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An investigation into the implementation of robot-assisted upper limb therapy within an Australian rehabilitative setting

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An investigation into the implementation of robot-assisted upper limb therapy within an Australian rehabilitative setting.

Nicholas Mark Flynn

A thesis submitted in total fulfilment of the requirements of the degree

Doctor of Philosophy (PhD by/with publication)

School of Allied Health
Faculty of Health Sciences
Australian Catholic University
1100 Nudgee Rd, Banyo

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Statement of Authorship

This thesis contains no material that has been extracted in whole or in part from a thesis that PhD candidate had submitted towards the award of any other degree or diploma in any other tertiary institution. No other person's work has been used without due acknowledgment in the main text of the thesis. All research procedures reported in the thesis received the approval of the relevant ethics/safety committees (where required).

The PhD candidate was principally involved in the ethics, literature review, design, applications, recruitment, data collection and analysis, manuscript and thesis preparation for Studies 1 to 4. The candidate was also primarily involved in presentation of research at national and local conferences.

Paul Bew, Clinical Lead physiotherapist, was chiefly responsible for the procurement and implementation of the InMotion device at the Brighton Rehabilitation Unit. He also provided the opportunity for a research project to be set up around the InMotion and was also involved in the initial design of the research program before his retirement.

Jessica Dennis, physiotherapist at Brighton Rehabilitation Unit, also contributed to recruitment, data collection methods and drafting of manuscript (Study 2 and 3) as well as fulfilling the role of industry-based representative on the research team.

Supervisors Professor Suzanne Kuys, Professor Elspeth Froude and Dr Deirdre Cooke were involved with considerable contributions in study design, review of drafts for ethical applications, data analysis and interpretation, and drafting of manuscripts and thesis chapters. Dr Michael Steele, biostatistician, contributed to data analysis (Study 2 and 3). For all co-authored manuscripts, the candidate was involved in the experimental design, performed data acquisition, analysed the data, interpreted results, and drafted and critically reviewed the manuscripts.

Name: Nicholas Mark Flynn

Signature: [redacted]

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"For precept must be upon precept, precept upon precept; line upon line, line upon line; here a little, and there a little." Isaiah 28:10

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Publications included in this thesis

- Study 1 – Flynn, N., Kuys, S., Froude, E., & Cooke, D. (2019). Introducing robotic upper limb training into routine clinical practice for stroke survivors: Perceptions of occupational therapists and physiotherapists. *Australian Occupational Therapy Journal*, 66(4), 530-538. https://doi.org/10.1111/1440-1630.12594

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Presentations

1. Guest speaker Queensland Physiotherapy Rehabilitation Network presenting outcomes of thesis literature review as well as results of Study 2 and Study 4, 11th November 2022.
2. Guest speaker at Motus Academy international webinar "Upper Limb Robotics: A Clinicians' Perspective" presenting results of Study 4, 24th February 2022. The Motus Academy is an international association providing continuing education in the area of robotics and advanced technologies as applied to healthcare. The PhD candidate is also a member of the Motus Academy international panel of experts.
3. Invited speaker to Master of Rehabilitation Post Graduate Program at Australian Catholic University and presented outcomes of thesis literature review and results of Study 2 - 19th April 2021.
4. Invited speaker to Better Rehabilitation evening workshop and presented results of Study 2 - 17th September 2020.
5. Invited speaker Brighton Research Advancement Committee Research Recap and presented overview of research program – 9th July 2019.

6. Invited speaker Centre for Disability and Development Research (CeDDR) Research Seminar and presented overview of research program – 18th April 2019.

7. Poster presentation at Smart Strokes 2021 "Upper limb practice by stroke survivors pre and post implementation of robot assisted upper limb therapy" (Study 2) – 12th August 2021

8. Poster presentation 9th August 2018 Smart Strokes Conference 2018 Sydney "Occupational therapists and physiotherapists perceptions of the introduction of robot-assisted upper limb therapy into their routine clinical practice" (Study 1).

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Abstract

Background: Robot-assisted upper limb therapy (RT-UL) is an emerging intervention for stroke survivors with upper limb (UL) impairments. Research into RT-UL has concentrated on investigating the clinical efficacy but implementation and use of RT-UL in routine practice has not yet been adequately explored. This is a notable gap in the field when considering that non-adoption and abandonment is common for health technologies in the clinical setting. The aim of this doctoral research program was to investigate the implementation and use of the InMotion, RT-UL device, for the first time in an Australian clinical setting.

Methods: A multiple methods approach was used in this program of research involving four studies, two qualitative and two quantitative. Study 1 explored therapists' perceptions of RT-UL prior to the implementation through discipline specific focus groups. Study 2 was an observational study that investigated the amount of UL practice performed by subacute stroke survivors pre and post RT-UL implementation. Study 3 involved audits of RT-UL computer data to investigate the sustainability of RT-UL as part of routine practice over a two-year period. Study 4 explored therapist perceptions of the RT-UL post implementation through discipline specific focus groups.

Results: Study 1 identified therapists were positive towards the implementation of RT-UL perceiving the device would provide opportunity for increased UL practice for strokes survivors in their clinical setting. The availability of a single RT-UL device may however create unique logistical challenges. Study 2 observed a significant increase in UL practice for stroke survivors including those with severe UL impairment following the implementation of RT-UL as part of routine practice. Study 3 discovered that RT-UL was in continued and regular use with stroke survivors two years after implementation. Study 4 found both disciplines continued to be accepting of RT-UL post implementation but it was physiotherapists who predominantly prescribed RT-UL. Implementation of RT-UL had been largely successful due to an increased level of UL practice for patients, the ease of using the device as part of routine practice and positive reception from patients. The implementation process was also clinician initiated and led.

Conclusion: This research program was the first to evaluate the implementation of RT-UL into the routine practices of an Australian rehabilitation setting. New knowledge was acquired about RT-UL use with stroke survivors including occupational therapists and physiotherapists perceptions, impact on the amount of UL practice able to be delivered, sustainability of RT-UL within the inpatient rehabilitation setting and barriers and facilitator to RT-UL implementation.

Abbreviations

ACU = Australian Catholic University

ADL = Activities of daily living

AMAT= Arm Motor Ability Test

ARAT= Action Research Arm Test

BI= Barthel Index

BBT= Box and Blocks Test

CAHAI = Chedoke Arm and Hand Activity Inventory

CIMT = Constraint induced movement therapy

FIM = Functional Independence Measure

FMA-UE = Fugl Meyer Assessment of the Upper Extremity

GRASP = Graded Repetitive Arm Supplementary Program

HREC = Hospital Human Research Ethics Committee

LH = Life Habits

MAL = Motor Activity Log

MIT-Manus = Massachusetts Institute of Technology Manus

MAS = Motor Assessment Scale

Memos = MEchatronic system for MOtor recovery after Stroke

MIS = Motricity Index Score

Mrs = modified Rankin Scale

PICF = Participant Information and Consent Form

QuickDASH = Quick version of the Disabilities of the Arm, Shoulder, and Hand

RT-UL = Robot-assisted upper limb therapy

SF-36 = The 36-Item Short Form Health Survey

SIS = Stroke Impact Score

SPSS = Statistical Package for the Social Sciences

SUS = System Usability Scale

TDF = Theoretical Domain Framework

UL = Upper limb

Chapter 1 – Introduction and background

Stroke is a leading cause of death and disability in Australia (Deloitte Access Economics, 2020). In 2020 an estimated 27,428 Australians experienced a stroke and a total of 445,087 Australians were living with the effects of stroke (Deloitte Access Economics, 2020). The majority of stroke survivors experience impairment in the upper limb (UL) with few going on to achieve complete recovery of the UL (Winstein et al., 2016). Upper limb impairment is a primary contributor to disability and associated with reduced quality of life for stroke survivors (Faria-Fortini et al., 2011; Morris et al., 2013). It is important that effective and viable approaches to rehabilitation of the UL following stroke are identified and successfully implemented within routine practice. Robot-assisted upper limb therapy (RT-UL) has been proposed to be one such intervention.

In broad terms, RT-UL involves the retraining of the UL by the application of an electromechanical device to the person's UL to assist with and facilitate the repetitive performance of prescribed UL movements (Mehrholz et al., 2018; Veerbeek et al., 2017). RT-UL is purported to provide retraining that is motivating, intensive, repetitive and requiring minimal therapist input (Morone et al., 2020). Over the past two decades there has been a growing body of evidence supporting the efficacy of RT-UL (Morone et al., 2020) and since the commencement of this research program in 2016 a number of new RT-UL clinical trials (Aprile et al., 2020; Dehem et al., 2019; Rodger et al., 2019) and systematic reviews have been published (Chen et al., 2020; Ferreira et al., 2021; Mehrholz, 2019; Veerbeek et al., 2017; Wu et al., 2021). RT-UL has been established as an effective intervention for improving UL strength and motor function and is recommended globally in stroke guidelines (Mehrholz et al., 2018; Morone et al., 2021; Stroke Foundation, 2022; Wu et al., 2021). Alongside Australia, countries with RT-UL recommended as part of national guidelines include Scotland, New Zealand, Netherlands, Canada, United Kingdom and Unites States of America.

Coinciding with the increase in RT-UL evidence has been the increased implementation of RT-ULinto routine practice (Morone et al., 2020). Although not available universally in Australia, RT-UL is now used with stroke survivors in a number of Australian rehabilitation facilities (Stroke Foundation, 2022). This emergence of RT-UL is reflective of the ongoing need for clinicians to improve the quality and quantity of UL practice for stroke survivors, and in particular those who have severe UL impairment (Hayward et al., 2021). There is also an onus on clinicians to be engaging with new technology to improve rehabilitation outcomes. Notably, the World Federation of Occupational Therapists (WFOT) designated the use of technology by occupational therapists as one of the professions top eight research priorities (Mackenzie et al., 2017).

The focus of robot-assisted therapy research has been on determining the efficacy of RT-UL for stroke survivors, and there has been limited exploration of the implementation of RT-UL once in the clinical setting. It is well known that new health technologies are not always readily adopted into routine practice and in some cases abandoned (Greenhalgh et al., 2017). The implementation of RT-UL in practice is important when considering the potential benefits of RT-UL for stroke survivors but also the significant financial outlay associated with the implementation of these robotic devices. Further investigation of the implementation of RT-UL into routine practice is needed and this was the focus of this research program.

1.1 Aims of this thesis

The overall aim of this doctoral research program was to investigate the use of the InMotion robotic device as it was implemented for the first time into an Australian clinical setting. The principal research outcome of this research program was to address the current gap in understanding relating to implementation of RT-UL into routine practice, and to provide substantial and practical guidance to clinicians involved in the rehabilitation of stroke survivors.

The implementation process for the InMotion device was investigated against eight outcome measures of implementation success (Proctor et al., 2011): acceptability, sustainability, feasibility, appropriateness, fidelity, penetration, implementation cost and adoption. An in-depth investigation of all eight implementation outcomes was beyond the scope of this research program. Consequently, acceptability, sustainability and feasibility were given priority and considered primary outcome measures for this research program with the remaining five outcome measures considered secondary outcome measures. Table 1.1 defines each of the eight implementation outcomes, the study in which each outcome was investigated and how each of the outcome was measured.

Table 1.1 Definitions and measurement of implementation outcomes for each of the studies

Implementation Outcomes	Definition	Study	Measurement
Primary outcomes			
Acceptability	Perception among implementation stakeholders (e.g. therapists) that a new intervention is agreeable, palatable, or satisfactory within a particular clinical setting.	Studies 1 & 4	Pre and post implementation focus groups with treating therapists System Usability Scale
Sustainability	Extent to which a newly implemented intervention is maintained within a service setting's ongoing, stable operations.	Study 3	Audit of RT-UL computer data
Feasibility	Extent to which new intervention can be successfully used or carried out within a given agency or setting	Studies 2 & 3	Observation of sub-acute stroke survivors therapy sessions Audit of RT-UL computer data
Secondary outcomes			
Appropriateness	Perceived fit, relevance, or compatibility of new intervention for a given practice setting, provider, or consumer; and/or perceived fit of the intervention to address a particular issue or problem.	Studies 1,2,3 & 4	Pre and post implementation focus groups with treating therapists Observation of sub-acute stroke survivors therapy sessions Audit of RT-UL computer data

Implementation Outcomes	**Definition**	**Study**	**Measurement**
Fidelity	Degree to which new intervention was implemented as intended (e.g. dosage or amount of program delivered).	Study 2	Observation of sub-acute stroke survivors therapy sessions
Penetration	Integration of new intervention into the practices within a service setting	Studies 2 & 3	Observation of sub-acute stroke survivors therapy sessions Audit of RT-UL computer data
Implementation cost	Cost impact of an implementation effort for a new intervention.	Study 3	A direct analysis of the cost-benefits of implementing RT-UL was beyond the scope of this research program, however, basic conclusions relating to the financial implications of implementing RT-UL were drawn from audit of RT-UL computer data.
Adoption	Intention, initial decision, or action to try or employ a new intervention.	Studies 1, 3 & 4	Pre and post implementation focus groups with treating therapists Audit of RT-UL computer data

Note. Adapted from definitions and measures described in Proctor et al. (2011).

1.2 Overview of the thesis

This thesis consists of seven chapters:

- Chapter 1 – Introduction and background
- Chapter 2 – Methods and design
- Chapter 3 – Study 1: *Introducing robotic upper limb training into routine clinical practice for stroke survivors: Perceptions of occupational therapists and physiotherapists.* (Pre-RT-UL implementation)
- Chapter 4 – Study 2: *Repetitions, duration and intensity of UL practice following the implementation of robot assisted therapy with sub-acute stroke survivors: An observational study.*
- Chapter 5 – Study 3: *Sustainability of upper limb robotic therapy for stroke survivors in an inpatient rehabilitation setting.*
- Chapter 6 – Study 4: *Implementing robotic upper limb training into routine clinical practice for stroke survivors: Perceptions of occupational therapists and physiotherapists.* (Post-RT-UL implementation)
- Chapter 7 – Discussion and conclusion

1.3 Background

This background section will explore the literature related to the use of RT-UL with stroke survivors and contextualise the reasons for the emergence of RT-UL in routine practice. This chapter will firstly cover the prevalence and impact of stroke on the UL, principles of UL stroke rehabilitation and current practice in post stroke UL rehabilitation. Following this an overview will be provided of the types of available RT-UL devices and the evidence related to RT-UL efficacy, safety and cost. A particular focus will be given to describing and summarising the literature related to the InMotion device, which is the robotic device investigated as part of this research program. Finally, this chapter will review the few studies that have previously explored RT-UL implementation within the clinical setting and summarise the ongoing gaps in the RT-UL implementation literature and how this program of research looked to address these gaps.

1.3.1 Upper limb impairment post-stroke

Upper limb impairment is a common and persistent challenge for stroke survivors. Of the 2806 stroke survivors audited as part of the 2019 Australian national stroke audit 72% experienced UL impairment (Stroke Foundation, 2020). For a majority of these stroke survivors their UL impairment will continue to linger for months and years after the initial event. Kwakkel et al. (2003) in their prospective cohort study with stroke survivors with severe UL impairment identified that at six months post stroke only 38% of participants showed some recovery of the UL and just 12% experienced complete recovery.

Upper limb impairment describes deficits at the level of the body systems and structures (Gillen & Nilsen, 2021) as per the International Classification of Function and Disability (World Health Organization, 2001) and these impairments can be categorised as either positive or negative (McCluskey et al., 2017). Positive UL impairments refer to exaggerated sensorimotor responses post stroke and include spasticity and hyperactive reflexes (McCluskey et al., 2017). Negative UL impairments involve a loss or reduction in the sensorimotor system and include weakness, reduced coordination and loss of sensation (McCluskey et al., 2017). Weakness is the most common UL impairment experienced by stroke survivors (Winstein et al., 2016). Upper limb impairments may also lead to secondary complications such as contracture, pain and learned non-use of the UL (Pollock et al., 2014).

The impact of these post stroke UL impairments is considered in terms of the impact on UL function (Gillen & Nilsen, 2021; Lang et al., 2013; McCluskey et al., 2017). The term *function* is not always clearly defined or used in a consistent way within the literature in relation to the ICF definition of function (Gillen & Nilsen, 2021). This is reflective of the multiple disciplines contributing to this field of research as well as the many and varied assessment tools used to measure UL function. Principally, the term function can be considered to refer to the use of the UL to perform a purposeful movement (e.g. grasping a pen or reaching for a cup) (Lang et al., 2013). Upper limb weakness has been found to have the most impact on post stroke UL function (Ada et al., 2006; Harris & Eng, 2007) but a reduction in function is often due to a combination of impairments (Lang et al., 2013).

Upper limb impairment has also been shown to negatively impact a stroke survivor's ability to perform their activities of daily living (ADL) and their quality of life as measured using a range of standardised outcome measures (Chang et al., 2016; Lieshout et al., 2020; Morris et al., 2013). In a cross-sectional study involving 85 stroke survivors, UL impairment (i.e. Rivermead Motor Assessment) was negatively associated with participant quality of life scores (i.e. Nottingham Health Profile) (Morris et al., 2013). In a prospective study of 2857 first-time stroke survivors, UL impairment (i.e. Fugl Meyer Assessment) at discharge from hospital was predictive of performance of ADL (i.e. Functional Independence Measure) and quality of life (i.e. Euro Quality of Life) at six months post stroke (Chang et al., 2016). In a more recent study involving 250 stroke survivors, UL strength (i.e. Motricity Index) was directly related to quality of life (i.e. Stroke Impact Scale) and improvement in UL strength over time resulted in improvement in participants' quality of life (Lieshout et al., 2020).

The efficacy of upper limb interventions like RT-UL should be evaluated in terms the capacity to reduce UL impairment and improve motor function as well as improve stroke survivors' performance of ADL and quality of life (Pollock et al., 2014). The efficacy of RT-UL at these different levels of recovery will be discussed in section 1.3.5, but now a synopsis will be given of the core principles underlying post stroke UL rehabilitation. This will help contextualise the proposed benefits of RT-UL and the reasons motivating clinicians to implement RT-UL into routine practice.

1.3.2 Principles of upper limb motor recovery post-stroke

Over the past three decades UL rehabilitation for stroke survivors has increasingly been informed and shaped by principles of neuroplasticity (Tunney, 2018). Neuroplasticity is defined as "the ability of the nervous system to respond to intrinsic or extrinsic stimuli by reorganising its structure, function and connections" (Cramer et al., 2011, p. 1592). Neuroplastic changes that translate to motor recovery are largely the result of performing movements that are repetitive, intensive and task-specific (Kleim & Jones, 2008; Maier et al., 2019). These principles form the basis for the efficacy of post stroke UL interventions and in particular RT-UL (Pollock et al., 2014; Stroke Foundation, 2022). These three principles of UL recovery will now be discussed.

Repetitive UL practice involves the repeated use of the paretic limb (Maier et al., 2019). The exact number of movement repetitions needed to effect neuroplastic change and UL improvement in people with stroke is uncertain (Kleim et al., 1998; Nudo et al., 1996; van Vliet et al., 2012). Very few clinical studies investigating post stroke UL interventions have reported the number of repetitions completed by participants making it difficult to be definitive (Vratsistas-Curto et al., 2021). In one randomised control trial, 85 stroke survivors participated in one hour per day of UL practice in which they completed either a 100 repetitions per session, 200 repetitions per session, 300 repetitions per session or an individualised maximum of repetitions for four days per week over a period of eight weeks (Lang et al., 2016). There was modest change in motor function (i.e. Action Research Arm Test) for the groups but no clear difference between groups. The prescribed number of repetitions completed by participants in this study likely needed to be greater to significantly effect recovery when considering the repetitions detailed in animal-based studies (e.g. 400-600 repetitions) (Kleim et al., 1998; Nudo et al., 1996). Further research is needed to fully understand the relationship between repetitions required and clinical outcomes, but it is likely that hundreds of repetitions are required.

Upper limb practice should not just be highly repetitive but also intensive (Kleim & Jones, 2008; Maier et al., 2019). Intensity of practice can be considered in terms of the amount of active therapy engaged in by a stroke survivor during a session or day (e.g. 30 minutes/day) or alternatively the number of UL repetitions performed within a defined time period (e.g. repetitions per minute) (Connell et al., 2014; Kimberley et al., 2010). As in the case of repetitive practice, intensity of practice has not been well reported in clinical trials and it is remains unclear what an effective level of intensity is needed for UL recovery (Vratsistas-Curto et al., 2021). A randomised control trial involving 32 inpatient stroke survivors compared the effects of participating in an UL program for either 1 hour (n=10), 2 hours (n=10) or 3 hours (n=10) a day, 5 days per week, for a period of 6 weeks (Han et al., 2012). All three groups experienced significant UL improvements (i.e. Fugl-Meyer Assessment and Action Research Arm Test) but participants who received 2 to 3 hours per day experienced greater improvement than those who received just one hour. Schneider et al. (2016), in a metanalysis of 14 randomised trials, concluded that an increase in therapy of 240% from usual therapy time (e.g. 30 minutes/day to 100 minutes/day) was required in order to significantly improve motor UL function. Such an increase in practice levels would be challenging for clinicians to facilitate as part of routine practice without a strategic shift in work procedures, e.g. lower patient to staffing ratios, or new intervention approaches. RT-UL practice is an intervention that has been identified to help address this challenge to increase the number of repetitions and intensity of UL practice for stroke survivors (Stewart et al., 2017). The capacity for RT-UL to facilitate an increase in both repetitions and intensity of UL practice in routine practice had not been previously investigated and was the focus of Study 2 in this program of research.

The third key principle of UL rehabilitation following a stroke is task-specific practice (Kleim & Jones, 2008; Maier et al., 2019). The principle of task-specific practice involves performance of UL movements that are related to the completion of a task (e.g. drinking from a cup) or a component of a whole task (e.g. grasping the cup) (French et al., 2016). Both animal and human studies have shown that repetitive motor practice alone is not sufficient to induce neuroplastic change but must be performed within the context of a specific task (Perez et al., 2004; Plautz et al., 2000). A systematic review involving 33 trials and 1,852 participants found a small but consistent improvement in the UL for stroke survivors who had engaged in repetitive task-specific practice (French et al., 2016). Task-specific practice can be challenging for stroke survivors with severe UL impairment who have minimal to no active movement of the hand or arm. RT-UL has the potential to enable task specific practice with stroke survivors including those with limited active movement. The capacity for RT-UL to facilitate task specific practice in routine practice, particularly with stroke survivors with severe UL impairment, has also not been previously investigated and was the focus of Study 2 and 3 in this program of research.

These three key principles of repetition, intensity and task specificity continue to be the primary objective for clinical practice in UL rehabilitation and underlie many of the current interventions used including RT-UL. Current UL rehabilitation interventions will be discussed in the next section followed by an overview of studies that have explored routine practice for post stroke UL rehabilitation. These two sections will help create a picture of the clinical framework into which RT-UL is being implemented.

1.3.3 Types of upper limb intervention post-stroke

RT-UL is a relatively recent addition to a range of evidence-based interventions that have emerged over the past three decades to address the physical impairments and functional loss in the UL following stroke. These interventions include constraint induced movement therapy, electrical stimulation, mirror therapy, biofeedback, virtual reality training and bilateral arm training (Pollock et al., 2014; Stroke Foundation, 2022). More traditional intervention methods to support and promote UL recovery after stroke also continue to be part of practice such as stretching and positioning, strength training, mental practice and activity-based practice (Pollock et al., 2014; Stroke Foundation, 2022). These interventions can be broadly categorised into impairment-based interventions (e.g. electrical stimulation, stretching and positioning, strengthening) and activity-based therapy or task specific practice (e.g. practice of daily living tasks, functional reaching tasks) (Hayward, Barker, Wiseman, & Brauer, 2013). "Usual therapy", or conventional therapy, typically involves a combination of these two categories of intervention (Pollock et al., 2014; Stroke Foundation, 2020). Upper limb therapy can be provided by a one or more health disciplines but principally undertaken by occupational therapy and physiotherapy within the Australian inpatient rehabilitation setting (Stroke Foundation, 2020; Vratsistas-Curto et al., 2021).

There are varying levels of evidence to support the effectiveness of UL interventions with stroke survivors. Internationally, clinical guidelines are available to assist clinicians to implement UL intervention programs. The Australian Clinical Guidelines for Stroke Management recommend eight interventions to reduce UL weakness and improve UL motor function (Stroke Foundation, 2022). These include strength training, constraint induced movement therapy, RT-UL, virtual reality training, electrical stimulation, mental practice, mirror therapy and repetitive task specific practice (Stroke Foundation, 2022). The guidelines classify the interventions as either strong or conditional recommendations. A strong recommendation indicates that the benefits of the intervention outweigh the harms for almost every stroke survivor and nearly all stroke survivors would want the intervention. A conditional recommendation indicates that the benefits outweigh the harms for most stroke survivors and the majority of stroke survivors would want the intervention.

Strength training (i.e. for UL weakness) and constraint induced movement therapy (i.e. arm activity) have strong recommendations in the Australian stroke guidelines with the remaining six interventions classified as conditional recommendations (Stroke Foundation, 2022). Specifically, strength exercises that involve progressive resistance training are indicated for stroke survivors with UL weakness (Dorsch et al., 2018). Similarly, constraint induced movement therapy (CIMT) has a strong recommendation for use with stroke survivors (Corbetta et al., 2015; Stroke Foundation, 2022). The implementation of CIMT is often limited by the considerable demand on the participants' and therapists' time to complete a program (Viana & Teasell, 2012). Additionally, implementation of CIMT may be restricted by the narrow patient eligibility criteria (e.g. some active wrist and finger extension, no significant pain, no spasticity or reduced range of joint motion, minimal cognitive deficits)(Corbetta et al., 2015; Morris et al., 2006; Taub & Uswatte, 1999). The remaining six interventions, including RT-UL, are conditional recommendations for use in routine practice as recommended in the Australian stroke guidelines. The guidelines also provide specific information in the use of these UL interventions with stroke survivors including clinical factors (e.g. severity of UL impairment) and practical considerations (e.g. availability of equipment). This information in the guidelines as it relates to RT-UL will be discussed in depth in section 1.3.5.

Overall, there are a range of evidence-based UL interventions available to clinicians to implement into routine practice. An overview of studies that have investigated what routine practice currently looks like for stroke survivors in terms of the type of interventions in use (i.e. impairment verses task-specific) and amount of UL practice performed will now be provided. This will highlight the current shortfall in routine practice to provide repetitive intensive task-specific practice, a primary beneficial feature of RT-UL.

1.3.4 Current routine practice for upper limb rehabilitation post stroke

It is well established that the amount of UL therapy received by people with stroke as part of routine clinical practice is sub-optimal (Hayward & Brauer, 2015). Following stroke, people are often limited in their capacity and opportunity to perform high amounts of repetitive movement, particularly when people have severe UL impairment and independent exercise of the stroke-affected UL is difficult or impossible (Hayward et al., 2013; Stewart et al., 2017). A systematic review involving 10 studies recording routine practice found people with stroke engaged in task-specific UL practice for on average only four minutes per session in physiotherapy and 17 minutes in occupational therapy and performed less than 32 repetitions per session (Hayward & Brauer, 2015); far fewer than the hundreds of repetitions believed to be required to facilitate neuroplastic change.

In a large observational study of 99 stroke survivors admitted to an Australian inpatient rehabilitation facility the amount of UL practice completed as part of routine practice was also low (Vratsistas-Curto et al., 2021). Participants in this study engaged on average in two designated UL sessions per week and completed 195 UL repetitions per week. The type of practice provided to participants in this study was task-specific and delivered in the form of UL groups (e.g. focused on reaching and in-hand manipulation tasks), dressing groups, one-on-one sessions with an individual therapist and independent practice completed on one's own without a therapist present. Participants observed in this study experiencing significant disability (i.e. modified Rankin Scale score of five on admission) performed 37 fewer UL repetitions per day than the total average of all participants

(Vratsistas-Curto et al., 2021). The 2019 Australian stroke audit of rehabilitation services also gives insight into the type of practice being performed by stroke survivors (Stroke Foundation, 2020). The audit found the most frequently used intervention with stroke survivors with UL impairment was repetitive task-specific practice (87%). The audit also recorded that 12% of stroke survivors had engaged in mechanically assisted training, inclusive of RT-UL, and 11% in constraint induced movement therapy.

The above studies and audits indicate that routine practice for Australian stroke survivors with UL impairment is currently limited and low in intensity. Routine practice, at least in Australia, primarily involves stroke survivors engaging in repetitive task specific practice with a small percentage receiving RT-UL as part of their UL program. There is a clear need to increase the number of repetitions and intensity of practice completed by stroke survivors particularly those with severe UL impairment. RT-UL has the potential to help address this challenge, but no study has been conducted to measure the impact of implementing RT-UL on the type and amount of UL practice performed by stroke survivors. This was the aim of Study 2 of this program of research. This is particularly important when considering the range of individual and environmental factors that can influence the translation of interventions from successful clinical trials into routine practice (Bayley et al., 2012; Jolliffe et al., 2019; McCluskey et al., 2013; Mudge et al., 2017). Identification and exploration of the factors impacting RT-UL implementation was the focus of Study 1 and Study 4 of this program of research.

An overview will now be provided of the literature relating to RT-UL.

1.3.5 Overview of RT-UL literature

This section of the thesis will firstly provide a working definition for RT-UL as well as detail the classification of RT-UL devices. There will be a focus on describing the InMotion device, the robotic device studied in this program of research. A summary will then be provided of current literature covering RT-UL efficacy, safety and cost. The final section will detail the existing studies that have explored the implementation of RT-UL as part of routine practice.

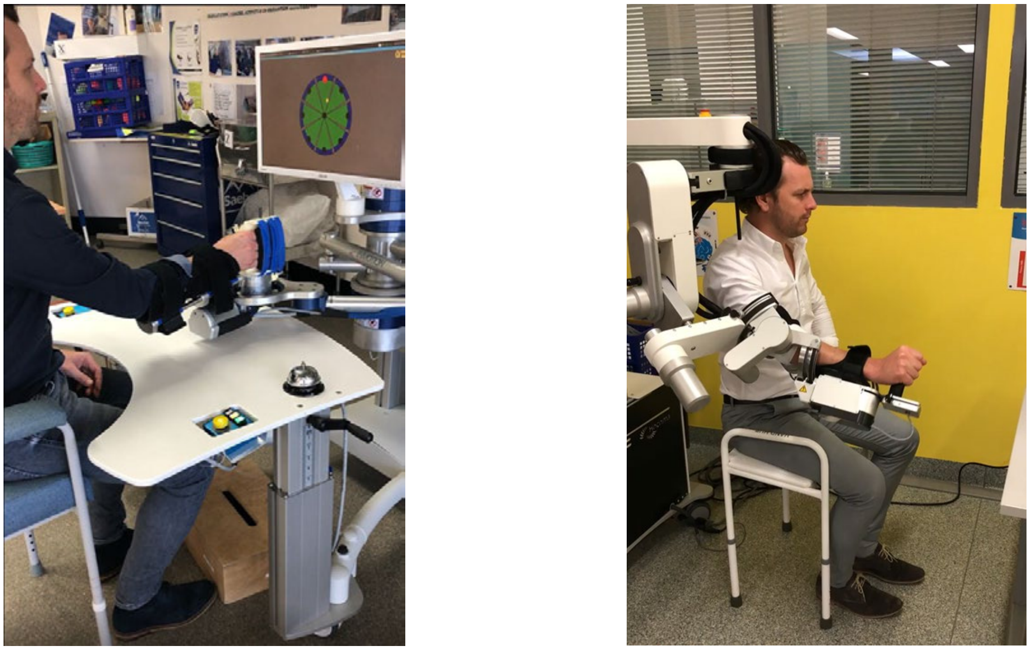
1.3.5.1 Defining and classifying UL robotics

There is no clear consensus within the literature as to what defines robot assisted upper limb therapy nor a therapeutic UL robotic device (Gandolfi et al., 2021). It has been suggested that an electromechanical device could be considered a therapeutic robot on account of essential componentry, namely; actuators (i.e. components that move the limb or joint), a sensor system (e.g. proprioceptive and force sensors) and a control system (i.e. controls the movement being performed) (Gandolfi et al., 2021). Jakob et al. (2018) proposed a definition adapted from industrial robotic devices, “a reprogrammable and multifunctional manipulator designed to perform different rehabilitation tasks through various programmed motions” (Jakob et al., 2018, p. S189). This lack of a clear definition has in part complicated the interpretation of the results of systematic reviews in which clinical trials using various devices have been homogenised to draw conclusions as to the efficacy of RT-UL (Mehrholz et al., 2018). The working definition for RT-UL used in this thesis is the retraining of the upper limb by the application of an electromechanical device to the person’s upper limb to assist with and facilitate the repetitive performance of prescribed upper limb movements (Mehrholz et al., 2018; Veerbeek et al., 2017). These upper limb movements facilitated by the robot are typically represented in real-time on an adjoining computer monitor as part of a game or task (Morone et al., 2020).

Upper limb robotics for stroke survivors can be classified in several ways. Firstly, these devices can be considered in terms of the type of movement being facilitated; active-assistive, active-resistive and passive. The majority of robotic devices used in trials and clinical practice are programmed to provide active-assisted movement in which the devices provide assistance to the user only as needed (Duret et al., 2019). Devices that facilitate active-assisted movement are considered to be a stronger driver of motor recovery than those that simply provide passive movement (Duret et al., 2019). Active-resisted movement may also be an optional feature of a device (Duret et al., 2019). This involves the user performing reaching tasks against resistance generated by the RT-UL device as a means of strength retraining. Rehabilitative UL robotics devices can also be described in terms of facilitating unilateral versus bilateral UL movement or proximal versus distal UL movement (Mehrholz et al., 2020).

Most commonly RT-UL devices are classified from a mechanical standpoint as either end-effectors or exoskeletons (Babaiasl et al., 2016; Morone et al., 2020). These two categories are now discussed in further detail. Figure 1.1 shows examples of these two categories of device.

Figure 1.1 (a) End-effector InMotion (b) Exoskeleton Armeo Power



<u>*1.3.5.2 End-effectors*</u>

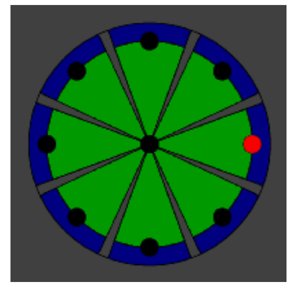
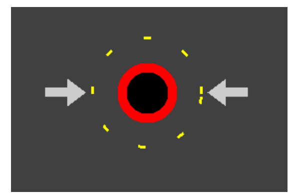
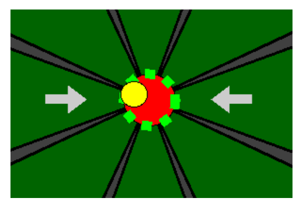
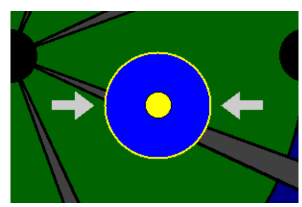
End-effectors (or endpoint manipulators) facilitate movement by providing force through the distally positioned manipulator (i.e. handle) and are by far the most commonly researched device (Fasoli, 2021). End-effector RT-UL devices include the MEchatronic system for MOtor recovery after Stroke (MEMOS), Bi-Manu Track, ReoGo and the InMotion, the latter being the RT-UL device investigated in this program of research. The original InMotion model was the Massachusetts Institute of Technology Manus (MIT-Manus) developed in 1989 (Gillen & Nilsen, 2021; Turchetti et al., 2014). Clinical trials with the

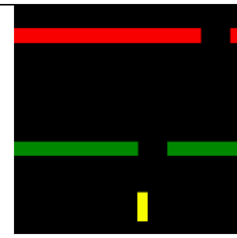
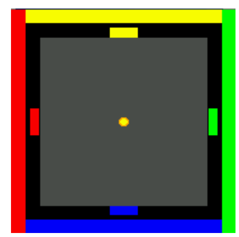
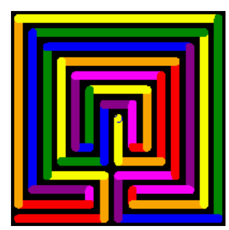
MIT-Manus commenced in 1994 at Burke Rehabilitation Hospital, New York. The MIT-Manus was then commercialised for the global market in 2009 as the 'CE' InMotion before the device was upgraded in 2015 to become the InMotion Arm with add-on hand component. The InMotion Arm (i.e. model SE4) with hand component (i.e. model HA4) was the device investigated in this program of research. The InMotion Arm was superseded in 2019 by the V2 InMotion ARM which is now the current InMotion model available. The V2 InMotion ARM has essentially the same function as the previous InMotion Arm device but is a third smaller in size with improved computer graphics and customisability of programs and evaluation reports. The InMotion series of devices are one of the most commonly used RT-UL in the world and by 2017 over 900 stroke survivors had been tested in clinical trials using these devices (Rodgers et al., 2017). The InMotion Arm with add-on hand component was used at the rehabilitation facility at which this program of research was undertaken and from this point forward will be referred to as the InMotion.

The InMotion facilitates movement at the shoulder and elbow with an optional hand component if required. The device automatically adapts to the patient's active movements providing active-assistance during use as well as active-resistance (Bionik Labs, 2021). The InMotion device includes a variety of inbuilt performance metrics that can be used to measure and monitor changes in UL kinematic control and force. These performance metrics include measurements of UL movement in terms of smoothness, accuracy, velocity (i.e. mean and maximum velocity), strength and initiation. The InMotion is not unique with regards to being able to measure UL motor performance. A majority of RT-UL devices available on the market, including both end-effectors and exoskeletons, are able to provide objective measures of an individual's UL performance. It has been proposed that these measures recorded by a RT-UL device are more sensitive to clinical change than standard UL assessment tools and less subject to floor or ceiling effects (Otaka et al., 2015). The clinical relevance of these RT-UL evaluative measures, for both therapists and stroke survivors, have not been comprehensively explored. The frequency of the use of the InMotion evaluative features in routine practice along with therapists' perception of the usefulness of these features were investigated in Study 3 and Study 4 of this program of research.

In terms of UL treatment provided by the InMotion, patients complete a therapist-selected, pre-programmed treatment protocol involving a series of therapy games presented on an adjoining computer screen. Table 1.2 lists and details each of these games. The primary treatment protocol of the InMotion is the clock game therapy protocol. This protocol is made up of a series of seven games. Within each game the patient moves the handle of the device to reposition a yellow circle pointer at a series of targets around a clock face presented on the adjoining computer screen. The sequence and number of targets presented on the clock changes between games. When the additional hand component is connected to the device the patient completes a different clock game protocol in which they are required to additionally grasp and release the target. The InMotion only provides the patient with active assistance when completing the clock game protocols. There are a number of additional games to the clock game (i.e. squeegee task, pong, Cretan square maze, race) but these games require the user to actively move their paretic limb with no assistance provided by the InMotion. These additional games are also detailed below in Table 1.2.

Table 1.2 List and descriptions of InMotion games

Game	Description	Image of game
Clock game	User starts at the central point of the clock and extends out to the presented dot at the 8 points around the circle. Always returning to the central dot after reaching each dot.	
Clock grasp game	User squeezes the hand component to hit the central ring and releases to hit a large outer ring target.	
Clock reach game	User is required to reach to a highlighted dot on the clock and "grasp/release" the dot using the hand module before then returning to "grasp/release" the centre dot again.	
Clock pick game	User is required to reach to a highlighted dot on the clock and grasp (pick up) the dot, carry the dot and release the dot again at the designated point on the clock.	

Game	Description	Image of game
Race	User is required to guide the dot through a series of gates.	
Squeegee	User is required to wipe the entire picture clean and involves multiple movements	
Pong	User is required to move the side bars to repel the moving dot.	
Cretan Square Maze	User is required to move from point to point through the square maze.	

