    - Patient ID
    - % usage over the last three days
    - Message notification
        - Patient profile
            - Settings
                - Consent/tablet/pairing/update information
                - Assigned apps and schedule
                - PHQ9 results
                - Messaging toggle
            - Messages
            - Usage
                - Graphical usage displays
                - Downloadable individual patient usage stats
- Apps
    - List of installed apps
- Logout
    - Return to RecoverNow login page
- Passcode
    - Used to access hidden tablet features

Remote App Installation

Therapists can login to a RecoverNow Google Play account and remotely install apps on RecoverNow tablets (Figure 3.5). Copying the Google Play Store web-link into the administration portal “Apps” sub-menu adds the apps to the administration portal and allows therapists to assign the app on certain days and for length of times via the patient profile settings menu.

Tracking Patient App Usage

The RecoverNow tablets track patient app usage and transmit this information to the administration portal using cellular data. Patient usage data is integrated into the platform in many different ways. Patients can see in the main patient interface how close they are to achieving their daily app usage goals. Therapists can see patient therapy adherence percentage on the admin portal patients list. With the patient profiles, therapists can see graphical representations of individual patient app usage and download usage statistics as a CSV file. User performance on apps (high scores, achievements, etc.) was not captured as this would have required a unique programming approach for each individual app in order to collect this information and use it with the RecoverNow platform. Instead, it was decided app usage tracking and the ability to assign new apps on an ad-hoc basis were more important considering the goals of the study.

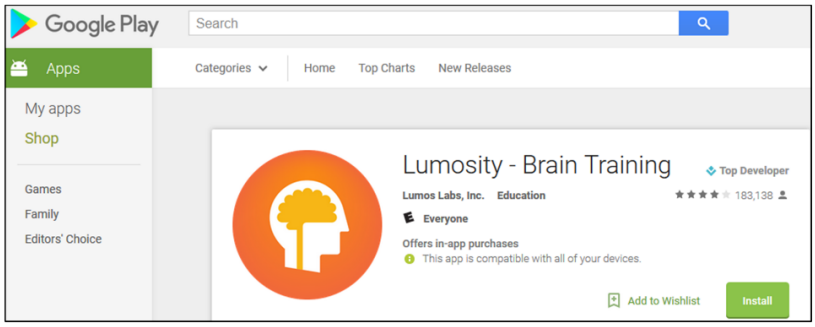
Security

A number of security measures were taken to protect patient information (usage time, assigned apps, app schedule, etc.). All data stored on the tablets, and data transmitted between the tablets and admin portal were encrypted. Google encrypts the Android operating system by default, meaning should any unauthorized user attempt to retrieve data from the tablet devices it would be unreadable. Similarly, SSL was used to encrypt tablet-to-administration portal communication rendering any captured information unreadable. The server upon which the administration portal is hosted, and therefore the data it houses, was also encrypted. Although the RecoverNow platform does not contain any personal identifying information, all of these measures provide further control to protect user privacy nonetheless.

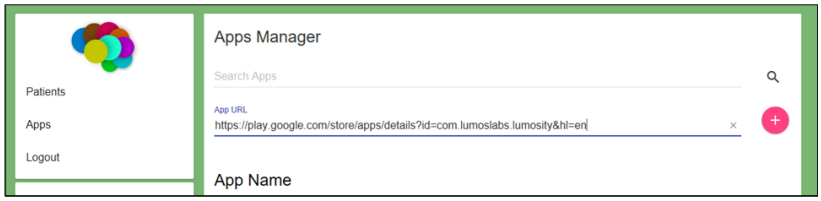
Measures were taken to block patients from accessing non-therapy related tablet features using a combination of software, passwords, and coding so patients could only use the devices to engage in

therapy through the RecoverNow platform. Even with the flexibility of the Android operating system, preventing users from accessing non-therapy related features was challenging.

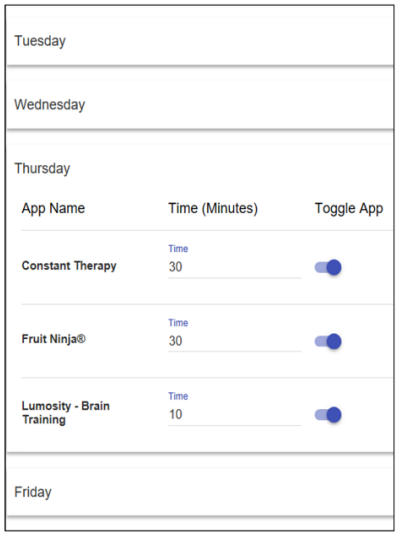
Step 1. Login to Google Play store and install desired application on RecoverNow tablets.



Step 2. Copy the link of the installed application into application list in the RecoverNow administration portal. This allows therapists the RecoverNow platform to interface with the application (including allowing therapists to add the application to patient therapy schedules).



Step 3. Add the application the patient's schedule (in the patient profile section of the administration portal) for the recommended amount of time. The application instantly appears on the patient's RecoverNow platform main menu.



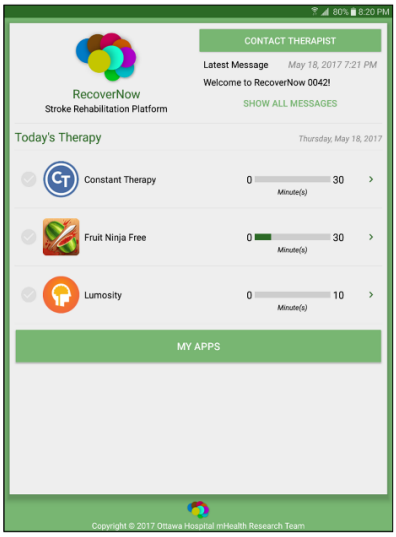


Figure 3.5. Steps to add a new application to the RecoverNow therapy library and patient therapy schedule.

At first, users were able to access the default launcher by long-pressing the “home button” on the bottom of the tablet. This was disabled by modifying the Android OS code. It was discovered that certain actions would cause the RecoverNow platform to crash resulting in the default launcher being displayed. The development team ran tests to identify the source of the crashes and implemented improvements to the RecoverNow code to prevent crashes.

Restricting user ability to access the internet while keeping cellular communication open between the device and administration portal was also challenging. Although internet browsers appear inaccessible from the RecoverNow user interface, many of the apps included in-app advertisements linking users to external websites. To prevent this, an app was used to block the tablet’s non-removable default web browser.

RecoverNow Soft-Launch

A soft-launch of RecoverNow was initiated before the RecoverNow cohort study began in proper. The purpose was to identify any final bugs in the platform which could seriously impact the quality of study results. Three acute stroke patients were invited to use the device but not permitted to leave acute care with the device. Once it was determined there were no issues with tablet usage tracking and patients could not access non-therapy features or crash the tablet, RecoverNow was fully launched.

Chapter 4. RecoverNow: A Mobile Tablet-Based Therapy Platform for Early Stroke Rehabilitation

Chapter Preface

The final major research component of the thesis reports the results of a cohort study exploring the feasibility of RecoverNow, a comprehensive mobile tablet-based therapy platform for early stroke rehabilitation. This study built upon the literature summarized in the scoping review presented earlier by adding to the sparse knowledge on the feasibility of mobile tablet-based therapy to stroke survivors in the acute care setting. Furthermore, this study was a direct continuation of the previous RecoverNow patient perspective study where patients indicated an interest in continuing to engage in mobile tablet-based therapy outside of acute care.

The goal of this study was to determine the feasibility of offering tablet-based care across the acute stroke continuum; from acute care to discharge destination, whether that be home, inpatient rehabilitation or another setting. Participants were invited to use RecoverNow during their acute stay and then at discharge asked if they were interested in taking the device with them for up to three months at which time they would be ask to return for a follow-up interview. The observed results will help refine the development of a pilot randomized controlled trial to establish the efficacy of RecoverNow. Feasibility was the primary outcome and was operationalized using five facets: recruitment rate, adherence rate, interview retention rate, proportion of successful follow-up interviews, and protocol deviations.