*Images extracted from InMotion arm user manual (Interactive motion technologies, 2016)

1.3.5.3 Exoskeletons

Exoskeleton RT-ULs are a more recent development and are less represented commercially and in research, being often more expensive to purchase than end-effector RT-ULs (Babaiasl et al., 2016; Turchetti et al., 2014). Exoskeleton RT-UL devices facilitate movement by torque actuators controlling one or more joints of the affected upper limb (Veerbeek et al., 2017). Exoskeleton devices provide greater support than the end-effector, enveloping the paretic limb with the actuators on the device aligning with the user's own joints (i.e. shoulder, elbow, wrist, hand) (Gandolfi et al., 2021). Unlike lower limb exoskeleton devices, the majority of upper limb exoskeletons are not movable devices with the patient seated with the device applied to their arm (Morone et al., 2020). Examples of exoskeleton RT-UL devices included the Armeo Power and Myomo (Duret et al., 2019; Morone et al., 2020). Further discussion of exoskeleton RT-ULs are beyond the scope of this thesis.

1.3.5.4 Clinical efficacy of RT-UL

This section will provide an overview of the literature related to the clinical efficacy of RT-UL to facilitate UL recovery for stroke survivors. Specifically, this section will discuss relevant clinical guidelines recommending RT-UL for stroke survivors as well as key systematic reviews that have investigated the efficacy of RT-UL. The largest RT-UL clinical trial to date, the RATULS trial, will also be specifically discussed as the device used in this trial was the InMotion. Following this, a summary will be given of the literature relating to the safety and cost-effectiveness of RT-UL.

RT-UL within stroke clinical guidelines

Robot assisted therapy for the UL post stroke is recommended in clinical stroke guidelines around the world. A recent systematic review appraised eight clinical stroke guidelines (published between 2010 to 2020) from six different countries in which RT-UL was recommended: Australia (2017), Canada (2015), United Kingdom (2016), Netherlands (2014), New Zealand (2010), Scotland (2010) and United States (2016 & 2019) (Morone et al., 2021). Guidelines were consistent in recommending that RT-UL be used to improve UL strength and motor function particularly as an adjunct to usual therapy (Morone et al., 2021). The guidelines however fell short of detailing which type of device to use as well as which stroke survivors would benefit most from RT-UL or optimal timing (i.e. stage of recovery) for introducing RT-UL into a rehabilitation program.

The Australian Clinical Guidelines for Stroke Management is a “living guideline” meaning that the guideline is an online document that is regularly updated as new evidence emerges as opposed to a periodical publication (Stroke Foundation, 2022). The online Australian Clinical Guidelines for Stroke Management supersede the Australian guideline appraised as part of the above systematic review (Morone et al., 2021). The current Australian guidelines recommend RT-UL to help improve stroke survivors’ UL strength, motor function and ADL performance (Stroke Foundation, 2022). The guideline also states that RT-UL is a safe intervention for stroke survivors and requires less one-on-one therapist input (i.e. can be used to provide semi-supervised practice) than conventional therapy (Stroke Foundation, 2022). The effectiveness of RT-UL is also proposed to come from the capacity for robotic devices to facilitate more intensive therapy (Stroke Foundation, 2022). The capacity for RT-UL to facilitate this semi-supervised intensive and repetitive UL practice in routine practice has not been investigated and was the focus of Study 2 in this program of research.

Although both international and Australian guidelines give support and some guidance for the use of RT-UL it is important to delve into the latest systematic reviews and clinical trials to obtain a clearer understanding of the evidence. Key RT-UL systematic reviews are now discussed along with the RATULS trial published in 2019, the largest RT-UL randomised control trial to date.

RT-UL systematic reviews and RATULS trial

Over the past two decades there has been a growing body of evidence supporting the efficacy of RT-UL. In a recent scoping review, a total of 85 clinical trials were found to have investigated the efficacy of RT-UL with stroke survivors (Gandolfi et al., 2021). Further to this, a number of systematic reviews have endeavoured to synthesise trials investigating the efficacy of RT-UL. Table 1.3 provides a summary of the most recent systematic reviews. The findings of these systematic reviews as they relate to the efficacy for RT-UL to address UL impairment, motor function ,performance of activities of daily living (ADL) and quality of life will be presented. The evidence related to which type of device to use and which stroke survivors would benefit most from RT-UL will also be discussed.

Table 1.3 Systematic reviews examining efficacy of Robot-assisted Upper Limb Therapy (RT-UL) with stroke survivors

Systematic review	Intervention	Last searched databases	Trials	Participants	Outcome measures	Conclusions
Wu et al. (2021)	RT-UL v usual therapy	April 2020	41	1916	Primary: FMA-UE	• RT-UL was superior in addressing motor function • End-effector devices were superior but not exoskeletons • RT-UL was only superior for people in chronic phase of recovery
Ferreira et al. (2021)	RT-UL v no therapy and usual therapy	February 2020	12	845	Primary: SIS, LH, SF-36	• RT-UL improved individual participation compared with no therapy but not superior to usual therapy
Chen et al. (2020)	RT-UL v therapist-mediated training	October 2019	35	2241	Primary: FMA-UE Secondary: ARAT, WMFT, BBT, 9-HPT, CAHAI, AMAT, FIM, BI, MAL, SIS, SF-36, mRS	• RT-UL was superior in improving motor function to therapist-mediated training • RT-UL was as effective as therapist-mediated in improving ADL performance and participation
Mehrholz et al. (2020)	RT-UL v any other therapy	July 2019	55	2654	Primary: FMA-UE, FIM, BI, WMFT Secondary: MIS, grip strength	• No RT-UL device more or less effective than another • No difference in effects when there are patient differences in terms of severity of UL impairment or phase of recovery post stroke (≤3 months v ≥ 3months)
Mehrholz et al. (2018)	RT-UL v any other therapy	February 2018	45	1619	Primary: BI, FIM, ABILHAND, SIS, Frenchay Arm Test Secondary: FMA-UE, MIS, WMFT, CAHAI	• RT-UL superior to usual therapy for improving UL strength, motor function and ADL performance

ADL: Activities of Daily Living, AMAT: Arm Motor Ability Test, ARAT: Action Research Arm Test, BI: Barthel Index, BBT: Box and Blocks Test, CAHAI: Chedoke Arm and Hand Activity Inventory, FIM: Functional Independence Measure, FMA-UE: Fugl Meyer Assessment of the Upper Extremity, LH: Life Habits, MAL: Motor Activity Log, MIS: Motricity Index Score, mRS: modified Rankin Scale, QuickDASH: Quick version of the Disabilities of the Arm, Shoulder, and Hand, SF-36: The 36-Item Short Form Health Survey, SIS: Stroke Impact Score

Since 2018 a Cochrane systematic review (Mehrholz et al., 2018) has played a large role in shaping the field's perspectives of the efficacy of RT-UL for stroke survivors. The review, involving 45 clinical trials and 1,619 participants, compared RT-UL with any other form of UL therapy. RT-UL was shown to be superior in improving UL strength (i.e. Motricity Index Score), motor function (i.e. Fugl-Meyer assessment) and ADL performance (i.e. Functional Independence Measure & Barthel Index) (Mehrholz et al., 2018). No serious risk of bias was found for the included studies as measured by the Cochrane 'Risk of bias' tool. More recent systematic reviews also found RT-UL to be superior for improving UL motor function post stroke (i.e. Fugl Meyer) (Chen et al., 2020; Wu et al., 2021). Further subanalysis identified that RT-UL is superior for improving UL motor function when delivered either as an add-on to usual therapy or when delivered alone (Chen et al., 2020).

RT-UL has also been investigated for efficacy on improving a person's ADL performance. Mehrholz et al. (2018) reported RT-UL was more effective than usual therapy for improving a person's ADL performance. A more recent systematic review by Chen et al. (2020) found RT-UL to be as effective as therapist-mediated UL training for improving ADL performance but not superior. This difference in findings to the Mehrholz et al. (2018) could primarily be attributed to the difference in the inclusion criteria for each review. Chen et al. (2020) review compared RT-UL with therapist-mediated UL training whereas

Mehrholz et al. (2018) additionally included trials that compared RT-UL with sham, blank intervention or usual care. The broader inclusion criteria used by Mehrholz et al. (2018) may have created a bias in favour of RT-UL. In addition also, Chen et al. (2020) investigated the efficacy of RT-UL to improve stroke survivors' quality of life. As in the case of ADL performance, RT-UL was found to be as effective as therapist mediated UL training for improving quality of life but not superior (Chen et al., 2020). This finding was also supported in a review which exclusively investigated the efficacy of RT-UL to improve stroke survivors' quality of life (Ferreira et al., 2021).

Overall, these reviews indicate that RT-UL is more effective than conventional therapy for improving stoke survivors UL strength and motor function and as effective as conventional therapy for improving ADL performance and quality of life. These findings support the use of RT-UL as part of routine practice whether as an adjunct to usual therapy sessions or as an integrated part of an UL rehabilitation program. A focus of this program of research was to determine how RT-UL is being used in routine practice by therapists providing inpatient rehabilitation.

To supplement the findings of their 2018 systematic review, Mehrholz et al. (2020) conducted a follow up systematic review involving a network analysis to investigate the potential impact of different RT-UL devices (e.g. end-effector versus exoskeleton), time post stroke (i.e. ≤ 3 months versus ≥ 3 months) and severity of UL impairment on the efficacy of RT-UL. The findings of this analysis indicated that RT-UL could potentially be effective when delivered by a range of RT-UL devices and with stroke survivors at various stages of recovery and varying degrees of UL impairment. Chen et al. (2020) in their systematic review also found no difference in RT-UL efficacy when analysed in terms of the type of device used (e.g. end-effector versus exoskeleton), unilateral versus bilateral RT-UL training, RT-UL as adjunct to usual therapy rather than alone, part of the arm trained (i.e. proximal UL versus distal UL versus both), time post stroke, participant age and total training time (i.e. hours of therapy provided). In contrast, Wu et al. (2021) in their systematic review concluded that RT-UL could potentially be more effective when delivered by a unilateral end-effector device. This is noteworthy when considering that the InMotion device investigated as part of this research program is classified as a unliteral end-effector. Additionally, RT-UL was found to be particularly beneficial for stroke survivors with moderate to severe UL impairment ≥ 3 months post stroke (Wu et al., 2021). The conclusions of this systematic review should be interpreted with some caution as studies were included only if a specific measure of UL function that is, Fugl Meyer Assessment of the Upper Extremity, was used. There were also large discrepancies in study and participant numbers for the subgroup analysis. Most notably the efficacy of RT-UL for time since stroke compared 32 studies with 809 participants (i.e. ≤ 3 months post stroke) against 11 studies with 457 participants (i.e. ≥ 3 months post stroke).

The specific RT-UL device to be investigated in this program of research, the InMotion, was used in the largest RT-UL randomised trial to date, i.e. RATULS trial (Rodgers et al., 2019). The RATULS trial was conducted in the United Kingdom and investigated the efficacy of the InMotion device. The trial involved 770 stroke survivors with participants randomly assigned to either RT-UL training (n=257), enhanced upper limb therapy (n=259) or usual care (n=254). The mean age of participants was 61 years (standard deviation of 14), at a median time since stroke of 240 days (interquartile range of 109-549 days). RT-UL training and enhanced upper limb therapy programs involved 3 x 45-minute sessions per week for 12 weeks and were provided in addition (i.e. adjunct) to usual care. The enhanced upper limb therapy program entailed repetitive functional task practice focused on participant-centred goals. Usual care in this study involved standard care provided by the local National Health Service i.e. 45 mins of each appropriate therapy (e.g. occupational therapy, physiotherapy) five days per week. The clinical outcome measures used in this trial were the Fugl Meyer Assessment of the Upper Extremity, modified Action Research Arm Test, Barthel Index and Stroke Impact Scale (Rodgers et al., 2019). In line with findings from the RT-UL systematic reviews, those participants who received RT-UL demonstrated significant improvements in motor function (i.e. Fugl Meyer) when compared to usual care at six months. There was no significant difference however between RT-UL and usual care for the other three outcome measures. There were also no clinically important outcome differences between RT-UL and enhanced upper limb at six months post intervention (Rodgers et al., 2019).

Overall, the research to date shows that RT-UL is an effective intervention particularly to address UL impairment and motor function for stroke survivors. RT-UL can be effective as a standalone intervention or when used in addition to conventional therapy. RT-UL can also be effective when delivered by a range of devices and when used by stroke survivors at various stages of recovery and with varying degrees of UL impairment. The next section will discuss the evidence related to the safety and cost-effectiveness of RT-UL. This will then be followed by a summary of the existing literature investigating the implementation of RT-UL into routine practice.

1.3.5.5 RT-UL safety and cost effectiveness

Prior to implementing a new intervention a clinician should not only take into consideration the effectiveness of the intervention but also potential safety risks and cost implications (Turpin & Higgs, 2017). A summary of the literature relating to the safety and cost effectiveness of RT-UL is now presented.

Safety is an important outcome by which to measure RT-UL when considering that UL pain post stroke is proportionate to the amount an individual uses their upper limb as well as the severity of their UL impairment (Lang, Wagner, et al., 2007; Ratnasababapathy et al., 2003). A number of RT-UL systematic reviews and clinical trials have included a measure of patient safety (Lo et al., 2010; Mehrholz et al., 2018; Rodgers et al., 2019). In Mehrholz et al. (2018) systematic review of RT-UL efficacy for stroke survivors (n= 1,619) there were no adverse events i.e. cardiovascular episodes, musculoskeletal injuries and pain. Further to this, no RT-UL device was found to be safer than another (Mehrholz et al., 2020). In terms of the InMotion device, no adverse events related to using the device occurred in the RATULS trial (n=257)(Rodgers et al., 2019).

In another clinical trial involving the InMotion device, safety was measured in terms of the incidence of participant reported pain and spasticity (i.e. Modified Ashworth Scale) (Lo et al., 2010). The trial involved 49 stroke survivors engaging in RT-UL (i.e. average 1,024 repetitions per session) compared to 50 participants receiving dose-matched intensive UL therapy (i.e. stretching, shoulder-stabilisation activities, arm exercises, and task specific reaching tasks) and 28 participants receiving usual care. There were no serious adverse events recorded for any of the treatment groups. Of the adverse events that occurred all were categorised as mild (e.g. transient muscle soreness) and involved 12 (24%) RT-UL participants and nine (18%) intensive UL therapy participants. There were no significant differences in scores on pain rating scales or spasticity measures between groups.

These findings should give confidence to clinicians that RT-UL is safe to implement as part of routine practice. In addition to questions of RT-UL efficacy and safety, clinicians and health administrators should also factor in the costs of implementing RT-UL.

1.3.5.6 Cost effectiveness of RT-UL

The cost-effectiveness of a new intervention is one of eight key measures of implementation success (Proctor et al., 2011). This is particularly important when considering the substantial expense associated with procuring an RT-UL device. For example, the cost of purchasing the InMotion device in 2015 investigated in this program of research was $174, 965 Australian dollars.

A small systematic review involving five clinical trials and 213 participants investigated the economic cost of robotic rehabilitation for adult stroke survivors (Lo et al., 2019). Four of the included studies investigated UL robotic therapy with one study investigating both UL and lower limb robotic therapy. Included studies compared the cost of providing robotic therapy against the cost of providing conventional therapy in dose-matched therapy sessions. Cost measures were calculated in terms of cost per patient session or cost per patient. Four of the five studies found RT-UL to be more cost effective than conventional therapy (Bustamante Valles et al., 2016; Hesse et al., 2014; Vanoglio et al., 2017; Wagner et al., 2011). Notably RT-UL was found to be cost effective when used by stroke survivors with more severe impairment and in the acute and subacute phase of recovery. This is worth noting as this program of research focused on RT-UL implementation with stroke survivors in the acute and subacute stage of recovery. The findings of this systematic review should however be interpreted with some caution due to the limited number of included studies.

The RATULS trial investigated the cost-effectiveness of RT-UL compared to intensive and usual therapy (Fernandez-Garcia et al., 2021). As detailed above, participants (n=770) where randomised into one of three programs: RT-UL (n=257), enhanced UL treatment (n=259) and usual care (n=254). A complex economic evaluation was undertaken, with cost-effectiveness measured in terms of the patients' mean cost to the health care system compared with gains on a self-reported quality of life questionnaire (i.e. EQ-5D-5L). A comparison of the mean cost and effect per patient was determined between the three groups. At six months, usual care was the least costly option (£3785) followed by enhanced UL treatment (£4451) with RT-UL the most expensive intervention (£5387). However, neither RT-UL nor the enhanced UL treatment were reported to be more cost-effective than usual care when measured in relation to quality of life. A notable weakness of the cost analysis in this study was that RT-UL was delivered one-on-one by the therapist. The study did not take into account the major advantage of RT-UL from a cost effectiveness point of view which is that stroke survivors are able to engage in either independent or semi-supervised RT-UL practice without one-on-one one input from the therapist. This feature allows the therapist to simultaneously treat other patients. Interestingly, Wagner et al. (2011) found no differences in costs between usual therapy and RT-UL delivered by the InMotion (i.e. MIT-manus version) when cost analysis factored in the capacity for therapists to see more than one patient when providing RT-UL.

RT-UL has the potential to be a cost-effective intervention but a direct analysis of the cost-benefits of implementing RT-UL into routine practice was beyond the scope of this research program. However, basic conclusions relating to the financial implications of implementing RT-UL will be drawn from audit data in Study 3 of this research program. A summary will now be provided of the existing literature that has explored the implementation process and use of RT-UL once part of routine practice.

1.3.5.7 Implementation of RT-UL

International clinical stroke guidelines have limited detail to inform clinicians as to the barriers and facilitators to implementing RT-UL into routine practice (Morone et al., 2021). This is reflective of only a small collection of studies having explored the use of RT-UL as part of clinical practice rather than the setting of a clinical trial (Celian et al., 2021; Lo et al., 2020; Mashizume et al., 2021; Stephenson & Stephens, 2017). These are all recent studies and have all been published since the commencement of this program of research. There are notable limitations to these existing studies on implementing RT-UL in the clinical setting that include; small samples sizes (i.e. ≤6 participants) (Celian et al., 2021; Stephenson & Stephens, 2017), exploration of RT-UL only as part of a broader set of rehabilitation technology (Celian et al., 2021; Lo et al., 2020) or not being informed by an implementation framework (Lo et al., 2020; Mashizume et al., 2021; Stephenson & Stephens, 2017). Despite these limitations some preliminary insights can be gleaned to inform this program of research. An overview of the barriers and facilitators to using RT-UL in routine practice from these studies is now provided.

Therapists with experience in using RT-UL as part of their routine practice have reported a number of barriers to implementation (Celian et al., 2021; Lo et al., 2020; Stephenson & Stephens, 2017). At a practical level, barriers have included limited availability of staff skilled and confident in the use of RT-UL, time pressures associated with using a new robotic device, absence of published guidelines, and low numbers of appropriate patients (Celian et al., 2021; Lo et al., 2020; Stephenson & Stephens, 2017). Some of these challenges are common to implementing any new intervention and likely due to limited pre-implementation planning and training (Lo et al., 2020; Scott et al., 2017). For example, time pressures associated with using a new robotic device could be the outcome of therapists having insufficient training in how to set up and deliver RT-UL. Other concerns appear more specific to implementing RT-UL such as storage and access issues, limitations of RT-UL to provide functional task specific practice and low numbers of appropriate patients. These factors particularly merit further investigation and were a focus of this program of research.

The model of service delivery adopted by rehabilitation facilities also contributed to the challenge of implementing RT-UL. In one study RT-UL was provided as a standalone service with a single therapist, i.e. robotic therapist, designated to running RT-UL sessions with patients in a location separate to the rest of the rehabilitation team (Lo et al., 2020). Consequently, RT-UL was poorly integrated with the rest of the patients' rehabilitation program and the robotic therapist felt isolated and unfulfilled in their role.

A number of factors have been reported that have facilitated the implementation of RT-UL into routine practice (Lo et al., 2020; Mashizume et al., 2021; Stephenson & Stephens, 2017). A strong motivator for therapists to incorporate RT-UL was the opportunity to provide highly intensive practice for patients with minimal input from therapy staff (Lo et al., 2020; Mashizume et al., 2021; Stephenson & Stephens, 2017). This was particularly appealing for stroke survivors with more severely impaired UL (Lo et al., 2020; Mashizume et al., 2021). Therapists perceived that RT-UL was effective for improving UL impairment and motor function for stroke survivors (Lo et al., 2020; Mashizume et al., 2021) and that these gains led to improvement in ADL performance (Mashizume et al., 2021; Stephenson & Stephens, 2017). RT-UL practice had the advantage of being able to be adjusted in the set up and training protocols to provide a “just right” challenge for stroke survivors (Lo et al., 2020; Mashizume et al., 2021). Finally, RT-UL evaluative tools were considered helpful for objectively monitoring patient progress and detecting subtle changes in motor performance and hence facilitated adoption of the RT-UL (Mashizume et al., 2021; Stephenson & Stephens, 2017).

The aforementioned barriers and facilitators highlighted in recent studies are helpful insights but there is a need to further expand this small body of research not just in terms of the number of studies but the methodologies used. Firstly, there is an absence of any objective data in the existing studies to measure RT-UL implementation and support or refute the opinions provided by therapists in these qualitative studies. This program of research used quantitative measures (including audits, observation study and surveys) in combination with therapist focus groups to more comprehensively investigate the RT-UL implementation process. Secondly, only a single study (Celian et al., 2021) employed an implementation framework to synthesise the information gathered on RT-UL implementation, and this single study included only two occupational therapists reflecting on their use of RT-UL for a one-off session with a stroke survivor. An implementation framework enables a more comprehensive and validated evaluation of the implementation process (McCluskey & O'Connor, 2017; Moullin et al., 2015). This program of research evaluated RT-UL implementation using a framework involving eight measures of implementation success; acceptability, sustainability, adoption, appropriateness, feasibility, fidelity, penetration, implementation cost (Proctor et al., 2011). Further to this, none of the studies to date have applied behavioural theory to explore or explain therapist perceptions of RT-UL implementation. Use of behavioural theory is important when seeking to measure subjective constructs such as therapist acceptability and adoption of a new technique or tool such as RT-UL (McCluskey & O'Connor, 2017). The Theoretical Domain Framework (TDF), a framework based on behavioural theory, was used in this research program as part of Study 1 and Study 4 to analyse therapist perceptions and behaviour relating RT-UL implementation. More detail on the TDF will be provided in the proceeding methodology chapter. Finally, the use of RT-UL within the Australian health care settings has not been explicitly investigated despite its emergence as part of routine practice for many Australian rehabilitation facilities (Lo et al., 2020).

Patient perceptions of new interventions such as RT-UL also need to be considered when seeking to understand the dynamics surrounding implementation (McCluskey & O'Connor, 2017). Few studies have explored patient perceptions of robotics and those conducted have focused on gaining patient perceptions as part of a design process (Hughes et al., 2011) or a clinical trial (Tedesco Triccas et al., 2018). Additionally these studies have been outside of the Australian clinical context i.e. United Kingdom. It is beyond the scope of this research program to extend the investigation to explore patient perceptions of the implementation process. This gap in the literature area for further research is discussed in Section 7.4.3 “Future research directions”.

To conclude, this program of research aimed to investigate the implementation of RT-UL within an Australian clinical setting in accordance with the eight measures of implementation success (Proctor et al., 2011). This involved the collection and integration of complimentary qualitative information and quantitative data to wholistically measure the implementation process. The methodologies used to carry out this investigation are now discussed in the following chapter.

Chapter 2 – Methods

Multiple research methods were used to investigate the implementation of the InMotion into routine practice including focus groups with therapists, observation of therapy sessions and auditing of InMotion computer data. This chapter will focus on providing detailed information regarding the methods of the four studies included in this program of research.

The program of research included two qualitative studies and two quantitative studies. The two qualitative studies explored therapists' perceptions of RT-UL prior to implementation (i.e. Study 1) and post implementation (i.e. Study 4). Study 2 and Study 3 were quantitative studies. Study 2 investigated UL practice performed by stroke survivors prior to and following RT-UL implementation and Study 3 investigated the sustainability of RT-UL as part of routine clinical practice. The stages of data collection for these four studies are illustrated below in Figure 2.1.

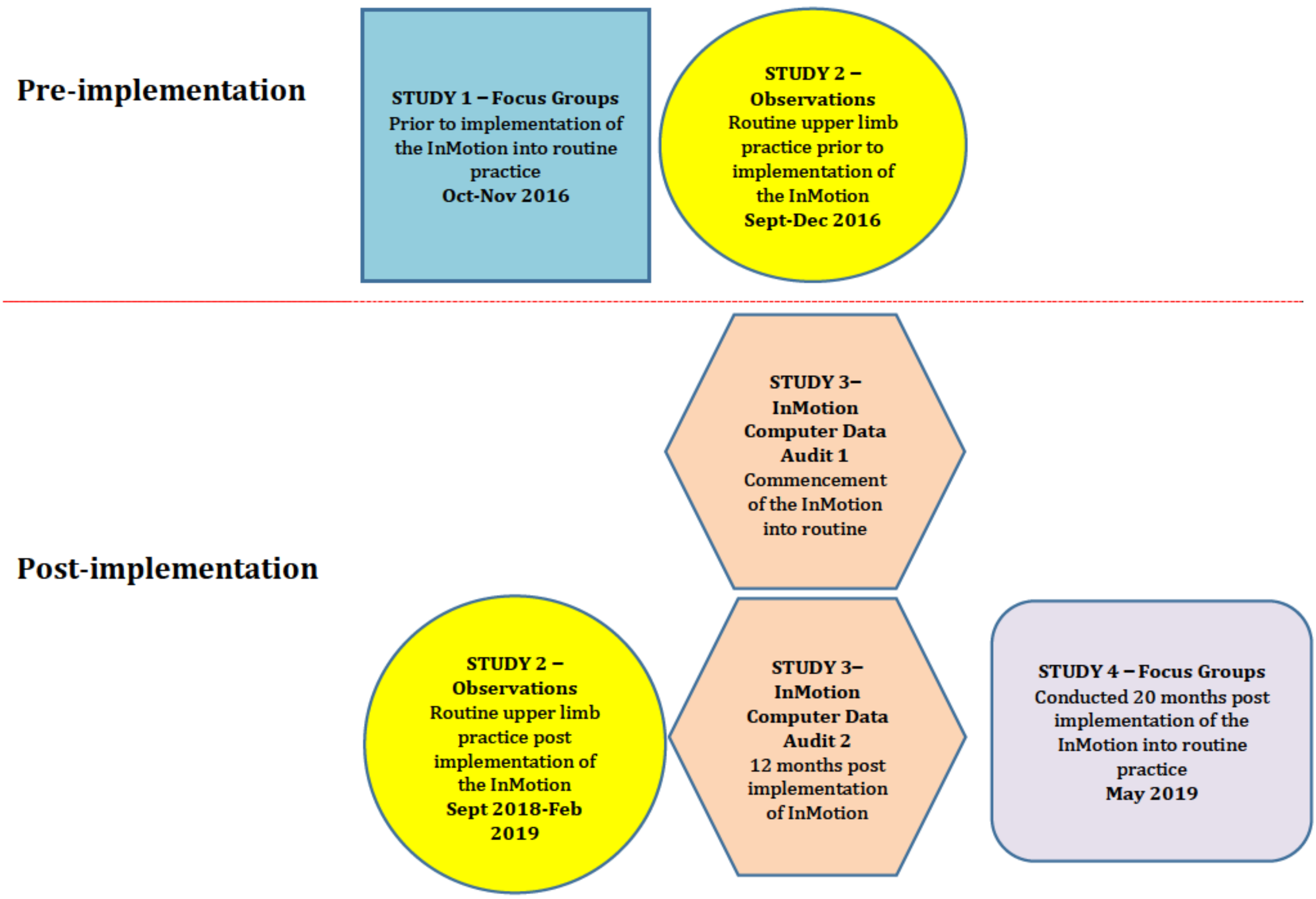
This chapter will also provide a detailed description of the setting, i.e. rehabilitation facility, in which the program of research was undertaken, an important consideration for the generalisability of the results. Finally, this chapter will describe the process of ethical approval and specific ethical considerations unique to the program of research.

2.1 Overview of data collection for included studies

Figure 2.1 illustrates the data collection process for the four studies included in this research program. This overview shows the data collection that occurred prior to and following implementation of the InMotion.

In Figure 2.1, the term "observations" (i.e. Study 2) refers to direct observation by the candidate of occupational therapy and physiotherapy sessions completed by subacute stroke survivors in the rehabilitation unit's gym. The term "audit" (i.e. Study 3) refers to the process of extraction and recording of patient usage data from the InMotion computer.

Figure 2.1 Overview of data collection stages and methods for each of the four studies



2.2 Multiple methods approach

The use of qualitative methods alongside quantitative methods within health research enables researchers to not only objectively record behaviours within the clinical setting but also explore the reasons for these behaviours (Taket, 2017). Such an approach is important in the investigation of the implementation of a new intervention into the routine practice (Proctor et al., 2011; Smart, 2006). Qualitative measures can be employed to explore and measure the acceptability, adoption and appropriateness of an intervention within the clinical setting (Proctor et al., 2011; Taket, 2017). The qualitative data collection method of focus groups with therapists was used in this program of research in both Study 1 and Study 4. Quantitative data collection methods can be used to measure the penetration, sustainability, feasibility and fidelity of the new intervention (Proctor et al., 2011). The quantitative methods specifically used in this program of research involved the direct observation of therapy sessions in Study 2 and auditing of the InMotion computer data in Study 3. When findings from both quantitative and qualitative studies are considered in combination understanding of the implementation process is enhanced. The qualitative and quantitative study designs used in this program of research are now described.

2.3 Qualitative study methodology

In terms of qualitative methodology, focus groups were used in both Study 1 and Study 4 to investigate therapist perceptions of the InMotion prior to and post implementation respectively. Focus groups are a method commonly employed to explore the perspectives of health professionals in relation to the implementation of new technology (Atkins et al., 2017; Davidson et al., 2017). Focus groups provide a unique context in which participants can interact and motivate one another more so than individual interview or questionnaires (Tausch & Menold, 2016). Further to this, the research program had a particular interest in understanding how the discipline groups, occupational therapy and physiotherapy, viewed the implementation process.

2.3.1 Participants

For both Study 1 and 4, focus groups were discipline specific i.e. occupational therapy or physiotherapy. This delineation facilitated a clear analysis of each discipline's perspectives on RT-UL, as well as providing opportunity for exploration of more discipline specific factors. This separation of disciplines also helped with the interpretation of the quantitative data of Study 2 and Study 3. For example, in both Study 2 and Study 3 occupational therapists in particular were observed to prescribe RT-UL less often than their physiotherapy colleagues. In Study 4 focus groups, occupational therapists explained that a primary reason for their infrequent prescription of RT-UL was due to the InMotion device being located in the physiotherapy area of the gym.

A small focus group was also conducted with rehabilitation assistants employed at the facility as part of Study 1. However, the information from this focus group was excluded as only two rehabilitation assistants were available to participate. The rehabilitation assistants were also not responsible for the prescription of RT-UL as part of routine practice.

2.3.2 Procedures

Focus group questions for Study 1 (Table 2.1) were designed to explore therapist perceptions of the pending implementation of the RT-UL into routine practice. Questions were developed out of a collaborative process among the research team. The research team determined that the questions for Study 1 should cover; participants' previous experiences with new rehabilitative technology and in particular RT-UL, awareness of evidence and clinical reasoning for RT-UL, overall perceptions of the InMotion being part of their practice and perceived barriers and facilitators in their workplace to the use of new technology and specifically the InMotion.

Questions used in Study 1 were reviewed and revised for Study 4 (Table 2.2) being largely shaped by the behavioural domains of the Theoretical Domain Framework (TDF) and findings from Study 1, 2 and 3. Version 2 of the TDF was used to formulate the majority of the focus group questions used in Study 4 (Atkins et al., 2017). The TDF is a validated framework that enables the analysis and categorisation of variables influencing health professionals' behaviour (Michie et al., 2005). The TDF has been specifically identified as a framework for implementation research particularly studies involving focus groups (Atkins et al., 2017). The TDF encompasses 14 domains; knowledge, skills, social/professional role and identity, beliefs about capabilities, optimism, beliefs about consequences, reinforcement, intentions, goals, memory/attention/decision process, environmental context and resources, social influences, emotion and behavioural regulation (Atkins et al., 2017).

Table 2.1 Study 1 focus group semi-structured interview questions

Semi-structured interview questions for Study 1 focus groups

1. Thinking back, what has been your experience when a significant piece of new rehabilitative technology has been introduced into your work setting or you have been new to a work setting where they were using unfamiliar technology? (E.g. Wii, Lifegait, Saebo)
    a. What was the new piece of technology?
    b. Was it easy or difficult to incorporate this new piece of technology into your own practice?
    c. Did you and other clinicians in that setting continue to use the device in the long term?
    d. What did you feel helped or hindered the technology being integrated into yours and the facilities daily therapy practices?
2. What experience or exposure have you had specifically in the use of robotic devices for the purpose of rehabilitation?
    a. What was the robotic technology?
    b. Was it easy or difficult to incorporate this new piece of technology into your own practice?
    c. Did you and other clinicians in that setting continue to use the device in the long term?
    d. What did you feel helped or hindered the technology being integrated into yours and the facilities daily therapy practices?
3. So, in your own words what is the reasoning behind using the InMotion system?
    a. What do you understand to be the clinical rationale behind the use of the InMotion system?
4. Are you aware of any evidence to support the use of the InMotion system or similar robotic devices in the rehabilitative setting?
    a. How did you come by this knowledge of the InMotion system (e.g. reading of articles, YouTube, visited InMotion website, discussion with other staff members)?
5. So to our main question do you think the InMotion is going to be useful here at Brighton and why or why not?
    a. What factors do you anticipate may help or hinder the InMotion system's integration into your use of it in daily therapy?
6. At a practical level how do you think the InMotion will be used here at Brighton?
    a. Which type of patients do you think will be suitable to use the InMotion system? Low level vs high level; neuro vs orthopaedics – and why these patients?
    b. Practically, when, how long & how often do you see yourself using it?
    c. If it is not in use, what would you do?
7. At a personal level, do you think the InMotion system is something you feel you will use in your own daily therapy practices?
    a. Practically, when, how long & how often?
8. How receptive do you think patients will be to using the InMotion system?

Table 2.2 Study 4 focus group semi-structured interview questions

Semi-structured interview questions for Study 4 focus groups

1. Do you think the InMotion system has been a useful addition to the Brighton rehabilitation service - why or why not?
    a. How do you feel it has impacted patient outcomes?
    b. Do you have a sense of what type of clients have gained the most benefits?
    c. Observational studies indicate that it has notably increased the number of functional repetitions being performed by patients. Do you think this is consistent with what has occurred more broadly, and do you feel this is improving patient outcomes?
2. Specifically, do you think the InMotion system has been a useful addition to your personal daily practice - why or why not?
    a. As an OT or PT, do you see the use of the InMotion device as part of your role?
    b. Usage records indicate that OT has used the device much less than the PTs, why do you think this is?
3. Tell me about how the InMotion is used in daily practice here at Brighton?
    a. In place of other upper limb interventions or in addition to your previous interventions?
    b. How do you decide who you would use the InMotion system with?
    c. How do you decide when to stop using the InMotion system with a patient?
4. Have there been any obvious barriers to incorporating the InMotion system into your daily practice?
    a. Do you feel that you now have the skills and knowledge, in terms of identifying suitable clients, set up etc to the use of the InMotion device yourself?
    b. In focus groups held prior to the implementation of the InMotion system, the potential interdisciplinary challenges of only having a single device were flagged as a potential barrier– has this been an issue?
5. What has helped make your use of the InMotion easier or supported your learning and practice with the device?
    a. Have management been involved directly in the implementation process?
    b. Training?
    c. Support from other staff?
6. How do you feel patients have responded to the InMotion system being part of their therapy program?
7. Has anyone had any issues with UL pain or any negative reactions to its use?
8. It was noted in the usage records that the hand module has only been used infrequently, is there any specific reason for this?
9. Have you found the evaluative qualities of the InMotion device helpful and if so why or why not?
10. Have you found the InMotion a reliable device to use as part of usual therapy?
    a. I am aware there have been some minor technical problems that have impacted on your use of the initial period since implementation. Can you tell me about these?
11. Is the technical support you have received and that is available sufficient? Timely? What would be your reflections in relation to the technical support you have received?
12. Do you have any safety concerns for use of the InMotion?
13. What games do you use the most and why?
14. What would be your advice to other rehabilitation facilities who are considering purchasing and implementing an upper limb robotic device?

The research team prioritised five domains likely to shape therapists' implementation of RT-UL and developed questions to promote discussion around these domains. The five domains were optimism, knowledge and skills, environmental context and resources, social/professional role and identity and belief about consequences. For example, to promote discussion relating to the domain of social/professional role and identity participants were asked "As an occupational therapist (or physiotherapist), do you see the use of the InMotion device as part of your role?".

Findings from studies 1, 2 and 3 also informed questions for the focus group questions of Study 4. For example, participants were asked if having only a single device was ultimately a barrier to their use in routine practice. This had been flagged by participants as a potential barrier in Study 1. In another example, therapists were asked why the audit data from Study 3 showed that the hand module on the InMotion had been infrequently used in routine practice. The use of questions based on the findings of the preceding three studies enabled richer interpretation of the findings of the initial three studies as well as helped integrate the four studies to create a more comprehensive picture of the implementation process.

Participants in Study 4 also individually completed the System Usability Scale (SUS) at the time of the focus group (Table 2.3.). The SUS was included as part of the data collection process for Study 4 to help clarify and quantify the individual perspectives of participants provided as part of the focus groups. The SUS is a brief survey that provides subjective data regarding the perceived usability of a product or service (Bangor, 2009). The survey entails 11 questions; 10 Likert scale questions and a single overall adjective rating scale of the user-friendliness of the product (Bangor, 2009; Bangor et al., 2008). A total usability score is calculated ranging from 0-100. One minor change was made to the SUS used in Study 4. The original SUS terminology of “system” being incorporated instead of the updated SUS terminology of “product” (Bangor et al., 2008). This was done to directly relate the survey questions to the InMotion and to be consistent with the terminology used in the InMotion user manual.

Table 2.3 Study 4 System Usability Scale (SUS)

1. I think that I would like to use this system frequently

Strongly disagree				Strongly Agree
1	2	3	4	5

2. I found the system unnecessarily complex

Strongly disagree				Strongly Agree
1	2	3	4	5

3. I thought the system was easy to use

Strongly disagree				Strongly Agree
1	2	3	4	5

4. I think that I would need the support of a technical person to be able to use this system

Strongly disagree				Strongly Agree
1	2	3	4	5

5. I found the various functions in this system were all well integrated

Strongly disagree				Strongly Agree
1	2	3	4	5

6. I thought there was too much inconsistency in this system

Strongly disagree				Strongly Agree
1	2	3	4	5

7. I would imagine that most people would learn to use this system very quickly

Strongly disagree				Strongly Agree
1	2	3	4	5

8. I found the system very awkward to use

Strongly disagree				Strongly Agree
1	2	3	4	5

9. I felt very confident using the system

Strongly disagree				Strongly Agree
1	2	3	4	5

10. I needed to learn a lot of things before I could get going with this system

Strongly disagree				Strongly Agree
1	2	3	4	5

11. Overall, I would rate the user-friendliness of this system as:

Worst Imaginable	Awful	Poor	OK	Good	Excellent	Best Imaginable

Note. Adapted from Figure 1 and Figure 2 in Bangor (2009)

2.3.3 Analysis

Version 2 of the Theoretical Domain Framework (TDF) was used to deductively analyse the focus group transcripts for both Study 1 and 4 (Atkins et al., 2017). To the candidate's knowledge this is the first program of research to apply behavioural theory to explain therapists' perceptions of RT-UL implementation. This is important as implementation success is principally contingent on behavioural change of health professionals (Atkins et al., 2017). The TDF has been used previously to analyse therapist behaviour in relation to the implementation of new UL interventions for stroke survivors such as somatosensory retraining (SENSe) (Cahill et al., 2021) as well as national stroke guidelines (McCluskey et al., 2013). The table of definitions for the TDF domains (Appendix 9.8) developed by Atkins et al. (2017) was used to directly inform the analysis process for Study 1 and Study 4. The analysis process for each of these studies is discussed in depth in Chapters 3 (Study 1) and Chapter 6 (Study 4) detailing the transcription and coding process.