Authors and their Contributions

- Michael Pugliese: study protocol, intervention development and testing, patient training, patient follow-up, data collection and analysis, final manuscript (in preparation).
- Dr. Dar Dowlatshahi: RecoverNow concept creator and development lead, study protocol, final manuscript.

- Dr. Tim Ramsay: study protocol, data analysis, final manuscript (in preparation).

Appendices

- Appendix 4.1: Application list

Abbreviations

- BI: Barthel Index
- FIM: Functional Independence Measure
- ICH: Intracerebral hemorrhage
- mRS: Modified Rankin Scale
- NIHSS: National Institutes of Health Stroke Scale
- OT: Occupational Therapy
- PHQ9: Patient Health Questionnaire
- SLP: Speech Language Pathology

Methods

Participants

An unblinded, single-group, prospective cohort design was used, and a convenience sample of 30 participants was recruited from the neurovascular ward of the Ottawa Hospital Civic Campus in Ottawa, Ontario, Canada by allied health professionals. Participants were given a RecoverNow tablet to use for three months and were invited by phone to participate in a follow-up interview at the end of this period. Participant characteristics were collected as baseline, tablet usage was collected across the three month period, and health outcome data was collected at the three-month follow-up interview.

We approached patients to participate if (1) there was a confirmed diagnosis of stroke and were admitted to the neurology unit and/or the neurology acute care unit, and (2) presented with mild to moderate communication and/or cognition deficits and/or mood symptoms and/or patients with score ≥ 1 on the National Institute of Health Stroke Score (NIHSS). We excluded patients with (1) pre-existing speech, language disorders and/or cognitive disorders, (2) severe disability from any cause that, in the opinion of the investigator, rendered the patients unable to complete the tasks required by the study, or (3) with severe comprehension deficits.

Intervention

Allied healthcare professionals prescribed patients therapeutic apps for stroke-induced deficits related to communication, cognition, and fine-motor ability based on individualized health assessments. Patients were given a brief training session, and completed depression screening using a RecoverNow tablet-integrated version of the Patient Health Questionnaire (PHQ9) by either an allied health professional or research staff member familiar with the RecoverNow platform. A detailed explanation of the intervention, therapy course, and training session content can be found elsewhere.[89,115] Patients could take the RecoverNow tablets with them upon discharge from acute care for up to three months

post-enrollment with the understanding they would attempt to engage in tablet-based therapy using RecoverNow for at least one hour a day.

Monitoring of Participant Usage after Discharge

Every effort was made to follow-up with participants one day after assigning a tablet, or after extended periods (three or more days) of non-usage as tracked by the webpage administration portal. Follow-up was done either in-person or via phone to identify reasons for lack of therapy adherence. If a participant continually demonstrated a lack of usage and/or interest and did not express a desire to continue using the RecoverNow tablet, a decision to end their involvement with the study was made by the primary investigator. Once a participant reached the study endpoint, arrangements were made by research personnel to retrieve the tablet.

Primary Outcome: Feasibility

Five criteria were used to establish feasibility and inform a future RCT of treatment efficacy (Table 4.1).

Table 4.1. The five facets of mobile tablet-based therapy feasibility

Facet	Definition	Justification
Recruitment rate	The number of patients enrolled divided by the total number admitted with stroke.	Will be used to determine the total sample size and number of RCT sites.
Adherence rate	The number of patients who completed the full course of the intervention divided by the total number enrolled.	Will be used to inform therapy tolerability.
Retention rate	The number of patients presenting for the 12-week follow-up assessment divided by the total number enrolled.	Will be used to adjust the final RCT sample size calculation.
The proportion of successful follow-up interviews	The number of patients who successfully completed the interview divided by the total number of interview participants.	Will be used to determine the acceptability of the follow-up interview and to predict attrition rates.
Protocol deviations	Deviation related to inclusion/exclusion criteria violations and deviations from therapy protocols.	Will be used to assist with the fine tuning of the RCT protocol.

Follow-Up Interview

All participants, regardless of therapy completion and adherence, were invited to participate in an in-person follow-up interview three months after their initial enrollment. In order to remain flexible, participants were asked to be interviewed within one week of their scheduled three-month completion date, and were invited to conduct a phone interview if unable or unwilling to travel to the Ottawa Hospital for an in-person interview. The final in-person interview consisted of the National Institutes of Health Stroke Scale (NIHSS),[116] Barthel Index (BI),[117,118] Modified Rankin Scale (mRS),[119] and Patient Health Questionnaire (PHQ9).[120-122] The phone-interview consisted of these same measures except the NIHSS. The purpose of the follow-up interview and the measures selected related strictly to evaluating the feasibility of the interview and its content; not to demonstrate efficacy or health improvements over time.

Secondary Outcome: Barriers to Care

We tracked barriers to mobile tablet-based care as a secondary outcome. These barriers were identified to help further refine the RecoverNow platform, improve the protocol of a future randomized controlled trial, and better integrate the platform into current standard stroke care. Although a low risk therapy, we tracked adverse events even if unrelated to the intervention.

Data Analysis

The analysis used descriptive statistics to summarize the characteristics of the stroke population included in the study. The RecoverNow patient set-up process was explored using data points collected at baseline including length of training sessions and details surrounding depression screening. A description of intervention feasibility used the five criteria discussed previously with one notable exception; adherence was lower than expected and require a more in-depth analysis than reporting a single adherence rate.

The analysis of tablet usage habits explored the number of days patients could have potentially used the tablet ("potential tablet days"), the number of days the tablet was actually used by the patients ("days used"), and average daily usage in minutes. We defined one or more minute of usage throughout a day as a day used. During the course of the study, research staff identified a glitch in the collection of tablet usage data. For certain patients, we observed random repetitions of usage statistics from particular days. Although we could be certain that the first usage value observed was true (based on how the RecoverNow platform was programmed to collect usage data), there was no way to determine the true usage statistics for the days filled with repeated values. Therefore, we kept the first usage value and marked the repeated usage values as zero to prevent overestimations of tablet usage.

We created a narrative summary of barriers to care and adverse events encountered during the follow-up period. Analyses of the primary and secondary outcomes included all recruited participants. A sub-group analysis explored expected sources of heterogeneity between participants with SLP needs, OT needs, and those with both needs. This analysis used simple linear regression to test the association between two continuous variables. A Wilcoxon sign-ranked test evaluated the significance between baseline and following PHQ9 scores. All statistical tests used a two-sided alpha set to 5% to determine statistical significance. Statistical analyses used SAS version 9.4, Microsoft Excel 2013, and IBM SPSS version 24.

Ethical Considerations

Due to the low risk of the intervention, and nature of the patient population recruited, a waiver of consent was obtained for this study. Standard care procedures were not interrupted and patient privacy was protected. All confidential patient information was entered into a password protected database document maintained on a secure server. Only study personnel had access to this document. All information contained in the tablets, administration portal and tablet-to-admin portal transmissions were encrypted. This study received Ottawa Hospital ethics approval (20140609-01H).

Results

Recruitment Rate and Participants

The successful enrollment of 30 participants was completed in 15 weeks. The study shut down for two weeks over the winter holidays. Over 15 weeks of enrollment, 107 patients were admitted to the neurovascular unit with acute stroke (Figure 4.1). Of these, 62/107 (58%) met the inclusion criteria. Eighteen patients were excluded because of a lack of deficits, 11 because of palliative needs, and 16 met study exclusion criteria. Of the eligible participants, five refused, one failed enrollment, 17 were repatriated to home hospital prior to being offered the study, and nine were missed. The final sample consisted of 30/62 (48% recruitment rate) of eligible patients (Table 4.2). Recruited participants were mostly male stroke survivors and were at least somewhat familiar with using computers. Over half had experience using touch-screen devices. Most participants (70%) had either OT or both OT and SLP needs. Although most of the strokes occurred in the medial cerebral artery (MCA), six intracranial hemorrhage (ICH) survivors were also recruited.

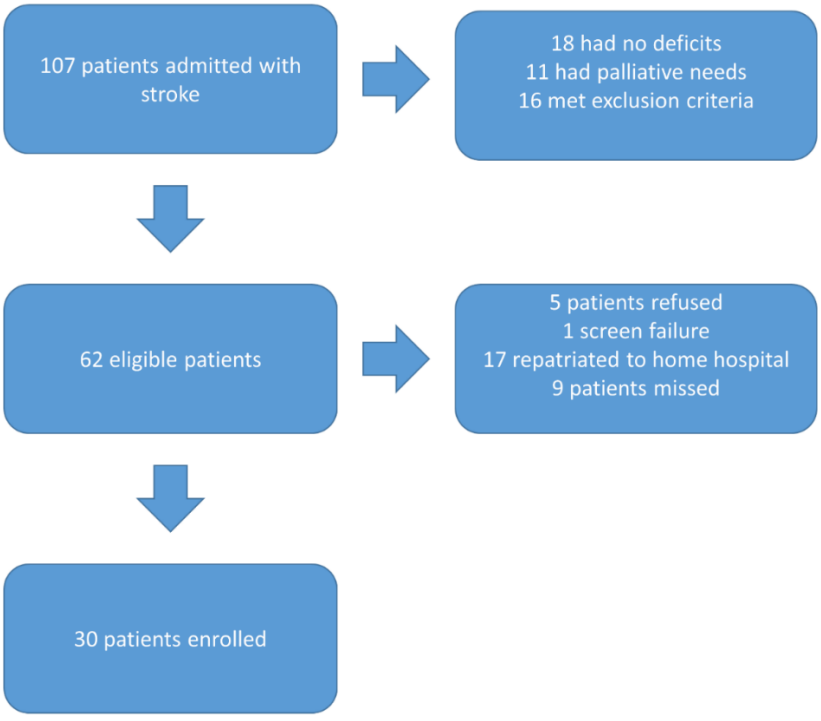


Figure 4.1. Flow chart of patients included in this study

Table 4.2. Participant characteristics

Characteristics	**n (%)**
Sex (% male)	21 (70%)
Age (median, range)	75, 40-95
Type of Stroke	
Ischemic	18 (60%)
ICH	6 (20%)
Others	6 (20%)
Education	
High school (no diploma)	6 (20%)
High school graduate	2 (10%)
College graduate	4 (13%)
University graduate	7 (23%)
Masters	7 (23%)
PhD	0 (0%)
Other	3 (10%)
Computer knowledge	
None	5 (17%)
Beginner	9 (30%)
Average	10 (33%)
Advanced	6 (20%)
Previous touchscreen device usage	
Yes	18 (60%)
No	12 (40%)
Deficits*	
Communication	9 (30%)
Cognitive	14 (47%)
Both	7 (23%)
Alpha-FIM (median, range)	72, 31-116

*Indicates deficits for which tablet-based therapy was assigned. Few patients with very minor OT or SLP deficits did not receive therapy for these deficits based on the clinical judgement of the appropriate allied health professional.

Therapy Initiation

Participants began RecoverNow within a median of four days post-stroke (Table 4.3). RecoverNow set-up, including app assignment, training, consent, depression screening, case-report form completion, and travel time to and from the neurovascular ward took an estimated median time of 41 minutes. Seventy-three percent of participants were successfully screened for depression using the PHQ9, among whom half were able to complete the questionnaire independently with minimal assistance. Two participants declined to answer the PHQ9 questionnaire because they were too tired,

two could not complete because of language barrier, three because of comprehension problems, and one was supposed to complete with their spouse but never did. Thirty-seven percent of screened participants were positive for depression (score of five or above).

Table 4.3. Mobile tablet-based therapy initiation

Therapy Initiation	**Median (Range) / n (%)**
Days post-stroke	4 (1-19)
Days post-admission	4 (1-19)
Initiated within 7-days post-stroke	21 (70%)
Set-up time (minutes)	41 (6-99)
SLP needs only	31 (15-60)
OT needs only	50 (20-94)
SLP and OT needs	35 (6-99)
Successful PHQ9 screen	22 (73%)
Independent	11 (50%)
Assisted	11 (50%)
PHQ9 results*	
Minimal	12 (63%)
Mild	6 (32%)
Moderate	1 (5%)
Moderate-severe	0 (0%)
Severe	0 (0%)

*****n = 19, three PHQ9 scores were lost because of a glitch in the RecoverNow administration portal.

Tablet Usage Habits

Only three participants made it to the final week of the three-month follow-up with their RecoverNow tablet, all other participants had either dropped out and returned the tablet or kept the tablet but abandoned their therapy. Participants accrued a median of 11 potential tablet days before abandoning therapy and used the device a median of five days during this time (Table 4.4). Overall, participants used the device half of the days they could have been engaging in therapy.

Table 4.4. Participant tablet usage habits overall and stratified by setting

	Median (Range)		
	Overall	**Acute Care**	**Post-Discharge**
Frequency (percent)	30 (100%)	30 (100%)	21 (70%)
Potential tablet Days	11 (2-84)	4 (1-15)	14 (0-78)
Days used (=> 1 minute)	5 (1-57)	2 (1-7)	5 (0-51)
% days used (=> 1 minute)	50 (15-100)	60 (15-100)	38 (0-100)
Adherent days (=> 1 hour)	0 (0-48)	0 (0-6)	0 (0-42)
Average daily usage (minutes)	12 (0-212)	13 (3-137)	10 (0-223)

Participants rarely met the one hour/day therapy goal, with the exception of one highly adherent participant who used the device for more than an hour for 57 out of the 73 days they had their tablet. This participant also used the device an average of three and a half hours a day until they could not continue due to worsening health as a result of multiple recurrent strokes. Overall though, average daily usage was low among participants (Figure 4.2) and the percentage of days used was well below 100% among most participants (Figure 4.3). One participant continually expressed a desire to keep the device and use it but rarely engaged in meaningful therapy sessions. Only a single participant voiced displeasure with the assigned apps using the messaging system, other participants did not express opinions about therapy or the device until research staff contacted them by phone.