2.4 Quantitative study methodology

Study 2 and Study 3 were both quantitative studies. Study 2 was an observational study of UL practice pre and post the implementation of RT-UL and Study 3 an audit of InMotion computer data records.

2.4.1 Participants

Participants for Study 2 and Study 3 included subacute stroke survivors undergoing UL rehabilitation as part of their inpatient program. Specifically, these participants were in the "early subacute" phase of their recovery (i.e. less than three months post event) (Bernhardt et al., 2017). However, the term "subacute" has been used in this thesis to refer to stroke survivors less than three months post-event. For both studies, patients were excluded if they had a serious complicating medical illness, pain or a pre-existing comorbidity impacting their participation in UL therapy. Severity of UL impairment was determined by patients raw score on the Motor Assessment Scale (MAS) item 6, with a score ≤3 categorised as severe UL impairment (Hayward et al., 2013).

Priority was given to stroke survivors in the subacute phase of recovery as it was unlikely to be able to easily recruit those in the chronic phase with the participating rehabilitation service generally being a subacute rehabilitation service. Additionally, at the time of study planning, available evidence suggested that RT-UL was more effective and clinically applicable to subacute stroke survivors than chronic stroke survivors (Mehrholz et al., 2015; Norouzi-Gheidari et al., 2012). This program of research was not seeking to establish efficacy of the RT-UL but rather explore implementation into routine practice. Therefore, patient recruitment was guided by the evidence suggesting RT-UL was more effective in subacute stroke survivors.

2.4.2 Procedures

Study 2 involved two separate observational study phases (i.e. Phase 1 and Phase 2) of UL practice performed by inpatient subacute stroke survivors. Phase 1 was undertaken from September 2016 to December 2016 (pre-implementation) and Phase 2 was conducted from September 2018 to February 2019 (post-implementation). The two observational periods were originally planned to both occur across a six-month period. However, the premature arrival of the InMotion device to the rehabilitation facility shortened the recruitment period for Phase 1 to just three months. Despite this shortened data collection period a sufficient number of participants were recruited to enable statistical comparison between the two phases (please refer to Chapter 4). The observations strategically occurred at the same months of the year to strengthen comparisons between the two datasets. A two-year interval between phases was planned to ensure sufficient time for staff to be trained in the use of the InMotion and for the device to become part of routine practice at the facility. This two-year period was also chosen to align with the data collection timeframes for Study 3.

In Study 3, data collection involved two audits: Audit 1 from September 2017-December 2017 and Audit 2 from September 2018-December 2018. In these audit periods the usage of the InMotion was recorded to measure the sustainability of RT-UL in routine practice. The timing of the audits was in line with previous recommendations that sustainability be measured across multiple points in time (Shelton & Lee, 2019) and span a period of two or more years from initial introduction (Wiltsey-Stirman et al., 2012).

This use of audits is an approach commonly used in implementation science and can provide rich and accurate objective data relating to the use of a new intervention in practice (McCluskey & O'Connor, 2017; Proctor et al., 2011). Auditing is also a method that has been specifically recommended for measuring the sustainability of a new intervention as part of routine practice (Proctor et al., 2011). For example, a study by Logan et al. (2006) audited patient files to evaluate occupational therapists' implementation of a new outdoor mobility program with stroke survivors. The occupational therapists recorded the duration and number of visits to participants homes and the activities completed in the outdoor mobility session. The audit data for Study 3 of this program of research was automatically collected by the InMotion computer and is detailed further in the proceeding section (2.4.3 Measures).

2.4.3 Measures

Study 2

The aim of the observations in Study 2 was to measure the type and amount of UL therapy performed by subacute stroke survivors before and after the implementation of the InMotion. Although time consuming, direct observation has been identified as a more accurate form of recording than other methods such as logbooks (Bagley et al., 2009; Kaur et al., 2013). The use of logbooks can be convenient for researchers but therapists routinely overestimate their input (Bagley et al., 2009; Kaur et al., 2013). Also, the research team was conscious to minimise the inconvenience of data collection on therapists at the rehabilitation facility.

The development of the protocol (Appendix 9.6) and recording form (Appendix 9.7) that guided the observations in Study 2 involved several steps. Firstly, a review of existing observational studies was undertaken including reviewing the procedures and measurement definitions provided in the methodologies of these studies (Hayward et al., 2013; Hayward & Brauer, 2015; Kimberley et al., 2010; Lang, MacDonald, et al., 2007; Lang et al., 2009). Out of this review process, a preliminary protocol and recording form were developed. The protocol and recording form were then pilot tested by researchers (NF and SK) during trial observations of patient sessions. Following these trials researchers compared their repetition counts and categorisation of therapy tasks for consistency before coming to a final consensus on the protocol and recording form.

A major challenge of developing the protocol was defining what would be considered a repetition for the various therapy tasks observed. Definitions given in existing observational studies helped to establish an overarching definition of a single repetition (Lang, MacDonald, et al., 2007; Lang et al., 2009). For the purposes of Study 2 a single definition was determined to be when a patient performed an active or assisted movement of the paretic UL from an initial resting position, through a prescribed motion and then returned to a resting position. The inclusion of the term "prescribed motion" in the definition was important and an outcome of using the protocol trial observations of stroke survivors at the rehabilitation facility. In these trial observations, members of the research team (NF and SK) initially had difficulty accurately and consistently recording incidental movements performed by patients. It was therefore decided that a repetition was only counted if considered to be therapeutic, that is, instructed or performed to complete a prescribed therapeutic task. This overarching definition was then used to generate specific definitions for a range of UL therapy tasks observed during the course of the study (see Appendix 9.2 for these specific definitions). For example, patients were observed threading coloured beads onto string with a single repetition recorded for each bead threaded.

A primary aim of Study 2 was to gain an understanding of the type of practice performed by participants. Upper limb practice observed in the study was therefore categorised as either impairment-related practice or task-specific practice. This distinction was deemed important as stroke survivors traditionally receive inadequate amounts of task-specific practice (Hayward & Brauer, 2015; Lang et al., 2009). Protocols from previous studies were again used to determine how tasks should be categorised (Hayward et al., 2013; Lang et al., 2009). These categories are detailed in Appendix 9.6. In Study 2, RT-UL practice was categorised under task-specific practice on the premise that the patient was required to execute a specific task as presented on the computer monitor.

Study 3

The InMotion computer usage data was recorded in Study 3 to measure the sustainability of RT-UL in routine practice. This data included the date of the session, prescribing therapists, duration of the RT-UL sessions and completed activities. This data were all automatically logged in the InMotion computer during each RT-UL session. Initially for data collection, the candidate reviewed patient summary reports automatically generated by the InMotion computer. A number of inconsistencies and missing data in the patient summary reports were identified suggesting the reports were not a completely accurate record of the RT-UL sessions. These issues were discussed with InMotion technical support in the United States of America. The technical support team identified a “bug” in the computer program that meant that the summary report was not providing a complete summary of the raw data collected by the computer. With guidance from the technical support team and the lead physiotherapist, the candidate was able to bypass the patient summary reports and directly extract the raw data from the InMotion computer. The data were then converted to a series of patient specific excel spreadsheets. These spreadsheets were organised by the candidate into a format that enabled analysis in SPSS. Although complicated and time consuming the extraction of the raw data from the computer resulted in a more detailed and accurate analysis than was possible with the original patient summary reports. For example, the raw data revealed both the patients active therapy time and rest periods when using the InMotion providing an objective measure of the intensity of therapy performed. Further details of the methods and procedures relating to Study 3 are provided in Chapter 5.

2.5 Setting

The participating rehabilitation facility, Brighton Rehabilitation Unit, was located in metropolitan Queensland, Australia. The rehabilitation unit is a stand-alone public facility and is not physically connected to an acute hospital. At the commencement of the research program the rehabilitation facility serviced 50 rehabilitation beds with approximately 600 rehabilitation admissions per year. However, midway through the research program the total rehabilitation beds were reduced to 42 due to patient prioritisation. The rehabilitation unit is a “mixed rehabilitation facility” meaning that patients with a variety of diagnoses receive rehabilitation within the facility (Stroke Foundation, 2020). Patients are referred from nearby acute hospitals. Approximately 30% of patients admitted to the facility have a primary diagnosis of stroke. Stroke survivors are routinely seen by both occupational therapists and physiotherapists on a daily basis, Monday to Friday. There are five full-time equivalent (FTE) physiotherapy positions and four and a half FTE occupational therapists. The facility is largely reflective of Australian rehabilitation services which are typically public facilities, located in a metropolitan area and providing mixed rehabilitation services five days per week inclusive of occupational therapy and physiotherapy (Stroke Foundation, 2020).

Patient rooms and dining areas are located on the floor above the rehabilitation gym. Patients are brought down by support staff to attend their therapy sessions in the rehabilitation gym. Occupational therapy and physiotherapy therapy sessions are carried out in a large gym area on the ground floor of the rehabilitation facility. Although interconnected by a short hallway, the occupational therapy and physiotherapy areas are two distinct spaces. The InMotion device was permanently located in the physiotherapy gym area of the rehabilitation facility.

2.6 Ethical approval

Ethical approval for all aspects of the research program were granted by The Prince Charles Hospital Human Research Ethics Committee (HREC) on the 10th of May 2016

(HREC/16/QPCH/36). The Australian Catholic University (ACU) HREC also approved the program of research (2016-266R) on the 1st of December 2016 with no additional requirements. Please see Appendix 9.1 and Appendix 9.2 for the respective ethical approval letters. The research program was approved as low risk but there were a number of ethical considerations relating to consent, anonymity and confidentiality. These are now discussed.

2.6.1 Consent process

A Participant Information and Consent Form (PICF) detailing the purpose of the study and participants' involvement was provided to discipline representatives who distributed to the therapists at the facility prior to the running of the focus groups. The candidate liaised with the discipline representative to confirm those therapists interested in participating and a suitable time and date to conduct the focus groups. Some participants had signed their consent forms prior to the day of the focus groups but the majority consented on the day. As stated on the PICF, participation was voluntary, and participants were free to decline or withdraw at any time without stating a reason with no effect on their relationship with either the Brighton rehabilitation unit or the Australian Catholic University.

A waiver of patient consent was granted for the observations (Study 2) and audit (Study 3). This waiver of consent was granted by the respective ethical bodies in accordance with section 2.3.10 of the National Statement on Ethical Conduct in Human Research (2007) with patient involvement deemed to carry no more than low risk. Specifically, the waiver was granted on the grounds that the studies entailed:

- an evaluation of routine clinical practice and did not involve a control and intervention group;
- observational by design with no direct intervention from the study investigator;
- demographic data, clinical outcome measures, InMotion computer data were collected as part of routine clinical practices of therapy staff;
- integral in the evaluation and reporting process associated with the funding scheme under which the InMotion was purchased.

Annual reports providing updates of data collection and publications were submitted and approved by both ethical bodies throughout the program of research.

2.6.2 Anonymity and confidentiality

All participants included in the program of research, including patients and therapists, were assigned a re-identifiable participant number (e.g. TH001). All information collected from participants was entered under this number into spreadsheets individually developed for each study. Identifiable information was kept separate in hardcopy form in a locked filing cabinet at the rehabilitation facility.

For Study 1 and Study 4 (i.e. focus group with therapists), demographic information related to the individual therapists was presented in summary format to maintain anonymity e.g. Occupational therapy participants were predominantly female (n = 5), had an average age of 29 years (24-39 years) and were six years post qualification (2-17 years). Direct statements from the transcripts cited in the results section were anonymously attributed to the therapists e.g. Physiotherapist 3. In Study 2 and Study 3 participants' (i.e. stroke survivors) demographic and clinical characteristics, observational data and InMotion computer data were collated and only summarised and averaged information was presented.

2.6.3 Data storage

As detailed above identifiable information was kept in hardcopy form in a locked filing cabinet at the rehabilitation facility. Computer files were stored on password protected computers in offices at rehabilitation facility and university. Only deidentified files were stored at the university. CloudStor, a secure password protected data management site, was used to enable off-site viewing and sharing of recordings of the interviews for transcription. Only members of the research team were provided with access to the Cloudstor. After five years hardcopies of collected information will be shredded and computer files deleted following a minimum of five years after conclusion of the program of research.

Chapter 3 – Therapists perceptions of the introduction of robotic upper limb training into routine clinical practice (Study 1).

Chapter 3 is the published manuscript of Study 1 with some minor updates for terminology to be consistent with the broader thesis.

Flynn, N., Kuys, S., Froude, E., & Cooke, D. (2019). Introducing robotic upper limb training into routine clinical practice for stroke survivors: Perceptions of occupational therapists and physiotherapists. *Australian Occupational Therapy Journal, 66*(4), 530-538. https://doi.org/10.1111/1440-1630.12594

3.1 Title

Introducing robotic upper limb training into routine clinical practice for stroke survivors: Perceptions of occupational therapists and physiotherapists.

3.2 Abstract

Background: Robot assisted upper limb therapy (RT-UL) is an emerging form of intervention for stroke survivors with upper limb deficits. There is, however, limited knowledge regarding therapists' perceptions of RT-UL and the factors influencing the implementation of RT-UL into the clinical setting. This is important when considering that therapists in Australia are primarily responsible for the prescription of RT-UL in daily practice. This study aimed to explore occupational therapists' and physiotherapists' perceptions of RT-UL and the perceived barriers and enablers influencing implementation.

Methods: Two discipline specific focus groups were conducted involving occupational therapists (n= 6) and physiotherapists (n = 6). Participants were members of the same multi-disciplinary team working in an Australian public health rehabilitation facility where RT-UL (i.e. InMotion) was being introduced for the first time. Focus groups explored therapist perceptions of the new RT-UL as well as perceived barriers and enablers to implementation. Focus groups were recorded, transcribed and deductively analysed using the Theoretical Domains Framework (TDF).

Results: Seven out of the 14 domains of the TDF were raised by participants during the focus groups; environmental context and resources, beliefs about consequences, optimism, knowledge, skills, social influences and social and professional role and identity. Therapists expressed their optimism towards the introduction of RT-UL but believed successful implementation would be primarily dependent on the availability of clinical leadership, training and a suitable client mix.

Conclusions: Therapists perceived that RT-UL would provide opportunity for increased upper limb practice particularly for patients with severe upper limb impairment. To facilitate implementation, support of RT-UL should come from both management and clinical leaders and training include RT-UL efficacy, device functionality and patient suitability. The availability of a single RT-UL device in a workplace may create unique interdisciplinary and logistical challenges.

3.3 Introduction

The amount of upper limb practice provided to stroke survivors is sub-optimal (Hayward & Brauer, 2015). Possible reasons for this lack of practice include stroke survivors' limited ability to perform independent practice and consequent dependence on one-on-one support from therapists (Stewart et al., 2017). Robot assisted therapy for the upper limb (RT-UL) presents as a viable intervention to help therapists overcome these clinical challenges when working with stroke survivors and is consequently an emerging form of therapy within rehabilitative facilities across Australia (Galea et al., 2016).

In broad terms, RT-UL involves retraining the upper limb by applying an electromechanical device to the person's upper limb to assist with and facilitate repetitive performance of prescribed upper limb movements (Veerbeek et al., 2017). RT-UL retraining is purported to be motivating, task-orientated, intensive and requiring minimal therapist input and can improve activities of daily living, motor control and strength in the impaired upper limb (Mehrholz et al., 2018; Veerbeek et al., 2017). However, further insight is needed into the implementation of these devices within the clinical setting. Such insights can be found through exploring the perspectives of therapists who are involved in the implementation process.

A recent systematic review (van Ommeren et al., 2018) investigated user perspectives (139 stroke survivors/carers and 384 health professionals) of electrical/mechanical devices used for upper limb rehabilitation. The primary motivation of the review was to understand which factors may influence the decision to purchase a device. Five primary factors were identified; (1) promotion of upper limb performance (i.e. intensity, task orientated) (2) patient and therapist attitude towards technology (i.e. motivating, affinity) (3) decision process (i.e. evidence based, safety, financial outlay) (4) usability (set up, adjustability) (5) applicability in practice (i.e. feedback, overtraining, comfort). Such insights are helpful, however, there is a need to understand if similar or different factors impact the actual implementation process of RT-UL in routine clinical practice, not just the acquisition process.

The perspectives of Australian therapists of RT-UL have not previously been investigated, nevertheless their views of other rehabilitative technology have been. The perspectives of 11 Australian physiotherapists were explored in relation to their prescription and use of technologies to improve mobility and physical activity (i.e. videogames, smart phone applications and activity monitors) (Hamilton, McCluskey, et al., 2018). Again, a complex set of patient and environmental factors were identified, including; the suitability of a technology to the patient needs and goals, patients' previous experiences with technology, patients' preferences and interests in technology as well as the space available to use certain technologies. Further to this, therapists explained that an advanced level of clinical reasoning was needed to continually adapt the technologies to provide the "just right" challenge for their patients. It is therefore of interest if therapists perceive that such an interplay of factors will shape the implementation of RT-UL into routine practice and merit specific strategies to aid implementation. This would seem particularly important when considering both the potential benefits of successful implementation of RT-UL for stroke survivors as well as the large financial outlay associated with purchase of these devices (Stewart et al., 2017).

Another significant variable to be considered in the implementation of RT-UL, is that upper limb management for people with stroke in Australia typically involves both occupational therapists and physiotherapists (Hayward & Brauer, 2015). Exploring interdisciplinary dynamics as they relate to RT-UL would also seem important. Finally, it would be valuable to gain an understanding of therapist perceptions of RT-UL prior to being introduced into practice as pre-existing practices and personal concepts of workplace norms can influence the implementation process (Smart, 2006).

The aim of this study was to investigate both occupational therapists' and physiotherapists' perceptions of RT-UL and explore the potential barriers and enablers to the implementation of a robotic device being introduced into an Australian rehabilitation facility for the first time. This study is part of a broader research program investigating the implementation of RT-UL into routine clinical practice and sits alongside quantitative studies evaluating the usage patterns of RT-UL by occupational therapists and physiotherapists and the impact of RT-UL on the type and dosage of upper limb practice performed by stroke survivors.

3.4 Methods

3.4.1 Design

Qualitative methodology involving two discipline specific focus groups was utilised to gain therapists' perspectives (i.e. occupational therapists and physiotherapists) of the introduction of RT-UL into their rehabilitation facility. Focus groups were conducted prior to the introduction of the InMotion system into routine clinical practice. Discipline specific focus groups were purposely conducted to enable analysis of individual discipline perspectives on RT-UL as well as provide opportunity for discussion of discipline specific factors if they emerged. Discipline specific focus groups were opportunistically held in each disciplines' weekly team meeting which aided recruitment and minimised the study impact on the therapists' daily routine.

Focus groups comprised a convenience sample of therapists working on the day focus groups were scheduled. All available therapists consented to participate in the study. An information sheet detailing the purpose of the study and participants' involvement was provided to discipline representatives who distributed the information to therapists prior to the focus groups. Participation was voluntary, and participants were free to withdraw at any time without stating a reason. Allied health assistants and students were excluded from the study as they were not responsible for the prescription of RT-UL as part of routine practice.

All participants were members of the same multi-disciplinary team working in an Australian public health rehabilitation facility. The facility was located in metropolitan Queensland and services 50 rehabilitation beds with an estimated 578 rehabilitation admissions per year of which approximately 18% of patients have a neurological diagnosis. Patients are seen by both occupational therapists and physiotherapists daily. Ethical approval was gained from the institutions' human research ethics committee HREC/16/QPCH/36.

Version 2 of the Theoretical Domain Framework (TDF) was used to deductively analyse focus group transcripts (Atkins et al., 2017). The TDF is a validated framework for use in the health setting providing a theoretical lens through which to analyse and categorise factors influencing health professionals' perspectives and behaviour (Michie et al., 2005). The TDF version 2 comprises 14 domains; knowledge, skills, social/professional role and identity, beliefs about capabilities, optimism, beliefs about consequences, reinforcement, intentions, goals, memory/attention/decision process (single domain), environmental context and resources, social influences, emotion and behavioural regulation (Atkins et al., 2017).

3.4.2 RT-UL Device

The InMotion system facilitates movement at the shoulder, elbow and hand (with the wrist fixed in neutral or pronation) and intuitively adapts to the person's active movements providing "assist-as-needed exercise guidance" (Bionik Labs, 2017). There is also a series of inbuilt evaluative tools which can be used to measure and monitor changes in upper limb kinematic control and force.

3.4.3 Procedure

Focus groups were led by one investigator (NF) using a series of semi-structured questions. No other external parties were present during the focus groups other than the investigator and participating therapists. Focus group questions were designed to explore therapist perceptions of the introduction of the RT-UL in their clinical setting. Specifically, questions covered: participants' previous experiences with new rehabilitative technology and in particular RT-UL, awareness of evidence and clinical reasoning for RT-UL, overall perceptions of the InMotion being part of their daily practice and perceived barriers and enablers in their workplace to the use of new technology and specifically the InMotion. As the InMotion system had yet to be introduced to the unit, a brief demonstrative video of the InMotion system was shown prior to commencing each focus group to provide participants with a basic orientation to the device. At the end of each focus group a summary was presented to the participants to confirm the key points raised in the discussion and provide opportunity for any further clarification. These points were then documented by the investigator to aid analysis. Focus groups lasted approximately 40 minutes.

Focus groups were audio recorded and transcribed verbatim. As part of the transcription process all participants were de-identified and allocated an alias. Transcription was conducted by one investigator (NF) and cross-checked by a second investigator (DC). Focus group transcripts were entered and stored in NVivo 11, a qualitative research software program, to facilitate the analysis process.

Prior to the commencement of coding, the two investigators independently reviewed the TDF guide developed by Atkins et al. (2017) and met to confer on their understanding of the TDF domains. Each investigator separately coded the transcripts, assigning relevant statements into one or more of the 14 domains. The two investigators then met to achieve consensus on coding and to allocate all statements under a single domain. Where consensus could not be reached, a third investigator (SK), was consulted to finalise categorisation.

3.5 Results

3.5.1 Participants

Two discipline specific focus groups were conducted with a total of 12 participants (6 occupational therapists; 6 physiotherapists). Occupational therapy participants were predominantly female (n = 5), had an average age of 29 years (24-39 years), were six years post qualification (2-17 years) with four years neurological experience (1-10 years). Physiotherapy participants were also predominantly female (n = 4), had an average age of 30 years (23-51 years), were eight years post qualification (1-30 years) with 6.5 years neurological experience (1-25 years). Each focus group included a senior therapist who had more experience than their discipline group (senior occupational therapist = 17 years; senior physiotherapist = 30 years).

Two occupational therapists and one physiotherapist reported brief exposure to the use of RT-UL during their undergraduate clinical experiences. None of the participants reported using RT-UL as part of their practice since graduating.

3.5.2 Responses

Seven out of the 14 TDF domains were discussed in depth by participants during the focus groups; environmental context and resources, beliefs about consequences, optimism, knowledge, skills, social influences, social and professional role and identity (single domain) and beliefs about capabilities. The remaining seven domains were not included in the results as these categories were only discussed superficially or not at all. Sub-themes were created within the “environmental context and resources” domain to further define specific constructs. The domains of “optimism” and “beliefs about consequences" have been combined below along with "knowledge" and "skills", however, participants' original statements were categorised under the relevant domain during analysis.

Environmental context and resources

This domain refers to the influence the work environment can have on health professionals' behaviour when implementing a new practice and includes practical elements such as the predictability and availability of patients, materials, time, staffing and technical support as well as broader constructs such as the organisational culture.

Eligible/suitable patients. The key environmental influence on the usage of the InMotion in daily practice reported by therapists was the number and flow of suitable patients.

> I think it's obviously dependent on (having) appropriate patients. (Occupational Therapist 5)

> I think it will have up and down phases … sometimes you got heaps of patients and then other times not so many. (Physiotherapist 5)

This was also highlighted as an issue by therapists who had used RT-UL as a student.

> The client group itself was hard cause you didn't have a consistent flow of people. (Occupational Therapist, 3)

> It (RT-UL device) was only really appropriate for a few patients (Occupational Therapist, 2)

Availability of device. Participants perceived that the availability of a single RT-UL device could present challenges relating to person and environment interaction. Firstly, the logistics of both disciplines (occupational therapy and physiotherapy) using the one device and secondly the availability of the device for use with multiple patients.

> We've got physios and OTs who will be potentially wanting to access that (InMotion). (Occupational Therapist 1)

> I guess the only potential issue that I can see is actually having too many (patients) that will want to use it- not enough time in the day with only one machine. (Physiotherapist 2)

Practical challenges. Participants also drew on past experiences as students with RT-UL to highlight a number of unique practical issues.

> When the system didn't work … there was no one to really assist with fixing that … so it was out of action. (Occupational Therapist 3)

> It was annoying the computer would always break - not the device itself, but the computer. (Physiotherapist 4)

In the positive, one participant recalled that there was only limited set up involved with RT-UL.

> No it was pretty quick. It didn't take long to set up at all. (Physiotherapist 4)

Organisational culture. Finally, participants described an organisational culture within the workplace that they felt would positively influence the implementation process.

> The other thing we're fortunate here I think there is quite good support from line managers. (Physiotherapist 2)

> (There) has been quite an outlay of money I think there will be bean counters who will probably have a vested interest…the ones who control the purse strings will probably want to have some awareness of how it's being used. (Occupational Therapist 1)

Optimism & belief about consequences

Optimism is concerned with therapists' confidence that a new practice is for the betterment or detriment of their practice and will achieve the intended goals. Overall, both disciplines were relatively optimistic towards the introduction of the InMotion.

> I'm really excited about starting to use the robotic technology. (Physiotherapist 3)

> I'm looking forward to trying it as soon as possible. (Occupational Therapist 1)

Specifically, they believed the InMotion had the potential to improve the quality and quantity of therapy provided to stroke survivors, particularly stroke survivors with severe upper limb impairment.

> (For) those low-level patients … who you want to spend a lot of time with but for caseload demands you can't achieve that dosage. (Occupational Therapist 2)

> I think it's got potential for a patient group (severe upper limb impairment) that we normally struggle to try and do meaningful practice with… (Physiotherapist 2)

The occupational therapists appeared more measured than their physiotherapy colleagues towards the implementation of the InMotion emphasising the need to first see the effectiveness of the device for themselves.

> Essentially, we're going to need to see with our own eyes that it's actually helping people because even if we're trained, even if we feel comfortable in its use but we don't value its use, we're not going to use it. (Occupational Therapist 2)

Therapists also believed the evaluative qualities of the InMotion would be particularly useful and potentially motivating for patients.

> I think seeing results on the screen, will probably help with motivation … keep people engaged or be a bit more engaged than with other therapies where you can't necessarily see a day-to-day change… (Occupational Therapist 5)

The only negative consequence flagged in the focus groups related to safety issues associated with using any new or unfamiliar rehabilitative technology.

> When you have a new piece of equipment that you're really not familiar with and you're not sure that your particular patient is suitable for it and if you are going to do them any harm if you set it up wrongly. (Physiotherapist 2)

Knowledge and skills

The majority of the occupational therapists and physiotherapists acknowledged that they had limited awareness of the evidence supporting the use and effectiveness of RT-UL or the functionality of the device.

> I know that there's been some studies …but no I haven't read anything specific about it. (Occupational Therapist 1)

> My lack of understanding about the system itself is I don't know whether it's also useful for people with reasonable function that you're wanting to get more sort of dexterity and control. (Physiotherapist 2)

Consequently, therapists recognised the importance and need for training to facilitate the implementation of the InMotion.

> I think it does rely on us having adequate training and the confidence to utilise it. (Physiotherapist 3)

> I guess knowing the background of the purpose of the equipment definitely makes it easier to start implementing in practice. (Occupational Therapist 3)

Social influence

Participants identified the potential for various social dynamics to play a part in the implementation of the InMotion. Therapists expressed the importance of a champion or a mentor to lead the implementation process as well as to ensure the sustainability of the device as part of practice.

> Whether they're physios or OTs or whoever but that mentoring is really important to help you get through and utilise it optimally. (Physiotherapist 2)

> I'm looking for somebody to be the guru for it so we actually can have a phone a friend to help overcome barriers. (Occupational Therapist 2)

Participants also described a generally positive social dynamic amongst themselves that was likely to facilitate the implementation of new technology.

> I think we're really good at having informal discussions as to why it wouldn't be utilised. (Physiotherapist 3)

> What is actually creating more value for clinicians (is) talking through and reflecting about successes or failures that somebody has had. (Occupational Therapist 2)

Social and professional role and identity

This category is concerned with understanding how a new practice fits within an individual's existing role and identity within a workplace.

Occupational therapy participants were particularly interested in which of the disciplines, occupational therapy or physiotherapy, would take the lead and responsibility for the implementation of the InMotion.

> Is it going to be the OT, the physio? I think one of the benefits here is that I think we haven't been overly precious about that over the years and I think that's a

positive thing as long as someone's actually getting the therapy that they require. (Occupational Therapist 1)

I'm very keen to see how we do share our toys so I hope that it works well (Occupational Therapist 2)

Physiotherapists specifically highlighted that it was important the InMotion did not replace fundamental elements of their role in the management of stroke survivors.

I hope it doesn't replace our upper limb management. I hope we use it as well as our own clinical practice as well hands on. (Physiotherapist 3)

3.6 Discussion

There were three key findings from this study. Firstly, therapists overall were positive towards the implementation of the RT-UL into their workplace and particularly optimistic with regards to the potential for RT-UL to address clinical challenges that exist in providing effective amounts of meaningful therapy for stroke survivors with severe upper limb impairment. Secondly, the availability of a single RT-UL device could present unique logistical challenges relating to how the device is used between the disciplines as well as with multiple patients. Thirdly, therapists identified that leadership, training and the availability of suitable patients would be essential factors determining the use of the RT-UL device in routine practice.

3.6.1 Therapists' optimism

Overall, participants were very positive about the prospect of the RT-UL being introduced into their workplace. They perceived that RT-UL could deliver a highly repetitive and motivating intervention. Participants also believed that RT-UL could be effective in improving the quality and quantity of practice able to be provided to stroke survivors with severe upper limb impairment. This optimism bodes well for the successful implementation of RT-UL into routine practice as therapists' pre-conceptions of a new intervention can be a defining factor (Smart, 2006). Interestingly though, the effectiveness of RT-UL specifically for stroke survivors with severe upper limb impairment has yet to be clearly established and has been identified as a priority for future studies in this field (Mehrholz et al., 2018).

Therapists also believed a chief advantage of implementing RT-UL would be the ability to increase practice dosage, i.e. number of movement repetitions, stroke survivors complete during routine therapy; namely those experiencing severe upper limb impairment. This potential for increased practice is generally considered the primary reason for the effectiveness of RT-UL (Mehrholz et al., 2018) with devices such as the InMotion purportedly able to facilitate over a thousand movement repetitions in a standard session (Bionik Labs, 2017). However, the specific number of RT-UL movement repetitions required to effect significant motor recovery has not been consistently measured or reported in efficacy studies (Mehrholz et al., 2018). It is questionable if this amount of practice can be consistently administered in routine clinical practice when factoring in potential practical challenges such as set up time, therapists' skills and availability of clinical support for trouble shooting. Further investigation is merited to determine the actual capacity for RT-UL to increase the dosage of practice for stroke survivors within a real-world clinical setting.

Despite some therapists recalling negative experiences with RT-UL as a student (e.g. break down and technical support issues), there was a notable absence of any directly negative statements regarding the implementation of the InMotion device. This is surprising considering that such practical issues have previously been flagged by therapists as major issues for the use of rehabilitative technology (Hamilton et al., 2018; van Ommeren et. al, 2018). This may be evidence of the strength of optimism surrounding the new device or simply reflective of the device not yet being introduced into routine practice. Follow up focus groups proceeding the implementation of the device could give greater insight into these practical aspects.

3.6.2 Implications of a single device

In this particular facility both occupational therapists and physiotherapists work collaboratively to manage stroke survivors' upper limb recovery. Such an interdisciplinary approach is reflective of practice more broadly in Australian rehabilitative settings (Hayward & Brauer, 2015). Participants thought having only a single RT-UL device available for both disciplines to use would likely present some distinct challenges such as where to locate the device (i.e. occupational therapy or physiotherapy department) and which discipline would be responsible for initiating RT-UL with patients. In a recent randomised control trial investigating the effectiveness of an upper limb electromechanical device (SMART Arm) both physiotherapists and occupational therapists were involved in the use of the device with their patients

(Barker et al., 2017). Interestingly, no issues were identified, relating to the shared interdisciplinary use of a single device in the rehabilitation setting. However, challenges may present when clear protocols are not in place. If applicable, specific strategies could be employed to address these interdisciplinary dynamics including the training of disciplines jointly as well as locating the RT-UL system in a central area or alternating the system's location between discipline areas during the year. Such strategies may help to promote RT-UL as part of each disciplines' routine practice as well as assist to maintain therapists' skills and confidence in the use of RT-UL.

The availability of a single device was also seen by therapists as potentially creating unique scheduling dilemmas, an issue not uncommon to new forms of rehabilitative technologies (Chen & Bode, 2011). Therapists and administrators will need to be mindful of establishing clear procedures around timetabling patients to facilitate the implementation process and enhance the feasibility of the intervention. Where possible therapy assistants could be upskilled to deliver RT-UL sessions and so broaden the times for appointments (i.e. evenings/weekends).

3.6.3 Leadership, training and availability of patients

Participants expressed that their uptake and ongoing use of the InMotion in routine practice was connected to three main elements; leadership, adequate training and availability of suitable patients.

The value placed on leadership by the focus groups was notable. Strong leadership at both managerial and clinical levels has been recognised as essential to a successful implementation process (Bradley et al., 2004). Senior management can provide crucial financial and administrative support needed to get a new intervention off the ground and leadership at a clinical level can provide the role modelling and support required for clinicians in daily practice (Hoffmann et al., 2017). Therapists in this study believed that senior management at their centre would be keenly interested in the RT-UL implementation process to ensure the financial investment was justified. This factor was seen as a clear driver for implementation. In terms of clinical leadership, participants expressed the need for a RT-UL champion, of either discipline, to lead the implementation process, provide training and to aid in day-to-day troubleshooting. Establishing this clinical leadership is an important step in the implementation process particularly when the initiative for RT-UL has come from senior management who may not be involved in the daily provision of therapy. It would also be prudent to ensure this clinical leadership is broader than any single individual so that troubleshooting and staff support can continue if a lead person is unavailable due to leave or work arrangements (i.e. part-time).

Secondly, therapists stressed the importance of receiving training to enable use of the RT-UL device as part of routine practice. Training has repeatedly been shown to be an effective strategy for changing health professionals practice and improving patient outcomes ((Forsetlund et al., 2009). Specifically, therapists in this study identified that training should include background knowledge of RT-UL (e.g. supporting evidence), skill acquisition in the various functions of the device and identification of the type of patient that would be suitable. One senior therapist believed that understanding which patients would be suitable for a new intervention was essential for safe practice.

Therapists may hesitate to implement a new intervention when there is a real or perceived risk of incurring injury to their patient, and this would seem pertinent in relation to RT-UL where stroke survivors are participating in highly repetitive practice. The occurrence of pain in the upper limb following a stroke has been found to be directly proportionate to the amount an individual uses their upper limb as well as the severity of their impairment (Lang, Wagner, et al., 2007; Ratnasabapathy et al., 2003) al., 2003). RT-UL is recognised as a relatively safe form of therapy with adverse events and dropouts being uncommon in efficacy studies (Mehrholz et al., 2018). Informing therapists of such findings as part of the training process should increase therapists' confidence when prescribing and delivering RT-UL.

Therapists perceived that the usage of RT-UL in routine practice was directly related to the availability of suitable RT-UL patients. This has been previously recognised as a factor determining both the acquisition and prescription of new rehabilitative technology in practice (Chen & Bode, 2011; Hamilton, Lovarini, et al., 2018). This would seem logical but highlights the importance of ensuring that the clinical context has an adequate number of appropriate patients, otherwise the usefulness of the intervention is questionable. Therapists further explained that the number of suitable patients for RT-UL may ebb and flow over time. This may result in therapists gradually losing skills and confidence to use RT-UL as part of their routine practice. Undertaking a pre-implementation audit of patient numbers and clinical demographics across a range of time periods should be a foundational part of the implementation process (McCluskey & O'Connor, 2017). Audit results could help determine the initial appropriateness of the purchase of an RT-UL device and may even aid in determining the most suitable type of

RT-UL device. The range of commercially available RT-UL devices is increasing, and it is important that health administrators and clinicians consider the type of device that will best meet the needs of their patients and staff. Additionally, audit data may help identify strategic times for staff retraining to refresh knowledge and skills and in turn increase confidence to incorporate RT-UL into their routine practice.

3.6.4 Implications for practice and research

An audit of patient admissions should be undertaken prior to RT-UL device acquisition to help ensure the device is suitable to a setting. Training should inform therapists of the efficacy, suitability and safety of RT-UL along with the functionalities of an RT-UL device. Consideration should also be given to the scheduling of the use the RT-UL to tackle potential logistical and interdisciplinary challenges. Further research is needed to determine if RT-UL increases the dosage of practice performed by stroke survivors once part of routine clinical practice.

3.7 Limitations

This study investigated the perceptions of occupational therapists and physiotherapists within a single rehabilitation facility in Australia and both groups were of a small size. Conclusions from this study are therefore reflective of the participants and their healthcare setting. Transferability of results to the respective professions as a whole should be made with caution. Inclusion of allied health assistants and students may have broadened the findings of this study. However, as neither group was to be involved in the prescription of RT-UL in daily practice these groups were excluded. Finally, the use of the TDF to guide data analysis may have limited identification of other relevant themes. This framework, however, enabled a structured and effective process of categorisation and placed the information in a format that is consistent with other studies in the field of implementation science.

3.8 Summary

Pending implementation of RT-UL into clinical practice was perceived positively by both occupational therapists and physiotherapists. Therapists identified the potential for RT-UL to improve the specificity and dosage of practice performed by stroke survivors, particularly those with severe upper limb impairment. However, further research is needed to determine if the purported number of RT-UL repetitions and associated improvement in clinical outcomes can be achieved in routine clinical practice when factoring in the various practical challenges for using upper limb robotic devices in the clinical setting.

The availability of a single RT-UL device within a rehabilitation facility may create unique interdisciplinary and scheduling challenges that need to be considered as part of the implementation process. Finally, therapists linked their potential use of RT-UL in routine practice to having the support of a clinical leader, training in use of the robotic device, and the availability of patients who would benefit from its use.

Chapter 4 – Repetitions, duration and intensity of upper limb practice following the implementation of robot assisted therapy (Study 2)

Chapter 4 is the published manuscript of Study 2 with some minor updates for terminology to be consistent with the broader thesis.

Flynn, N., Froude, E., Cooke, D., & Kuys, S. (2020). Repetitions, duration and intensity of upper limb practice following the implementation of robot assisted therapy with sub-acute stroke survivors: an observational study. *Disability and Rehabilitation: Assistive Technology*, *17*(6), 675–680. https://doi.org/10.1080/17483107.2020.1807621

4.1 Title

Repetitions, duration and intensity of upper limb practice following the implementation of robot assisted therapy with sub-acute stroke survivors: An observational study.

4.2 Abstract

Background: Robot assisted upper limb (UL) therapy has been identified as an intervention with the potential to help improve the amount of practice performed by stroke survivors. This study aimed to measure the amount of UL practice (i.e. repetitions, duration, intensity) performed by subacute stroke survivors, in particular those with severe UL impairment, pre and post implementation of robot assisted upper limb therapy (RT-UL) into an inpatient rehabilitation setting.

Methods: Two observational study phases (pre-RT-UL and post-RT-UL) were undertaken of occupational therapy and physiotherapy sessions performed by subacute stroke survivors. Upper limb tasks observed and recorded in therapy were classified as either impairment-related therapy or activity-related.

Results: In the pre-RT-UL observational phase, 7 subacute stroke survivors were observed across 11 days involving 25 therapy sessions. Post-RT-UL, 12 subacute stroke survivors were observed across 12 days involving 29 therapy sessions. There were no significant differences in characteristics of patients observed in each phase ($p > 0.05$). The mean difference (95% CI) between pre and post RT-UL for repetitions (reps) (569 (1 to 1136)) and intensity (7 (4 to 11)) reps/min of practice increased for all patients, including those with severe UL impairment (337 (37 to 638)) reps and (8 (2 to 14)) reps/minute, with the duration of therapy unchanged.