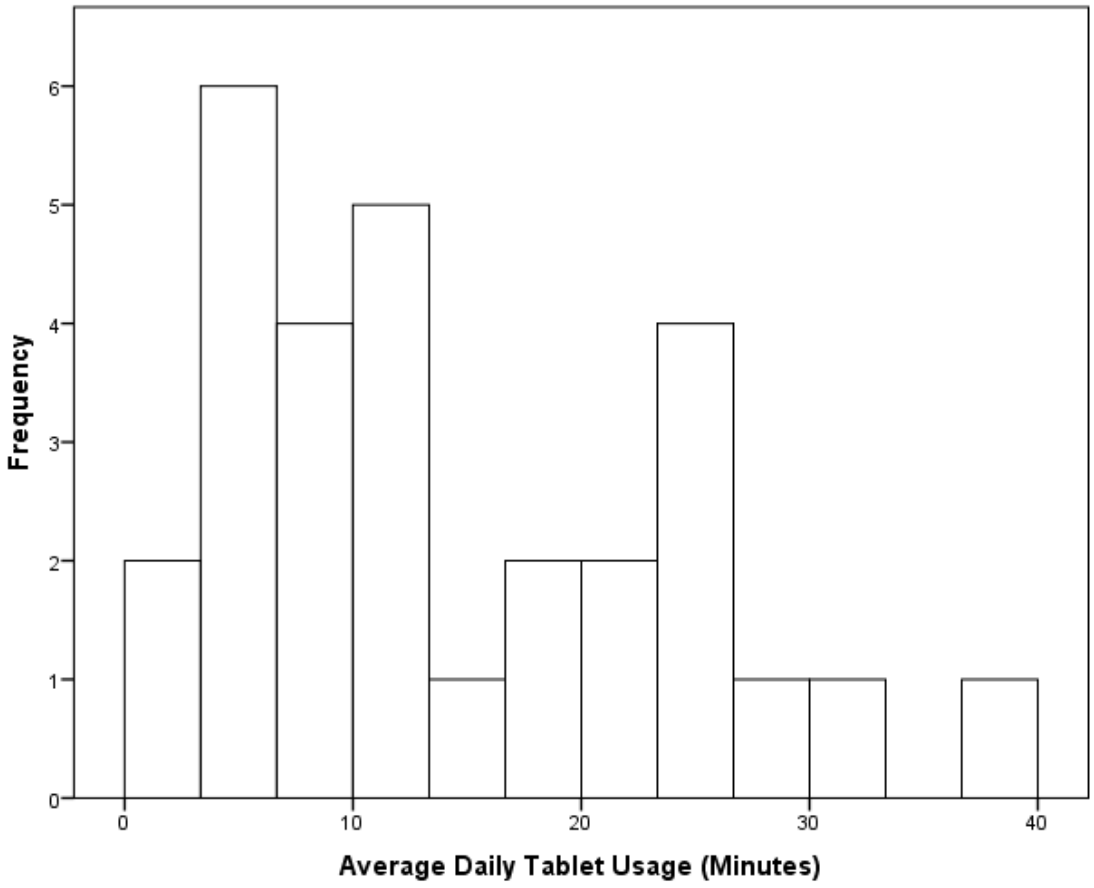


Figure 4.2. Overall average daily tablet usage. One extreme outlying participant was excluded from this figure.

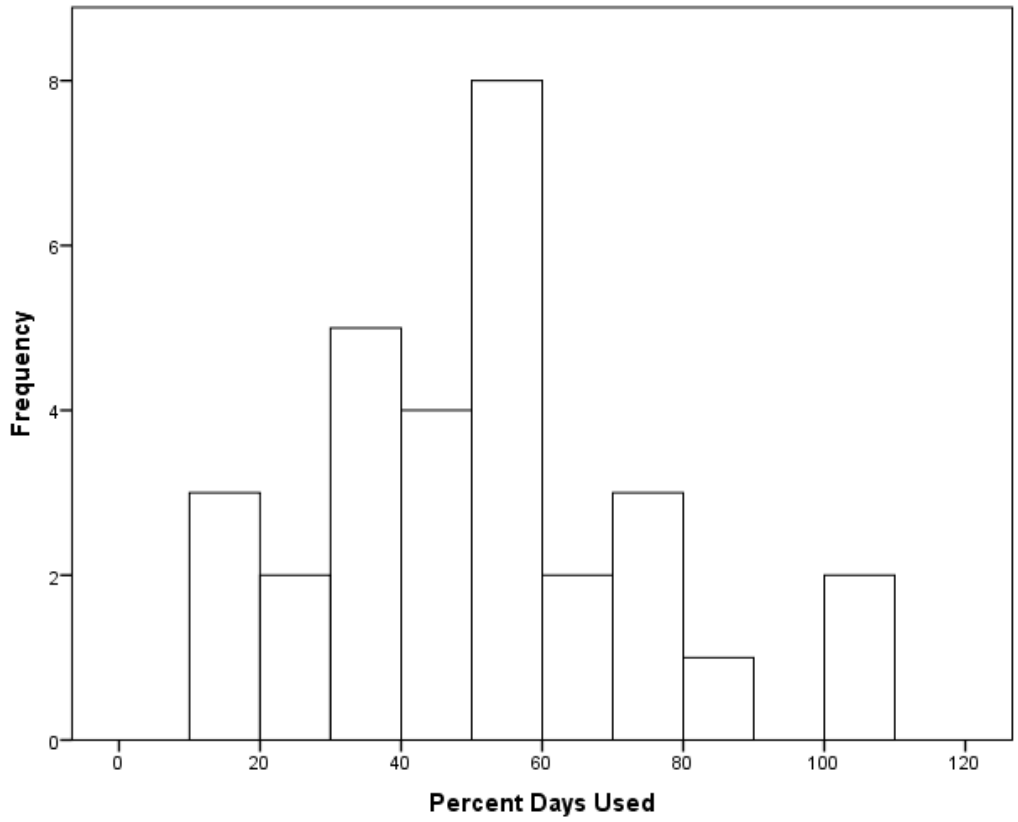


Figure 4.3 Overall percent days RecoverNow was used for 1 minute or more.

Tablet Usage Habits in Acute Care

Most of the invited participants were initially interested in using the device during their acute stay with only five invited patients declining to try the device. No participants dropped out during their acute stay although the tablet was removed from one participants as their condition deteriorated to the point where they could no longer use the device. Participants spent a median of four days in acute care with the tablet during which they used the device a median of two days. Participants used the device a median of 60% of the acute care days where they had access to the tablet. Average daily tablet usage in acute care was well below the one hour a day target (median = 14 minutes/day).

Tablet Usage Habits Post-Discharge

Despite low acute care usage, 21 (70%) participants agreed to take the tablet with them upon being discharged from the hospital. Participants accrued a median of 14 potential tablet days post-

discharge before abandoning therapy. Post-discharge median daily usage and percentage of days used were lower compared to acute care (Table 4.4) and four patients did not use the device at all once discharged. Compared to patients discharged to an inpatient rehabilitation facility, those discharged to home accrued more potential tablet days before abandoning therapy, used it more per day, and for a greater percentage of days (Table 4.5). Patient discharged to inpatient rehabilitation tended to use the device minimally despite accruing a median of 13 potential tablet days before reaching their study endpoint.

Table 4.5. Outpatient usage habits by discharge destination

	Median (Range) / n (%)	
	Inpatient Rehabilitation	Home/Retirement Home
Frequency (percent)	7 (33%)	14 (66%)
Potential tablet days	13 (0-78)	16 (0-77)
Days used (=> 1 minute)	1 (0-36)	7 (0-51)
% days used (=> 1 minute)	7 (0-100)	43 (0-81)
Adherent days (=> 1 hour)	0 (0-12)	1 (0-42)
Average daily usage (minutes)	0 (0-23)	13 (0-223)

Tablet Usage Habits Stratified by Rehabilitation Needs

There was variation in tablet usage habits between patients with different rehabilitative needs. Overall, patients with SLP needs, and both SLP and OT needs accrued the most potential tablet days before abandoning therapy, although all three groups appeared to use the device a similar number of times during this period and accrued very few adherent days. However, patients with both needs had a noticeably higher median daily usage than the other two groups (Table 4.6).

Further differences between groups appeared when stratifying by acute care and post-discharge settings. Participants with SLP needs tended to use the device every day in acute care, much more the other two participant sub-groups. However, it should also be noted these participants spent less time in acute care the other participant sub-groups and therefore accrued less potential tablet days. All patients

with only SLP needs agreed to take the device with them upon discharge, 50% of patients with only OT needs took the device and 71% of patients with both needs took the device.

Table 4.6. Tablet usage habits stratified by patient rehabilitation needs and therapy setting.