Conclusions: This is the first study to have observed an increase in UL practice with the inclusion of RT-UL as part of routine clinical practice. This increase in practice is considered to be due to RT-UL providing highly supportive and expeditious semi-supervised practice. Notably, RT-UL was able to be implemented within the existing organisational structures with only basic training of therapy staff.

4.3 Introduction

Motor recovery in the upper limb (UL) following stroke is largely dependent on a person's ability to engage in practice that is highly repetitive, intensive and task-specific (Arya et al., 2011). However, this can be a challenge for therapists to provide in the clinical setting particularly when people have severe UL impairment and independent exercise is difficult or impossible (Hayward & Brauer, 2015). Previous research into usual UL therapy found people with stroke performed less than 32 UL repetitions per therapy session (Hayward & Brauer, 2015) at an average intensity of one repetition per minute (Kimberley et al., 2010). Stroke survivors themselves have also reported an insufficient amount of UL therapy when in hospital and described limited access to rehabilitative technology, such as robot assisted upper limb therapy (RT-UL) (Hughes et al., 2014).

In essence, RT-UL retraining involves the facilitation of repetitive UL movements with the assistance of an electromechanical device supporting the paretic arm (Veerbeek et al., 2017). RT-UL devices (e.g. InMotion) can purportedly facilitate highly intensive practice, enabling over a thousand movement repetitions in a 60-minute session (Conroy et al., 2011) with only minimal input from the therapist (Stewart et al., 2017). Most importantly, RT-UL has been shown to be effective in improving activities of daily living performance, motor control and strength in the impaired UL (Mehrholz et al., 2018; Rodgers et al., 2019; Veerbeek et al., 2017).

This potential for RT-UL to increase the amount of practice performed by stroke survivors is encouraging, however, a range of individual and environmental factors can impact the successful implementation of UL best-practice into the clinical setting (Bayley et al., 2012; Jolliffe et al., 2019; McCluskey et al., 2013; Mudge et al., 2017). Factors such as patient motivation, therapist knowledge, attitude and skill, clinical leadership, safety concerns, set up of the device and organisational resources may impact usage of robotic devices in the clinical setting(Atkins et al., 2017; van Ommeren et al., 2018).

This study aimed to measure the amount of UL practice (i.e. repetitions, duration, intensity) performed by subacute stroke survivors, in particular those with severe UL impairment, pre and post the implementation of RT-UL into an inpatient rehabilitation setting.

4.4 Methods

4.4.1 Design

Two separate observational study phases (i.e. pre-RT-UL and post RT-UL) were undertaken of occupational therapy and physiotherapy sessions completed by subacute stroke survivors across an entire day in the central gym area. The pre-RT-UL observational phase was conducted between September 2016 and December 2016, prior to the implementation of the InMotion into the rehabilitation practice setting. The post-RT-UL observational phase was conducted from September 2018 to February 2019, 20 months after the introduction of the InMotion into this clinical setting. A 20-month interval between the pre-RT-UL and post RT-UL phases provided sufficient time for the InMotion system to be embedded into routine clinical practice, and training of all occupational therapy and physiotherapy staff in its use completed. Training involved either individual or small group based practical education sessions led by the senior physiotherapy staff.

4.4.2 Site

The participating rehabilitation facility was located in metropolitan Queensland, Australia. The facility services 50 rehabilitation beds with approximately 600 rehabilitation admissions per year, of which approximately 30% of patients have a primary diagnosis of stroke. Stroke survivors are typically seen by both occupational therapists and physiotherapists on a daily basis, Monday to Friday. The InMotion system was permanently located in the physiotherapy gym area of the rehabilitation unit. Ethical approval for the study was gained from The Prince Charles Hospital Human Research Ethics Committee (HREC) (HREC/16/QPCH/36) and the Australian Catholic University HREC (2016-266R).

4.4.3 Participants

Subacute stroke survivors (i.e. less than 3 months post event) undergoing UL rehabilitation as part of an inpatient program were eligible for inclusion in the study. For the post RT-UL observational phase, patients also needed to be engaged in RT-UL as part of their UL rehabilitation program. Patients were excluded if they had a serious complicating medical illness, pain or a pre-existing comorbidity impacting their participation in UL therapy. Severity of UL impairment was determined by patients raw score on the Motor Assessment Scale (MAS) item 6, with a score ≤3 categorised as severe UL impairment (Hayward et al., 2013).

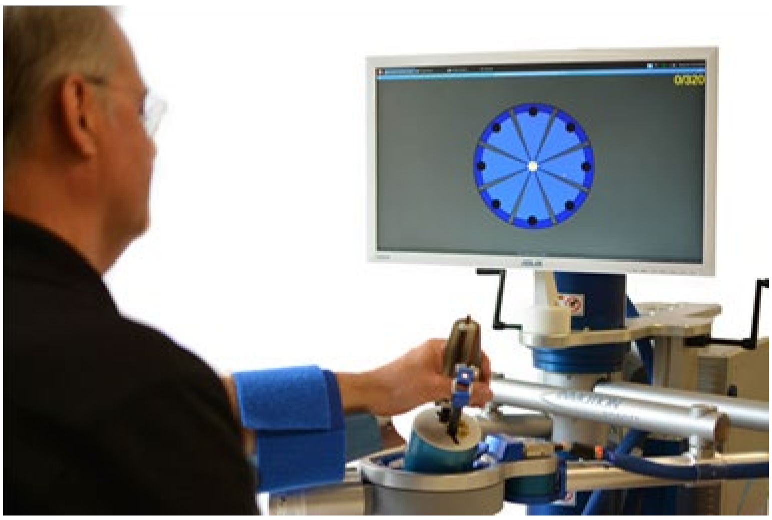
4.4.4 Recruitment

The rehabilitation unit was visited on a weekly basis (NF) during both the pre and post RT-UL observation phases. A convenience sample of eligible patients for observation was selected pragmatically based upon patient and staff schedules on the day of each observational research visit. As the study progressed, patient types that were underrepresented in the dataset (e.g. gender and UL severity) were prioritised for observation.

4.4.5 Robot-assisted upper limb therapy device (InMotion)

The InMotion system (Figure 4.1) facilitates movement at the shoulder, elbow and hand (with the wrist fixed in neutral or pronation) and intuitively adapts to the person's active movements providing "assist-as-needed exercise guidance" (Bionik Labs, 2017). The InMotion system also includes a series of inbuilt evaluative tools that can be used to measure and monitor changes in UL kinematic control and force.

Figure 4.1 InMotion system (Bionik Labs, 2017)



4.4.6 Measures

The observational protocol and recording form developed to record repetitions, duration and intensity of UL practice initially involved the review of previous observational studies investigating UL practice for stroke survivors (Hayward et al., 2013; Hayward & Brauer, 2015; Kimberley et al., 2010; Lang, MacDonald, et al., 2007; Lang et al., 2009). The protocol and recording form subsequently developed were pilot tested and refined during trial observations of patient sessions. Observational data were collected by one investigator (NF) for both observation phases to ensure consistency of recording. Where it was uncertain how to categorise or count a specific task, the activity observed was recorded and consensus reached with the research team.

To enable accurate recording of therapy, only a single patient was observed on each observational day. All occupational therapy and physiotherapy gym-based sessions in that day were observed except where the sole purpose of the session was assessment. Where a patient was observed on more than one day the average dose for both minutes and repetitions were determined across the total number of observation days. During session observations, the investigator aimed to be unobtrusive and did not interfere or assist with the therapy session being observed. Time and repetitions were totalled at the end of each session.

UL repetitions were manually counted using a clicker. A single repetition was defined as the patient performing an active or assisted movement of the paretic UL from an initial resting position, through a prescribed motion and then returning to a resting position (Lang, MacDonald, et al., 2007). A repetition was only counted if considered to be therapeutic, that is, instructed or performed to complete a prescribed therapeutic task.

Repetitions also included obvious attempts to perform the prescribed therapy task (whether the patient was successful or not). Movements associated with assessment or that were incidental in nature were not counted. Duration of therapy was measured in minutes using a digital stopwatch. Intensity of UL practice was defined and calculated as the number of UL repetitions performed per minute (Kimberley et al., 2010).

UL therapy tasks were categorised as either impairment-related therapy or activity-related based on previously developed coding lists for observing UL practice by stroke survivors (Hayward et al., 2013; Lang et al., 2009). Definitions for the categories and the repetitions of UL movements utilised in this study are shown in Table 4.1. The discipline that provided each UL therapy session, either occupational therapy or physiotherapy, was noted.

Table 4.1 Definitions of movements, repetitions and examples for impairment-related and activity-related upper limb task practice

Category	Definition	Definition of single repetition	Examples
Impairment-related			
Active exercise	Any movement in which the patient attempted or moved the limb through a specific motion	One movement from initial position and back again	Side-lying shoulder flexion/extension
Passive Exercise	Any movement of the limb by a therapist or a device, without any effort by the patient	One movement from initial position and back again	Stretches; passive range of patient's fingers by therapist
Sensory	Any activity done to receive/enhance somatosensory input	One period of the activity	Weight bearing where one period of bearing weight through the paretic arm was counted as one repetition
Activity-related			
Functional tasks	Any movement that accomplishes/attempts to accomplish a functional task. For more complex functional tasks movements were recorded as subunits of the whole task.	One completion of the functional task	Reaching for a cup Throwing a beanbag Preparing a cup of coffee (contained subunits) Making a bed (contained subunits)
RT-UL	Any movement that accomplishes/attempts to accomplish a task presented on the InMotion computer monitor.	One movement from initial position and back again as displayed on the computer monitor	Clock game task = starting at the central dot of the clock presented on the computer monitor, reaching out to the presented dot on the outer edge of the clock and then returning to the central dot Pick game = Reaching, grasping, transporting and releasing (with active-assistance from the InMotion device) a highlighted dot to designated positions on the computer screen.

Note. Adapted from table in Lang et al. (2009). Abbreviation: RT-UL – Robot assisted upper limb therapy

Impairment-related therapy involved patients completing tasks to directly address deficits in body function and structure and included active exercise, passive exercise and sensory tasks. Activity-related therapy involved patients executing functional tasks either basic or complex. Complex functional task repetitions were recorded as subunits of the whole task. For example, 11 subunit repetitions were counted in observation of a patient using their paretic UL to prepare a cup of coffee including filling kettle with water, carrying the cup, carrying the spoon, opening the coffee jar, putting the lid back on the coffee jar, opening the fridge door, removing the lid from the milk, putting lid on the milk, reopening the fridge door, stirring the coffee and carrying the coffee. RT-UL was categorised under activity-related therapy with the patient required to execute a specific functional task as presented on a computer monitor.

4.4.7 Data Analysis

Data are presented descriptively as mean (SD) to describe repetitions, duration of therapy (minutes) and intensity of therapy (repetitions/minute). Types of UL therapy data (activity-related, activity-related without RT-UL, impairment-based, RT-UL alone) are described separately. Between group analysis was undertaken to examine differences between the amount of UL therapy practice pre- and post-RT-UL for all subacute stroke survivors. Results for observations of those with severe UL impairment (MAS score ≤3) were also examined separately in both pre and post RT-UL. Independent sample *t*-tests (or non-parametric equivalent) were used to compare pre and post RT-UL measures. For categorical data a Chi-square test for independence or

Fisher's Exact test were used. All data were analysed using SPSS v. 25 and statistical significance set at <0.05.

4.5 Results

4.5.1 Participants

Pre RT-UL, 7 subacute stroke survivors were observed across 11 days, involving 25 therapy sessions (9 occupational therapy sessions; 16 physiotherapy sessions). Post-RT-UL, 12 subacute stroke survivors were observed across 12 days involving 29 therapy sessions (10 occupational therapy sessions; 19 physiotherapy sessions). Fourteen sessions involved RT-UL, 13 of which were led by physiotherapy. RT-UL practice performed by patients required only intermittent input from the treating therapist. There were no significant differences in characteristics of patients observed pre-RT-UL and those observed post RT-UL ($p > 0.05$). Demographic data and clinical characteristics of patients observed as part of the pre and post RT-UL observations is summarised in Table 4.2.

Pre RT-UL, 5 subacute stroke survivors with severe UL impairment were observed across 8 days involving 19 sessions (8 occupational therapy sessions; 11 physiotherapy sessions). Post RT-UL, 5 subacute stroke survivors with severe UL impairment were observed across 5 days involving 10 sessions (3 occupational therapy sessions; 7 physiotherapy sessions). Patients with severe UL impairment engaged in 6 sessions that involved RT-UL, all were led by physiotherapy. There were no significant differences in patients' characteristics with severe UL impairment between pre-RT-UL and post RT-UL ($p > 0.05$) (Table 4.2).

Table 4.2 Demographics and clinical characteristics of all patients and those with severe upper limb impairment in the pre and post robot assisted upper limb therapy (RT-UL) observations

Patient characteristic	**All stroke patients (n = 19)**		**Patients with severe UL impairment (n = 10)**	
	Pre RT-UL (*n* = 7)	Post RT-UL (*n* = 12)	Pre RT-UL (*n* = 5)	Post RT-UL (*n* = 5)
Age (years), mean (SD)	68 (11)	68 (15)	67 (13)	61 (19)
Gender, n females (%)	4 (57)	2 (17)	2 (40)	1 (20)
Stroke type, n ischaemic (%)	5 (71)	12 (100)	3 (60)	5 (100)
Paretic arm, n right (%)	4 (57)	5 (42)	3 (60)	1 (20)
Severe UL impairment, n ≤3 MAS Item 6 (%)	5 (71)	5 (42)	5 (100)	5 (100)
Days post stroke at time of observation, mean (SD)	32 (17)	28 (24)	36 (19)	32 (23)
FIM Admission, mean (SD)	65 (31)	89 (22)	69 (36)	75 (21)

Abbreviation: FIM – Functional Independence Measure, MAS – Motor Assessment Scale, RT-UL – Robot Assisted Upper Limb Therapy, UL – Upper Limb

4.5.2 Upper limb therapy practice for all stroke patients

Table 4.3 summarises UL therapy practice (repetitions, duration, intensity) for all patients pre and post RT-UL. Total UL repetitions increased post RT-UL (p-value = 0.01) and there was no change in total UL therapy duration (p-value = 0.38). Intensity of UL practice increased post RT-UL (*p*-value = 0.001). Activity-related UL repetitions increased post RT-UL (*p*-value = 0.01) with no change in the duration of activity-related

UL therapy time post RT-UL (*p*-value = 0.55). Intensity of activity-related UL practice increased post RT-UL (*p*-value = 0.001). There was no difference between pre and post RT-UL for activity-related UL practice without RT-UL and no change in impairment-related practice.

4.5.3 Upper limb therapy practice for stroke patients with severe impairment

UL therapy practice for stroke survivors with severe UL impairment pre and post RT-UL is summarised in Table 4.3. Total UL repetitions for patients with severe UL impairment increased post RT-UL (p-value = 0.04) but there was no change in the total UL therapy time (p-value = 0.92). Intensity of UL practice increased post RT-UL (p-value = 0.009). Activity-related UL repetitions for patients with severe UL did not increase post RT-UL (*p*-value = 0.06). There was no change in the duration of activity-related UL therapy post RT-UL (*p*-value = 0.92). Intensity of activity-related UL practice increased post RT-UL (*p*-value = 0.009). There was no difference between pre and post RT-UL for activity-related UL practice without RT-UL and no change in impairment-related practice.

Table 4.3 Mean (SD) for type and dosage of Upper Limb (UL) therapy over the day and mean difference (95% CI) between pre and post robot-assisted upper limb therapy (RT-UL)

UL therapy per day	Pre-RT-UL (n = 7)		Post-RT-UL (n = 12)		Difference between Pre and Post RT-UL	
	All (n = 7)	Severe UL impairment (n = 5)	All (n = 12)	Severe UL impairment (n = 5)	All	Severe UL impairment
Repetitions						
Total	282 (231)	265 (227)	851(682)	602 (183)	569 (1 to 1136)	337 (37 to 638)
Activity-related	236 (258)	200 (258)	796 (689)	531 (203)	561 (-16 to 1137)	331 (-81 to 670)
Activity-related without RT-UL	236 (258)	200 (258)	247 (295)	59 (65)	11 (-272 to 295)	-141 (-457 to 176)
Impairment-related	26 (57)	37 (66)	54 (60)	71 (68)	28 (-31 to 87)	34 (-63 to 132)
RT-UL alone	n/a	n/a	549 (428)	472 (175)	n/a	n/a
Minutes						
Total	55 (46)	59 (52)	71 (38)	60 (33)	17 (-24 to 58)	1 (-62 to 65)
Activity-related	48 (50)	50 (58)	60 (38)	42 (21)	12 (-30 to 55)	-8 (-72 to 56)
Activity-related without RT-UL*	48 (50)	50 (58)	31 (25)	13 (16)	-17 (-64 to 30)	-37 (-108 to 34)
Impairment-related	7 (14)	9 (16)	11 (15)	18 (18)	5 (-10 to 19)	9 (-15 to 33)
RT-UL alone	n/a	n/a	29 (17)	29 (11)	n/a	n/a
Intensity (reps/min)						
Total	5 (3)	4 (2)	12 (5)	12 (5)	7 (4 to 11)	8 (2 to 14)
Activity-related	4 (3)	2 (2)	13 (4)	14 (4)	9 (5 to 13)	11 (7 to 16)
Activity-related without RT-UL*	4 (3)	2 (2)	6 (4)	3 (3)	3 (-2 to 7)	1 (-3 to 4)
Impairment-related	2 (3)	2 (3)	4 (7)	3 (3)	3 (-3 to 9)	0 (-4 to 5)
RT-UL alone	n/a	n/a	18 (4)	16 (3)	n/a	n/a

*Mean and SD remains unchanged due to no RT-UL being available for clinical use pre-RT-UL

4.6 Discussion

This study aimed to quantify UL practice in terms of repetitions, duration and intensity performed by sub-acute stroke survivors, including those with severe UL impairment, in an inpatient rehabilitative setting pre and post the implementation of RT-UL. Upper limb repetitions and intensity of practice increased for all patients, including those with severe UL impairment, with the duration of therapy unchanged. This would appear to be the first study to have observed an increase in UL practice when RT-UL is implemented into routine clinical practice. These findings are noteworthy firstly from the perspective that highly repetitive and intensive UL training is essential for motor recovery (Kleim & Jones, 2008) and secondly therapists have previously found this difficult to provide to stroke survivors in the clinical setting (Hayward & Brauer, 2015).

An increase in UL practice was the proposed outcome of RT-UL providing a uniquely supportive and efficient form of UL practice that requires minimal input from the therapist. The InMotion provided physical assistance at the patient's elbow, wrist and hand and presented up to 80 therapy targets sequentially to the patient on the computer monitor before any therapist involvement was required. Conventionally, UL practice for stroke survivors has involved one-on-one input from the therapist particularly patients with severe UL impairment (Hayward & Brauer, 2015; Stewart et al., 2017). This can result in periods of downtime or reduced intensity of practice for the patient if they are unable to complete repetitive UL movement unassisted while the therapist attends to other patients or tasks. Other recommended strategies for extra practice for patients with severe UL impairment such as room-based programs and UL groups (Stewart et al., 2017) may not be as effective due to the reliance on staff or family. The capacity for semi-supervised practice also distinguishes RT-UL as a potentially cost-effective means of increasing practice levels (Hesse et al., 2014; Masiero et al., 2014; Wagner et al., 2011).

The idea that RT-UL could potentially replace the role of the therapist (Laffont et al., 2014) or supersede other forms of effective UL rehabilitation was not evident in this study. The amount of UL practice performed separate to RT-UL (i.e. "impairment-related" and "activity-related without RT-UL") remained unchanged. Patients continued to engage in a broad range of UL tasks with RT-UL being just one of the many interventions used as part of an UL program. Therapists remained essential throughout the delivery of these programs to prescribe and grade tasks, provide feedback on performance, facilitate exercise of isolated muscle groups and supervise tasks in standing. Therapist involvement, although minimal, was also crucial in the delivery of RT-UL including the identification of appropriate therapeutic protocols, monitoring of fatigue and pain levels and interpretation of evaluative measures.

A stroke survivor's opportunity to engage in effective UL practice can be limited by a range of factors specific to the clinical environment in which they are receiving therapy (Jolliffe et al., 2019). These may include attitudes of therapists, organisational structures and availability of resources (Atkins et al., 2017; van

Ommeren et al., 2018). A number of these factors were identified in the focus groups of Study 1 prior to the commencement of this observational study. Therapists acknowledged the potential for RT-UL to increase UL practice but felt this was dependent on having the support of clinical leaders and receiving adequate training in the use of the RT-UL. The availability of a single robotic device was also perceived by therapists as presenting logistical challenges. Despite these perceived challenges, RT-UL was able to be successfully implemented within the existing leadership structure and therapy schedules with only basic training of therapy staff. A potential implication of only a single RT-UL device being available was that RT-UL was almost exclusively prescribed and provided by the physiotherapists, as opposed to the occupational therapists, due in at least part to the InMotion being located in the physiotherapy gym area. In addition to this, the capacity for RT-UL to enable semi-supervised practice appeared particularly conducive to the work patterns in the physiotherapy gym where therapists were frequently responsible for treating two to three patients at one time.

The scope of this study did not extend to investigating the correlation between practice levels and patient UL outcome measures; however, some assumptions can be made. Schneider et al. (2016) suggest that a 240% increase in practice minutes is needed to reduce activity limitations in stroke survivors. This conclusion being with the assumption that increased therapy minutes results in increased UL repetitions. The implementation of RT-UL saw an increase of more than 200% in UL practice (i.e. 282 reps/day pre-RT-UL to 851 reps/day post RT-UL) for stroke survivors but without an increase in the duration of UL therapy time. Practice performed outside the gym (e.g. independent or family facilitated practice on the ward) was not recorded so it is possible that patients may have undertaken even more practice during an entire day. It appears feasible that the extra practice necessary to reduce activity limitations in stroke survivors could be achieved with the inclusion of RT-UL into routine clinical practice.

4.7 Study limitations

There were several limitations to this study. A relatively small sample of convenience was recruited in both observational phases from a single rehabilitation unit located in a metropolitan area. Although statistical conclusions were able to be drawn from data the transferability of these results to the broader rehabilitation context should be done with caution. Patients observed in the pre-implementation phase were not the same as those observed in the post-implementation phase, however, no differences in demographics or clinical characteristics were found between the two groups. Additionally, the scope of the study did not extend to the collection and analysis of patient clinical outcome measures, so no conclusions could be made as to the effect of the increase in practice on patient recovery. Despite the investigator (NF) being vigilant to be unobtrusive and not to interfere or assist with therapy sessions during data collection, it is possible that therapists altered their behaviour when under direct observation.

4.8 Conclusions

This study observed an increase in UL repetitions and intensity of practice by sub-acute inpatient stroke survivors, including those with severe UL impairment, following the implementation of RT-UL into routine clinical practice. Notably, this increase in practice was achieved without an increase in the time spent in therapy by patients. Further pragmatic studies involving the use of RT-UL in routine clinical practice with larger sample sizes are needed to support the generalisation of these results.

Chapter 5 – The sustainability of upper limb robotics therapy in the rehabilitation setting (Study 3)

Chapter 5 is the published manuscript of Study 3 with some minor updates for terminology to be consistent with broader thesis.

Flynn, N., Froude, E., Cooke, D., Dennis, J., & Kuys, S. (2021). The sustainability of upper limb robotic therapy for stroke survivors in an inpatient rehabilitation setting. *Disability and Rehabilitation*, 1-6.
https://doi.org/10.1080/09638288.2021.1998664

5.1 Title

Sustainability of upper limb robotic therapy for stroke survivors in an inpatient rehabilitation setting.

5.2 Abstract

Background: To investigate the sustainability of robot-assisted upper limb therapy (RT-UL) as part of routine occupational therapy and physiotherapy clinical practice.

Methods: Two separate audits, 12 months apart, of RT-UL computer data records were undertaken to determine sustainability in a subacute rehabilitation unit. Records of the two audits were compared in terms of the number of subacute stroke survivors using RT-UL, number of RT-UL sessions, duration of RT-UL sessions and disciplines prescribing RT-UL.

Results: During Audit 1 58% (n=18) of stroke survivors received RT-UL compared to 50% (n=7) in Audit 2. The total number of RT-UL sessions reduced between audits (148 sessions v 36 sessions) reflecting the overall reduction in admission rates for stroke survivors. There was no significant difference between audits in the average number of RT-UL sessions per patient (p=0.203) nor length of sessions (p=0.762). Patients engaged in active therapy more than three quarters of the time when on the robotic device. Physiotherapists were the primary prescribers of RT-UL when compared to occupational therapists.

Conclusions: RT-UL was in continued and regular use with stroke survivors 2 years after initial implementation within an inpatient rehabilitation setting. RT-UL practice was intensive and used routinely with patients.

5.3 Introduction

Robot-assisted upper limb therapy (RT-UL) is an emerging technology in the field of rehabilitation and is globally recognised as part of best practice for stroke survivors with upper limb deficits (Stroke Foundation, 2022; Teasell et al., 2020). RT-UL has been shown to be effective in improving motor control and strength in the upper limb (UL) following stroke (Mehrholz et al., 2018; Rodgers et al., 2019; Veerbeek et al., 2017). Despite this growing body of evidence, little is understood as to how these devices are implemented and used clinically and in particular the sustainability of RT-UL as part of routine practice.

Sustainability, as it relates to the implementation of a specific health intervention, involves the continued use of an intervention over a period of years to achieve desired health outcomes (McCluskey & O'Connor, 2017). Despite being identified as a vital domain within implementation science, sustainability has been largely under investigated for many health interventions with the focus being on initial adoption (Shelton & Lee, 2019). The sustainability of RT-UL in practice is important when considering the potential benefits of RT-UL for patients, particularly those with severe upper limb impairment (Teasell et al., 2020). There is also significant financial outlay associated with the procurement and implementation of these robotic devices. However, no studies have directly investigated the sustainability of RT-UL in practice.

To measure sustainability there is a need to objectively record (i.e. audit) the use of the intervention as part of daily practice (McCluskey & O'Connor, 2017). RT-UL usage in this study will be considered from the perspective of the number and characteristics of stroke survivors using RT-UL in routine practice, duration of RT-UL use in UL programs and types of RT-UL activities used. A better understanding of these variables across a prolonged timeframe will create a picture of the long-term viability of RT-UL in a clinical practice setting. Ultimately this knowledge will enhance therapists' and health administrators' decision making around the acquisition and implementation of RT-UL in their specific clinical setting.

5.4 Methods

5.4.1 Design

Two separate audits were undertaken to measure the sustainability of the InMotion device as a routine intervention for subacute stroke survivors (i.e. less than 3 months post-stroke) at an Australian rehabilitation unit. Audit 1 was conducted between September 2017 and December 2017 and Audit 2 between September 2018 and December 2018.

5.4.2 Site

The participating rehabilitation facility was located in metropolitan Brisbane, Australia. The facility services 42 rehabilitation beds with approximately 600 rehabilitation admissions per year, of which approximately 30% of patients have a primary diagnosis of stroke. Stroke survivors are typically seen by both occupational therapists and physiotherapists on a daily basis, Monday to Friday. The InMotion device was permanently located in the physiotherapy gym area of the rehabilitation unit. Ethical approval was gained from the rehabilitation unit human research ethics committee.

5.4.3 Participants

All subacute stroke survivors admitted to this inpatient rehabilitation unit during the audit periods were eligible for inclusion in this study.

5.4.4 Robot-assisted upper limb therapy device (InMotion)

The InMotion is a robotic device that facilitates movement at the shoulder and elbow with an additional hand component if required. The device intuitively adapts to the person's active movements providing "assist-as-needed exercise guidance" during use (Bionik Labs, 2021). The InMotion device includes a series of inbuilt evaluative tools that can be used to measure and monitor changes in UL kinematic control and force. Users of this device complete a therapist-selected, pre-programmed treatment protocol with therapy tasks presented on an adjoining computer screen. In addition to the standardised treatment protocol users can also complete additional therapeutic games (including 'maze', 'pong' and 'squeegee') on the device.

5.4.5 Procedure

Initial implementation of the InMotion device into clinical use at the participating rehabilitation unit occurred in November 2016. Audit 1 commenced in September 2017, 10 months post the initial implementation period with the InMotion deemed having been sufficiently embedded in usual practice for both occupational therapists and physiotherapists by that time. During this 10-month implementation period, the InMotion had been tested, trialled and made operational, that is, it was routinely being initiated and delivered as part of patients' upper limb rehabilitation programs. Additionally, both therapy disciplines had received training sessions which involved either individual or small group based practical education sessions led by a senior physiotherapist. The second audit was conducted two years post initial implementation. This timing of the audits was in line with previous recommendations that sustainability be measured across multiple points in time (Shelton & Lee, 2019) and span a period of two or more years from "initial implementation" (i.e. when the intervention is first introduced into practice) (Wiltsey-Stirman et al., 2012).

During both audit periods, investigators visited the rehabilitation unit on a weekly basis and liaised with therapy staff to identify patients meeting the inclusion criteria. Once identified, patient demographics and clinical outcome measures were gathered from the medical records for all stroke survivors admitted to the unit during the audit periods, whether they used or did not use the RT-UL during their inpatient rehabilitation stay. Clinical outcome measures recorded by the treating therapist included patients Functional Independence Measure (FIM) score on admission and Motor Assessment Scale (MAS) Item 6 on admission. The FIM is a measure of disability scored out of 126; a higher score relates to a greater level of independence (Keith, 1987)

. The FIM has been previously shown to have excellent reliability (inter-rater 0.94; test-retest 0.93) and validity in measuring disability (Radomski & Latham, 2014). The severity of upper limb impairment was determined using the MAS Item 6 score. The MAS is a motor assessment tool encompassing both upper and lower limb function (Carr et al., 1985). Item 6 is a measure of upper arm function scored on a seven-point scale, from zero indicating no functional recovery to six indicating good functional recovery (Carr et al., 1985). Patient performance on Item 6 of the MAS has been used previously as a measure of upper limb severity for stroke survivors (Hayward et al., 2013).

The RT-UL usage data was collected for those patients who had commenced use of the robotic device as part of their upper limb program during inpatient rehabilitation. RT-UL usage data were extracted from the InMotion computer. When the patient's admission extended beyond the audit period, RT-UL usage data continued to be collected in order to record the total amount of usage by a patient across their admission.

5.4.6 Measures

Sustainability was measured by comparing InMotion usage data across the two audit periods. Data was collected in terms of the number of subacute stroke survivors who used the InMotion, number of InMotion sessions completed by each individual patient during their admission and the amount of time the InMotion was used by each patient. The amount of RT-UL time was measured in relation to each session and across the patient's admission. Time on the InMotion was then further considered in terms of active RT-UL use, rest periods, evaluative tasks and hand module use. Active RT-UL included the time in which the patient was actively engaged in completing an initiated task on the InMotion. Active RT-UL was interspersed with rest periods where the patient remained seated at, or attached to, the device but was not actively engaged in completing an initiated protocol or a therapeutic game. Patients completed evaluative tasks on the InMotion for the purpose of objectively measuring and monitoring changes in UL kinematic control and force. A hand module was available to be attached to the InMotion to enable patients to perform grasp/release movements in combination with reach. Finally, data was collected in relation to the discipline of the prescribing therapist (i.e. occupational therapy and physiotherapy) for each InMotion session including student therapists.

5.4.7 Data Analysis

Descriptive statistics including mean and standard deviations were used to report the number of RT-UL sessions completed by each patient in each audit period. The usage data is described separately in terms of patients, sessions and duration (minutes) for each audit and in total. Comparisons between the first and second audit periods were completed to analyse the sustainability of the InMotion. Independent sample t-tests (or non-parametric equivalent) were used to compare audit RT-UL measures. Categorical data was analysed using a Chi-square test for independence or Fisher's Exact test. All data were analysed using Statistical Package for the Social Sciences (SPSS) v. 25 and statistical significance set at <0.05.

5.5. Results

5.5.1 Participants

During Audit 1, 31 stroke survivors were admitted to the unit, 18 received RT-UL (58%) and during Audit 2, 14 stroke survivors were admitted and 7 received RT-UL (50%). Across both audits, stroke survivors provided with RT-UL had significantly lower scores on MAS Item 6 (*p*-value = 0.0002) and had a longer length of stay in rehabilitation than those who did not receive RT-UL (*p*-value = 0.002).

In Audit 2, patients in RT-UL had significantly higher admission FIM (*p*-value = 0.007) and MAS Item 6 scores (*p*-value = 0.04) than those participating in RT-UL in audit 1 as well as shorter length of stay in inpatient rehabilitation (*p*-value = 0.02). There were no differences between audits in the demographics and clinical characteristics of non-RT-UL users. Demographic data and clinical characteristics of stroke survivors included in both audits is summarised in Table 5.1.

Table 5.1 Demographic data and clinical characteristics of stroke survivors (upper limb robotic users and non-robotic users) across both audit periods

Patient Characteristics	**Audit 1**		**Audit 2**		**Total**	
	Robotic users (N=18)	Robotic non-users (N=13)	Robotic users (N=7)	Robotic non-Users (N=7)	Robotic users (N=25)	Robotic non-users (N=20)
Age, years, mean (95% CI)	67 (63-72)	71 (64-78)	68 (53-83)	73 (57-89)	67 (63-72)	72 (65-79)
Gender, female, n (%)	8 (44%)	6 (46%)	0 (0)	3 (43%)	8 (32%)	9 (45%)
Stroke type, ischaemic, n (%)	16 (89%)	11 (85%)	7 (100%)	5 (71%)	23 (92%)	16 (80%)
Hemiparetic arm, n (%), right	10 (56%)	6 (46%)	4 (57%)	6 (86%)	14 (56%)	12 (60%)
MAS Item 6 admission score, mean (range)	1.2 (0-2)	4 .3 (3-6)	2.6 (1-4)	4.7 (3-7)	1.6 (1-2)	4.4 (3-5)
Days in rehab, mean (95% CI)	65 (42-88)	18 (17-39)	33 (8-59)	29 (19-39)	56 (38-74)	28 (21-35)
Admission FIM score, mean (range)	54 (42-66)	78 (64-92)	88 (68-107)	69 (47-91)	64 (52-75)	75 (64-85)

FIM = Functional Independence Measure; MAS = Motor Assessment Scale

5.5.2 Sustainability

Tables 5.2 and 5.3 summarise RT-UL usage in both audit periods. A total of 148 RT-UL sessions were conducted across Audit 1 and 36 RT-UL sessions during Audit 2. The number of RT-UL sessions reduced between audits, coinciding with an overall reduction in the number of sub-acute stroke survivors admitted for rehabilitation. There was no significant difference in the average number of RT-UL sessions per patient nor the length of the sessions between Audits 1 and 2. Distribution of RT-UL usage with respect to active therapy and rest time per session remained unchanged, and the hand module was utilised commensurately across both audit periods. The number of sessions involving evaluative tasks also remained the same. In Audit 1, RT-UL sessions were initiated by both physiotherapists and occupational therapists, including students from each discipline. In Audit 2, RT-UL sessions were only initiated by physiotherapists with no sessions initiated by occupational therapists.

5.5.3 Overall usage patterns

Across both audit periods patients engaged in a total 184 RT-UL sessions for a duration of 123 hours, with greater than 75% of this time involving active therapy time. The RT-UL users on average participated in nine RT-UL sessions per admission for an average of 38 minutes/session, with minimal rest time during each session (i.e. 5 minutes/session). Patients using RT-UL completed the evaluative tasks on average twice during their admission, and almost a quarter of patients utilised the hand module as part of their therapy.

Table 5.2 Clinical use of upper limb robotic therapy by subacute stroke survivors across both audit periods

Robotic Usage	Audit 1 (n = 18)	Audit 2 (n = 7)	Total (n=25)
Patients			
Utilised evaluative capacity of robotic	18 (100%)	6 (86%)	24 (96%)
Utilised hand module of robotic	4 (22%)	2 (29%)	5 (20%)
Sessions			
Total	148	36	184
Involving evaluative capacity of robotic	30 (22%)	8 (22%)	38 (21%)
Involving hand component of robotic	27 (18%)	5 (14%)	32 (17%)
Physiotherapist initiated	112 (76%)	36 (100%)	148 (80%)
Physiotherapy student initiated	8 (5%)	0 (0)	8 (4%)
Occupational therapist initiated	26 (18%)	0 (0)	26 (14%)
Occupational therapy student initiated	2 (1%)	0 (0)	2 (1%)
Minutes			
Total	5966	1432	7398
Active robotic use	4569 (77%)	1116 (78%)	5685 (77%)
Use of evaluative capacity	555 (9%)	105 (7%)	660 (9%)
Rest time while seated at robotic device	842 (14%)	210 (15%)	1052 (14%)

Table 5.3 Clinical use of upper limb robotic therapy by subacute stroke survivors for whole of admission

Robotic Usage	Audit 1 (n = 18)	Audit 2 (n = 7)	Total (n=25)	Mean Differences (95% CI)
Sessions				
Per patient (95% CI)	11 (7-14)	7 (1-13)	9 (7-12)	Not applicable
Per patient involving evaluation (95% CI)	2 (2-2)	2 (1-3)	2 (1-2)	Not applicable
Minutes				
Mean per admission (SD)	429 (372)	239 (202)	376 (340)	190 (-120 to 499)
Mean per session (SD)	38 (12)	38 (8)	38 (11)	0 (-11 to 10)
Mean active-RT-UL per session (SD)	26 (11)	28 (7)	27 (10)	1 (-11 to 8)
Mean rest time per session (SD)	5 (5)	6 (3)	5 (4)	-1 (-5 to 3)

5.6 Discussion

This study found that RT-UL was a sustainable intervention, in continued and regular use with stroke survivors two years after initial implementation within an inpatient rehabilitation setting. These findings are noteworthy firstly from the viewpoint of RT-UL being part of best-practice in the rehabilitation of the upper limb following stroke as well as the significant expense involved in acquiring and implementing RT-UL.

Technology abandonment is a commonly encountered problem for health services (Greenhalgh et al., 2017). Reasons for this are unclear and likely complex involving a range of patient, staff, technical, financial, and governance issues (Greenhalgh et al., 2017). Despite this, there is a scarcity of research directly exploring sustainability of health technologies (Nadalin-Penno et al., 2019) with much of the research having focused on initial implementation (Greenhalgh et al., 2017). In the case of RT-UL technology, clinical practice implementation has remained largely unaddressed with the majority of research undertaken involving clinical efficacy trials (Mehrholz et al., 2018). This would appear to be the first study to have investigated the sustainability of RT-UL in routine clinical practice.

The key drivers for the sustainability of RT-UL in this particular study relate to the findings of Study 1 and Study 2 conducted at this same unit when the RT-UL was initially acquired. Study 2, an observational study, found a significant increase in the amount of UL practice for stroke survivors was following the implementation of the

InMotion. This increase in practice was attributed to the supportive and efficient form of practice provided by the robotic device and providing the opportunity for semi-supervised or independent practice by the patients. This is positive from the perspective that provision of unsupervised practice is important for increasing overall practice levels but is often not able to be implemented in the rehabilitation setting (Stewart et al., 2017).

Another apparent driver for clinical uptake of the RT-UL was highlighted in focus groups of Study 1 with the therapists run prior to the implementation of the device at the participating facility where it was expressed that there would be an accountability to senior management to use the InMotion due to the large amount of funds outlaid to acquire the device. Interestingly, therapists also foresaw that the usage patterns of the RT-UL would be strongly dependent on admission rates of stroke survivors. This is a valuable finding when considering the cost-benefits of RT-UL. Previous studies have analysed the cost-benefits of RT-UL at an individual patient level (Imms et al., 2015; Rodgers et al., 2019), whereas the current study highlights the importance of also looking at the financial viability of RT-UL from the perspective of the whole rehabilitation service.

In addition to the question of sustainability, the current study provided several insights into the use of RT-UL more broadly. Of note was stroke survivors prescribed RT-UL had a greater level of upper limb impairment and overall disability than those who were not prescribed RT-UL. This pattern of prescription is consistent with clinical guidelines which advise that RT-UL maybe most appropriate for those stroke survivors with dense hemiplegia (Teasell et al., 2020). Typically, stroke survivors with more severe UL impairment are largely dependent upon the therapist for physical assistance to engage in meaningful practice (Hayward et al., 2013). As detailed above, RT-UL offers these stroke survivors an opportunity for independent or semi-supervised intensive UL practice. Conversely, stroke survivors with less impaired UL were underrepresented in the group prescribed RT-UL. With greater levels of UL movement and power the priority for these patients would likely be on more complex and real-world object usage for task specific practice (French et al., 2016).

Intensity of practice is important for upper limb recovery for stroke survivors (Kwakkel, 2006). In this study RT-UL was identified to be an intensive form of UL practice with patients engaged in active therapy more than three quarters of the time when on the robotic device. In a comparative study, patients participating in a Graded Repetitive Arm Supplementary Program (GRASP), also an adjunct UL intervention for stroke survivors, engaged in active UL practice only 64% of their session (Connell et al., 2014). This high level of intensity from RT-UL practice is a notable finding from the perspective that the efficacy of RT-UL, as seen in clinical trials, has been primarily attributed to this intensity of practice (Mehrholz et al., 2018). It is therefore encouraging that this intensity of practice was evident within a real-world clinical setting where human and organisational variables are also influencing patient RT-UL practice.

UL practice involving computer games has previously been considered a form of "pre-functional" training as opposed to task orientated practice (French et al., 2016). Task-orientated practice should involve direct practice of activities of daily living (French et al., 2016). This potential limitation of RT-UL may in part explain the inconclusiveness within the literature as to whether RT-UL improves outcomes at an activity and participatory level. Mehrholz et al. (2018) in their systematic review concluded that RT-UL may improve stroke survivors' capacity to engage in activities of daily living whereas Veerbeek et al. (2017), in a systematic review drawing from a similar pool of studies, alternatively concluded that RT-UL did not significantly improve activities of daily living. Overall, RT-UL could be considered a "bridging" intervention, facilitating a basic form of movement practice until there is sufficient UL strength and power to advance to more complex and real-world task specific practice.

Therapists in the current study routinely used the evaluative tools of the InMotion which involved the detailed measurement of UL kinematic control and force. On average stroke survivors underwent RT-UL evaluation twice during their program, typically at the beginning and end of the rehabilitation stay. Evaluative reports were produced by the InMotion computer and included graphical representations of the stroke survivors UL performance in relation to UL acceleration, speed, accuracy and movement coordination. Stroke survivors have previously identified that feedback on performance from rehabilitative technology is important and may enhance motivation for therapy and practice (Nasr et al., 2016). This would seem particularly important where robotic evaluative measures are able to detect and display very subtle improvements or change both in quality and degree of movement for stroke survivors (Dipietro et al., 2009). Such changes may fail to be detected or be poorly represented through less sensitive or commonly used clinical outcome measures.

The InMotion is one of only a few robotic devices that has an optional hand module that can be used to facilitate hand movements in combination with shoulder and elbow movements. However, the hand module was used only a quarter of the time with patients in this study. This is notable from the perspective that recovery of hand function is crucial to independence in a range of activities of daily living (Faria-Fortini et al., 2011; Kim, 2016). The hand module is a relatively new addition to the InMotion device and the limited use seen in this study may be reflective of the unique technical challenges associated with the design of robotic hand componentry for stroke survivors (Aggogeri et al., 2019). Additionally, therapists may have had limited knowledge of how to use and apply the hand module. The exact reasons for the limited use of the hand module are not clear and merits further exploration (e.g. interviewing of prescribing therapists and patients) to potentially improve the design and functionality of the device.

5.7 Study limitations

There were several limitations to this study. This study investigated the use of RT-UL within a single rehabilitation facility in Australia and conclusions from this study are therefore reflective of this healthcare setting. Transferability of results to healthcare settings more broadly should be made with caution. Despite the investigator (NF) being vigilant to be unobtrusive and not to interfere with the decision making of therapist in relation to use of RT-UL during data collection, it is possible that therapists altered their behaviour in response to the audits being conducted. Finally, this study did not extend to the collection and analysis of UL outcome measures, so no conclusions could be made as to the impact on UL recovery or outcomes for these particular individuals, the appropriateness of timing of RT-UL commencement or cessation for individual stroke survivors.

5.8 Conclusions

This study found that RT-UL is a sustainable intervention for stroke survivors within an inpatient rehabilitative setting. Stroke survivors with severe UL impairment were more likely to be prescribed RT-UL, however, use of the optional hand module was limited. Further research is needed to explore the clinical reasoning behind the prescription of RT-UL by therapists and the most effective time to incorporate RT-UL along the rehabilitative continuum for stroke survivors.

Chapter 6 - Therapists perceptions following the implementation of robotic upper limb training into routine clinical practice (Study 4)

The following chapter is presented in manuscript format with the intention to submit this chapter for publication.

6.1 Title

Implementing robotic upper limb training into routine clinical practice for stroke survivors: Perceptions of occupational therapists and physiotherapists.

6.2 Abstract:

Background: There is a limited understanding of therapist acceptance of robot assisted upper limb therapy (RT-UL) and the factors influencing implementation. This study aimed to explore occupational therapists and physiotherapists acceptance and use of RT-UL as part of their routine clinical practice.

Methods: Two discipline-specific focus groups were conducted involving occupational therapists (n = 5) and physiotherapists (n = 4). Focus group questions were developed and transcriptions analysed using the Theoretical Domains

Framework (TDF). Additionally, participants individually completed the System Usability Scale (SUS).

Results: Out of the 14 domains of the TDF, nine were covered in depth by participants during the focus groups: environmental context and resources, beliefs about consequences, knowledge, skills, decision making, reinforcement, social influences, social/professional role and identity (single domain) and beliefs about capabilities. Physiotherapists recorded higher ratings of the InMotion on the SUS than the occupational therapists.

Conclusions: Both disciplines were accepting of RT-UL but it was physiotherapists who predominantly prescribed RT-UL, largely due to the device being located in the physiotherapy rehabilitation gym. Other factors facilitating RT-UL implementation included (1) increase in repetitive, intensive independent practice for stroke survivors, (2) ease of use, (3) strong patient acceptance and (4) implementation process being clinician-led. Alternatively, therapists reported the hand module difficult to set up with patients and the reason for the infrequent use. Functional-based UL practice took priority over RT-UL once stroke survivors demonstrated sufficient active movement and RT-UL was not used in isolation but part of a combination of UL interventions.

6.3 Introduction:

There is a need to continue to develop and implement interventions that are effective in facilitating upper limb (UL) recovery for stroke survivors (Hayward et al., 2021; Stinear et al., 2020). Robot assisted upper limb therapy (RT-UL) has emerged in recent years with the potential to improve UL outcomes for stroke survivors (Chen et al., 2020; Mehrholz et al., 2018; Wu et al., 2021) with a range of devices now commercially available and being used in practice (Fasoli, 2021). Research into RT-UL has primarily focused on determining the efficacy of the intervention (Mehrholz et al., 2018; Rodgers et al., 2019; Wu et al., 2021). One implication of this lack of research is that international clinical stroke guidelines recommending RT-UL provide little practical guidance as how best to implement RT-UL into routine practice (Morone et al., 2021). This information may be found in exploring the perceptions and experiences of therapists using RT-UL as part of their routine daily practice.

The studies that have explored therapists' perspectives of the use of RT-UL have involved small samples sizes, considered RT-UL only as part of a broader set of rehabilitation technology or focused on the design process as opposed to actual implementation (Celian et al., 2021; Lo et al., 2020; Stephenson & Stephens, 2017; van Ommeren et al., 2018). Further to this, exploration of therapist perceptions related to the implementation of a new intervention should be informed by behavioural theory (Atkins et al., 2017). The Theoretical Domain Framework (TDF) is a validated framework that enables the analysis and categorisation of variables influencing health professionals behaviour (Michie et al., 2005). The TDF encompasses 14 domains; knowledge, skills, social/professional role and identity, beliefs about capabilities, optimism, beliefs about consequences, reinforcement, intentions, goals, memory/attention/decision process, environmental context and resources, social influences, emotion and behavioural regulation (Atkins et al., 2017). A structured and multifaceted exploration of therapists' perceptions of RT-UL implementation is important when considering the upfront expense of procuring and implementing RT-UL and the crucial role therapists have in this process. The aim of this current study was to explore therapist perceptions of RT-UL as part of their routine clinical practice using the TDF.

6.4 Methods:

6.4.1 Design

Qualitative methodology was utilised to gain therapists perspectives of the implementation of RT-UL into their rehabilitation facility involving focus groups. Participants also individually completed the SUS. Ethical approval was gained from the institutions' HRECs.

6.4.2 Site & device

Participants were from a rehabilitation facility located in metropolitan Queensland, Australia. The facility services 42 rehabilitation beds with approximately 600 rehabilitation admissions per year, of which approximately 30% of patients have a primary diagnosis of stroke. Stroke survivors are generally seen by both occupational therapists and physiotherapists on a daily basis, Monday to Friday.

The InMotion is a robotic device that enables movement at the shoulder and elbow with an additional hand module if required. The InMotion adapts to the person's own active movements facilitating active-assisted exercise (Bionik Labs, 2021). The device also includes a series of inbuilt evaluative tools. Users complete a pre-programmed treatment protocol with therapy tasks presented on an adjoining computer screen. Users can also complete additional therapeutic computer games on the device (including 'maze', 'pong' and 'squeegee').

The InMotion device was permanently located in the physiotherapy gym area of the rehabilitation facility. The procurement of the device was initiated and carried out by a senior physiotherapist at the rehabilitation facility. Senior physiotherapy staff also led the training of both occupational therapists and physiotherapists in the use of the InMotion.

6.4.3 Procedure

Version 2 of the Theoretical Domain Framework (TDF) was used to generate a number of the focus group questions and to deductively analyse the transcripts (Atkins et al., 2017). The research team prioritised five out of the 14 available TDF domains and developed questions to promote discussion around these domains. The five domains were optimism, knowledge and skills, environmental context and resources, social/professional role and identity and belief about consequences. For example, to promote discussion relating to the domain of social/professional role and identity participants were asked "As an occupational therapist (or physiotherapist), do you see the use of the InMotion device as part of your role?". Focus group questions were also informed by results from earlier studies (i.e. Study 1, Study 2 and Study 3) at this same rehabilitation centre in which pre-implementation focus groups, clinical practice observations and computer data audits were undertaken of the InMotion to investigate upper limb task practice in therapy, and RT-UL usage patterns by therapists.

The System Usability Scale (SUS) was completed individually by participants at the time of the focus groups to provide a more comprehensive picture of therapists' experiences of the InMotion. The SUS is a brief survey that provides subjective data regarding the perceived usability of a product or service (Bangor, 2009). The survey entails 11 questions, 10 Likert scale questions and a single overall adjective rating scale of the user-friendliness of the product (i.e. worst imaginable, awful, poor, OK, good, excellent, best imaginable) (Bangor, 2009; Bangor et al., 2008). A total usability score is calculated ranging from 0-100. Total scores can be considered in terms of the following ranges; below 50 not acceptable, 50-70 marginal and above 70 acceptable (Bangor et al., 2008; Radder et al., 2018). The original SUS terminology of "system" was used in the survey completed by participants to refer to the InMotion device as opposed to the updated SUS terminology of "product" (Bangor et al., 2008). This choice of the term "system" to describe the InMotion was to be consistent with the terminology used in the InMotion user manual.

Focus groups were made up of a convenience sample of therapists who were working on the day the focus groups were held. Therapists were notified of the date, time and purpose of the focus groups prior to the day of the focus groups to aid recruitment. Therapist consent was gained prior to participation in the focus groups. The two focus groups were discipline specific; occupational therapists and physiotherapists, enabling a clearer analysis of individual discipline perspectives on RT-UL, as well as providing opportunity for discussion of more discipline specific factors if they emerged.

Focus groups were led and facilitated at the rehabilitation facility by one investigator (NF). Focus group questions explored therapists' perceptions of the acceptability, practicality and usefulness of the InMotion in their clinical setting having been available for use as part of routine practice for 20 months. Focus groups were audio recorded and transcribed verbatim for content analysis. Two investigators separately coded the transcripts using the TDF guide (Atkins et al., 2017). Despite five domains having been prioritised in the questions investigators were open to assigning relevant statements into any one of the 14 domains. Investigators then met to achieve consensus on coding and to allocate all statements under a single domain. A third investigator (SK) reviewed the coded statements to help finalise categorisation.

6.5 Results:

6.5.1 Participants

Two discipline specific focus groups were conducted with a total of nine participants (5 occupational therapists; 4 physiotherapists). Occupational therapy participants were predominantly female (n = 4), had an average age of 32 years (range 21-41 years), average of ten years post qualification (range <1-20 years) with an average of five years' experience in working with neurological clients (range <1-15 years). Physiotherapy participants were also predominantly female (n = 3), had an average age of 37 years (range 24-54 years), were on average 15 years post qualification experience (range 2-30 years) and had an average of 12 years' experience working with neurological clients (range 2-25 years). Therapists were also asked to rate their level of experience with the InMotion in terms of "no experience", "minimal experience", "experienced" or "expert". Two occupational therapists described themselves as "experienced" and the remaining three described themselves as having "minimal experience". One of the three occupational therapists acknowledged had only used the InMotion as part of the training and not in practice with their own patients. Of the physiotherapists, one described themselves as “expert”, two “experienced” and one as having “minimal experience”. Occupational therapists’ average SUS score of 59.0 (50.0-75.0) and the physiotherapists 74.0 (52.5-90.0). In terms of participants adjective ratings of the user-friendliness of the device, one occupational therapist assigned “OK” and the remaining four occupational therapists selected “Good”. Two physiotherapists rated the system as “Excellent” and the other two physiotherapists “Good”.

6.5.2 Responses

Nine out of the 14 TDF domains were discussed in depth by participants during the focus groups; environmental context and resources, beliefs about consequences, knowledge, skills, decision making, reinforcement, social influences, social and professional role and identity (single domain) and beliefs about capabilities. The remaining five domains were not included in the results as these categories were only discussed superficially or not at all. Sub-themes were created within the “environmental context and resources” domain to further define specific constructs. The domains of “knowledge” and “skills” have been combined; however, participants’ original statements were categorised under the relevant domain during analysis.

Environmental context and resources

Participants identified a number of environmental and organisational factors that they believed influenced the implementation process.

Physical location. The primary environmental influence on the use of the InMotion in daily practice reported by therapists was the physical location of the device in the physiotherapy area of the gym. Physiotherapists highlighted how this was particularly conducive to their practice.

> It's in the middle of the gym … you're always reminded that its around and thinking who you could use it with. (Physiotherapist 3)

> Being accessible and in the gym, you can set people up and still work with other patients rather than having to be in a separate area or separate room. (Physiotherapist 4)

Alternatively, the occupational therapists identified that the location of the device did mean they did not use the device as often as their physiotherapy colleagues.

> It is in the far end (of the gym), it's almost out of sight out of mind for me sometimes. (Occupational Therapist 3)

> I mean part of its environmental here, we've got two very separate spaces … It's probably in the best space to get the most use. (Occupational Therapist 1)

> In some way perhaps the way we work as OTs is part of that … we don't tend to have the same continuous cycle through the gym space … you're often

> upstairs dealing with other ADL (Activities of Daily Living) type practice or something like that which we can't do in a gym space. (Occupational Therapist 1)

Set up of the device. Perceptions were mixed when participants reflected on the setting-up of the device.

> Certainly doesn't take half an hour. It's one of the advantages of it is that it is quite quick. (Physiotherapist 3)

> Some people who are, just really don't have the endurance … to kind of perform it for a feasible amount of time. It's not really worth the set up. (Physiotherapist 2)

Organisational challenges. Participants described a range of organisational factors that impacted their use of the device including personal work schedules and admission rates of suitable patients for its use.

> And it's tricky because I'm only here part-time and haven't been here that long and probably haven't a huge number of patients that the robot's been suitable. (Occupational Therapist 4)

> It probably depends on the mix of patients that we've got at that time. Earlier in the year we were through summer really busy with stroke patients, so it was used quite a lot. (Physiotherapist 3)

> In terms of actually embedding it into our practice I don't feel like we ever had the luxury of focusing on that in a really structured way. There's been like ad hoc kind of attempts. (Occupational Therapist 2)

Belief about consequences

Overall, both disciplines were very positive with regards to the perceived clinical advantages of having implemented the InMotion into clinical care.

> It definitely provides a very high intensity and repetition count for patients especially with densely affected upper limbs. (Physiotherapist 1)

> It's definitely been a change for us in terms of getting overall dosage. (Occupational Therapist 2)

> You don't have to stress about being there one on one with them. The machine really is that one assist that they need which is really cool. (Physiotherapist 2)

> Gives them some variety in their treatment as well so it's not so mundane day in day out. (Physiotherapist 2)

Participants did stress that RT-UL was just one part of their overall approach to facilitating UL recovery with their patients.

> My biggest piece of advice would be that it's not the answer. It's a part of the therapy that we offer. Yes, I think overall it's definitely beneficial, but it shouldn't replace upper limb therapy. (Physiotherapist 1)

> There's very few patients that would just do the robot. They're normally having a combination of evidence-based interventions. (Physiotherapist 3)

> I think it's been a useful adjunct to the other functional things that we would typically do … I think it's been useful from a team perspective. (Occupational Therapist 1)

Knowledge and skills

Participants provided reflection in relation to their personal knowledge and skill in using the device. Physiotherapists, as the main prescribers of RT-UL, reported a familiarity with using the pre-programmed treatment protocols of the InMotion but acknowledged a need to understand more of the other functions.

> I feel like I know the real basics to it, the core fundamentals but I'm not sure how I'd go with explaining all of it, the real intricacy. (Physiotherapist 2)

> If you are going into the nitty gritty the robotic reports and things, I think they're quite hard to understand. (Physiotherapist 1)

The physiotherapists also described how it had been a relatively easy process to acquire their knowledge and skill in the use of the device.

> You can kind of teach yourself once you know the basics you can just sit down in a spare half an hour and just have a play on it, figure out how it works. (Physiotherapist 1)

> It probably depends on your own learning style but I often find its easier for me to get on and do it myself. (Physiotherapist 3)

Alternatively, the occupational therapists described a limited knowledge and skill base.

> I haven't had a lot of patients so it's difficult to develop your skills and confidence using it when it's so sporadic. (Occupational Therapist 1)

> I think a more thorough orientation may have encouraged me to use it more or have a bit more confidence to identify "I think that patient would benefit". (Occupational Therapist 4)

> I can remember parts of it, but I still wouldn't be able to go and take a patient through it now since I haven't used it since receiving that information (training). (Occupational Therapist 5)

Both therapy disciplines reflected on the challenges in using the optional hand module of the InMotion.

> But the hand piece was a little bit confusing. (Occupational Therapist 3)

> The hand piece can be a little bit technical to put on. (Physiotherapist 1)

A lack of knowledge from referral sources was highlighted as influencing the use of the InMotion.

> I think there was a little bit of misconception by others (referring agencies) out there as well. That they were hearing about this magical robot thing. And like we were getting referrals from other rehab units saying, referring people just for the robot and they didn't really understand like how it was being utilised … It wasn't like it was going to be the cure. Which is kind of what the impression was. (Occupational Therapist 1)

Decision processes

Participants provided key insight into their reasons for deciding when and why to incorporate RT-UL into their patient rehabilitation programs.

> I think it's when we know someone's come in with a dense hemiplegia, we prioritise trying to get them started. (Physiotherapist 3)

> I would tend to identify it as an initial modality. (Occupational Therapist 2)

> 98% of the time I'm only using the robotic program (active-assisted movements) itself rather than the other 5 options (active movements only) ... instead of using them I would use more functional based activities … So mainly I use the robot for the active-assisted therapy it offers. (Physiotherapist 1)

Physiotherapists also highlighted where they felt RT-UL was not indicated for their patients.

> To train that grasp I'd probably preference other treatments. (Physiotherapist 2)

> The other games I don't find that helpful in terms of training the patient in a functional way. If they're at the skill level where they can actively move the robot and do the games more likely I would start doing more functional based tasks with them. (Physiotherapist 1)

Physiotherapists reported using the hand module on occasions when the patient had good distal return of movement but identified the limitations of the hand module.

> I've used it with a couple of patients that have more distal weakness in their stroke... was a nice component of their program. (Physiotherapist 3)

> Tryin' to train that grasp I'd probably preference other treatments over just that open, close, open, close, open, close. (Physiotherapist 2)

> It's not really a functional grasp it's just a lumbricals' exercise really. (Physiotherapist 1)

It was also flagged by one of the occupational therapists how the evaluative elements of the InMotion can make clear where patient movement patterns are breaking down, and in doing so assist in treatment planning.

> The reports are quite interesting for isolating the type of movement they're getting or the area where their deficit is… when I have taken time to look at the data, I do find that it tends to make me go back to the drawing board maybe with the exercises I am prescribing away from the robot. (Occupational Therapist 2)

Social and professional role and identity

Both therapy disciplines recognised that the physiotherapists had taken the lead with the implementation process but neither discipline perceived this to be a negative outcome of the implementation process.

> I don't see it's a massive problem that the physios are taking the primary lead… I think when it comes down to it, is the patient using it? Is the patient benefiting from it? Regardless of who's actually doing that. (Occupational Therapist 1)

> I mean it's often the physios that are starting off on the InMotion but it doesn't have to be. (Physiotherapist 3)

> Culturally there's a lot of blurring between the disciplines so I think it's sort of just negotiated generally rather than it being actually recorded or directed to anywhere in particular. (Occupational Therapist 2)

It was also an expectation that students would be able to incorporate RT-UL into their patient rehabilitation programs.

> Certainly, the ones (students) on clinical placement if their patients are indicated for it then yep, it's an expectation that they'll be confident enough, or you know train them up to be confident enough to set patients up on it and it's just part of their therapy. (Physiotherapist 3)

Reinforcement

Therapists described how patients' use of RT-UL was reinforced by the visual feedback provided on the computer screen of the InMotion and the ability to independently operate the machine.

> The feedback that I've been consistently getting from them is that they feel like they can do things on it that they can't trying to complete other activities or exercises. (Occupational Therapist 4)

> Surprised me with how interested they are. All of the games are quite simplistic. (Occupational Therapist 2)

> They do tend to fixate on that robot screen really well especially patients who are easily distracted they seem to respond really well to the screen of the robot. I've always been kind of like pretty amazed at how attentive they can be to a robot screen when they're otherwise quite distractible. (Physiotherapist 1)

> I think the patients really enjoy the fact that they can operate it themselves once they've learnt how to do it. That's one thing I've noticed they're you know really quite engaged and it's like they're driving their own therapy, which I think's really important. (Physiotherapist 3)

Social influence

Broader influences including patients' family and management at the facility were believed to have enhanced the use of the InMotion device in practice.

> I also find families really like it as well when they're coming down to see the patient strapped to a fancy schmancy, you know, very expensive piece of technology they, families do tend to enjoy that. (Physiotherapist 1)

> And it’s a cool point of difference as well. Because seems to be like when execs (executives) come through they’re always looking at the robot. And it’s just I guess one of those things that sets us aside. (Physiotherapist 2)

Beliefs about capabilities

Therapists acknowledged that their own level of confidence certainly plays a part in initial use of the device.

> Although I think its reasonably easy to use. I just don’t have the confidence because it’s been so erratic when it’s been relevant for me to use. (Occupational Therapist 4)

> It’s the confidence initially. Whereas now I know how to use it quite well it’s not really an issue anymore. (Physiotherapist 2)

6.6 Discussion

Much of RT-UL research to date has focused on determining the efficacy of this form of treatment (Mehrholz et al., 2018; Wu et al., 2021) but these trials provide limited insight into the factors influencing the implementation of RT-UL into routine clinical practice. This study used the Theoretical Domain Framework to gain insight into therapist acceptance of RT-UL as part of routine practice and the variables that can shape the RT-UL implementation process.

Proctor et al. (2011, p. 67) described intervention acceptability as “the perception among implementation stakeholders that a given treatment, service, practice, or innovation is agreeable, palatable, or satisfactory”. The responses of participants in this study indicated that they were generally accepting of the introduction of RT-UL into routine clinical practice, particularly for stroke survivors. The acceptance of a new intervention can be linked to the therapists’ overall perception that the advantages outweigh the disadvantages (Wensing & Grol, 2020). Therapists were able to clearly identify the clinical advantages of RT-UL in terms of the capacity to increase the amount and intensity of practice for patients, facilitate semi-supervised or independent practice and providing a motivating form of practice.

These advantages were seen as particularly relevant for stroke survivors with dense UL hemiplegia. The clinical relevance and advantage of RT-UL for this group of stroke survivors was also highlighted previously (Lo et al., 2020) in a study exploring therapist perceptions of upper and lower limb robotics. Clinical trials indicate that the use of RT-UL can address UL impairment with stroke survivors who have moderate to severe UL deficits (Hesse et al., 2014; Klamroth-Marganska et al., 2014; Rodgers et al., 2019). However, RT-UL has not consistently been found to be superior to usual therapy for measures of activity and participation (Chen et al., 2020; Ferreira et al., 2021; Mehrholz et al., 2018; Veerbeek et al., 2017). It was reported in this current study that once stroke survivors demonstrated sufficient return of active UL movement then functional-based UL practice took priority and

RT-UL was less utilised or ceased. RT-UL was also not used in isolation but part of a combination of UL interventions.

Although it was reported by both occupational therapists and physiotherapists that the implementation of RT-UL had been as a positive addition to the rehabilitation facility, it was the physiotherapists who were described as the primary adopters. This had been established in Study 3 which investigated the sustainability of RT-UL in routine practice which found that 80% of RT-UL sessions in the initial two years post-implementation had been prescribed by the physiotherapists. The primary reason for physiotherapists in this clinical setting being the primary prescriber of RT-UL appeared to be that the InMotion was located in the physiotherapy area of the gym. The physical location of a new intervention can influence the implementation process, with availability at the point of care being important for uptake. Lo et al. (2020) identified that the location of a robotic device was an important consideration in the implementation process but was often overlooked. In the focus group with the occupational therapists it was identified that the location of the InMotion in the physiotherapy area meant they had been less inclined to incorporate RT-UL into their practice. The occupational therapists also highlighted that other clinical priorities (i.e. functional retraining on the ward) and staff employment arrangements (i.e. working part-time rather than full time) had contributed to their more limited use of the InMotion. This difference in RT-UL use between the two therapy disciplines was not perceived as a negative outcome of the implementation process. One of the occupational therapists reflected that the introduction of RT-UL had been useful from a whole of "team perspective", appreciating that UL rehabilitation was an area in which the two disciplines collaboratively worked together.

The variance in RT-UL use by the two disciplines was evident in their System Usability Scale (SUS) ratings, with physiotherapists recording notably higher scores, reflective of their greater amount of exposure to the device. The SUS has been previously used to determine stroke survivors' perspectives of RT-UL usability (Nijenhuis et al., 2015; Radder et al., 2018) but not therapists. However, the scale has been used previously to measure health professionals' perspectives of the usability of other forms of technology such as electronic health records and 3D mapping applications for home modification design (Bloom et al., 2021; Hamm et al., 2019). Therapist's comfort with accessing and interacting with RT-UL technology was important to quantify in this study to compliment and confirm the perspectives communicated in the focus groups. The use of tools like the SUS in future implementation studies may help strengthen the qualitative findings of focus groups or interviews particularly when participant numbers are small. It may also be a helpful tool as part of clinical practice to gain a quick snapshot of clinician confidence in using RT-UL particularly if there has been an extended time period since initial training. Lower scores could be used as an indicator for staff to undergo refresher training in the use of the device.

Successful implementation of a new intervention, such as RT-UL, should involve careful forward planning and strategic coordination (Lo et al., 2020). Without such planning and strategy, change in practice is likely to be minimal or short-lived (McCluskey & O'Connor, 2017). It is somewhat remarkable how successful the implementation of RT-UL had been at the rehabilitation facility in this current study, with one participant describing the implementation process as being largely ad hoc. Although not directly discussed in the focus groups, this relative success could be attributed in part to the implementation process being both initiated and led by clinicians i.e. senior physiotherapists. The importance of nominating clinical champions to lead an implementation process is supported in the broader implementation literature (Miech et al., 2018). However, what is less evident is the potential advantage and effectiveness of an implementation process that is also initiated by clinicians. A study by Chen et al. (2018), demonstrated the effectiveness of a surgeon initiated and led policy to restrict the number of knee arthroscopies to align with practice guidelines. The value of an implementation process that is clinician-initiated, not just clinician-led, merits further exploration within the field of implementation science. The fact that the implementation process was initiated and led by senior physiotherapists also likely contributed to the physiotherapists being the primary users of the device.

The InMotion was described by participants as being easy to use. The physiotherapists explained that once having had the initial training they were confident to independently sit down and explore the functionality of the InMotion. It was also an expectation that physiotherapy students would be able to incorporate RT-UL into their programs. Although the occupational therapists were limited in their use of RT-UL they also described the device as being relatively easy to use. How easy a particular technology is to use is crucial to uptake. In a survey of 292 health care professionals, Hughes et al. (2014) identified that ease of set up and use was ranked the second most important quality of rehabilitation technology behind supporting evidence. One participant in this current study reported that for set up to be warranted a patient needed to be able to participate in RT-UL for a good amount of time. Also, the hand module was described as being difficult to set up with patients. Difficulty with the hand module has previously been noted in Study 3 which revealed that the hand module of the InMotion was used only a quarter of the time by patients.

Patient acceptance of an intervention can strongly influence the implementation process of new technology for therapists (Chen & Bode, 2011). Therapist participants in this study perceived that RT-UL was well received by patients and their families. Participants reported that patients enjoyed being able to practice independently on the robot, giving them a greater sense of control over their own therapy. It was also believed that patients were motivated by having greater freedom of movement when practicing on the device than compared other forms of UL therapy. Finally, the RT-UL games presented on the screen were observed and reported by therapists to be very engaging for patients.

6.7 Study Limitations

This study explored the views of a small sample of occupational therapists and physiotherapists within a single rehabilitation facility in Australia. The small sample of participants interviewed means that data saturation was unlikely to have been reached. Conclusions from this study are therefore indicative of the participants and their clinical setting and should be considered with this in mind. The use of the TDF to guide the development of the focus group questions and analysis process may have limited identification of other relevant themes. However, this framework facilitated a structured process of categorisation in line with other studies in the field of implementation science. It is also acknowledged that the inclusion of patient participants alongside therapists' would have provided a more comprehensive picture of the implementation process.

6.8 Conclusion

RT-UL is recommended in international guidelines for stroke survivors but there is limited understanding of how RT-UL is implemented in routine practice. This study explored occupational therapists and physiotherapists perception of RT-UL 20 months following implementation. RT-UL was generally perceived by therapists to be an acceptable form of therapy for stroke survivors, enabling an increase in the number of repetitions of upper limb movement practice and intensity of independent practice. The implementation was impacted by the physical location of device, enhanced through being a clinician-led process, and a device that was perceived to be easy to use and had strong patient acceptance. Future research should investigate the potential advantages of clinician-initiated implementation of practice innovations as well as explore patient perceptions of RT-UL use as part of their rehabilitation programs.

Chapter 7 - Discussion and conclusion

The InMotion is one of the most commonly used RT-UL devices with at least 250 systems worldwide (Rodgers et al., 2017). Despite this global presence, the rehabilitation facility investigated as part of this research program is the first Australian facility to implement the InMotion into routine clinical practice. The process surrounding the implementation into daily practice of robotic devices for UL therapy, such as the InMotion, has been under addressed with much of the research having focused on determining clinical efficacy. This is noteworthy when considering the very large financial outlay required to procure and implement RT-UL and that non-adoption and abandonment is common for health technologies in the clinical setting (Greenhalgh et al., 2017).

Implementation success cannot simply be measured by the presence of a robotic device in a department, access to its use by staff and patients or efficacy of research conducted in the context of a clinical trial or laboratory setting. Other key outcomes of implementation success for a new and costly treatment method should also include its acceptability, sustainability, adoption, appropriateness, feasibility, fidelity, penetration, and implementation cost (Proctor et al., 2011). This research program investigated the implementation of the InMotion using these implementation outcome measures. Acceptability, sustainability and feasibility were primary outcome measures for this research program with the remaining five considered secondary outcome measures. A number of research methods were used to measure different aspects of these key outcomes. This included four studies, two qualitative and two quantitative. This chapter provides a summary of the main findings of these four studies. The clinical implications of these findings are then discussed in light of the aforementioned eight measures of implementation success. Following this discussion are a series of practical questions to guide health professionals and administrators' decision-making with respect to the implementation of RT-UL. This chapter will also discuss the limitations of the studies and future directions for research.

7.1 Summary of Findings

7.1.1 - Study 1

Therapist acceptance of new technology is an important factor influencing implementation (Chen & Bode, 2011; Liu et al., 2015; Proctor et al., 2011). Australian occupational therapists' and physiotherapists' perspectives on the use of RT-UL in daily practice have not previously been explored, while international studies have chiefly focused on gathering therapists' opinions to aid the design process of upper limb robotic devices as opposed to actual implementation (van Ommeren et al., 2018). Existing clinical practice habits, practices and routines as well as personal concepts of workplace norms can influence therapist acceptance of new interventions and the implementation process (Smart, 2006).

Study 1, the first of two qualitative studies, aimed to explore occupational therapists' and physiotherapists' perceptions of RT-UL and the perceived barriers and enablers prior to the implementation of the InMotion device into the rehabilitation unit. Two discipline-specific focus groups were conducted, one with occupational therapists (n= 6) and another with physiotherapists (n= 6) employed at the rehabilitation unit involved in this study. The Theoretical Domain Framework (TDF) was used to analyse and categorise the factors influencing therapist perspectives (Atkins et al., 2017).

Study 1 determined that both the occupational therapists and physiotherapists were accepting of the planned introduction of RT-UL into their workplace and perceived that RT-UL would provide opportunity for increased upper limb practice particularly for patients with severe upper limb impairment. Therapists perceived that senior management would be keen to ensure the financial investment in the InMotion was justified and that this would be a strong driver of the implementation process. They also identified that training, support and mentoring from clinical leaders on the ground would be essential for successful RT-UL implementation. The training they receive should cover information relating RT-UL efficacy, device functionality and patient suitability. Prior to the introduction of the InMotion in this clinical setting, therapists also predicted that the availability of only one InMotion device may create unique interdisciplinary and logistical challenges.

7.1.2 - Study 2

RT-UL has been identified as a potential means of addressing the challenges associated with increasing the amount and intensity of practice performed by stroke survivors in routine therapy (Hayward & Brauer, 2015). RT-UL clinical trials have had participants safely engaging in highly intensive practice involving hundreds of repetitions of UL movement (Conroy et al., 2019; Lo et al., 2010; Rodgers et al., 2017). However, it has not been explored if this intensity of practice is achievable within a real-world clinical setting once various patient, staff, technical and organisational factors are in play. Study 2 investigated RT-UL use within routine practice measuring the amount of UL practice (i.e. repetitions, duration, intensity) performed by subacute stroke survivors pre and post implementation of the InMotion. This study focused specifically on determining if the amount of practice administered in RT-UL research trials was achievable and had an impact on the overall amount of practice of UL movement repetitions able to be achieved by stroke survivors using a RT-UL within a rehabilitation facility.

Prior to the introduction of RT-UL stroke survivors were found to be completing 282 upper limb movement repetitions per day at an intensity of five repetitions per minute. Following the implementation of the RT-UL, daily UL practice was demonstrated to have significantly increased to 851 repetitions per day at an intensity of 12 repetitions per minute. This significant increase in practice repetitions and intensity was observed for stroke survivors with severe upper limb impairment as well as those with mild to moderate levels of UL impairment. Importantly, this increase in practice was achieved without an increase in the time spent in therapy by patients, or a reduction in other task specific practice undertaken with their treating therapists and in addition to the RT-UL use. It was proposed that the increase in UL practice was the outcome of RT-UL providing a uniquely supportive and efficient form of UL practice and capable of enabling hundreds of additional repetitions to patient UL treatment sessions. These findings indicate that the highly intensive practice undertaken in research trials is achievable within the clinical setting. This is the first study to have observed an increase in UL practice when RT-UL is implemented into routine clinical practice. This study provides particular insight into the measure of RT-UL fidelity, that is, the extent to which RT-UL was able to be implemented as intended. The fidelity of RT-UL once implemented will be discussed further in section 7.2 Implications for clinical practice.

7.1.3 - Study 3

Technology abandonment is common in health services (Greenhalgh et al., 2017; Liu et al., 2015) and the sustainability of technology in clinical practice has been largely overlooked in implementation literature (Greenhalgh et al., 2017; Proctor et al., 2015). The aim of Study 3 was to investigate the sustainability of RT-UL as part of routine occupational therapy and physiotherapy clinical practice in the rehabilitation unit involved in this study. Data collection involved two audits of RT-UL use: Audit 1 from September 2017 to December 2017 and Audit 2 from September 2018 to December 2018.

It was found that RT-UL was a sustainable intervention being used regularly with stroke survivors two years after initial acquisition and implementation of the InMotion to the rehabilitation facility. This is an important finding when considering the high purchase cost involved in acquiring these devices and training of staff as well as the potential benefits for UL recovery for stroke survivors. Study 3 also found that approximately half of sub-acute stroke survivors admitted to the rehabilitation unit during the audit periods were prescribed robotics as part of their upper limb program. However, overall admission numbers of stroke survivors did decrease between audits, from 31 stroke survivors in Audit 1 to 14 stroke survivors in Audit 2. As a result, the number of stroke survivors using the InMotion decreased from 18 RT-UL users in Audit 1 to 7 RT-UL users in Audit 2. This finding, perhaps was not surprising, has implications when considering the financial viability of the InMotion in the clinical setting. Finally, Study 3 also found that stroke survivors with severe UL impairment were more likely to be prescribed RT-UL than those with mild to moderate UL impairment. The optional hand module was only used in a quarter of RT-UL sessions. In addition to sustainability, these findings also shed light on other important implementation outcome measures of appropriateness and penetration. These measures are discussed further in section 7.2 “Implications for clinical practice”.

Results of Study 1, 2 and 3 were then explored in the follow up focus group with treating therapists in Study 4, 20 months after initial implementation of the InMotion within the clinical setting.

7.1.4 - Study 4

Study 4 explored occupational therapists and physiotherapists perceptions of the acceptability of RT-UL and the implementation process 20 months after introduction into routine practice. Focus group questions were shaped by the Theoretical Domain Framework (TDF) and findings from Study 1, 2 and 3. Therapists also individually completed the System Usability Scale (SUS), a brief survey to provide subjective data regarding their perceived usability of the InMotion.

The focus groups revealed that therapists continued to be accepting of RT-UL as part of their routine practice on the basis that RT-UL provided patients with an intensive and motivating form of semi-supervised practice. Equally they recognised the importance of using RT-UL in combination with other UL interventions and progressing patients to functional-based UL practice once there was sufficient active movement.

It was explained that physiotherapists were the main prescribers of RT-UL primarily due to the InMotion being located in the physiotherapy area of the rehabilitation gym at the centre being studied. Limited use by the occupational therapists was also reflective of their prioritisation of ADL retraining on the ward. These comments within the focus groups were supported by physiotherapists recording higher usability scores on the SUS. Therapists also reported that the limited use of the hand module of the InMotion was due to the difficulties they experience with setting up this component of the device.

7.2 Implications for clinical practice

This program of research has investigated the implementation of RT-UL within routine clinical practice. The implementation process and the implications for clinical practice will now be considered in terms of eight measures of implementation success: acceptability, sustainability, feasibility, appropriateness, fidelity, penetration, cost and adoption (Proctor et al., 2011).