	Median (Range) / n (%)		
Overall	SLP Only	OT Only	Both
Frequency (percent)	9 (30%)	14 (47%)	7 (23%)
Potential tablet days	16 (2-60)	8 (3-83)	17 (2-84)
Days used (=> 1 minute)	6 (1-29)	4 (1-14)	5 (1-57)
% days used (=> 1 minute)	45 (25-83)	51 (15-100)	50 (18-78)
Adherent days (=> 1 hour)	0 (0-6)	0 (0-2)	1 (0-48)
Average daily usage (minutes)	11 (5-27)	9 (2-30)	22 (5-212)
Acute care			
Frequency (percent)	9 (30%)	14 (47%)	7 (23%)
Potential tablet days	2 (1-8)	6 (1-15)	7 (1-9)
Days used (=> 1 minute)	1 (1-4)	3 (1-7)	1 (1-6)
% days used (=> 1 minute)	100 (38-100)	59 (15-100)	67 (33-100)
Adherent days (=> 1 hour)	0 (0-1)	0 (0-1)	0 (0-6)
Average daily usage (minutes)	10 (3-33)	12 (3-43)	15 (3-137)
Post-discharge			
Frequency (percent)	9 (43%)	7 (33%)	5 (24%)
Potential tablet days	14 (0-58)	14 (0-78)	64 (6-77)
Days used (=> 1 minute)	5 (0-28)	3 (0-12)	36 (0-51)
% days used (=> 1 minute)	38 (0-81)	15 (0-100)	58 (0-80)
Adherent days (=> 1 hour)	0 (0-5)	0 (0-1)	12 (0-42)
Average daily usage (minutes)	10 (0-26)	2 (0-28)	23 (0-223)

Post-discharge, patients with both SLP and OT needs accrued far more potential tablet days before abandoning therapy than those with either communication or cognitive deficits. Patients with both needs also used the device more often, accrued more adherent days, and had a higher median daily usage than the other two patients groups (Figure 4.4). The SLP and OT needs groups were similar, except those with SLP needs tended to use the device for more minutes a day.

We explored the relationship between participant demographic factors and tablet usage habits to explain the higher usage observed among participants with both rehabilitation needs. Participants with both needs had a median alpha-FIM (on which higher scores are indicated of higher functional ability) between those with only SLP needs and only OT needs. However, the alpha-FIM was only

significantly correlated with the number of times the tablet was used (r = .38, p = .04, n = 30) and not potential tablet days, percentage of days used, adherent days, or daily usage.

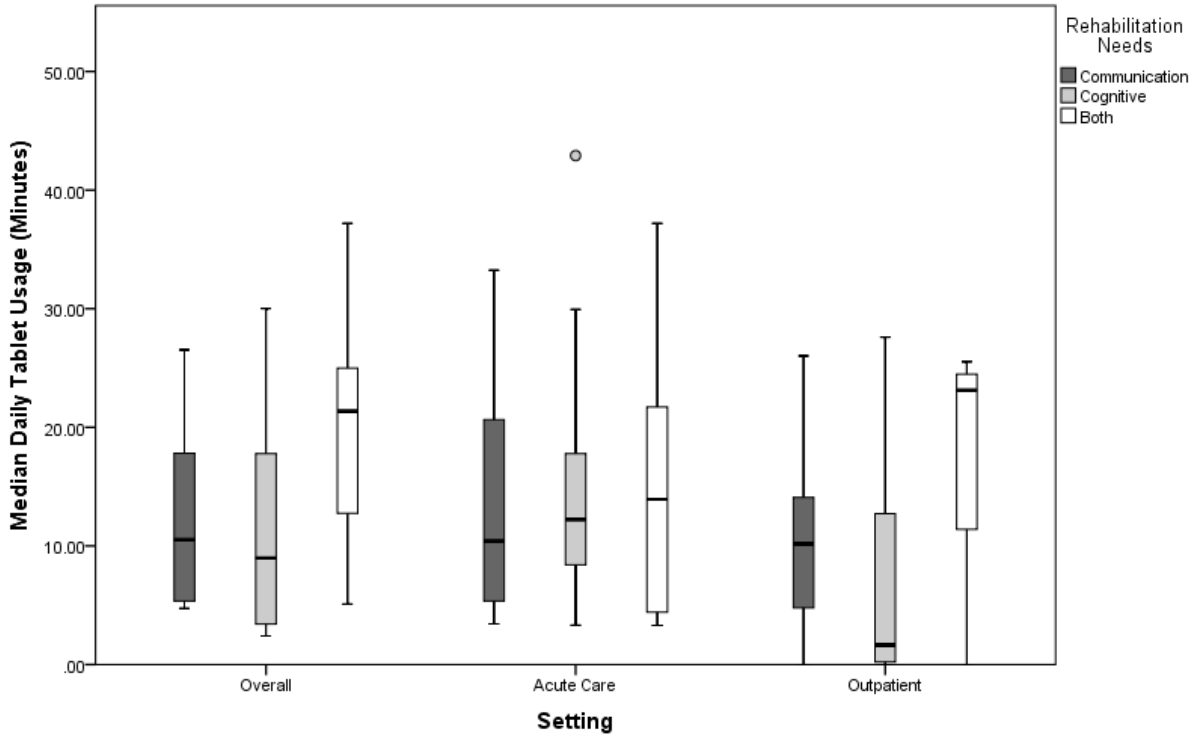


Figure 4.4 Participant median daily tablet usage in minutes by post-stroke deficits and therapy setting.

Retention Rate and Follow-up Interviews

Follow-up interview participation was 77% with only seven participants declining both an in-person or telephone-based interview (Table 4.7). Two participants were terminally ill and could or would not participate in an interview, one expressed that both interview options were inconvenient due to transport and financial challenges. The reasons for not participating from the remaining four participants were either unknown or not given. Only 21% of interviews were conducted during a face-to-face appointment at The Ottawa Hospital Civic Campus, the remaining interviews were telephone-based. Common reasons for declining in-person interviews were the difficulty of commuting to the Hospital Campus. One participant scheduled for an in-person interview was accidentally sent home by an administrative clerk in another part of the hospital when they became lost. The majority of

interviews took place within one week of the scheduled three-month interview date. Interviews falling outside of this range were related to the difficulty contacting participants or participant interview date preferences.

Two phone interviews were conducted with participant caregivers because the participants' communication abilities had deteriorated. These interviews were not considered complete because the PHQ9 questionnaire could not be completed. One further participant could not complete the PHQ9 because of a language barrier. Therefore, 87% of conducted interviews were successfully completed. Interviewed participants had low depression scores (only 21% screened positive with mild or moderate depression) and low levels of disability. Among the twelve participants who completed depression screening at both baseline and follow-up, there was no significant change in PHQ9 scores ($p = 0.37$).

Protocol Deviations

There was only a single deviation from inclusion/exclusion criteria with one enrollment failure due to patient deficits (Table 4.8). This participant was not included in the analyses presented here, nor were they part of the 30 patient convenience sample as they did not complete therapy initiation. There was a single therapy protocol deviation where a patient left before an ordered occupational therapy assessment could be performed. This participant still accrued tablet days with apps assigned for communication deficits and was thus included in the study and analysis. Other deviations were minor and related to research procedures. Patients often left without research staff being notified despite instructions on patient charts. This resulted in the one tablet being lost over the course of the study. Over the course of the study, seven chargers were lost and replacements had to be acquired by staff.

Table 4.7. Retention rate and results of 3-month follow-up interviews.

Follow-up Interview	**Median (Range) / n (%)**
Retained for follow-up interview?	
Yes	23 (77%)
No	7 (23%)
Interview format	
Face-to-face at hospital	5 (21%)
Telephone	18 (78%)
Within one week of 3-month follow-up date?	
Yes	19 (83%)
No	4 (17%)
Interviews completed	20 (87%)
Interview results	
NIHSS (n=5)	1 (0-5)
Modified Rankin Scale (n=23)	2 (0-5)
Barthel Index (n=23)	95 (5-100)
PHQ9 Score (n=20)	3 (0-14)
PHQ9 Results (n=20)	
Minimal	15 (79%)
Mild	3 (16%)
Moderate	1 (5%)
Moderate-severe	0 (0%)
Severe	0 (0%)

Table 4.8. Summary of result for the five feasibility facets

	Median (Range) / % (n)
Recruitment rate	48%
Tablet usage habits (Average daily usage in minutes)	12 (0-212)
Acute care	13 (3-137)
Post-discharge*	10 (0-223)
Retention rate	23 (77%)
Completed interviews**	20 (87%)
Protocol deviations	2

*N = 21, **N = 23

Barriers to Care

Barriers related to the therapy device, patient characteristics, and the surrounding environment or system were identified (Table 4.9). Patients often noted the assigned apps were either too difficult, too easy or not interesting/likeable necessitating the need for therapists to make therapy adjustments via the administration portal. However, therapists were usually only made aware of this when research staff contacted patients by phone after three or more days of non-usage. Despite being part of the training session, only a single participant used the messaging system to communicate their discontent with the assigned therapy, likely due to the number of steps required to send a message.