7.2.1 RT-UL acceptance an outcome of advantages outweighing disadvantages

Proctor et al. (2011, p. 67) described intervention acceptability as “the perception among implementation stakeholders that a given treatment, service, practice, or innovation is agreeable, palatable, or satisfactory”. The acceptance of a new intervention can be linked to the stakeholders’ overall perception that the advantages outweigh the disadvantages (Wensing & Grol, 2020). Stakeholders investigated as part of this program of research were occupational therapists and physiotherapists providing RT-UL to stroke survivors within an inpatient rehabilitation setting. The clinical advantages of RT-UL were clear to therapists in this program of research.

The primary advantages reported by therapists were that RT-UL enabled a highly repetitive and intensive form of UL practice with minimal input from therapy staff. This was particularly the case for stroke survivors with more severe UL impairment. Therapists were conscious of the historical challenges of providing stroke survivors with satisfactory levels of UL practice i.e. hundreds of repetitions per session. Therapists perceived that the implementation of RT-UL into their routine practice had genuinely helped address this challenge. Such perceptions were also supported by findings in Study 2 that showed a significant change in the amount and intensity of UL practice following the implementation of the InMotion. RT-UL has often been promoted as having the potential to increase UL practice but this is the first study to demonstrate such an increase in clinical practice.

Therapists can have busy caseloads and are often simultaneously managing multiple patients potentially diminishing the quality and quantity of active therapy and one-on-one therapy able to be provided to stroke survivors. The advantage of being able to provide independent practice to patients via the InMotion was repeatedly raised in the Study 4 focus groups. Traditional UL programs typically rely on direct one-on-

one assistance from the therapist (Stewart et al., 2017) to physically support, guide and facilitate use of the weak UL as well as repeatedly set up objects and items for the therapy tasks. In contrast, the InMotion provided both support for the stroke survivors' weak UL as well as automatically presenting tasks on the screen. The increase in the amount and intensity of practice recorded in Study 2 was largely attributed to these two advantages.

Therapists reported that patients were motivated by being able to independently engage in their own UL practice as well as the digital gaming aspect of RT-UL. The motivational qualities of RT-UL for stroke survivors have been previously identified (Chong et al., 2014) alongside similar forms of digital gaming (Putrino et al., 2017). Therapists in Study 4 pointed out that patients were motivated by the InMotion tasks even though the computer graphics were very simple. This is important to note as cognitive and perceptual deficits may limit stroke survivors' ability to process and interact with more complex computer graphics. Stroke survivors with such deficits have been underrepresented in RT-UL clinical trials (Everard et al., 2020) with little known about inpatient stroke survivors' perceptions of the use of RT-UL. As key stakeholders in the implementation process and clinical use of RT-UL, further exploration is needed of stroke survivors' experiences of using RT-UL as part of their recovery.

Therapists acknowledged the limitations of the InMotion particularly in relation to the awkwardness of the hand module and the "pre-functional" nature of the training. However, these disadvantages did not dominate discussions nor undermine their overall acceptance of RT-UL as part of the routine practice at the facility. Therapists were able to factor these limitations into their professional reasoning process when prescribing RT-UL. If hand function was a focus, then other forms of therapy were prioritised over RT-UL and once there was sufficient active UL movement for practice of daily tasks RT-UL was also phased from a patient's UL program.

7.2.2 RT-UL sustainability vs advancing practice

Sustainability refers to the extent to which a newly implemented intervention is maintained and continues as part of routine clinical practice (Proctor et al., 2011). It could be argued that sustainability is the most important outcome measure of implementation success. The introduction of a new intervention may result in short term benefits but unless this contribution is ongoing the overall value of the implementation process is questionable (Nadalin-Penno et al., 2019). There has been a preoccupation with investigating the initial phase of implementation with little attention paid to the ongoing viability of new interventions (Proctor et al., 2015; Shelton & Lee, 2019). In this program of research RT-UL was found to be in continued and regular use two years after initial implementation. This is the first study to have considered the sustainability of RT-UL as part of routine practice. The clinical advantages discussed in the previous section related to improved intensity and independent practice are likely reasons for the ongoing use of the InMotion at the participating rehabilitation facility.

It is positive that RT-UL was found to be sustainable but best practice is an evolving phenomenon (Boulanger et al., 2018). Factors that initially facilitated implementation and drove sustainability may ultimately hinder the ongoing advancement of the therapy provided by a rehabilitation service. Therapists may become too comfortable with using a particular intervention and be reluctant to incorporate other new forms of therapy. This may be relevant to RT-UL which has the distinct advantage of facilitating UL practice with minimal input from the therapist. Ongoing evaluation of the impact of the device on patient outcomes and therapists' practices is therefore important.

Robotic technology is continually advancing, and there is an onus on clinicians to be aware of and responsive to these advancements. These advances may be in the form of software updates which include additional games, enhancements of graphics and data reporting or hardware developments that improve the ergonomics or adjustability of a device. Foresight is also needed as to when an existing device has ultimately been superseded by a new model and needs to be replaced. Evidence surrounding UL rehabilitation is also rapidly changing. It is likely that in the coming decade there will be further clear recommendations as to which stroke survivors benefit most from robotics in terms of phase of recovery and severity of UL impairment. It is essential that clinicians are abreast of such evidence and refine their professional reasoning in response to these advancements to appropriately prescribe robotics and obtain the best outcomes for their patients.

7.2.3 Practical determinants of RT-UL feasibility

Feasibility considers the everyday factors that influence the use of a new intervention in a specific clinical setting (Proctor et al., 2011). It is concerned with the impact of practical elements such as availability of resources, training requirements and intervention set up (Proctor et al., 2011). The relative success of the implementation of the InMotion at the rehabilitation facility involved in this program of research was in part an outcome of device location and ease of set up for the arm component. However, the implementation process was not without challenges including limited functionality of the InMotion hand module, use of a single device between disciplines and skill limitations among staff. These facilitators and challenges to the feasibility of RT-UL are now discussed.

The RT-UL device was positioned in the centre of the physiotherapy open-plan gym and this appeared to be a strong facilitator to use in routine practice. Therapists pointed out that if the device was alternatively located in a separate individual room, then use in daily practice would likely have been far less. The location of a robotic device in a separate area to the primary treatment area can negatively impact the integration of RT-UL as part of the patient's broader rehabilitation program as well as decrease staff motivation to use the device (Lo et al., 2020). The location of the RT-UL within the gym area of the rehabilitation facility in this program of research appeared to fit comfortably with the workflow of the physiotherapists. Patients moved between RT-UL and other activities with minimal interruption to their program. This easy integration of RT-UL into the workflow of the gym was also enabled by the minimal time required to set up patients on the device.

Conversely, the availability of a single device did appear to impact on the integration of RT-UL by occupational therapists. This limited uptake by the occupational therapists was not necessarily seen as a negative outcome, but an element of feasibility needing to be planned for and even negotiated by the rehabilitation team. This is to ensure the maximum use of the device in the clinical setting as well as allay any potential interdisciplinary tensions that could arise from a lack of opportunity to use the device.

How easy or difficult an intervention is to physically set up and use also contributes to feasibility (Proctor et al., 2011). Therapists at the participating rehabilitation facility described the InMotion arm component as being relatively straight forward to set up and use with patients. Even physiotherapy students were expected to be able to quickly incorporate RT-UL within their rehabilitation programs. However, the add-on hand module was more awkward than the arm component resulting in the hand module only being used a quarter of the time with patients. Aggogeri et al. (2019), in their state-of-the-art paper on hand RT-UL devices, emphasised the ongoing challenges of designing and developing robotics to train such a biomechanically complex area of the body. Refinement of hand RT-UL will be discussed further below in section 7.4 Future research directions.

An obvious but important factor in the feasibility of RT-UL was training of staff in the use of RT-UL. Prior to the implementation process in Study 1, therapists recognised that training was crucial for successful implementation of the RT-UL into routine practice. Initial training of staff did not appear to be a particularly difficult aspect of the implementation process with all existing and new staff, including students, undergoing training in the use of the InMotion. Some of the physiotherapists reported that they additionally carried out their own self-directed training on the device. The capacity and confidence of therapists to translate the knowledge and skills acquired in this initial training was influenced by the length of time between the training and having opportunity to use RT-UL with a patient. This was specifically a challenge for some of the occupational therapists. They reflected that the scarcity of stroke survivors as part of their own caseload following the training as well as being employed part-time resulted in a decreased opportunity to apply the skills learnt. This appeared to result in reduced confidence to incorporate the device into routine practice. This highlights the point that training in a new intervention like robotics should be ongoing and where possible responsive to the circumstances of individual staff members. Regular auditing of RT-UL computer data and completion of intermittent usability measures, like the system usability scale, may help rehabilitation units identify when refresher training is needed for staff in the use of RT-UL devices.

7.2.4 Appropriateness of RT-UL to the inpatient rehabilitation setting

Appropriateness, as a measure of implementation success, refers to the "perceived fit, relevance, or compatibility of new intervention for a given practice setting, provider, or consumer; and/or perceived fit of the intervention to address a particular issue or problem" (Proctor et al., 2011, p. 69). Clinicians and administrators may be accepting of implementing a new intervention but ultimately discover the intervention is not the right fit for a certain team member or clinical contexts. This program of research particularly provided insight into two aspects of RT-UL appropriateness. Firstly, the appropriateness of RT-UL to the role of the occupational therapists and physiotherapists at the rehabilitation facility and secondly to address the need to increase UL practice for stroke survivors.

Appropriateness can be considered in light of the domain of "professional role and identity" within the Theoretical Domain Framework (Atkins et al., 2017). This domain considers aspects related to profession role and identity and the impact on the implementation. This domain was explored within the focus groups in Study 1 and Study 4. The occupational therapists were accepting of the RT-UL but found that RT-UL was not all together appropriate to their role. As discussed in section 7.2.3, the location of the device in the physiotherapy area of the gym limited the occupational therapists use of the device. However, the occupational therapists also highlighted their need to carry out ADL retraining on the ward on a separate level of the building to the physical location of the robotic device in the therapy gym also limited their use of the RT-UL.

It was interesting that the occupational therapists did not have any philosophical concerns with incorporating RT-UL into their practice. It has been proposed that the use of similar therapeutic modalities, i.e. electrical stimulation, in occupational therapy practice may be indicative of a departure from core occupational therapy philosophy (Gustafsson et al., 2016; Joosten, 2015). Participants in this study were not directly asked to provide an opinion on RT-UL from a philosophical standpoint but none of the occupational therapists identified this as an issue. This may be reflective of occupational therapists who work in a clinical capacity placing greater value in other qualities (i.e. clinical efficacy, novelty, patient preferences and feasibility) above the potential congruency of an intervention with discipline philosophy.

In Study 1, therapists recognised the need to increase the amount of practice stroke survivors engaged in and particularly those patients with severe upper limb. They perceived RT-UL could address this need within their clinical setting. Study 2 then confirmed an increase in the amount of practice once RT-UL was implemented including stroke survivors with severe UL impairment. In Study 4, both disciplines described how the implementation of RT-UL had helped increase the amount of practice provided to stroke survivors. These findings indicate an overall appropriateness of RT-UL to address practice levels for stroke survivors within the inpatient rehabilitation setting. This is a positive finding and clinicians and administrators should be encouraged that the implementation RT-UL, along with other initiatives such as group practice and unsupervised room-based self-directed UL programs (e.g. GRASP) (Harris et al., 2009; Stewart et al., 2017) may enable stroke survivors to engage in sufficient levels of UL practice.

7.2.5 Fidelity of RT-UL in context of RATULS trial

Fidelity considers how an intervention used in clinical trials has been employed in routine clinical practice (Proctor et al., 2011). Fidelity can be evaluated in terms of adherence to a program, dose or amount of intervention delivered or the quality of the program provided (Proctor et al., 2011). Conclusions as to the fidelity of RT-UL within this program of research can be drawn from comparing the findings of Study 2 and Study 3 with the protocol of the RATULS trial (Rodgers et al., 2019; Rodgers et al., 2017). In the RATULS trial, participants who received RT-UL demonstrated significant improvements in motor function (i.e. Fugl Meyer assessment) when compared to usual care. The RATULS trial is the largest robotic trial to date and specifically involved the delivery of RT-UL via the InMotion. A comprehensive study protocol for the RATULS trial has been separately published to compliment the main paper and provides a detailed description of the treatment delivered during the trial

(Rodgers et al., 2017). Conclusions as to the fidelity of RT-UL in routine practice are now discussed.

Participants in the RATULS trial engaged in RT-UL three times per week for 12 weeks. Participants completed a median of 35 (IQR 31-36) RT-UL sessions within this 12-week period. Study 3 of this program of research recorded that RT-UL users participated on average in nine RT-UL sessions (95% confidence intervals 7-12 sessions) across an average length of stay of eight weeks at the rehabilitation facility. There are a number of potential reasons for this lower frequency of RT-UL practice. Firstly, there were participants in Study 3 who only engaged in one or two RT-UL sessions for the purpose of UL evaluation and not treatment. Also, therapists reported in Study 4 that patients were progressed onto more advanced forms of UL practice, e.g. task specific practice, once sufficient gains in active UL movement had been made. Other patients simply may not have liked RT-UL and chosen not to continue but this was not reported by therapists in focus groups. Therapists reported that fatigue impacted some patients' use of RT-UL and this may also have contributed to patients engaging in fewer sessions than seen in the RATULS trial. Finally, practical reasons related to patient and staff scheduling are likely also to have contributed to fewer sessions be conducted. This program of research study did not extend to the collection and analysis of patient clinical outcome measures, so it could not be determined if the number of sessions was sufficient to improve UL outcomes for the stroke survivors.

In the RATULS trial, RT-UL sessions were run for a duration of 45 minutes in addition to usual care. The exact number of repetitions completed as part of these sessions was not documented but the protocol detailed that the aim was >350 UL repetitions per session (i.e. intensity of seven repetitions per minute). An earlier clinical trial involving the InMotion (Conroy et al., 2011) had participants achieve an average 672 UL repetitions within a 60-minute session (i.e. intensity of 11.2 repetitions per minute). In Study 2, RT-UL practice was not a separate session but was typically embedded as part of usual therapy. Practice on the InMotion replaced impairment-related interventions (e.g. active exercises) with task specific practice remaining unchanged post-RT-UL implementation. The practice lasted an average of 29 minutes, with an average of 449 RT-UL repetitions completed at an intensity of 18 repetitions per minute. Study 2 therefore demonstrated that the highly intensive RT-UL practice sessions delivered in clinical trials (Conroy et al., 2011; Rodgers et al., 2019) were achievable in routine practice and even able to be surpassed. As stated above participant clinical outcome measures were not collected so it could not be determined if the increased intensity offset the lower number of total RT-UL sessions completed by stroke survivors.

All sessions in the RATULS trial were conducted face-to-face by either a therapist or therapy assistant whereas RT-UL sessions observed in Study 2 were almost exclusively semi-supervised. This is an important distinction as a key advantage of RT-UL is purported to be the reduced reliance of patients on their therapist to engage in intensive practice. In Study 2, therapists were observed attending to other patients while the RT-UL user independently and safely completed their RT-UL practice. RT-UL has been previously identified with the potential to support semi-supervised practice (Stroke Foundation, 2022) but this is the first study to observe this advantage within routine practice.

Participants in the RATULS trial only completed the clock game therapy protocol and did not complete any of the additional games available on the InMotion. The clock game is the only activity on the InMotion that provides "active-assistance" to the arm. The audit data of Study 3 showed that participants primarily completed the clock game therapy protocol but also engaged in the other games including squeegee, pong and race. The inclusion of these other games into a stroke survivors RT-UL session was likely the outcome of therapists wanting to give variety to the RT-UL sessions and enhance patient motivation, though this was not investigated during this program of research.

In the RATULS trial participants included acute, sub-acute and chronic stroke survivors at a median of 233 (IQR 102—549) days post-stroke. This program of research exclusively included sub-acute stroke survivors. In Study 2 participants were on average 32 days post-stroke, an important distinction to the RATULS trial. RT-UL has the potential to be effective with stroke survivors both in the acute, sub-acute and chronic phase of recovery (Mehrholz et al., 2020). However, access to a RT-UL device in the Australian context is likely to be in the early phase of recovery within an inpatient hospital facility.

Overall, this investigation into the fidelity of RT-UL as part of routine practice when compared to the RATULS clinical trial was mixed in its findings. In the positive, the amount of UL practice per session described in the trial was achievable in routine practice and even able to be exceeded. In routine practice RT-UL required only semi-supervised input from the therapists as opposed to the one-on-one support given in the RATULS trial. Robotic practice was also incorporated as part of routine UL practice as opposed to in addition to usual therapy. However, the number of total sessions completed by participants was much less than that observed in the RATULS trial and did not always involve the use of the prescribed therapy protocol. These aspects may have impacted the efficacy of RT-UL within routine practice.

7.2.6 RT-UL penetration and potential cost implications

Penetration of a new intervention considers the depth to which a new intervention is integrated into a service setting (Proctor et al., 2011). Collecting and analysing local data is important to determine penetration of a new intervention (Proctor et al., 2011). Specifically, penetration can be measured in terms of the number of eligible patients who receive an intervention compared to the total number of those eligible for the intervention (Proctor et al., 2011; Stiles et al., 2002). The penetration of RT-UL at the rehabilitation facility investigated in this program of research can be evaluated from the findings of Study 3. In Study 3, two audits were conducted of inpatient stroke survivors use of RT-UL at the rehabilitation facility. During Audit 1, 31 stroke survivors were admitted to the unit, 18 received RT-UL (58%) and during Audit 2, 14 stroke survivors were admitted and seven received RT-UL (50%). The penetration of RT-UL was largely determined by therapist decision to prescribe and prioritise RT-UL with stroke survivors with severe UL impairment.

Auditing patient numbers and records should be a standard part of any pre and post implementation process (McCluskey & O'Connor, 2017). The results of this program of research indicate that auditing prior to RT-UL implementation should focus on three important aspects; the total number of stroke survivors admitted to a facility per year, how many of these individuals experience UL impairment and degree of their UL impairment. These findings can help predict the likely penetration of RT-UL into routine practice. Findings from such audits may help clinicians and administrators decide to proceed or not proceed with the purchase of a device. Audit data may result in facilities firstly renting an RT-UL device as opposed to purchasing the device upfront.

Post-implementation audits may reveal the need for a second RT-UL device. For example, a high number of patients may be prescribed RT-UL but due to only a single device being available the frequency of sessions per patient is low (e.g. once per week) or too brief (e.g. 15-minute sessions). Post-implementation audits may demonstrate limitations with a particular device that mean a complimentary device may be needed. For example, the limited penetration of the InMotion hand module component seen in Study 3 audits merits consideration of a complimentary device to better facilitate practice involving the hand. It also meant that other forms of hand practice needed to be incorporated into patient programs.

Penetration of a new intervention can also be considered from the perspective of the number of providers who deliver a given service or treatment compared to the total number of providers trained in or expected to deliver the service (Proctor et al., 2011). As discussed in the previous section (section 7.2.5), this program of research showed that RT-UL had penetrated routine practice of physiotherapy staff to a greater degree than the occupational therapists. Study 3 found that 80% of all RT-UL sessions were prescribed by physiotherapists despite both disciplines being trained in the use of RT-UL. Such penetration data can help identify where specific implementation strategies maybe needed to improve uptake such as refresher training, nomination of a discipline champion or improved access to the device.

Finally, the degree of RT-UL penetration has potential cost implications. Previous studies have analysed the cost-benefits of RT-UL at an individual patient level (Imms et al., 2015; Rodgers et al., 2019). However, the financial viability of RT-UL should also consider the overall number of stroke survivors treated at the rehabilitation facility and the proportion of these likely to be suited for use of RT-UL at some stage of their rehabilitation program. Undertaking a formal cost-benefit analysis was beyond the scope of this program of research but findings from Study 3 have identified that future cost-benefit analysis should factor in overall admission rates.

7.2.7 Adoption of RT-UL be both clinician-initiated and clinician-led

Adoption, as a measure of implementation success, focuses on the initial decision to employ an intervention as part of routine practice (Proctor et al., 2011). The adoption of the InMotion at the rehabilitation facility in this program of research was both initiated and led by the clinicians, in particular senior physiotherapy staff. This is important as it is well recognised that clinician-led implementation of health interventions is crucial for success (McKee et al., 2017). Clinical leadership typically comes in the form of a "champion", an individual(s) who demonstrates a particular strength of conviction and commitment to the implementation process (Miech et al., 2018) and is present at the frontlines of services delivery (Bonawitz et al., 2020). The National Stroke Foundation of Australia specifies that a clinical champion is vital for any team looking to implement interventions from the stroke guidelines, of which RT-UL is one. This essential driving force of a clinical champion appeared to override many potential barriers in this particular rehabilitation setting. Even when the original champion for RT-UL in the rehabilitation unit retired in the initial phase of implementation, a fellow physiotherapist took up the role and continued to promote and facilitate RT-UL use within the unit. The continued presence of a RT-UL champion ensured both successful implementation in the initial phase as well as sustained use of RT-UL (Stroke Foundation, 2022). Nonetheless staff turnover and rotation between departments has the potential to derail the implementation process and strategies including RT-UL refresher training for new staff should be in place to minimise the impact of these changes.

Further to this, the implementation of RT-UL was not just led by the therapy staff but also initiated. This appeared to result in greater buy in to the implementation process particularly from the physiotherapy staff. It is questionable if the implementation process would have been as successful if the initiative had come from the management at the facility and not the therapy staff. This indicates a fundamental openness and acceptance of RT-UL from the outset and that this is likely to have contributed to the relative success of the implementation process.

7.2.8 Questions to guide implementation planning

There are many factors that can influence the implementation of a new intervention into routine practice (Atkins et al., 2017; McCluskey & O'Connor, 2017). Below are a series of practical questions, generated from this program of research, to guide health professionals and administrators' decision-making with respect to the implementation of RT-UL. This list focuses on factors specific to the acquisition and implementation of RT-UL.

Acceptability

- What are clinicians' perceptions of the advantages and disadvantages of implementing RT-UL prior to implementation? Do they believe the advantages will outweigh the disadvantages?

- How do clinicians' perceptions of these advantages and disadvantages align with the actual evidence for RT-UL?
- What are patients' and their families' perceptions of RT-UL as part of routine practice? Do they believe it would be a helpful and motivating form of therapy?

Sustainability

- What measures will be in place to facilitate the continued use of the robotic device by clinicians beyond the initial 6-12 months after implementation?
- Will training in the use of RT-UL be part of all new clinicians' orientation process?
- How will clinicians and administrators stay abreast of software and hardware updates related to the robotic device?

Feasibility

- Where is the best location for the device to promote use as part of routine practice?
- Which discipline will take responsibility for the prescription of the RT-UL as part of routine practice? Or will it be a joint decision between disciplines?
- What support is available for the robotic device for set-up, training and ongoing technical support/problem management once implemented?

Appropriateness

- Which individual clinicians or disciplines group(s) perceive RT-UL to be compatible with their role?
- Do clinicians believe there is a specific need that RT-UL will meet within their routine practice?

Fidelity

- Is there sufficient staffing and access to the RT-UL device to enable stroke survivors to engage in three times per week RT-UL sessions?
- Will RT-UL practice occur "as part of" usual care or "in addition to" usual care?

Penetration & cost implications

- Has an audit of stroke survivor admissions to the facility been undertaken (i.e. 12-month period)? If so, what were the number (percentage) of stroke survivors with UL deficits? What was the severity of these UL deficits?
- Were there notable ebbs and flows in the number of stroke survivors with UL deficits? Are the ebbs and flows likely to result in in the deskilling of staff members in the use of RT-UL? How will this deskilling be addressed?
- Are the number of likely RT-UL users sufficient to justify the cost implementing the device into routine practice? Is renting a robotic device, as opposed to purchasing upfront, the best initial step in the implementation process?

- Will the availability of a single RT-UL device be sufficient to facilitate the practice demands of the stroke survivors admitted to the facility (i.e. frequency of sessions and duration of sessions)?

Adoption

- Is the implementation of RT-UL an initiative of clinicians or is it a directive from management?
- Has an RT-UL "champion(s)" been designated from among clinicians to lead the implementation process? Who will replace this champion if they are unable to fulfill the role? (e.g. resign, change in role or take extended leave)

7.3 Limitations of the research

There were several limitations to the studies completed as part of this program of research. The limitations for each study have been detailed within the individual study manuscripts and are summarised here.

Most notably the implementation of RT-UL was only investigated within a single rehabilitation facility in Australia and conclusions are therefore reflective of this healthcare setting. However, as detailed in Section 2.5 "Setting" the participating rehabilitation facility was largely reflective of Australian rehabilitation services which are typically public facilities, located in a metropolitan area and providing mixed rehabilitation services five days per week inclusive of occupational therapy and physiotherapy (Stroke Foundation, 2020).

In Study 2, a relatively small sample of convenience was recruited in both observational phases, and the patients observed in the pre-implementation phase were not the same as those observed in the post-implementation phase. However, no statistical differences in demographics or clinical characteristics were found between the two groups. Despite the candidate(NF) being careful to be unobtrusive and not to interfere with the decision making of therapists in relation to use of RT-UL during therapy session, it is possible that therapists changed their practices in response to the observations and audits being conducted in Study 2 and Study 3. Also, participants in these studies did not extend to stroke survivors in the chronic phase of recovery or with an alternate diagnosis (e.g. traumatic brain injury and UL orthopaedic). However, patients meeting these criteria were very few across the program of research with the rehabilitation facility being primarily focused on the subacute phase of recovery.

As highlighted in the previous section “Implications for clinical practice”, Study 2 and Study 3 did not extend to the collection and analysis of UL outcome measures. Consequently, no conclusions could be made as to the impact of RT-UL on the UL recovery or outcomes for participants. Also, demographic and clinical details of participants collected were from charts and relied on the accuracy of the therapists recording this information. However, the therapists were qualified and skilled in the administration of these measures

The use of the Theoretical Domain Framework to guide the development of questions and analysis of the focus groups for Study 1 and 4 may have limited identification of other relevant themes. This framework, however, enabled a structured and effective process of categorisation and placed the information in a format that is consistent with other studies in the field of implementation science.

7.4 Future research directions

This program of research has generated new knowledge of the implementation of RT-UL within routine practice as well as identified gaps and directions for future research. These gaps and future directions are now discussed.

7.4.1 Exploration of patient perceptions

Client preferences should be a key driver of therapists' decision-making process when selecting evidenced-based interventions for stroke survivors (Bennett & Bennett, 2000). The perspectives of stroke survivors using RT-UL as part of their UL rehabilitation program are largely absent from the literature. The focus for their inclusion in the few studies that have been conducted has been largely to assist in the design process of a robotic device (Hughes et al., 2011; Hughes et al., 2014), or reflect on experiences as part of clinical trial (Tedesco Triccas et al., 2018). Future studies need to broaden to also gather stroke survivors' perspectives of RT-UL when the intervention has been part of their own personal recovery. Questions remain as to stroke survivors' perspectives about the perceived benefits of RT-UL as well as motivational qualities of RT-UL. A clearer understanding of stroke survivors' perceptions will help inform therapists decision making process as well as identify factors influencing RT-UL implementation.

7.4.2 Determining RT-UL dosage for routine practice

Study 2 of this research program demonstrated the potential for RT-UL to significantly increase both the number of repetitions and intensity of UL practice performed by inpatient stroke survivors. The assumption is that this increased practice would translate to improvements in clinical outcomes for patients (Schneider et al., 2016) particularly at the level of impairment (Wu et al., 2021). However, Study 3 highlighted that the number of RT-UL sessions completed across the entirety of a patients' admission did not equate to the number seen in clinical trials such as the RATULS study (e.g. 35 sessions) by Rodgers et al. (2019). This indicates that the practice levels seen in clinical trials in terms of total sessions of RT-UL may not be achievable within the context of routine practice. Other forms of intensive UL practice have been shown to be effective at a lower dosage level than administered in original clinical trials. For example, the high resource demand of implementing CIMT in its original form has meant that a number of modified forms of CIMT have been developed (Page et al., 2008). Modified CIMT has since been shown to be effective in improving UL function for stroke survivors (Fleet et al., 2014; Page et al., 2008). Future research should look to pragmatically investigate the dosage of RT-UL needed to improve stroke survivors UL function once part of routine practice.

7.4.3 Timing of RT-UL use

Research into the efficacy of RT-UL needs to continue to focus on improving understanding of what stage of recovery is RT-UL most effective (i.e. acute, sub-acute, chronic) and the impact of other patient characteristics including: severity of UL impairment, area of UL impairment (i.e. proximal versus distal), UL dominance (i.e. dominant versus non-dominant) and cognitive status. As proposed by the Canadian stroke guidelines (Teasell et al., 2020), RT-UL would seem most suited to stroke survivors with severe UL impairment. It would also appear to be most applicable to UL retraining for stroke survivors in the acute and sub-acute phase of recovery when potential for changes at impairment level are most probable (Bernhardt et al., 2017; Mehrholz et al., 2018). Stroke survivors are also more likely to have access to these devices as part of their inpatient setting. Stroke survivors with these clinical characteristics have been underrepresented in clinical trials. As found in Study 3, RT-UL presents as a bridging form of UL practice for stroke survivors with more limited active UL movement, until there is sufficient UL movement and power for more complex real-world task specific practice. Future RT-UL trials should give priority to determining the efficacy of RT-UL for acute and subacute stroke survivors.

How RT-UL can and should be used as part of a broader UL program for stroke survivors needs investigation. The RATULS trial investigated RT-UL as adjunct to usual therapy (Rodgers et al., 2019) whereas Study 2 of this research program found that RT-UL was not used as an adjunct but rather embedded within a stroke survivor's program in place of other forms of impairment-based UL practice. There is promising research emerging exploring the use of RT-UL in combination with other evidenced based approaches such as mirror therapy (Lee et al., 2022), functional electrical stimulation (Resquín et al., 2016), bilateral arm training and constraint induced movement therapy (Hung et al., 2019). Further to this, RT-UL application to diagnostic groups other than stroke within the adult rehabilitation setting merits future investigation. In particular, RT-UL has potential application to a wider range of neurological conditions affecting the UL including multiple sclerosis (Sampson et al., 2016) along with orthopaedic conditions (Padilla-Castañeda et al., 2018).

7.4.4 Refinement of RT-UL hand modules

Study 3 revealed that the hand module on the InMotion was used only a quarter of the time with patients. Therapists reflected in Study 4 that this was largely due to the hand module facilitating only a basic grasp-release pattern as well as being difficult to set up. The biomechanical complexity of the hand leads to a range of technical challenges to developing an effective hand module component for RT-UL devices (Aggogeri et al., 2019). The capacity for RT-UL to address stroke survivor limitations in ADL performance is not as evident as motor impairment and function. The recovery of hand function is crucial to independence in a range of ADL tasks (Faria-Fortini et al., 2011; Kim, 2016). Advancement of RT-UL hand module components of the InMotion or other UL robotic devices may result in improved outcomes at the activity and participation level of recovery for stroke survivors. Soft wearable RT-UL hand devices such as the neomano, carbonhand and RELab tenoexo also show potential for improving hand function and ADL performance by enabling direct ADL practice (Bützer et al., 2020; Plessis et al., 2021; Radder et al., 2018). Such devices also have potential to be used by participants within their own home, not limited to the clinical setting. Further exploration is needed to improve the design and functionality of RT-UL hand devices particularly in the hope of improving activity and participation-based outcomes for stroke survivors.

7.5 Conclusion

This research program has evaluated the success of implementing one of the most common RT-UL devices, InMotion, into the routine practices of an Australian rehabilitation setting. Implementation success has been considered with respect to eight key measures; acceptability, sustainability, feasibility, appropriateness, fidelity, penetration, cost implications and adoption. New knowledge has been acquired about RT-UL in routine practice for stroke survivors including occupational therapists and physiotherapists perceptions, impact on the amount of UL practice able to be delivered (both repetitions and intensity of practice), sustainability of RT-UL within the inpatient rehabilitation setting and barriers and facilitator to RT-UL implementation. Successful implementation of evidence-based practices like RT-UL should involve careful forward planning and strategic coordination (McCluskey & O'Connor, 2017). Without such planning and strategy, change in practice has the potential to be minimal or short-lived (McCluskey & O'Connor, 2017). These findings provide substantial insight and practical guidance to clinicians and health administrators considering the implementation of RT-UL into their clinical context.

Chapter 8 - References

Ada, L., O'Dwyer, N., & O'Neill, E. (2006). Relation between spasticity, weakness and contracture of the elbow flexors and upper limb activity after stroke: An observational study. *Disability and Rehabilitation*, *28* (13-14), 891-897. https://doi.org/10.1080/09638280500535165

Aggogeri, F., Mikolajczyk, T., & O'Kane, J. (2019). Robotics for rehabilitation of hand movement in stroke survivors. *Advances in Mechanical Engineering*, *11*(4). 1687814019841921. https://doi.org/10.1177/1687814019841921

Aprile, I., Germanotta, M., Cruciani, A., Loreti, S., Pecchioli, C., Cecchi, F., Montesano, A., Galeri, S., Diverio, M., Falsini, C., Speranza, G., Langone, E., Papadopoulou, D., Padua, L., & Carrozza, M. C. (2020). Upper limb robotic rehabilitation after stroke: A multicenter, randomized clinical trial. *Journal of Neurologic Physical Therapy*, *44*(1), 3-14. https://doi.org/10.3138/ptc.34.2.077

Arya, K. N., Pandian, S., Verma, R., & Garg, R. K. (2011). Movement therapy induced neural reorganization and motor recovery in stroke: A review. *Journal of Bodywork and Movement Therapies*, *15*(4), 528-537. https://doi.org/http://dx.doi.org/10.1016/j.jbmt.2011.01.023

Atkins, L., Francis, J., Islam, R., O'Connor, D., Patey, A., Ivers, N., Foy, R., Duncan, E. M., Colquhoun, H., Grimshaw, J. M., Lawton, R., & Michie, S. (2017). A guide to using the theoretical domains framework of behaviour change to investigate implementation problems. *Implementation Science*, *12*(1), 77. https://doi.org/10.1186/s13012-017-0605-9

Babaiasl, M., Mahdioun, S. H., Jaryani, P., & Yazdani, M. (2016). A review of technological and clinical aspects of robot-aided rehabilitation of upper-extremity after stroke. *Disability and Rehabilitation: Assistive Technology*, *11*(4), 263-280. https://doi.org/10.3109/17483107.2014.1002539

Bagley, P., Hudson, M., Green, J., Forster, A., & Young, J. (2009). Do physiotherapy staff record treatment time accurately? An observational study. *Clinical Rehabilitation*, *23*(9), 841-845. https://doi.org/10.1177/0269215509102949

Bangor, A. (2009). Determining what individual SUS scores mean: adding an adjective rating scale. *Journal of Usability Studies*, *4*(3), 114-123.

Bangor, A., Kortum, P. T., & Miller, J. T. (2008). An empirical evaluation of the system usability scale. *International Journal of Human–Computer Interaction*, *24*(6). 574-594. https://doi.org/10.1080/10447310802205776

Barker, R. N., Hayward, K. S., Carson, R. G., Lloyd, D., & Brauer, S. G. (2017). SMART arm training with outcome-triggered electrical stimulation in subacute stroke survivors with severe arm disability: A randomized controlled trial. *Neurorehabilitation & Neural Repair*, *31*(12), 1005-1016. https://doi.org/10.1177/1545968317744276

Bayley, M. T., Hurdowar, A., Richards, C. L., Korner-Bitensky, N., Wood-Dauphinee, S., Eng, J. J., McKay-Lyons, M., Harrison, E., Teasell, R., Harrison, M., & Graham, I. D. (2012). Barriers to implementation of stroke rehabilitation evidence: Findings from a multi-site pilot project. *Disability & Rehabilitation*, *34*(19), 1633-1638. https://doi.org/10.3109/09638288.2012.656790

Bützer, T., Lambercy, O., Arata, J., & Gassert, R. (2020). Fully Wearable Actuated Soft Exoskeleton for Grasping Assistance in Everyday Activities. Soft robotics, 8(2), 128-143. https://doi.org/10.1089/soro.2019.0135

Bennett, S., & Bennett, J. W. (2000). The process of evidence-based practice in occupational therapy: Informing clinical decisions. *Australian Occupational Therapy Journal*, *47*(4), 171-180. https://doi.org/https://doi.org/10.1046/j.1440-1630.2000.00237.x

Bernhardt, J., Hayward, K. S., Kwakkel, G., Ward, N. S., Wolf, S. L., Borschmann, K., Krakauer, J. W., Boyd, L. A., Carmichael, S. T., Corbett, D., & Cramer, S. C. (2017). Agreed definitions and a shared vision for new standards in stroke recovery research: The Stroke recovery and rehabilitation roundtable taskforce. *International Journal of Stroke*, *12*(5), 444-450. https://doi.org/10.1177/1747493017711816

Bionik Labs. (2017). *Bionik Labs*. Retrieved 29 June from http://bionikusa.com/

Bionik Labs. (2021). *Bionik Labs*. Retrieved 30 November from http://bionikusa.com/

Bloom, B. M., Pott, J., Thomas, S., Gaunt, D. R., & Hughes, T. C. (2021). Usability of electronic health record systems in UK EDs. *Emergency Medicine Journal*, *38*(6), 410-415. https://doi.org/10.1136/emermed-2020-210401

Bonawitz, K., Wetmore, M., Heisler, M., Dalton, V. K., Damschroder, L. J., Forman, J., Allan, K. R., & Moniz, M. H. (2020). Champions in context: Which attributes matter for change efforts in healthcare? *Implementation Science*, *15*(1), 62. https://doi.org/10.1186/s13012-020-01024-9

Boulanger, J. M., Lindsay, M. P., Gubitz, G., Smith, E. E., Stotts, G., Foley, N., Bhogal, S., Boyle, K., Braun, L., Goddard, T., Heran, M. K. S., Kanya-Forster, N., Lang, E., Lavoie, P., McClelland, M., O'Kelly, C., Pageau, P., Pettersen, J., Purvis, H., . . . Butcher, K. (2018). Canadian stroke best practice recommendations for acute stroke management: Prehospital, emergency department, and acute inpatient stroke care, 6th edition, update 2018. *International Journal of Stroke*, *13*(9), 949-984. https://doi.org/10.1177/1747493018786616

Bradley, E. H., Webster, T. R., Baker, D., Schlesinger, M., Inouye, S. K., Barth, M. C., Lapane, K. L., Lipson, D., Stone, R., & Koren, M. J. (2004). Translating research into practice: Speeding the adoption of innovative health care programs. *Issue Brief (Commonwealth Fund)*(724), 1-12.

Bustamante Valles, K., Montes, S., Madrigal, M. d. J., Burciaga, A., Martínez, M. E., & Johnson, M. J. (2016). Technology-assisted stroke rehabilitation in Mexico: A pilot randomized trial comparing traditional therapy to circuit training in a

robot/technology-assisted therapy gym. *Journal of NeuroEngineering and Rehabilitation*, *13*(1), 83. https://doi.org/10.1186/s12984-016-0190-1
Cahill, L. S., Carey, L. M., Mak-Yuen, Y., McCluskey, A., Neilson, C., Connor, D. A., & Lannin, N. A. (2021). Factors influencing allied health professionals' implementation of upper limb sensory rehabilitation for stroke survivors: A qualitative study to inform knowledge translation. *BMJ Open*, *11*(2), e042879. https://doi.org/10.1136/bmjopen-2020-042879
Carr, J. H., Shepherd, R. B., Nordholm, L., & Lynne, D. (1985). Investigation of a new motor assessment scale for stroke patients. *Physical Therapy*, *65*(2), 175-180. http://ezproxy.acu.edu.au/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=ccm&AN=107583449&site=ehost-live&scope=site
Celian, C., Swanson, V., Shah, M., Newman, C., Fowler-King, B., Gallik, S., Reilly, K., Reinkensmeyer, D. J., Patton, J., & Rafferty, M. R. (2021). A day in the life: A qualitative study of clinical decision-making and uptake of neurorehabilitation technology. *Journal of NeuroEngineering & Rehabilitation (JNER)*, *18*(1), 1-12. https://doi.org/10.1186/s12984-021-00911-6
Chang, W. H., Sohn, M. K., Lee, J., Kim, D. Y., Lee, S.-G., Shin, Y.-I., Oh, G.-J., Lee, Y.-S., Joo, M. C., Han, E. Y., Kang, C., & Kim, Y.-H. (2016). Predictors of functional level and quality of life at 6 months after a first-ever stroke: the KOSCO study. *Journal of Neurology*, *263*(6), 1166-1177. https://doi.org/10.1007/s00415-016-8119-y
Chen, C. C., & Bode, R. K. (2011). Factors influencing therapists' decision-making in the acceptance of new technology devices in stroke rehabilitation. *American Journal of Physical Medicine & Rehabilitation*, *90*(5), 415-425. https://doi.org/10.1097/PHM.0b013e318214f5d8
Chen, H. Y., Harris, I. A., Sutherland, K., & Levesque, J. F. (2018). A controlled before-after study to evaluate the effect of a clinician led policy to reduce knee arthroscopy in NSW. *BMC Musculoskeletal Disorders*, *19*(1), 148. https://doi.org/10.1186/s12891-018-2043-5
Chen, Z., Wang, C., Fan, W., Gu, M., Yasin, G., Xiao, S., Huang, J., & Huang, X. (2020). Robot-assisted arm training versus therapist-mediated training after stroke: A systematic review and meta-analysis. *Journal of Healthcare Engineering*, 8810867. https://doi.org/10.1155/2020/8810867
Chong, L., Rusák, Z., Horváth, I., & Linhong, J. (2014). Influence of complementing a robotic upper limb rehabilitation system with video games on the engagement of the participants: A study focusing on muscle activities. *International Journal of Rehabilitation Research*, *37*(4), 334-342. https://doi.org/10.1097/MRR.0000000000000076
Connell, L. A., McMahon, N. E., Simpson, L. A., Watkins, C. L., & Eng, J. J. (2014). Investigating measures of intensity during a structured upper limb exercise program in stroke rehabilitation: an exploratory study. *Archives of Physical Medicine and Rehabilitation*, *95*(12), 2410-2419. https://doi.org/10.1016/j.apmr.2014.05.025

Conroy, S. S., Whitall, J., Dipietro, L., Jones-Lush, L. M., Zhan, M., Finley, M. A., Wittenberg, G. F., Krebs, H. I., & Bever, C. T. (2011). Effect of gravity on robot-assisted motor training after chronic stroke: A randomized trial. *Archives of Physical Medicine & Rehabilitation*, *92*(11), 1754-1761. https://doi.org/10.1016/j.apmr.2011.06.016

Conroy, S. S., Wittenberg, G. F., Krebs, H. I., Zhan, M., Bever, C. T., & Whitall, J. (2019). Robot-assisted arm training in chronic stroke: Addition of transition-to-task practice. *Neurorehabilitation & Neural Repair*, *33*(9), 751-761. https://doi.org/10.1177/1545968319862558

Corbetta, D., Sirtori, V., Castellini, G., Moja, L., & Gatti, R. (2015). Constraint-induced movement therapy for upper extremities in people with stroke. *Cochrane Database of Systematic Reviews, 2015*(10), CD004433. https://doi.org/10.1002/14651858.CD004433.pub3

Cramer, S. C., Sur, M., Dobkin, B. H., O'Brien, C., Sanger, T. D., Trojanowski, J. Q., Rumsey, J. M., Hicks, R., Cameron, J., Chen, D., Chen, W. G., Cohen, L. G., deCharms, C., Duffy, C. J., Eden, G. F., Fetz, E. E., Filart, R., Freund, M., Grant, S. J., . . . Vinogradov, S. (2011). Harnessing neuroplasticity for clinical applications. *Brain*, *134*(6), 1591-1609. https://doi.org/10.1093/brain/awr039

Dehem, S., Gilliaux, M., Stoquart, G., Detrembleur, C., Jacquemin, G., Palumbo, S., Frederick, A., & Lejeune, T. (2019). Effectiveness of upper-limb robotic-assisted therapy in the early rehabilitation phase after stroke: A single-blind, randomised, controlled trial. *Annals of Physical and Rehabilitation Medicine*, *62*(5), 313–320. https://doi.org/10.1016/j.rehab.2019.04.002

Davidson, P. M., Halcomb, E. J., & Gholizadeh, L. (2017). Focus groups in health research. In P. Liamputtong (Ed.), *Research methods in health: Foundations for evidence-based practice* (3rd ed., pp. 84-104). Oxford University Press.

Deloitte Access Economics. (2020). *No Postcode Untouched Stroke in Australia 2020*. Australia Retrieved from file:///C:/Users/niflynn/Downloads/No%20Postcode%20Untouched%2030%20October%20Final%20report%20(1).pdf

Dipietro, L., Krebs, H. I., Fasoli, S. E., Volpe, B. T., & Hogan, N. (2009). Submovement changes characterize generalization of motor recovery after stroke. *Cortex*, *45*(3), 318-324. https://doi.org/10.1016/j.cortex.2008.02.008

Dorsch, S., Ada, L., & Alloggia, D. (2018). Progressive resistance training increases strength after stroke but this may not carry over to activity: A systematic review. *Journal of Physiotherapy*, *64*(2), 84-90. https://doi.org/10.1016/j.jphys.2018.02.012

Duret, C., Grosmaire, A.-G., & Krebs, H. I. (2019). Robot-assisted therapy in upper extremity hemiparesis: Overview of an evidence-based approach. *Frontiers in Neurology*, *10*, 412. https://doi.org/10.3389/fneur.2019.00412

Everard, G. J., Ajana, K., Dehem, S. B., Stoquart, G. G., Edwards, M. G., & Lejeune, T. M. (2020). Is cognition considered in post-stroke upper limb robot-assisted

therapy trials? A brief systematic review. *International Journal of Rehabilitation Research*, *43*(3), 195-198. https://doi.org/10.1097/MRR.0000000000000420
Faria-Fortini, I., Michaelsen, S. M., Cassiano, J. G., & Teixeira-Salmela, L. F. (2011). Upper extremity function in stroke subjects: Relationships between the international classification of functioning, disability, and health domains. *Journal of Hand Therapy*, *24*(3), 257-265. https://doi.org/http://dx.doi.org/10.1016/j.jht.2011.01.002
Fasoli, S. E. (2021). Rehabilitation technologies to promote upper limb recovery after stroke. In G. Gillen & D. Nilsen (Eds.), *Stroke Rehabilitation: A Function-based Approach* (pp. 475-495). https://doi.org/http://dx.doi.org/10.1016/B978-0-323-63994-1.00021-8
Fernandez-Garcia, C., Ternent, L., Homer, T. M., Rodgers, H., Bosomworth, H., Shaw, L., Aird, L., Andole, S., Cohen, D., Dawson, J., Finch, T., Ford, G., Francis, R., Hogg, S., Hughes, N., Krebs, H. I., Price, C., Turner, D., Van Wijck, F., . . . Vale, L. (2021). Economic evaluation of robot-assisted training versus an enhanced upper limb therapy programme or usual care for patients with moderate or severe upper limb functional limitation due to stroke: Results from the RATULS randomised controlled trial. *BMJ Open*, *11*(5), e042081. https://doi.org/10.1136/bmjopen-2020-042081
Ferreira, F. M. R. M., Chaves, M. E. A., Oliveira, V. C., Martins, J. S. R., Vimieiro, C. B. S., & Van Petten, A. M. V. N. (2021). Effect of robot-assisted therapy on participation of people with limited upper limb functioning: A systematic review with GRADE recommendations. *Occupational Therapy International*, *2021*, 6649549. https://doi.org/10.1155/2021/6649549
Fleet, A., Page, S. J., MacKay-Lyons, M., & Boe, S. G. (2014). Modified constraint-induced movement therapy for upper extremity recovery post stroke: What is the evidence? *Topics in Stroke Rehabilitation*, *21*(4), 319-331. https://doi.org/10.1310/tsr2104-319
Flynn, N., Froude, E., Cooke, D., Dennis, J., & Kuys, S. (2021). The sustainability of upper limb robotic therapy for stroke survivors in an inpatient rehabilitation setting. *Disability & Rehabilitation*, 1-6. https://doi.org/10.1080/09638288.2021.1998664
Flynn, N., Froude, E., Cooke, D., & Kuys, S. (2020). Repetitions, duration and intensity of upper limb practice following the implementation of robot assisted therapy with sub-acute stroke survivors: An observational study. *Disability & Rehabilitation: Assistive Technology*, *17*(6), 675–680. https://doi.org/10.1080/17483107.2020.1807621
Flynn, N., Kuys, S., Froude, E., & Cooke, D. (2019). Introducing robotic upper limb training into routine clinical practice for stroke survivors: Perceptions of occupational therapists and physiotherapists. *Australian Occupational Therapy Journal*, *66*(4), 530-538. https://doi.org/10.1111/1440-1630.12594

Forsetlund, L., Bjørndal, A., Rashidian, A., Jamtvedt, G., O'Brien, M. A., Wolf, F. M., Davis, D., Odgaard-Jensen, J., & Oxman, A. D. (2009). Continuing education meetings and workshops: Effects on professional practice and health care outcomes. *Cochrane Database of Systematic Reviews, 2009*(2), CD003030. https://doi.org/10.1002/14651858.CD003030.pub2

French, B., Thomas, L. H., Coupe, J., McMahon, N. E., Connell, L., Harrison, J., Sutton, C. J., Tishkovskaya, S., & Watkins, C. L. (2016). Repetitive task training for improving functional ability after stroke. *Cochrane Database of Systematic Reviewsn 11*(11), CD006073. https://doi.org/10.1002/14651858.CD006073.pub3

Galea, M. P., Khan, F., Amatya, B., Elmalik, A., Klaic, M., & Abbott, G. (2016). Implementation of a technology-assisted programme to intensify upper limb rehabilitation in neurologically impaired participants: A prospective study. *Journal of Rehabilitation Medicine*, *48*(6), 522-528. https://doi.org/10.2340/16501977-2087

Gandolfi, M., Valè, N., Posteraro, F., Morone, G., Dell'orco, A., Botticelli, A., Dimitrova, E., Gervasoni, E., Goffredo, M., Zenzeri, J., Antonini, A., Daniele, C., Benanti, P., Boldrini, P., Bonaiuti, D., Castelli, E., Draicchio, F., Falabella, V., Galeri, S., . . . Mazzoleni, S. (2021). State of the art and challenges for the classification of studies on electromechanical and robotic devices in neurorehabilitation: A scoping review. *European Journal of Physical and Rehabilitation Medicine*, *57*(5), 831-840. https://doi.org/10.23736/S1973-9087.21.06922-7

Gillen, G., & Nilsen, D. M. (2021). Upper extremity function and management. In G. Gillen & D. Nilsen (Eds.), *Stroke Rehabilitation: A Function-based Approach* (pp. 413-474). Elsevier. https://doi.org/http://dx.doi.org/10.1016/B978-0-323-63994-1.00020-6

Greenhalgh, T., Wherton, J., Papoutsi, C., Lynch, J., Hughes, G., A'Court, C., Hinder, S., Fahy, N., Procter, R., & Shaw, S. (2017). Beyond adoption: A new framework for theorizing and evaluating nonadoption, abandonment, and challenges to the scale-up, spread, and sustainability of health and care technologies. *Journal of Medical Internet Research*, *19*(11), e367. https://doi.org/10.2196/jmir.8775

Gustafsson, L., Molineux, M., & Bennett, S. (2016). What are the limits of occupational therapy practice? *Australian Occupational Therapy Journal*, *63*(2), 134-134. https://doi.org/10.1111/1440-1630.12283

Hamilton, C., Lovarini, M., McCluskey, A., Folly de Campos, T., & Hassett, L. (2018). Experiences of therapists using feedback-based technology to improve physical function in rehabilitation settings: A qualitative systematic review. *Disability & Rehabilitation*, 1-12. https://doi.org/10.1080/09638288.2018.1446187

Hamilton, C., McCluskey, A., Hassett, L., Killington, M., & Lovarini, M. (2018). Patient and therapist experiences of using affordable feedback-based technology in rehabilitation: A qualitative study nested in a randomized controlled trial.

Clinical Rehabilitation, *32*(9), 1258-1270. https://doi.org/10.1177/0269215518771820
Hamm, J., Money, A. G., Atwal, A., & Ghinea, G. (2019). Mobile three-dimensional visualisation technologies for clinician-led fall prevention assessments. *Health Informatics Journal*, *25*(3), 788-810. https://doi.org/10.1177/1460458217723170
Han, C., Wang, Q., Meng, P.-p., & Qi, M.-z. (2012). Effects of intensity of arm training on hemiplegic upper extremity motor recovery in stroke patients: A randomized controlled trial. *Clinical Rehabilitation*, *27*(1), 75-81. https://doi.org/10.1177/0269215512447223
Harris, J. E., & Eng, J. J. (2007). Paretic upper-limb strength best explains arm activity in people with stroke. *Physical Therapy*, *87*(1), 88-97. https://doi.org/10.2522/ptj.20060065
Harris, J. E., Eng, J. J., Miller, W. C., & Dawson, A. S. (2009). A self-administered graded repetitive arm supplementary program (GRASP) improves arm function during inpatient stroke rehabilitation. *Stroke*, *40*(6), 2123-2128. https://doi.org/doi:10.1161/STROKEAHA.108.544585
Hayward, K. S., Barker, R. N., Wiseman, A. H., & Brauer, S. G. (2013). Dose and content of training provided to stroke survivors with severe upper limb disability undertaking inpatient rehabilitation: An observational study. *Brain Impairment*, *14*(3), 392-405. https://doi.org/10.1017/BrImp.2013.31
Hayward, K. S., & Brauer, S. G. (2015). Dose of arm activity training during acute and subacute rehabilitation post stroke: A systematic review of the literature. *Clinical Rehabilitation*, *29*(12), 1234-1243. https://doi.org/10.1177/0269215514565395
Hayward, K. S., Kramer, S. F., Dalton, E. J., Hughes, G. R., Brodtmann, A., Churilov, L., Cloud, G., Corbett, D., Jolliffe, L., Kaffenberger, T., Rethnam, V., Thijs, V., Ward, N., Lannin, N., & Bernhardt, J. (2021). Timing and dose of upper limb motor intervention after stroke: A systematic review. *Stroke*, *52*(11), 3706-3717. https://doi.org/doi:10.1161/STROKEAHA.121.034348
Hesse, S., Heß, A., Werner C, C., Kabbert, N., & Buschfort, R. (2014). Effect on arm function and cost of robot-assisted group therapy in subacute patients with stroke and a moderately to severely affected arm: A randomized controlled trial. *Clinical Rehabilitation*, *28*(7), 637-647 611p. https://doi.org/10.1177/0269215513516967
Hoffmann, T., Bennett, S., & Mar, C. D. (2017). Embedding evidence-based practice into routine clinical care. In T. Hoffmann, S. Bennett, & C. D. Mar (Eds.), *Evidence-Based Practice Across the Health Professions* (3rd ed., pp. 409-427). Elsevier Health Sciences.
Hughes, A.-M., Burridge, J., Freeman, C. T., Donnovan-Hall, M., Chappell, P. H., Lewin, P. L., Rogers, E., & Dibb, B. (2011). Stroke participants' perceptions of robotic and electrical stimulation therapy: A new approach. *Disability and*

Rehabilitation: Assistive Technology, *6*(2), 130-138. https://doi.org/10.3109/17483107.2010.509882
Hughes, A.-M., Burridge, J. H., Demain, S. H., Ellis-Hill, C., Meagher, C., Tedesco-Triccas, L., Turk, R., & Swain, I. (2014). Translation of evidence-based Assistive Technologies into stroke rehabilitation: users' perceptions of the barriers and opportunities. *BMC Health Services Research*, *14*(1), 124-124. https://doi.org/10.1186/1472-6963-14-124
Hung, C. S., Hsieh, Y. W., Wu, C. Y., Chen, Y. J., Lin, K. C., Chen, C. L., Yao, K. G., Liu, C. T., & Horng, Y. S. (2019). Hybrid rehabilitation therapies on upper-limb function and goal attainment in chronic stroke. *Occupational Therapy Journal of Research*, *39*(2), 116-123. https://doi.org/10.1177/1539449218825438
Imms, C., Wallen, M., & Laver, K. (2015). Robot assisted upper limb therapy combined with upper limb rehabilitation was at least as effective on a range of outcomes, and cost less to deliver, as an equal dose of upper limb rehabilitation alone for people with stroke. *Australian Occupational Therapy Journal*, *62*(1), 74-76. https://doi.org/10.1111/1440-1630.12188
Interactive motion technologies. (2016). InMotion arm user manual In.
Jakob, I., Kollreider, A., Germanotta, M., Benetti, F., Cruciani, A., Padua, L., & Aprile, I. (2018). Robotic and sensor technology for upper limb rehabilitation. *PM & R: Journal of Injury, Function & Rehabilitation*, *10*(9), S189-S197. https://doi.org/10.1016/j.pmrj.2018.07.011
Jolliffe, L., Hoffmann, T., & Lannin, N. A. (2019). Increasing the uptake of stroke upper limb guideline recommendations with occupational therapists and physiotherapists: A qualitative study using the Theoretical Domains Framework. *Australian Occupational Therapy Journal*, *66*(5), 603-616. https://doi.org/10.1111/1440-1630.12599
Joosten, A. V. (2015). Contemporary occupational therapy: Our occupational therapy models are essential to occupation centred practice. *Australian Occupational Therapy Journal*, *62*(3), 219-222. https://doi.org/10.1111/1440-1630.12186
Kaur, G., English, C., & Hillier, S. (2013). Physiotherapists systematically overestimate the amount of time stroke survivors spend engaged in active therapy rehabilitation: An observational study. *Journal of Physiotherapy*, *59*(1), 45-51. https://doi.org/10.1016/S1836-9553(13)70146-2
Keith, R. A. (1987). The functional independence measure : A new tool for rehabilitation. *Advances in Clinical Rehabilitation*, *1*, 6-18. https://ci.nii.ac.jp/naid/10020578979/en/
Kim, D. (2016). The effects of hand strength on upper extremity function and activities of daily living in stroke patients, with a focus on right hemiplegia. *Journal of Physical Therapy Science*, *28*(9), 2565-2567. https://doi.org/10.1589/jpts.28.2565
Kimberley, T. J., Samargia, S., Moore, L. G., Shakya, J. K., & Lang, C. E. (2010). Comparison of amounts and types of practice during rehabilitation for

traumatic brain injury and stroke. *Journal of Rehabilitation Research & Development*, *47*(9), 851-861. https://doi.org/10.1682/JRRD.2010.02.0019
Klamroth-Marganska, V., Blanco, J., Campen, K., Curt, A., Dietz, V., Ettlin, T., Felder, M., Fellinghauer, B., Guidali, M., Kollmar, A., Luft, A., Nef, T., Schuster-Amft, C., Stahel, W., & Riener, R. (2014). Three-dimensional, task-specific robot therapy of the arm after stroke: A multicentre, parallel-group randomised trial. *The Lancet Neurology*, *13*(2), 159-166. https://doi.org/10.1016/s1474-4422(13)70305-3
Kleim, J. A., Barbay, S., & Nudo, R. J. (1998). Functional reorganization of the rat motor cortex following motor skill learning. *Journal of Neurophysiology*, *80*(6), 3321-3325.
Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage. *Journal of Speech, Language & Hearing Research*, *51*(1), S225-S239. https://doi.org/10.1044/1092-4388(2008/018)
Kwakkel, G. (2006). Impact of intensity of practice after stroke: Issues for consideration. *Disability & Rehabilitation*, *28*(13/14), 823-830. https://doi.org/10.1080/09638280500534861
Kwakkel, G., Kollen, B. J., van der Grond, J., & Prevo, A. J. H. (2003). Probability of regaining dexterity in the flaccid upper limb: Impact of severity of paresis and time since onset in acute stroke. *Stroke*, *34*(9), 2181-2186. http://ezproxy.acu.edu.au/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=mdc&AN=12907818&site=ehost-live&scope=site
Laffont, I., Bakhti, K., Coroian, F., van Dokkum, L., Mottet, D., Schweighofer, N., & Froger, J. (2014). Innovative technologies applied to sensorimotor rehabilitation after stroke. *Annals of Physical and Rehabilitation Medicine*, *57*(8), 543-551. https://doi.org/http://dx.doi.org/10.1016/j.rehab.2014.08.007
Lang, C. E., Bland, M. D., Bailey, R. R., Schaefer, S. Y., & Birkenmeier, R. L. (2013). Assessment of upper extremity impairment, function, and activity after stroke: Foundations for clinical decision making. *Journal of Hand Therapy*, *26*(2), 104-114. https://doi.org/10.1016/j.jht.2012.06.005
Lang, C. E., MacDonald, J. R., & Gnip, C. (2007). Counting repetitions: An observational study of outpatient therapy for people with hemiparesis post-stroke. *Journal of Neurologic Physical Therapy*, *31*(1), 3-10. http://ezproxy.acu.edu.au/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=ccm&AN=105873370&site=ehost-live
Lang, C. E., MacDonald, J. R., Reisman, D. S., Boyd, L., Jacobson Kimberley, T., Schindler-Ivens, S. M., Hornby, T. G., Ross, S. A., & Scheets, P. L. (2009). Observation of amounts of movement practice provided during stroke rehabilitation. *Archives of Physical Medicine and Rehabilitation*, *90*(10), 1692-1698. https://doi.org/http://dx.doi.org/10.1016/j.apmr.2009.04.005

Lang, C. E., Strube, M. J., Bland, M. D., Waddell, K. J., Cherry-Allen, K. M., Nudo, R. J., Dromerick, A. W., Birkenmeier, R. L., & Cherry-Allen, K. M. (2016). Dose response of task-specific upper limb training in people at least 6 months poststroke: A phase II, single-blind, randomized, controlled trial. *Annals of Neurology*, *80*(3), 342-354. https://doi.org/10.1002/ana.24734

Lang, C. E., Wagner, J. M., Edwards, D. F., & Dromerick, A. W. (2007). Upper extremity use in people with hemiparesis in the first few weeks after stroke. *Journal of Neurologic Physical Therapy*, *31*(2), 56-63. http://ezproxy.acu.edu.au/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=ccm&AN=105871333&site=ehost-live&scope=site

Lee, Y.-c., Li, Y.-c., Lin, K.-c., Yao, G., Chang, Y.-j., Lee, Y.-y., Liu, C.-t., Hsu, W.-l., Wu, Y.-h., Chu, H.-t., Liu, T.-x., Yeh, Y.-p., & Chang, C. (2022). Effects of robotic priming of bilateral arm training, mirror therapy, and impairment-oriented training on sensorimotor and daily functions in patients with chronic stroke: Study protocol of a single-blind, randomized controlled trial. *Trials*, *23*(1), 566. https://doi.org/10.1186/s13063-022-06498-0

Lieshout, E. C. C. v., van de Port, I. G., Dijkhuizen, R. M., & Visser-Meily, J. M. A. (2020). Does upper limb strength play a prominent role in health-related quality of life in stroke patients discharged from inpatient rehabilitation? *Topics in Stroke Rehabilitation*, *27*(7), 525-533. https://doi.org/10.1080/10749357.2020.1738662

Liu, L., Miguel Cruz, A., Rios Rincon, A., Buttar, V., Ranson, Q., & Goertzen, D. (2015). What factors determine therapists' acceptance of new technologies for rehabilitation – a study using the Unified Theory of Acceptance and Use of Technology (UTAUT). *Disability & Rehabilitation*, *37*(5), 447-455. https://doi.org/10.3109/09638288.2014.923529

Lo, A. C., Guarino, P. D., Richards, L. G., Haselkorn, J. K., Wittenberg, G. F., Federman, D. G., Ringer, R. J., Wagner, T. H., Krebs, H. I., Volpe, B. T., Bever, C. T., Jr., Bravata, D. M., Duncan, P. W., Corn, B. H., Maffucci, A. D., Nadeau, S. E., Conroy, S. S., Powell, J. M., Huang, G. D., & Peduzzi, P. (2010). Robot-assisted therapy for long-term upper-limb impairment after stroke. *New England Journal of Medicine*, *362*(19), 1772-1783. https://doi.org/10.1056/NEJMoa0911341

Lo, K., Stephenson, M., & Lockwood, C. (2019). The economic cost of robotic rehabilitation for adult stroke patients: A systematic review. *JBI Database of Systematic Reviews Implementation Reports*, *17*(4), 520-547. https://doi.org/10.11124/jbisrir-2017-003896

Lo, K., Stephenson, M., & Lockwood, C. (2020). Adoption of robotic stroke rehabilitation into clinical settings: A qualitative descriptive analysis. *International Journal of Evidence-Based Healthcare*, *18*(4), 376-390. https://doi.org/10.1097/XEB.0000000000000231

Logan, P. A., Walker, M. F., & Gladman, J. R. F. (2006). Description of an occupational therapy intervention aimed at improving outdoor mobility. *British Journal of*

Occupational Therapy, *69*(1), 2-6. https://doi.org/10.1177/0308022606900102
Mackenzie, L., Coppola, S., Alvarez, L., Cibule, L., Maltsev, S., Loh, S. Y., Mlambo, T., Ikiugu, M. N., Pihlar, Z., Sriphetcharawut, S., Baptiste, S., & Ledgerd, R. (2017). International occupational therapy research priorities: A Delphi study. *OTJR: Occupation, Participation and Health*, *37*(2), 72-81. https://doi.org/10.1177/1539449216687528
Maier, M., Ballester, B. R., & Verschure, P. F. M. J. (2019). Principles of neurorehabilitation after stroke based on motor learning and brain plasticity mechanisms. *Frontiers in Systems Neuroscience*, *13,* 74. https://doi.org/10.3389/fnsys.2019.00074
Mashizume, Y., Zenba, Y., & Takahashi, K. (2021). Occupational therapists' perceptions of robotics use for patients with chronic stroke. *The American Journal of Occupational Therapy*, *75*(6). https://doi.org/10.5014/ajot.2021.046110
Masiero, S., Armani, M., Ferlini, G., Rosati, G., & Rossi, A. (2014). Randomized trial of a robotic assistive device for the upper extremity during early inpatient stroke rehabilitation. *Neurorehabilitation & Neural Repair*, *28*(4), 377-386. https://doi.org/10.1177/1545968313513073
McCluskey, A., Lannin, N., Schurr, K., & Dorsch, S. (2017). Optimising motor performance and sensation after brain impairment. In M. Curtin & J. Adams (Eds.), *Occupational Therapy for People Experiencing Illness, Injury or Impairment* (7th ed.). Elsevier.
McCluskey, A., & O'Connor, D. (2017). Implementing evidence: Closing research–practice gaps. In T. Hoffmann, S. Bennett, & C. D. Mar (Eds.), *Evidence-Based Practice Across the Health Professions* (3rd ed., pp. 384-408). Elsevier Health Sciences.
McCluskey, A., Vratsistas-Curto, A., & Schurr, K. (2013). Barriers and enablers to implementing multiple stroke guideline recommendations: A qualitative study. *BMC Health Services Research*, *13*(1), 323-323. https://doi.org/10.1186/1472-6963-13-323
McKee, G., Codd, M., Dempsey, O., Gallagher, P., & Comiskey, C. (2017). Describing the implementation of an innovative intervention and evaluating its effectiveness in increasing research capacity of advanced clinical nurses: Using the consolidated framework for implementation research. *BMC Nursing*, *16*, 21. https://doi.org/10.1186/s12912-017-0214-6
Mehrholz, J. (2019). Is electromechanical and robot-assisted arm training effective for improving arm function in people who have had a stroke?: A Cochrane review summary with commentary. *American Journal of Physical Medicine & Rehabilitation*, *98*(4), 339-340. https://doi.org/10.1097/PHM.0000000000001133
Mehrholz, J., Pohl, M., Platz, T., Kugler, J., & Elsner, B. (2015). Electromechanical and robot-assisted arm training for improving activities of daily living, arm

function, and arm muscle strength after stroke. *Cochrane Database of Systematic Reviews, 2015*(11), CD006876. https://doi.org/10.1002/14651858.CD006876.pub3

Mehrholz, J., Pohl, M., Platz, T., Kugler, J., & Elsner, B. (2018). Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke. *Cochrane Database of Systematic Reviews. 9*(9), CD006876. https://doi.org/10.1002/14651858.CD006876.pub5

Mehrholz, J., Pollock, A., Pohl, M., Kugler, J., & Elsner, B. (2020). Systematic review with network meta-analysis of randomized controlled trials of robotic-assisted arm training for improving activities of daily living and upper limb function after stroke. *Journal of Neuroengineering & Rehabilitation*, *17*(1), 83. https://doi.org/10.1186/s12984-020-00715-0

Michie, S., Johnston, M., Abraham, C., Lawton, R., Parker, D., & Walker, A. (2005). Making psychological theory useful for implementing evidence based practice: A consensus approach. *Quality & Safety in Health Care*, *14*(1), 26-33. https://doi.org/10.1136/qshc.2004.011155

Miech, E. J., Rattray, N. A., Flanagan, M. E., Damschroder, L., Schmid, A. A., & Damush, T. M. (2018). Inside help: An integrative review of champions in healthcare-related implementation. *SAGE Open Medicine*, *6*, 2050312118773261. https://doi.org/10.1177/2050312118773261

Morone, G., Cocchi, I., Paolucci, S., & Iosa, M. (2020). Robot-assisted therapy for arm recovery for stroke patients: State of the art and clinical implication. *Expert Review of Medical Devices*, *17*(3), 223-233. https://doi.org/10.1080/17434440.2020.1733408

Morone, G., Palomba, A., Martino Cinnera, A., Agostini, M., Aprile, I., Arienti, C., Paci, M., Casanova, E., Marino, D., La Rosa, G., Bressi, F., Sterzi, S., Gandolfi, M., Giansanti, D., Perrero, L., Battistini, A., Miccinilli, S., Filoni, S., Sicari, M., . . . Straudi, S. (2021). Systematic review of guidelines to identify recommendations for upper limb robotic rehabilitation after stroke. *European Journal of Physical & Rehabilitation Medicine*, *57*(2), 238-245. https://doi.org/10.23736/S1973-9087.21.06625-9

Morris, D. M., Taub, E., & Mark, V. W. (2006). Constraint-induced movement therapy: Characterizing the intervention protocol. *Europa Medicophysica*, *42*(3), 257-268.

Morris, J. H., van Wijck, F., Joice, S., & Donaghy, M. (2013). Predicting health related quality of life 6 months after stroke: The role of anxiety and upper limb dysfunction. *Disability & Rehabilitation*, *35*(4), 291-299. https://doi.org/10.3109/09638288.2012.691942

Moullin, J. C., Sabater-Hernández, D., Fernandez-Llimos, F., & Benrimoj, S. I. (2015). A systematic review of implementation frameworks of innovations in healthcare and resulting generic implementation framework. *Health*

Research Policy & Systems, *13*(1), 16. https://doi.org/10.1186/s12961-015-0005-z
Mudge, S., Hart, A., Murugan, S., & Kersten, P. (2017). What influences the implementation of the New Zealand stroke guidelines for physiotherapists and occupational therapists? *Disability & Rehabilitation*, *39*(5), 511-518. https://doi.org/10.3109/09638288.2016.1146361
Nadalin-Penno, L., Davies, B., Graham, I. D., Backman, C., MacDonald, I., Bain, J., Johnson, A. M., Moore, J., & Squires, J. (2019). Identifying relevant concepts and factors for the sustainability of evidence-based practices within acute care contexts: A systematic review and theory analysis of selected sustainability frameworks. *Implementation Science*, *14*(1), 108. https://doi.org/10.1186/s13012-019-0952-9
Nasr, N., Leon, B., Mountain, G., Nijenhuis, S. M., Prange, G., Sale, P., & Amirabdollahian, F. (2016). The experience of living with stroke and using technology: Opportunities to engage and co-design with end users. *Disability & Rehabilitation: Assistive Technology*, *11*(8), 653-660. https://doi.org/10.3109/17483107.2015.1036469
National Health and Medical Research Council, Australian Research Council, & Australia., U. (2007). *National Statement on Ethical Conduct in Human Research*. Retrieved from https://www.nhmrc.gov.au/about-us/publications/national-statement-ethical-conduct-human-research-2007-updated-2018#block-views-block-file-attachments-content-block-1
Nijenhuis, S., Prange, G., Amirabdollahian, F., Sale, P., Infarinato, F., Nasr, N., Mountain, G., Hermens, H., Stienen, A., Buurke, J., & Rietman, J. (2015). Feasibility study into self-administered training at home using an arm and hand device with motivational gaming environment in chronic stroke. *Journal of Neuroengineering & Rehabilitation*, *12*(1), 1-12. https://doi.org/10.1186/s12984-015-0080-y
Norouzi-Gheidari, N., Archambault, P. S., & Fung, J. (2012). Effects of robot-assisted therapy on stroke rehabilitation in upper limbs: Systematic review and meta-analysis of the literature. *Journal of Rehabilitation Research & Development*, *49*(4), 479-495. https://doi.org/10.1682/JRRD.2010.10.0210
Nudo, R. J., Milliken, G. W., Jenkins, W. M., & Merzenich, M. M. (1996). Use-dependent alterations of movement representations in primary motor cortex of adult squirrel monkeys. *Journal of Neuroscience*, *16*(2), 785-807. https://doi.org/10.1523/jneurosci.16-02-00785.1996
Otaka, E., Otaka, Y., Kasuga, S., Nishimoto, A., Yamazaki, K., Kawakami, M., Ushiba, J., & Liu, M. (2015). Clinical usefulness and validity of robotic measures of reaching movement in hemiparetic stroke patients. *Journal of Neuroengineering & Rehabilitation*, *12*, 66-66. https://doi.org/10.1186/s12984-015-0059-8
Padilla-Castañeda, M. A., Sotgiu, E., Barsotti, M., Frisoli, A., Orsini, P., Martiradonna, A., Laddaga, C., & Bergamasco, M. (2018). An orthopaedic robotic-assisted

rehabilitation method of the forearm in virtual reality physiotherapy. *Journal of Healthcare Engineering*, *2018*, 7438609. https://doi.org/10.1155/2018/7438609
Page, S. J., Levine, P., Leonard, A., Szaflarski, J. P., & Kissela, B. M. (2008). Modified constraint-induced therapy in chronic stroke: Results of a single-blinded randomized controlled trial. *Physical Therapy*, *88*(3), 333-340. https://doi.org/10.2522/ptj.20060029
Perez, M. A., Lungholt, B. K., Nyborg, K., & Nielsen, J. B. (2004). Motor skill training induces changes in the excitability of the leg cortical area in healthy humans. *Experimental Brain Research*, *159*(2), 197-205. https://doi.org/10.1007/s00221-004-1947-5
Plautz, E. J., Milliken, G. W., & Nudo, R. J. (2000). Effects of repetitive motor training on movement representations in adult squirrel monkeys: Role of use versus learning. *Neurobiology of Learning & Memory*, *74*(1), 27-55. https://doi.org/https://doi.org/10.1006/nlme.1999.3934
Plessis, T. d., Djouani, K. D., & Oosthuizen, C. R. (2021). A Review of active hand exoskeletons for rehabilitation and assistance. *Robotics*, *10*(1), 40. https://doi.org/10.3390/robotics10010040
Pollock, A., Farmer, S. E., Brady, M. C., Langhorne, P., Mead, G. E., Mehrholz, J., & van Wijck, F. (2014). Interventions for improving upper limb function after stroke. *Cochrane Database of Systematic Reviews, 2014*(11), CD010820. https://doi.org/10.1002/14651858.CD010820.pub2
Proctor, E., Luke, D., Calhoun, A., McMillen, C., Brownson, R., McCrary, S., & Padek, M. (2015). Sustainability of evidence-based healthcare: Research agenda, methodological advances, and infrastructure support. *Implementation Science*, *10*(1), 88. https://doi.org/10.1186/s13012-015-0274-5
Proctor, E., Silmere, H., Raghavan, R., Hovmand, P., Aarons, G., Bunger, A., Griffey, R., & Hensley, M. (2011). Outcomes for implementation research: Conceptual distinctions, measurement challenges, and research agenda. *Administration & Policy in Mental Health*, *38*(2), 65-76. https://doi.org/10.1007/s10488-010-0319-7
Putrino, D., Zanders, H., Hamilton, T., Rykman, A., Lee, P., & Edwards, D. J. (2017). Patient engagement is related to impairment reduction during digital game-based therapy in stroke. *Games for Health Journal*, *6*(5), 295-302. https://doi.org/10.1089/g4h.2016.0108
Radder, B., Prange-Lasonder, G. B., Kottink, A. I. R., Melendez-Calderon, A., Rietman, J. S., & Buurke, J. H. (2018). Feasability of a wearable soft-robotic glove to support impaired hand function in stroke patients. *Journal of Rehabilitation Medicine*, *50*(7), 598-606. https://doi.org/10.2340/16501977-2357
Radomski, M. V., & Latham, C. A. T. (2014). Assessing roles and competence. In *Occupational Therapy for Physical Dysfunction* (7th ed.). Wolters Kluwer Health.

Ratnasabapathy, Y., Broad, J., Baskett, J., Pledger, M., Marshall, J., & Bonita, R. (2003). Shoulder pain in people with a stroke: A population-based study. *Clinical Rehabilitation*, *17*(3), 304-311. http://ezproxy.acu.edu.au/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=ccm&AN=106694983&site=ehost-live&scope=site

Resquín, F., Cuesta Gómez, A., Gonzalez-Vargas, J., Brunetti, F., Torricelli, D., Molina Rueda, F., Cano de la Cuerda, R., Miangolarra, J. C., & Pons, J. L. (2016). Hybrid robotic systems for upper limb rehabilitation after stroke: A review. *Medical Engineering & Physics*, *38*(11), 1279-1288. https://doi.org/https://doi.org/10.1016/j.medengphy.2016.09.001

Rodgers, H., Bosomworth, H., Krebs, H. I., van Wijck, F., Howel, D., Wilson, N., Aird, L., Alvarado, N., Andole, S., Cohen, D. L., Dawson, J., Fernandez-Garcia, C., Finch, T., Ford, G. A., Francis, R., Hogg, S., Hughes, N., Price, C. I., Ternent, L., . . . Shaw, L. (2019). Robot assisted training for the upper limb after stroke (RATULS): A multicentre randomised controlled trial. *The Lancet*. *394*(10192), 51–62. https://doi.org/https://doi.org/10.1016/S0140-6736(19)31055-4

Rodgers, H., Shaw, L., Bosomworth, H., Aird, L., Alvarado, N., Andole, S., Cohen, D. L., Dawson, J., Eyre, J., Finch, T., Ford, G. A., Hislop, J., Hogg, S., Howel, D., Hughes, N., Krebs, H. I., Price, C., Rochester, L., Stamp, E., . . . Wilkes, S. (2017). Robot assisted training for the upper limb after stroke (RATULS): Study protocol for a randomised controlled trial. *Trials*, *18*(1), 340-340. https://doi.org/10.1186/s13063-017-2083-4

Sampson, P., Freeman, C., Coote, S., Demain, S., Feys, P., Meadmore, K., & Hughes, A. M. (2016). Using functional electrical stimulation mediated by iterative learning control and robotics to improve arm movement for people with multiple sclerosis. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *24*(2), 235-248. https://doi.org/10.1109/TNSRE.2015.2413906

Schneider, E. J., Lannin, N. A., Ada, L., & Schmidt, J. (2016). Increasing the amount of usual rehabilitation improves activity after stroke: A systematic review. *Journal of Physiotherapy*, *62*(4), 182-187. https://doi.org/10.1016/j.jphys.2016.08.006

Scott, I., Del Mar, C., Hoffmann, T., & Bennett, S. (2017). Embedding evidence-based practice into routine clinical care - Evidence-based practice across health professions. In T. Hoffmann, S. Bennett, & C. Del Mar (Eds.), *Evidence-Based Practice Across the Health Professions* (3rd ed., pp. 384-408). Elsevier Health Sciences.