A few patients expressed frustration due to in-app advertisements in the free version of apps. These apps would periodically take over the entire screen and require patients to repeatedly tap a small button to close the advertisement and return to the game. Notably, this was even challenging for healthy research staff members who were training participant as these advertisements would occasionally refuse to close requiring the application to be re-started. Some patients reported issues with glitches in either the RecoverNow platform or specific apps however, these glitches were not observed by research staff and could reflect patient confusion about how the platform or applications worked. The language of the assigned communication applications was a barrier in one instance. However, this patient had their speech language therapy content translated for them by their caregivers.

Participants frequently had difficulty manipulating the touch-screen due to either the finger isolation required or because of long nails. Many patients had trouble using the device because of worsening health or post-stroke symptoms. A handful of participants either became terminally ill, experienced further strokes, lost the ability to read, could not focus on the device, look at the screen for long periods of time without getting headaches, had difficulty following application instructions, or were too tired to use the device. One participant had forgot their training when contacted by research staff,

likely due to further stroke events. A participant with mobility deficits in acute care noted they were unable to reach the device in the morning because it was placed out of reach. Other patient barriers were generally reflective of good patient health; patients leaving their tablets when they went on trips and being too busy with their daily affairs.

Table 4.9. Identified barriers to mobile tablet-based stroke rehabilitation.

Device Barriers	**Proposed Solution***
App difficulty (too easy/too hard)	Track Performance
Apps with poor touch responsiveness	Adjust sensitivity settings
Disliked app content	Collaborative App Selection
In-app advertisements	Purchase add-free versions of apps
Glitches	Continue development
Language	Select apps with language packs
Patient Barriers	
Fine-motor (dexterity/nails)	Provide stylus pen
Deterioration of health	None
Could not read	Adjust therapy, caregiver assistance
Difficulty focusing on/looking at device	None
Difficulty following instructions	Caregiver assistance
Too tired	None
Forgot training	Provide additional training, train caregiver
Placed out of reach	Bedside tablet sling
Left on trip without tablet	None
Too busy	None
Lost charger, battery died	Case with charger slot/attachment
System Barriers	
Patients discharged without being seen	Communication with hospital staff
Contacting patients	
Discharge to inpatient rehabilitation	Coordinate with rehabilitation centres
Discharged home (out of date information)	Collect preferred contact information

*Proposed solutions elaborated in discussion for frequently encountered barriers

System barriers directly affected research staff which indirectly affected tablet-based care. Poor communication between hospital and research staff resulted in a patient being discharged before research staff could inform the participant they could take the tablet with them. After this point, patients were made aware they could take the tablet upon enrolling. Contacting patients after periods on non-usage was often difficult because patient either had outdated contact information, or were

moved to an inpatient rehabilitation center room without a telephone or the ability to be easily moved to a room with a phone.

Patient sub-groups encountered different barriers to care (Table 4.10). Those with SLP needs tended to lose interest, find therapy too easy, and be too busy. Patients with only OT needs tended to experience barriers related to touch and cognitive issues. Patients with both OT and SLP needs tended to find the assigned therapy too hard. These participants also intended to encounter a number of barriers with a frequency in between those seen with the other two groups (too easy, too busy, touch issues, cognitive issues).

Table 4.10. The frequency of encountered barriers stratified by patient deficits.

Rehabilitation Needs	**Health Issues**	**Lost Interest***	**Too Easy**	**Too Hard**	**Too Busy**	**Too Tired**	**Touch Issues****	**Cognitive Issues*****	**Other Barriers**
SLP	22%	67%	44%	22%	44%	0%	0%	0%	33%
OT	14%	43%	7%	29%	0%	14%	29%	29%	29%
Both	14%	43%	14%	43%	29%	14%	14%	14%	29%

*Disliked therapy content or felt therapy was not helping.
** Fine-motor (nails and dexterity) or difficulty with poor app responsiveness.
***Difficulty focusing on tablet, difficulty looking at tablet, difficulty following instructions.

Patients experienced some difficulties using the PHQ9 screening questionnaire (Table 4.11). Some participants had difficulty reading the PHQ9 questions and selecting response radio buttons because of their small size. This was difficult even when patients requiring reading glasses had them on hand. One patient had difficulty with the questionnaire because of the amount of content displayed on screen at once: instructions, all of the questions, the response choices, and the all of the response bubbles for each questions. The screen only included the English version of the PHQ9 so patients without sufficient English language abilities could not complete depression screening. A number of patients could not be screened due to aphasia or if aphasia was mild, could be screened but needed to the questionnaire read to them. Similarly, patients with visual neglect needed questions read and the answers inputted into the device for them. Other patients refused, or wish to be screened later and were discharged before screening could be completed.

Table 4.11. Barriers to tablet-based post-stroke depression screening

Device Barriers	**Proposed Solution**
Small fonts and buttons	Make fonts and buttons larger
Overwhelming information	Present one question at a time
English-only screen	Include language options
Patient Barriers	
Aphasia	If mild, read questions to patient
Visual neglect	Read questions and select options for patient
Patient refusal	None
System Barriers	
Patients discharged before being screened	Remind patients to complete screen

Adverse Events

Six participants experienced adverse health events unrelated to the tablet-based therapy. Three patients experienced further stroke events, two patients became terminally ill, and another caught a gastro-intestinal illness during their inpatient rehabilitation stay. These events either occurred after therapy had been abandoned or led to therapy being abandoned. The one highly adherent patient was readmitted after another stroke and presented with worsened communication deficits and new cognitive and fine-motor deficits. Despite this, they continued to be highly adherent until further strokes rendered them unable to use the tablet.

Discussion

Recruitment of 30 patients was completed in 15 weeks with few patients being missed or declining to participate. Despite initial interest in using tablet technology for therapeutic purposes, therapy adherence was low, likely due to the barriers to care identified throughout follow-up. Most patients were retained for a follow-up interview and were able to complete an in-person or telephone interview. The study implications and limitations are discussed below.

Recruitment Rate

The ease and speed with which participants were recruited reflected the general interest by patients in using tablet technology for therapy.[85,90] During the 15 weeks of study recruitment there were 107 stroke, of which 67 (58%) met study inclusion criteria. Unexpectedly, 17 eligible patients were

repatriated to their home hospital before being offered to join the study. Repatriation has become common practice for patient undergoing thrombectomy with patients being sent to The Ottawa Hospital for the procedure and then returned to their home hospital upon procedure completion. Trials will need to account for this occurrence as thrombectomy is a standard of care procedure and repatriation from procedure-performing centres is common across North America. Excluding these participants would lead to a lower recruitment rate, however partnering with nearby community hospitals would help to capture these patients and improve the number of stroke survivors eligible for participation.

Therapy Initiation

Therapy was initiated a median of four days post-stroke, earlier than previous RecoverNow studies in response to feedback from the RecoverNow patient engagement survey indicating patients preferred to start therapy earlier.[90] The time required to train participants was fairly short, rarely exceeding more than 1 hour. Higher functioning patients, especially those with previous tablet experience may not require as extensive training as other patients and could be left to explore the device independently. This independent discovery of the device may encourage participants to continue using the device and would lower the amount of time acute care personnel would have to dedicate to training sessions.

Tablet-Based Depression Screening

Tablet-based screening of stroke patients for depression appears to be feasible in the acute setting with the majority of participants successfully completing screening despite encountered barriers. The PHQ9's presentation should be tailored to the stroke population to increase the proportion of patients who can complete screening with minimal assistance. Specifically, providing large buttons for indicated responses, large text for easy reading, and presentation of questions on the screen one by one in order to avoid overwhelming responders. However, it is likely that patients with visual neglect and

certain degrees of receptive aphasia will always require assistance to complete tablet-based depression screening.

Among all participants who completed the screen, 37% of participants were positive for depression which agrees with previous post-stroke depression literature.[6] Despite depression being a common post-stroke complication and depression screening being a part of clinical guidelines, screening is often not performed.[69] This is thought to be due to a number of factors including patient hesitation to discuss depression during the acute care period. Patients may feel more comfortable performing a tablet-based screen independently instead of discussing their mental health face-to-face with a healthcare practitioner. However, it is essential the results of these tablet-based questionnaires be collected and reviewed by a healthcare professional, and that guideline-based care is offered to patients screening positive for post-stroke depression.

Tablet Usage Habits and Barriers to Care

Previous RecoverNow studies found patients with mild aphasia used the tablet formore than one hour a day during their acute stay.[89] The next phase found patients with both aphasia and cognitive deficits were interested in using the device and that 1 hour a day of therapy was reasonable.[90] However, patient adherence to the one hour a day therapy regiment was almost non-existent and patients engaged in tablet therapy far less than expected.

Tablet Usage Habits: From Acute Care to Discharge Destination

We had hypothesized that patients could use their time in acute care to engage in tablet-based therapy due to the lack activities available for promoting recovery.[75] It was also suggested that because of the inaccessibility of inpatient and community rehabilitation services, patients unable to access these services could use the device to access therapy.[76-81] Patients spent very little time engaging in tablet-based therapy both inside and outside of acute care. Discharged destination was also related to tablet usage habits as patients discharged to inpatient rehabilitation barely used the devices at all compared to

those discharged home, perhaps reflecting satisfaction with the amount of therapy from traditional rehabilitation services.

Barriers to Care and Tablet Usage Habits

The low tablet usage both inside and outside of acute care can be at least partially explained by the various barriers to care encountered by patients. Many participants had issues with therapy difficulty (either too easy or too hard), the fine-motor skills required (due to impaired dexterity, long nails, or poor touch-response by certain applications), and cognitive issues (trouble paying attention, following complex instructions, looking at the device for long periods of time). Others lost interest in using the device either because they disliked the therapy content or because they felt like the device was not helping with their deficits.

The convenience and usability of tablet-based therapies were reported as being an important aspect of therapy administration by participants in studies conducted by other research teams.[98,99,105] The low usage seen in this study in comparison to previous RecoverNow cohorts may also reflect design flaws unique to this new iteration of RecoverNow. Participants reported miscellaneous glitches, and even though these appeared to disappear when research staff was present, they likely frustrated patients. A wider variety of applications was used in order to include therapy for participants with cognitive and fine-motor deficits. Free versions of apps were used to save costs, many of which contained ads which were difficult to close, which led to participant frustration.

The Importance of Regular Patient Contact

Regular patient contact during the follow-up period turned out to be an important part of the therapy procedure. Only a single user used the messaging system to express their displeasure with the assigned therapy. Patients may have forgotten about the messaging system or found it too complex to use as multiple steps needed to be followed: (1) navigate to the RecoverNow homepage if in an application, (2) click on the message button, (3) click a button acknowledging that it may take some time

for therapists to read the message, (4) select a message to be sent. Furthermore, the font size and radio button options for the messaging were small which may have added further difficulty.

Only when contacted by research staff did patients express opinions about therapy. Future studies should consider using simplified messaging systems or consider other means for keeping regular contact with patients. Other tablet-based therapy studies with stroke patients have used regularly scheduled teleconferences to stay in touch with patients, although this requires a high-quality internet connection that may not be available to all stroke survivors.[99,104] Regardless of the method used to stay in regular contact with patients, it should be simple and convenient.

Patient Characteristics, Barriers to Care, and Tablet Usage Habits

This study offered tablet-based therapy to acute stroke patients with a broader range and severity of deficits than previous RecoverNow[89,90] to improve our understanding of treatment feasibility. Specifically it was unclear how acute stroke patients with mild-to-moderate OT needs, particular those with cognitive deficits would adhere to a tablet-based therapy without any regularly scheduled meetings with clinicians. There were notable variations in usage habits and barriers encountered between participants with different deficits.

Patients with only SLP needs kept the tablet for fewer days than those with OT or both needs. These patients tended to be less disabled (as indicated by alpha-FIM scores) and were quickly discharged. These patients also reported barriers seemingly reflective of higher functioning more frequently than the other two patient groups: they had lost interest in using the device, the tasks were too easy, or they were too busy with their daily affairs. This combination of being highly functional and being able to quickly leave acute care and return to their daily life may have led these patients to quickly lose interest in tablet therapy.

The usage habits of patients with OT needs were similar to those with SLP needs, and only marginally lower than those with both deficits within the acute setting. However, far more of these

patients declined to take the device upon discharge. Those who did agree to take the device used it less frequently and for shorter sessions than the other patient sub-groups because of frequently encountered barriers to care. It is not surprising these patients experience difficulty using the tablet as a certain level of finger dexterity and cognitive ability is needed to manipulate the device without frustration. Although RecoverNow was administered with the intention of patients being able to engage in therapy independently without assistance, these patients could likely overcome their difficulties and engage in tablet-based therapy with some help from family or caregivers.[85,90]

Patients with both SLP and OT needs used the device the most overall. There are a few possible explanations for why this group of participants had better usage habits than the other groups. Patient with both needs may have been neither too disabled to use the device, nor too healthy to lose interest in therapy. It may be that a more nuanced profile of patient deficits beyond the assignment of mild or moderate disability and SLP and/or OT needs is needed to identify the ideal tablet therapy candidate post-stroke. Patients with both SLP and OT needs may have been assigned therapy content better matching their preferences compared to other groups because of the large number of apps needed to treat their deficits. This may reflect the importance of providing patients with therapy options and then collaborating to choose a therapy course that will be both beneficial for the patient as well as interesting. Patients with both needs also distinguished themselves from the other two groups by having the highest proportion of patients with previously tablet or touchscreen experience. Asking acute stroke patients to learn new technology while they are still dealing with the frustrations of their newly limited abilities could lead to low usage.

Retention Rate and Interview Completion

Patients were not interested in returning for an in-person interview preferring the convenience of a phone interview. Patients may not have felt required to return because they did not need to sign a consent form laying out study expectations. Participants may not have been interested in coming for an

interview without the promise of being able to access a physician. Participants often noted the need to drive far distances, arrange transportation, and finding parking as deterrents. Other participant also noted significant mobility difficulties as complicating the logistics of arranging an in-person interview at the hospital and expressed a desire to perform a phone interview instead. However, most interviews were completed once initiated.

Protocol Deviations

Only two major protocol deviations related to inclusion/exclusion criteria and therapy procedures were encountered throughout the study. The clear criteria set for eligible patients and the smooth integration of a simple intervention into existing therapy procedures in the acute setting likely contributed to the small number of protocol deviations observed.

Limitations

The focus on feasibility and characteristics of the current RecoverNow platform led to some limitations. Patient performance on assigned applications was not measured meaning it was not possible to determine if patients were improving on therapy activities. This was a necessary trade-off, which gave therapists the flexibility to add new apps to the RecoverNow tablets as patient needs changed. There were glitches in the usage data causing seemingly random repetitions of certain data points. This issue was dealt with conservatively by assigned a usage of zero minutes for the repeated values. The usage data does not reflect whether patients were actively engaging with the applications or idly interacting with the device. However, a threshold was set to try and separate non-significant tablet activity from true attempts at engaging in therapy. Although there were no means of identifying who actually used the RecoverNow tablets, therapists and research staff made it clear during the training phase that the tablet was solely intended to be used for the patient's recovery activities.

The sample size for this study was small, however this was by design. A small convenience sample was desired to quickly collect information of the feasibility of the current iteration of

RecoverNow. Although this meant no reliable preliminary estimates of treatment efficacy could be calculated, this was not a study goal. The follow-up interview did not include any qualitative section where patients could reflect upon their experience with the RecoverNow tablet. However, the main purpose of the interviews was to determine patient willingness to present for a follow-up interview.

Moving Forward

A number of lessons have learned about the feasibility of early mobile-tablet based therapy following stroke. The reported findings can be used to help guide others interested in developing and providing tablet-based stroke therapy interventions and inform protocols for further studies. A few lessons in particular are worth reiterating:

- Acute stroke patients are generally interested in at least attempting tablet-based therapy and are willing to start within their first-week post-stroke.
- Not all acute stroke patients are suitable for tablet-based therapy; careful consideration of patient deficits is required to identify patients likely to successfully and consistently engage in tablet-based therapy following stroke.
- The tablet-based therapy interface needs to be tailored to the stroke population to make it as easy to use as possible to promote therapy engagement and minimize frustration.
- Providing a wide variety of application choices, and the opportunity for patients to collaborate with therapists on the selection of treatment content may be important in maximizing patient interest in therapy.
- Patients with no previous tablet experience may initially require more time and assistance to successfully and consistently engage in tablet therapy following stroke.
- Regular contact with patients using a simple and convenient method is important to promote consistent therapy engagement by addressing barriers to care.

- Patients prefer the convenience of telephone interviews; these should be offered to maximize participation in follow-up interviews.

Conclusions

Mobile tablet-based stroke rehabilitation from acute care to discharge destination may be challenging under certain conditions because of frequently encountered barriers to care. Reducing the frequency of the most common barriers to tablet-based care is essential for therapy to be successful. Mobile tablet-based therapies may only improve access to early stroke rehabilitation for particular patients and with frequent and convenient patient-therapist contact.

Chapter Summary

This chapter reported the results of a cohort study designed to further our understanding of the feasibility of early mobile tablet-based stroke rehabilitation. This study built upon the tablet-based therapy literature by initiating therapy in the acute care setting and continuing therapy throughout the acute phase of stroke regardless of setting. This study also built on previous RecoverNow studies by including participants with mild to moderate SLP and OT needs, and by including tablet-based depression screening. The next chapter will discuss the current state of the mobile tablet-based stroke rehabilitation literature in light of the findings reported in this thesis, and provide suggestions for future research.

Appendix 4.1 – RecoverNow Application List

Appendix Table 4.1. RecoverNow Application List

Application Name	
Anagram Twist	Magic Piano
Awesome Memory	Math Academy
Bingo	Memory Matches
Blankety-Blank	Memory Matches 2
Boggle for Tablet	Morphos
Calculator Free	My Mosaic
Candy Crush	Parking Mania Free
Chain of Thought	Piano Free With Songs
Constant Therapy	Pop Words
Counting Money	RhymieStymie
Crossy Road	Scrabble
Dexteria	Search 4 It
Dr. Driving	Series 1
Einstein Brain trainer HD	Slide Me Out
Fit Brains	Smash Hit
Flow Free	Solitaire
Fruit Ninja	Sudoku by Ticbits
Get+Together	Tactus Therapy
Glow Puzzle	This is to That
iVolution	Word Explorer
Jigty Jigsaw Puzzle	Yahtzee
Just Saying	
Lumosity	

Chapter 5. Mobile Tablet-Based Stroke Rehabilitation Research

Stroke is a growing global burden affecting millions of people every year leaving many survivors with a variety of deficits preventing them from functioning independently.[1-8] Although stroke rehabilitation effectively improves post-stroke deficits,[12-14,16-19] many patients have difficulty accessing therapies in the acute,[75] inpatient[76,79], and outpatient settings due to a lack of resources.[80,81] The barriers to accessing timely stroke rehabilitation care and the current, rapidly-evolving state of mobile technology, has created an opportunity to explore the possibilities of providing tablet-based stroke care in order to improve access to rehabilitation. Of particular interest is providing the possibility of providing tablet-based rehabilitation in the acute setting as earlier stroke initiation is associated with improved recovery compared to later initiation.[13,14,16-19] The scoping review and cohort study reported in this thesis were undertaken to summarize and advance our understanding of treatment feasibility, a necessary step before studies of treatment efficacy are commenced.

The Current State of Mobile Tablet-Based Stroke Rehabilitation Research

The scoping review described a field consisting of small observational studies focusing mostly on chronic or subacute stroke patients and attempting interventions for communication or fine-motor skills. The overall patient experience reported by the included studies was positive although a number of barriers to tablet-based care were identified. In spite of these barriers, we were able to conclude that a variety of home and inpatient-based MTBTs may be feasible for subacute and chronic stroke patients however, we were not able to make the same conclusions for acute stroke patients. The review identified two important knowledge gaps with regards to feasibility: (1) treatment adherence, and (2) the feasibility of tablet-based therapy for acute stroke patients.

Treatment adherence is a major component of treatment feasibility as it logically follows that in order for a treatment to be efficacious, patients must adhere to the prescribed treatment regimen. Stroke rehabilitation studies in particular have shown that more intensive therapies results in greater

functional recovery,[10,16-19,62] highlighting the need track therapy adherence as a study of treatment efficacy would likely be negative if patients do not adhere to their tablet-based therapy regimens. It is certainly possible to track tablet-based therapy adherence with RecoverNow using application analytics to track daily tablet usage, although our implementation of this method was found to be flawed (see chapter four). However, other strategies are possible but likely require the expertise of software engineers rather than epidemiologists.

Research on tablet-based therapy for acute stroke patients was limited to the previous two RecoverNow studies, the results of which suggested patients were highly interested in tablet-based therapy and highly adherent. However, the third RecoverNow study included in this thesis reported very low therapy adherence, likely due to higher than anticipated frequency of barriers to care. Patients did not contact the study team or therapists when they encountered a barrier to care, rather they waited to be contacted and temporarily abandoned therapy until the issues was resolved. Disappointing as it may appear at first glance to see a study with low therapy adherence, many important lessons were learned. These are valuable lessons we can carry forward into future studies to improve the administration of tablet-based acute stroke rehabilitation therapies. These improvements will lead to minimization of known barriers to tablet-based care and in turn maximize therapy adherence.

The Continued Advancement of Mobile Tablet-Based Stroke Rehabilitation Research

Feasibility studies of tablet-based care should continue, even for frequently-studied communication and fine-motor deficits, to determine the administrative methods that minimize barriers to care and maximize treatment adherence. These studies could benefit from an iterative testing design where the tablet-based intervention is improved throughout the course of the study based on user feedback. Incorporating user experiences on an ongoing basis could improve tablet administrative methods and features faster than restrictive study designs that do not allow the intervention to evolve through the study. Studies of treatment efficacy may be appropriate for interventions with well

understood barriers to care, refined administrative methods, and adequate treatment adherence. Based on the collective results of three feasibility studies, RecoverNow will move onto establishing the efficacy of tablet-based communication therapy in the acute setting. The lessons learned here will be used to refine therapy administration and in particular, improve patient-therapist communication.

Final Conclusions

Mobile tablet-based therapy is a new field and the feasibility of providing effective stroke rehabilitation care remains unknown. Continued advancements of tablet-based therapies following stroke depends on improving upon past studies and striving for high-quality research which attempt to fill research gaps and improve upon interventions targeting for frequently targeted deficits. As the worlds' population continues to age, stroke survivors will continue to need access to stroke rehabilitation, and in order to keep up with demand, resource-efficient means are needed to compensate for the lack of therapists and limited space in rehabilitation facilities. Mobile tablet-based therapy may not be a solution for all stroke survivors, but may be able to help improve therapy-access and maximize recovery for a significant number of stroke survivors.

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