Shelton, R. C., & Lee, M. (2019). Sustaining evidence-based interventions and policies: Recent innovations and future directions in implementation science. *American Journal of Public Health*, *109*, S132-S134. https://doi.org/10.2105/AJPH.2018.304913

Smart, A. (2006). A multi-dimensional model of clinical utility. *International Journal for Quality in Health Care*, *18*(5), 377-382. https://doi.org/10.1093/intqhc/mzl034

Stephenson, A., & Stephens, J. (2017). An exploration of physiotherapists' experiences of robotic therapy in upper limb rehabilitation within a stroke rehabilitation centre. *Disability & Rehabilitation: Assistive Technology*, *13*(3), 245–252. https://doi.org/10.1080/17483107.2017.1306593

Stewart, C., McCluskey, A., Ada, L., & Kuys, S. (2017). Structure and feasibility of extra practice during stroke rehabilitation: A systematic scoping review. *Australian Occupational Therapy Journal*, *64*(3), 204-217. https://doi.org/10.1111/1440-1630.12351

Stiles, P. G., Boothroyd, R. A., Snyder, K., & Zong, X. (2002). Service penetration by persons with severe mental illness: how should it be measured? *Journal of Behavioral Health Services and Research*, *29*(2), 198-207. https://doi.org/10.1007/bf02287706

Stinear, C. M., Lang, C. E., Zeiler, S., & Byblow, W. D. (2020). Advances and challenges in stroke rehabilitation. *The Lancet Neurology*, *19*(4), 348-360. https://doi.org/10.1016/S1474-4422(19)30415-6

Stroke Foundation. (2020). *National Stroke Audit: Rehabilitation Services Report 2020*. Retrieved from https://informme.org.au/media/drtlcbvp/rehab_strokeservicesreport_2020.pdf

Stroke Foundation. (2022). *Clinical Guidelines for Stroke Management* Retrieved 10 February from https://informme.org.au/en/Guidelines/Clinical-Guidelines-for-Stroke-Management-2017

Taket, A. (2017). The use of mixed methods in health research. In P. Liamputtong (Ed.), *Research Methods in Health: Foundations for Evidence-Based Practice* (3rd ed., pp. 84-104). Oxford University Press.

Taub, E., & Uswatte, G. (1999). Constraint-induced movement therapy: A new family of techniques with broad application. *Journal of Rehabilitation Research & Development*, *36*(3), 237-251. https://ezproxy.acu.edu.au/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=ccm&AN=106631656&site=ehost-live&scope=site

Tausch, A. P., & Menold, N. (2016). Methodological aspects of focus groups in health research: Results of qualitative interviews with focus group moderators. *Global Qualitative Nursing Research*, *3*, 2333393616630466. https://doi.org/10.1177/2333393616630466

Teasell, R., Cotoi, A., Chow, J., Wiener, J., Iliescu, A., Hussein, N., & Salter, K. (2020). *Stroke Rehabilitation Clinicians Handbook.* http://www.ebrsr.com/

Tedesco Triccas, L., Burridge, J. H., Hughes, A. M., Meadmore, K. L., Donovan-Hall, M., Rothwell, J. C., & Verheyden, G. (2018). A qualitative study exploring views and experiences of people with stroke undergoing transcranial direct current stimulation and upper limb robot therapy. *Topics in Stroke Rehabilitation*, 1-9. https://doi.org/10.1080/10749357.2018.1493072

Tunney, N. (2018). Is there a best approach to the rehabilitation of adult hemiplegia? *Physical Therapy Reviews*, *23*(6), 348-354. https://doi.org/10.1080/10833196.2018.1539293
Turchetti, G., Vitiello, N., Trieste, L., Romiti, S., Geisler, E., & Micera, S. (2014). Why effectiveness of robot-mediated neurorehabilitation does not necessarily influence its adoption. *IEEE Reviews in Biomedical Engineering*, *7*, 143-153. https://doi.org/10.1109/RBME.2014.2300234
Turpin, M., & Higgs, J. (2017). Clinical reasoning and evidence-based practice - Evidence-based practice across health professions. In T. Hoffmann, S. Bennett, & C. D. Mar (Eds.), *Evidence-based practice across the health professions* (3rd ed., pp. 384-408). Elsevier Health Sciences.
van Ommeren, A. L., Smulders, L. C., Prange-Lasonder, G. B., Buurke, J. H., Veltink, P. H., & Rietman, J. S. (2018). Assistive technology for the upper extremities after stroke: Systematic review of users' needs. *JMIR Rehabilitation and Assistive Technology*, *5*(2), e10510. https://doi.org/10.2196/10510
van Vliet, P., Matyas, T. A., & Carey, L. M. (2012). Training principles to enhance learning-based rehabilitation and neuroplasticity. In L. M. Carey (Ed.), *Stroke Rehabilitation: Insights from Neuroscience and Imaging* (pp. 116-127). Oxford University Press. https://doi.org/10.1093/med/9780199797882.003.0009
Vanoglio, F., Bernocchi, P., Mulè, C., Garofali, F., Mora, C., Taveggia, G., Scalvini, S., & Luisa, A. (2017). Feasibility and efficacy of a robotic device for hand rehabilitation in hemiplegic stroke patients: A randomized pilot controlled study. *Clinical Rehabilitation*, *31*(3), 351-360. https://doi.org/10.1177/0269215516642606
Veerbeek, J. M., Langbroek-Amersfoort, A. C., van Wegen, E. E. H., Meskers, C. G. M., & Kwakkel, G. (2017). Effects of robot-assisted therapy for the upper limb after stroke. *Neurorehabilitation & Neural Repair*, *31*(2), 107-121. https://doi.org/10.1177/1545968316666957
Viana, R., & Teasell, R. (2012). Barriers to the implementation of constraint-induced movement therapy into practice. *Topics in Stroke Rehabilitation*, *19*(2), 104-114. https://doi.org/10.1310/tsr1902-104
Vratsistas-Curto, A., Sherrington, C., & McCluskey, A. (2021). Dosage and predictors of arm practice during inpatient stroke rehabilitation: An inception cohort study. *Disability & Rehabilitation*, *43*(5), 640-647. https://doi.org/10.1080/09638288.2019.1635215
Wagner, T. H., Lo, A. C., Peduzzi, P., Bravata, D. M., Huang, G. D., Krebs, H. I., Ringer, R. J., Federman, D. G., Richards, L. G., Haselkorn, J. K., Wittenberg, G. F., Volpe, B. T., Bever, C. T., Duncan, P. W., Siroka, A., & Guarino, P. D. (2011). An economic analysis of robot-assisted therapy for long-term upper-limb impairment after stroke. *Stroke*, *42*(9), 2630-2632. https://doi.org/10.1161/STROKEAHA.110.606442

Wensing, M., Grol, R., & Grimshaw, J. (2020). Determinants of implementation. In M. Wensing, R. Grol & J. Grimshaw (Eds.), *Improving Patient Care : The Implementation of Change in Health Care* (pp. 155-171). John Wiley & Sons. https://doi.org/10.1002/9781119488620

Wiltsey-Stirman, S., Kimberly, J., Cook, N., Calloway, A., Castro, F., & Charns, M. (2012). The sustainability of new programs and innovations: A review of the empirical literature and recommendations for future research [journal article]. *Implementation Science*, *7*(1), 17. https://doi.org/10.1186/1748-5908-7-17

Winstein, C. J., Stein, J., Arena, R., Bates, B., Cherney, L. R., Cramer, S. C., Deruyter, F., Eng, J. J., Fisher, B., Harvey, R. L., Lang, C. E., MacKay-Lyons, M., Ottenbacher, K. J., Pugh, S., Reeves, M. J., Richards, L. G., Stiers, W., & Zorowitz, R. D. (2016). Guidelines for adult stroke rehabilitation and recovery. *Stroke*, *47*(6), e98-e169. https://doi.org/doi:10.1161/STR.0000000000000098

World Health Organization. (2001). *International Classification of Functioning Disability and Health (ICF)*. Geneva : World Health Organization.

Wu, J., Cheng, H., Zhang, J., Yang, S., & Cai, S. (2021). Robot-assisted therapy for upper extremity motor impairment after stroke: A systematic review and meta-analysis. *Physical Therapy*, *101*(4), pzab010. https://doi.org/10.1093/ptj/pzab010

Chapter 9 - Research Portfolio Appendices

9.1 Appendix 1 – The Prince Charles Hospital Ethics Approval

Enquiries to: ResearchTPCH@health.qld.gov.au
Office Ph: (07) 3139 4198
(07) 3139 4500
Our Ref: Low Risk Final Approval

Queensland Government

1 O May 2016

The Prince Charles Hospital
Human Research Ethics Committee
The Prince Charles Hospital
Building 14
Rode Road,
Chermside QLD 4032

Mr Paul Bew
Physiotherapy Department
Brighton Rehabilitation Unit
Dolphin House (Eventide Aged Care Facility)
Brighton Hospital
Brighton , QLD 4017

Dear Mr Bew,

RE: HREC/16/QPCH/36: An investigation into the clinical utility of robot-assisted upper limb therapy within an Australian rehabilitative setting.

Thank you for submitting your Low Risk project for ethical and scientific review. I am pleased to advise that The Prince Charles Hospital Human Research Ethics Committee reviewed your submission and upon recommendation, the Chair has granted final approval for your low risk project.

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Human Research (2007), NHMRC and Universities Australia Australian Code for the Responsible Conduct of Research (2007) and the CPMP/ICH Note for Guidance on Good Clinical Practice.

I am pleased to advise that The Prince Charles Hospital Human Research Ethics Committee has granted approval of this research project. The documents reviewed and approved on 10 May 2016 include:

Document	Version	Date
Low Risk Application	AU/10/DE55219	
Protocol	1	8 April 2016
Participant Information Sheet & Consent Form: Therapist Group	2	4 May 2016
System Usability Scale	1	8 April 2016
Intrinsic Motivation Inventory	1	8 April 2016
Wolf Motor Function Test Summary	1	8 April 2016
National Institutes of Health Stroke Scale	1	8 April 2016
Questionnaire: Stroke Impact Scale	3	
Response to request for further information		4 May 2016

This information will be tabled at the next HREC meeting held 26 May 2016 for noting.

Please note the following conditions of approval:

1. A **waiver of consent** has been granted for access to clinical data from medical records of patients using the InMotion therapy.

2. The Principal Investigator will immediately report anything which might warrant review of ethical approval of the project in the specified format, including any unforeseen events that might affect continued ethical acceptability of the project.

3. Amendments to the research project which may affect the ongoing ethical acceptability of a project must be submitted to the TPCH HREC for review. Major amendments should be reflected in a cover letter from the principal investigator, providing a description of the changes, the rationale for the changes, and their implications for the ongoing conduct of the study. Hard copies of the revised amendments, the cover letter and all relevant updated documents with tracked changes must also be submitted to the TPCH HREC coordinator as per standard HREC SOP. Further advice on submitting amendments is available from http://www.health.qld.gov.au/ohmr/documents/researcher_userguide.pdf

4. Proposed amendments to the research project which may affect both the ethical acceptability and site suitability of the project must be submitted firstly the TPCH HREC for review and, once TPCH HREC approval has been granted, submitted to the RGO.

5. Amendments which do not affect either the ethical acceptability or site acceptability of the project (e.g. typographical errors) should be submitted in hard copy to the TPCH HREC coordinator. These should include a cover letter from the principal investigator providing a brief description of the changes and the rationale for the changes, and accompanied by all relevant updated documents with tracked changes.

6. In accordance with Section 3.3.22 (b) of the National Statement the Principal Investigator will report to the TPCH HREC annually in the specified format and a final report is to be submitted on completion of the study. https://www.health.qld.gov.au/metronorth/research/ethics-governance/post-approval-reporting/default.asp

7. The Principal Investigator will notify the TPCH HREC if the project is discontinued at the participating site before the expected completion date, with reasons provided. Any plan to extend the duration of the project past the approved period, the Principal Investigator will submit any associated required documentation for TPCH HREC approval ***before*** expiry of the project, listed below.

8. The Hospital & Health Service Administration and the Human Research Ethics Committee may inquire into the conduct of any research or purported research, whether approved or not and regardless of the source of funding, being conducted on hospital premises or claiming any association with the Hospital; or which the Committee has approved if conducted outside The Prince Charles Hospital & Health Services.

HREC approval is valid until **10 May 2019.**

Please advise The Prince Charles Hospital Human Research Ethics Committee of the date you commence the research project for the approved site(s) using the Notification of Commencement Form: https://www.health.qld.gov.au/metronorth/research/ethics-governance/post-approval-reporting/default.asp

If the research does not commence within 3 months of this letter, please inform the committee in formal correspondence of any delays occurring with your project.

Should you have any queries about the HREC's consideration of your project please contact the Manager of Research, Ethics & Governance Unit on 3139 4500. The HREC terms of Reference, Standard Operating Procedures, membership and standard forms are available from http://www.health.qld.gov.au/ohmr/html/regu/regu_home.asp.

You are reminded that this letter constitutes ethical approval only. *You must not commence this research project at a site until separate authorisation from the Hospital and Health Service CEO or Delegate of that site has been obtained.*

A copy of this approval must be submitted to the relevant Hospital & Health Services Research Governance Officer/s or Delegated Personnel with a completed Site Specific Assessment (SSA) Form for authorisation from the CEO or Delegate to conduct this research at the site/s listed below.

The HREC wishes you every success in your research.

Yours faithfully

[redacted]

Chair
The Prince Charles Hospital
Human Research Ethics Committee

List of approved Sites:

No.	Site:
1.	Brighton Health Campus

9.2 Appendix 2 – Australian Catholic University Ethics Approval

Nick Flynn

From:	Pratigya Pozniak [redacted] on behalf of Res Ethics <Res.Ethics@acu.edu.au>
Sent:	Thursday, 1 December 2016 8:38 AM
To:	Suzanne Kuys; Elspeth Froude
Cc:	Res Ethics; [redacted]
Subject:	2016-266R Registration of External Ethics Approval .

Dear Suzanne,

Principal Investigator: Dr Suzanne Kuys
Co-Investigator: Dr Diedre Cooke, Dr Elspeth Froude Student Researcher: Mr Nick Flynn (HDR Student) Ethics Register Number: 2016-266R Project Title: An investigation into the clinical utility of robot assisted upper limb therapy within an Australian rehabilitative setting.
Risk Level: Multi Site
Date Approved: 01/12/2016
Ethics Clearance End Date: 31/12/2018

The Australian Catholic University Human Research Ethics Committee has considered your application for registration of an externally approved ethics protocol and notes that this application has received ethics approval from The Prince Charles Hospital [Reference: HREC/16/QPCH/36].

The ACU HREC accepts the ethics approval with no additional requirements, save that ACU HREC is informed of any modifications of the research proposal and that copies of all progress reports and any other documents be forwarded to it. Any complaints involving ACU staff must also be notified to ACU HREC (National Statement 5.3.3)

We wish you well in this research project.

Regards,

Kylie Pashley
on behalf of ACU HREC Chair, Dr Nadia Crittenden Ethics Officer | Research Services Office of the Deputy Vice Chancellor (Research) res.ethics@acu.edu.au

9.3 Appendix 3 - Publication Study 1

Australian Occupational Therapy Journal

Occupational Therapy Australia

Australian Occupational Therapy Journal (2019) doi: 10.1111/1440-1630.12594

Feature Article

Introducing robotic upper limb training into routine clinical practice for stroke survivors: Perceptions of occupational therapists and physiotherapists

Nicholas Flynn,[1] Suzanne Kuys,[1] Elspeth Froude[2] and Deirdre Cooke[1,3]

[1]*School of Allied Health, Australian Catholic University, Brisbane, Queensland,* [2]*School of Allied Health, Australian Catholic University, North Sydney, New South Wales and* [3]*Mater Private Hospital Rehabilitation Unit, South Brisbane, Queens land, Australia*

Introduction: *Robot-assisted therapy for the upper limb (RT-UL) is an emerging form of intervention for stroke survivors with upper limb deficits. However, there is limited knowledge regarding therapists' perceptions of RT-UL and the factors influencing the implementation of RT-UL into the clinical setting. This is important when considering that therapists in Australia are primarily responsible for the prescription of RT-UL in daily practice. This study aimed to explore occupational therapists' and physiotherapists' perceptions of RT-UL and the perceived barriers and enablers influencing implementation.*

Methods: *Two discipline-specific focus groups were conducted involving occupational therapists (n = 6) and physiotherapists (n = 6). Participants were members of the same multidisciplinary team working in an Australian public health rehabilitation facility where RT-UL (i.e. InMotion2) was being introduced for the first time. Focus groups explored therapist perceptions of the new RT-UL as well as perceived barriers and enablers to implementation. Focus groups were recorded, transcribed and deductively analysed using the Theoretical Domains Framework (TDF).*

Results: *Out of the 14 domains of the TDF, 7 were raised by participants during the focus groups: environmental context and resources, beliefs about consequences, optimism, knowledge, skills, social influences, and social and professional role and identity. Therapists' expressed their optimism towards the introduction of RT-UL but believed successful implementation would be primarily dependent on the availability of clinical leadership, training and a suitable client mix.*

Conclusion: *Therapists perceived that RT-UL would provide opportunity for increased upper limb practice particularly for patients with severe upper limb impairment. To facilitate implementation, support of RT-UL should come from both management and clinical leaders and training include RT-UL efficacy, device functionality and patient suitability. The availability of a single RT-UL device in a workplace may create unique interdisciplinary and logistical challenges.*

KEY WORDS *implementation, occupational therapy, physical therapy, robotics, stroke rehabilitation, upper extremity.*

Nicholas Flynn PhD Candidate, Grad Cert Occ Thy, Bach Occ Thy; Lecturer. **Suzanne Kuys** PHd, BPhty (Hons); Professor. **Elspeth Froude** PhD, BOccThy (Hons). **Deirdre Cooke** PhD, MS., BOccThy (Hons), GradDipBus (Admin); Associate Professor.

Correspondence: Nicholas Flynn, School of Allied Health, Australian Catholic University, 1100 Nudgee Road, Banyo QLD 4014, Australia. Email: nick.flynn@acu.edu.au

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Introduction

The amount of upper limb practice provided to stroke survivors is suboptimal (Hayward & Brauer, 2015). Possible reasons for this lack of practice include stroke survivors' limited ability to perform independent practice and consequent dependence on one-on-one support from therapists (Stewart, McCluskey, Ada, & Kuys, 2017). Robot-assisted therapy for the upper limb (RT-UL) presents as a viable intervention to help therapists overcome these clinical challenges when working with stroke survivors and is consequently an emerging form of therapy within rehabilitative facilities across Australia (Galea *et al.*, 2016).

In broad terms, RT-UL involves retraining the upper limb by applying an electromechanical device to the person's upper limb to assist with and facilitate repetitive performance of prescribed upper limb movements (Veerbeek, Langbroek-Amersfoort, van Wegen, Meskers,

& Kwakkel, 2016). RT-UL retraining is purported to be motivating, task-orientated, intensive and requiring minimal therapist input and can improve activities of daily living, motor control and strength in the impaired upper limb (Mehrholz, Pohl, Platz, Kugler, & Elsner, 2018; Veerbeek *et al.*, 2016). However, further insight is needed into the implementation of these devices within the clinical setting. Such insights can be found through exploring the perspectives of therapists who are involved in the implementation process.

A recent systematic review (van Ommeren *et al.*, 2018) investigated user perspectives (139 stroke survivors/carers and 384 health professionals) of electrical/mechanical devices used for upper limb rehabilitation. The primary motivation of the review was to understand which factors may influence the decision to purchase a device. Five primary factors were identified; (i) promotion of upper limb performance (i.e. intensity, task orientated), (ii) patient and therapist attitude towards technology (i.e. motivating, affinity), (iii) decision process (i.e. evidence based, safety, financial outlay), (iv) usability (set up, adjustability); and (v) applicability in practice (i.e. feedback, overtraining, comfort). Such insights are helpful; however, there is a need to understand if similar or different factors impact the actual implementation process of RT-UL in routine clinical practice, not just the acquisition process.

The perspectives of Australian therapists of RT-UL have not previously been investigated, nevertheless their views of other rehabilitative technology have been. The perspectives of 11 Australian physiotherapists were explored in relation to their prescription and use of technologies to improve mobility and physical activity (i.e. videogames, smart phone applications and activity monitors) (Hamilton, McCluskey, Hassett, Killington & Lovarini, 2018). Again, a complex set of patient and environmental factors were identified, including; the suitability of a technology to the patient needs and goals, patients' previous experiences with technology, patients' preferences and interests in technology as well as the space available to use certain technologies. Further to this, therapists explained that an advanced level of clinical reasoning was needed to continually adapt the technologies to provide the 'just right' challenge for their patients. It is therefore of interest if therapists perceive that such an interplay of factors will shape the implementation of RT-UL into routine practice and merit-specific strategies to aid implementation. This would seem particularly important when considering both the potential benefits of successful implementation of RT-UL for stroke survivors as well as the large financial outlay associated with purchase of these devices (Stewart *et al.*, 2017).

Another significant variable to be considered in the implementation of RT-UL, is that upper limb management for people with stroke in Australia typically involves both occupational therapists and physiotherapists (Hayward & Brauer, 2015). Exploring interdisciplinary dynamics as they relate to RT-UL would also seem important. Finally, it would be valuable to gain an understanding of therapist perceptions of RT-UL prior to being introduced into practice as pre-existing practices and personal concepts of workplace norms can influence the implementation process (Smart, 2006).

The aim of this study was to investigate both occupational therapists' and physiotherapists' perceptions of RT-UL and explore the potential barriers and enablers to the implementation of a robotic device being introduced into an Australian rehabilitation facility for the first time. This study is part of a broader research program investigating the implementation of RT-UL into routine clinical practice and sits alongside quantitative studies evaluating the usage patterns of RT-UL by occupational therapists and physiotherapists and the impact of RT-UL on the type and dosage of upper limb practice performed by stroke survivors.

Methods

Design

Qualitative methodology involving two discipline-specific focus groups was utilised to gain therapists' perspectives (i.e. occupational therapists and physiotherapists) of the introduction of RT-UL into their rehabilitation facility. Focus groups were conducted prior to the introduction of the InMotion2 system into routine clinical practice. Discipline-specific focus groups were purposely conducted to enable analysis of individual discipline perspectives on RT-UL as well as provide opportunity for discussion of discipline-specific factors if they emerged. Discipline-specific focus groups were opportunistically held in each disciplines' weekly team meeting which aided recruitment and minimised the study impact on the therapists' daily routine.

Focus groups comprised a convenience sample of therapists working on the day focus groups were scheduled. All available therapists consented to participate in the study. An information sheet detailing the purpose of the study and participants' involvement was provided to discipline representatives who distributed the information to therapists prior to the focus groups. Participation was voluntary, and participants were free to withdraw at any time without stating a reason. Allied health assistants and students were excluded from the study as they were not responsible for the prescription of RT-UL as part of routine practice.

All participants were members of the same multidisciplinary team working in an Australian public health rehabilitation facility. The facility was located in metropolitan Queensland and services 50 rehabilitation beds with an estimated 578 rehabilitation admissions per year of which approximately 18% of patients have a neurological diagnosis. Patients are seen by both

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occupational therapists and physiotherapists daily. Ethical approval was gained from the institutions' human research ethics committee HREC/16/QPCH/36.

Version 2 of the Theoretical Domain Framework (TDF) was used to deductively analyse focus group transcripts (Atkins *et al.*, 2017). The TDF is a validated framework for use in the health setting providing a theoretical lens through which to analyse and categorise factors influencing health professionals' perspectives and behaviour (Michie *et al.*, 2005). The TDF version 2 comprises 14 domains: knowledge, skills, social/professional role and identity, beliefs about capabilities, optimism, beliefs about consequences, reinforcement, intentions, goals, memory/attention/decision process (single domain), environmental context and resources, social influences, emotion and behavioural regulation (Atkins *et al.*).

RT-UL Device

The InMotion2 system (Fig. 1) facilitates movement at the shoulder, elbow and hand (with the wrist fixed in neutral or pronation) and intuitively adapts to the person's active movements providing 'assist-as-needed exercise guidance' (Bionik Labs, 2017). There is also a series of inbuilt evaluative tools which can be used to measure and monitor changes in upper limb kinematic control and force.

Procedure

Focus groups were led by one investigator (NF) using a series of semi-structured questions. No other external parties were present during the focus groups other than the investigator and participating therapists. Focus group questions were designed to explore therapist perceptions of the introduction of the RT-UL in their clinical setting. Specifically, questions covered: participants' previous experiences with new rehabilitative technology and in particular RT-UL, awareness of evidence and clinical reasoning for RT-UL, overall perceptions of the InMotion2 being part of their daily practice and perceived barriers and enablers in their workplace to the use of new technology and specifically the InMotion2. As the InMotion2 system had yet to be introduced to the unit, a brief demonstrative video of the InMotion2 system was shown prior to commencing each focus group to provide participants with a basic orientation to the device. At the end of each focus group, a summary was presented to the participants to confirm the key points raised in the discussion and provide opportunity for any further clarification. These points were then documented by the investigator to aid analysis. Focus groups lasted approximately 40 minutes.

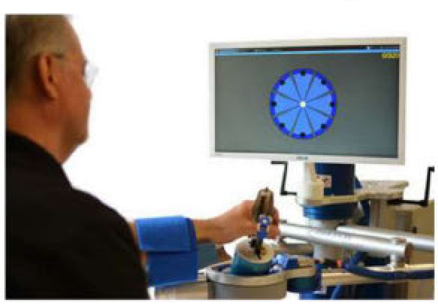

FIGURE 1: *InMotion System. Reprinted from Bionik Labs (2017). Retrieved from http://bionikusa.com/. BIONIK, Inc. © with permission.*

Focus groups were audio recorded and transcribed verbatim. As part of the transcription process all participants were de-identified and allocated an alias. Transcription was conducted by one investigator (NF) and cross-checked by a second investigator (DC). Focus group transcripts were entered and stored in NVivo 11, a qualitative research software program, to facilitate the analysis process.

Prior to the commencement of coding, the two investigators independently reviewed the TDF guide developed by Atkins *et al.* (2017) and met to confer on their understanding of the TDF domains. Each investigator separately coded the transcripts, assigning relevant statements into one or more of the 14 domains. The two investigators then met to achieve consensus on coding and to allocate all statements under a single domain. Where consensus could not be reached, a third investigator (SK), was consulted to finalise categorisation.

Results

Participants

Two discipline-specific focus groups were conducted with a total of 12 participants (six occupational therapists and six physiotherapists). Occupational therapy participants were predominantly female (n = 5), had an average age of 29 years (24–39 years), were six years post-qualification (2–17 years) with four years neurological experience (1–10 years). Physiotherapy participants were also predominantly female (n = 4), had an average age of 30 years (23-51 years), were eight years post-qualification (1–30 years) with 6.5 years neurological experience (1–25 years). Each focus group included a senior therapist who had more experience than their discipline group (senior occupational therapist = 17 years; senior physiotherapist = 30 years).

Two occupational therapists and one physiotherapist reported brief exposure to the use of RT-UL during their undergraduate clinical experiences. None of the participants reported using RT-UL as part of their practice since graduating.

Responses

Out of the 14 TDF domains, 7 were discussed in depth by participants during the focus groups: environmental

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context and resources, beliefs about consequences, optimism, knowledge, skills, social influences, social and professional role and identity (single domain), and beliefs about capabilities. The remaining seven domains were not included in the results as these categories were only discussed superficially or not at all. Subthemes were created within the 'environmental context and resources' domain to further define specific constructs. The domains of 'optimism' and 'beliefs about consequences' have been combined below along with 'knowledge' and 'skills'; however, participants' original statements were categorised under the relevant domain during analysis.

Environmental context and resources

This domain refers to the influence the work environment can have on health professionals' behaviour when implementing a new practice and includes practical elements such as the predictability and availability of patients, materials, time, staffing and technical support, as well as broader constructs such as the organisational culture.

Eligible/suitable patients

The key environmental influence on the usage of the InMotion2 in daily practice reported by therapists was the number and flow of suitable patients.

> I think it's obviously dependent on (having) appropriate patients. (Occupational Therapist 5)

> I think it will have up and down phases … sometimes you got heaps of patients and then other times not so many. (Physiotherapist 5)

This was also highlighted as an issue by therapists who had used RT-UL as a student.

> The client group itself was hard cause you didn't have a consistent flow of people. (Occupational Therapist, 3)

> It (RT-UL device) was only really appropriate for a few patients. (Occupational Therapist, 2)

Availability of device

Participants perceived that the availability of a single RT-UL device could present challenges relating to person and environment interaction. Firstly, the logistics of both disciplines (occupational therapy and physiotherapy) using the one device, and secondly, the availability of the device for use with multiple patients.

> We've got physios and OTs who will be potentially wanting to access that (InMotion2). (Occupational Therapist 1)

> I guess the only potential issue that I can see is actually having too many (patients) that will want to use it- not enough time in the day with only one machine. (Physiotherapist 2)

Practical challenges

Participants also drew on past experiences as students with RT-UL to highlight a number of unique practical issues.

> When the system didn't work … there was no one to really assist with fixing that … so it was out of action. (Occupational Therapist 3)

> It was annoying the computer would always break - not the device itself, but the computer. (Physiotherapist 4)

In the positive, one participant recalled that there was only limited set up involved with RT-UL.

> No it was pretty quick. It didn't take long to set up at all. (Physiotherapist 4)

Organisational culture

Finally, participants described an organisational culture within the workplace that they felt would positively influence the implementation process.

> The other thing we're fortunate here I think there is quite good support from line managers. (Physiotherapist 2)

> (There) has been quite an outlay of money I think there will be bean counters who will probably have a vested interest…the ones who control the purse strings will probably want to have some awareness of how it's being used. (Occupational Therapist 1)

Optimism and Belief about consequences

Optimism is concerned with therapists' confidence that a new practice is for the betterment or detriment of their practice and will achieve the intended goals. Overall, both disciplines were relatively optimistic towards the introduction of the InMotion2.

> I'm really excited about starting to use the robotic technology. (Physiotherapist 3)

> I'm looking forward to trying it as soon as possible. (Occupational Therapist 1)

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Specifically, they believed the InMotion2 had the potential to improve the quality and quantity of therapy provided to stroke survivors, particularly stroke survivors with severe upper limb impairment.

> (For) those low-level patients … who you want to spend a lot of time with but for caseload demands you can't achieve that dosage. (Occupational Therapist 2)

> I think its got potential for a patient group (severe upper limb impairment) that we normally struggle to try and do meaningful practice with… (Physiotherapist 2)

The occupational therapists appeared more measured than their physiotherapy colleagues towards the implementation of the InMotion2 emphasising the need to first see the effectiveness of the device for themselves.

> Essentially we're going to need to see with our own eyes that it's actually helping people because even if we're trained, even if we feel comfortable in its use but we don't value its use, we're not going to use it. (Occupational Therapist 2)

Therapists also believed the evaluative qualities of the InMotion2 would be particularly useful and potentially motivating for patients.

> I think seeing results on the screen, will probably help with motivation … keep people engaged or be a bit more engaged than with other therapies where you can't necessarily see a day to day change … (Occupational Therapist 5)

The only negative consequence flagged in the focus groups related to safety issues associated with using any new or unfamiliar rehabilitative technology.

> When you have a new piece of equipment that you're really not familiar with and you're not sure that your particular patient is suitable for it and if you are going to do them any harm if you set it up wrongly. (Physiotherapist 2)

Knowledge and skills

The majority of the occupational therapists and physiotherapists acknowledged that they had limited awareness of the evidence supporting the use and effectiveness of RT-UL or the functionality of the device.

> I know that there's been some studies … but no I haven't read anything specific about it. (Occupational Therapist 1)

> My lack of understanding about the system itself is I don't know whether it's also useful for people with reasonable function that you're wanting to get more sort of dexterity and control. (Physiotherapist 2)

Consequently, therapists recognised the importance and need for training to facilitate the implementation of the InMotion2.

> I think it does rely on us having adequate training and the confidence to utilise it. (Physiotherapist 3)

> I guess knowing the background of the purpose of the equipment definitely makes it easier to start implementing in practice. (Occupational Therapist 3)

Social Influence

Participants identified the potential for various social dynamics to play a part in the implementation of the InMotion2. Therapists expressed the importance of a champion or a mentor to lead the implementation process as well as to ensure the sustainability of the device as part of practice.

> Whether they're physios or OTs or whoever but that mentoring is really important to help you get through and utilise it optimally. (Physiotherapist 2)

> I'm looking for somebody to be the guru for it so we actually can have a phone a friend to help overcome barriers. (Occupational Therapist 2)

Participants also described a generally positive social dynamic among themselves that was likely to facilitate the implementation of new technology.

> I think we're really good at having informal discussions as to why it wouldn't be utilised. (Physiotherapist 3)

> What is actually creating more value for clinicians (is) talking through and reflecting about successes or failures that somebody has had. (Occupational Therapist 2)

Social and professional role and identity

This category is concerned with understanding how a new practice fits within an individual's existing role and identity within a workplace.

Occupational therapy participants were particularly interested in which of the disciplines, occupational therapy or physiotherapy, would take the lead and responsibility for the implementation of the InMotion2.

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> Is it going to be the OT, the physio? I think one of the benefits here is that I think we haven't been overly precious about that over the years and I think that's a positive thing as long as someone's actually getting the therapy that they require. (Occupational Therapist 1)

> I'm very keen to see how we do share our toys so I hope that it works well. (Occupational Therapist 2)

Physiotherapists specifically highlighted that it was important the InMotion2 did not replace fundamental elements of their role in the management of stroke survivors.

> I hope it doesn't replace our upper limb management. I hope we use it as well as our own clinical practice as well hands on. (Physiotherapist 3)

Discussion

There were three key findings from this study. Firstly, therapists overall were positive towards the implementation of the RT-UL into their workplace and particularly optimistic with regard to the potential for RT-UL to address clinical challenges that exist in providing effective amounts of meaningful therapy for stroke survivors with severe upper limb impairment. Secondly, the availability of a single RT-UL device could present unique logistical challenges relating to how the device is used between the disciplines as well as with multiple patients. Thirdly, therapists identified that leadership, training and the availability of suitable patients would be essential factors determining the use of the RT-UL device in routine practice.

Therapists' optimism

Overall, participants were very positive about the prospect of the RT-UL being introduced into their workplace. They perceived that RT-UL could deliver a highly repetitive and motivating intervention. Participants also believed that RT-UL could be effective in improving the quality and quantity of practice able to be provided to stroke survivors with severe upper limb impairment. This optimism bodes well for the successful implementation of RT-UL into routine practice as therapists' preconceptions of a new intervention can be a defining factor (Smart, 2006). Interestingly though, the effectiveness of RT-UL specifically for stroke survivors with severe upper limb impairment has yet to be clearly established and has been identified as a priority for future studies in this field (Mehrholz *et al*., 2018).

Therapists also believed a chief advantage of implementing RT-UL would be the ability to increase practice dosage, that is, the number of movement repetitions stroke survivors complete during routine therapy. They perceived this increase in dosage would be most applicable to those experiencing severe upper limb impairment. This potential for increased practice is generally considered the primary reason for the effectiveness of RT-UL (Mehrholz *et al*., 2018) with devices such as the InMotion2 purportedly able to facilitate over a thousand movement repetitions in a standard session (Bionik Labs, 2017). However, the specific number of RT-UL movement repetitions required to effect significant motor recovery has not been consistently measured or reported in efficacy studies (Mehrholz *et al*.). It is questionable if this amount of practice can be consistently administered in routine clinical practice when factoring in potential practical challenges such as set up time, therapists' skills and availability of clinical support for trouble shooting. Further investigation is merited to determine the actual capacity for RT-UL to increase the dosage of practice for stroke survivors within a real-world clinical setting.

Despite some therapists recalling negative experiences with RT-UL as a student (e.g. break down and technical support issues), there was a notable absence of any directly negative statements regarding the implementation of the InMotion2 device. This is surprising considering that such practical issues have previously been flagged by therapists as major issues for the use of rehabilitative technology (Hamilton *et al*., 2018; van Ommeren et. al, 2018). This may be evidence of the strength of optimism surrounding the new device or simply reflective of the device not yet being introduced into routine practice. Follow-up focus groups proceeding the implementation of the device could give greater insight into these practical aspects.

Implications of a single device

In this particular facility, both occupational therapists and physiotherapists work collaboratively to manage stroke survivors' upper limb recovery. Such an interdisciplinary approach is reflective of practice more broadly in Australian rehabilitative settings (Hayward & Brauer, 2015). Participants thought having only a single RT-UL device available for both disciplines to use would likely present some distinct challenges such as where to locate the device (i.e. occupational therapy or physiotherapy department) and which discipline would be responsible for initiating RT-UL with patients. In a recent randomised control trial investigating the effectiveness of an upper limb elelectromechanical device (SMART Arm), both physiotherapists and occupational therapists were involved in the use of the device with their patients (Barker, Hayward, Carson, Lloyd, & Brauer, 2017). Interestingly, no issues were identified, relating to the shared interdisciplinary use of a single device in the rehabilitation setting. However, challenges may present when clear protocols are not in place. If applicable, specific strategies could be employed to address these interdisciplinary dynamics, including the training of disciplines jointly as well as locating the RT-UL system

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in a central area or alternating the system's location between discipline areas during the year. Such strategies may help to promote RT-UL as part of each disciplines' routine practice as well as assist to maintain therapists' skills and confidence in the use of RT-UL.

The availability of a single device was also seen by therapists as potentially creating unique scheduling dilemmas, an issue not uncommon to new forms of rehabilitative technologies (Chen & Bode, 2011). Therapists and administrators will need to be mindful of establishing clear procedures around timetabling patients to facilitate the implementation process and enhance the feasibility of the intervention. Where possible therapy assistants could be upskilled to deliver RT-UL sessions and so broaden the times for appointments (i.e. evenings/weekends).

Leadership, training and availability of patients

Participants expressed that their uptake and ongoing use of the InMotion2 in routine practice was connected to three main elements: leadership, adequate training and availability of suitable patients.

The value placed on leadership by the focus groups was notable. Strong leadership at both managerial and clinical levels has been recognised as essential to a successful implementation process (Bradley *et al.*, 2004). Senior management can provide crucial financial and administrative support needed to get a new intervention off the ground and leadership at a clinical level can provide the role modelling and support required for clinicians in daily practice (Hoffmann, Bennett, & Mar, 2017). Therapists in this study believed that senior management at their centre would be keenly interested in the RT-UL implementation process to ensure the financial investment was justified. This factor was seen as a clear driver for implementation. In terms of clinical leadership, participants expressed the need for a RT-UL champion, of either discipline, to lead the implementation process, provide training and to aid in day to day troubleshooting. Establishing this clinical leadership is an important step in the implementation process particularly when the initiative for RT-UL has come from senior management who may not be involved in the daily provision of therapy. It would also be prudent to ensure this clinical leadership is broader than any single individual so that troubleshooting and staff support can continue if a lead person is unavailable due to leave or work arrangements (i.e. part-time).

Secondly, therapists stressed the importance of receiving training to enable use of the RT-UL device as part of routine practice. Training has repeatedly been shown to be an effective strategy for changing health professionals practice and improving patient outcomes (Forsetlund *et al.*, 2009). Specifically, therapists in this study identified that training should include background knowledge of RT-UL (e.g. supporting evidence), skill acquisition in the various functions of the device and identification of the type of patient that would be suitable. One senior therapist believed that understanding which patients would be suitable for a new intervention was essential for safe practice. Therapists may hesitate to implement a new intervention when there is a real or perceived risk of incurring injury to their patient and this would seem pertinent in relation to RT-UL where stroke survivors are participating in highly repetitive practice. The occurrence of pain in the upper limb following a stroke has been found to be directly proportionate to the amount an individual uses their upper limb as well as the severity of their impairment (Lang, Wagner, Edwards, & Dromerick, 2007; Ratnasabapathy *et al.*, 2003). RT-UL is recognised as a relatively safe form of therapy with adverse events and dropouts being uncommon in efficacy studies (Mehrholz *et al.*, 2018). Informing therapists of such findings as part of the training process should increase therapists' confidence when prescribing and delivering RT-UL.

Therapists perceived that the usage of RT-UL in routine practice was directly related to the availability of suitable RT-UL patients. This has been previously recognised as a factor determining both the acquisition and prescription of new rehabilitative technology in practice (Chen & Bode, 2011; Hamilton, Lovarini, McCluskey, Folly de Campos, & Hassett, 2018). This would seem logical but highlights the importance of ensuring that the clinical context has an adequate number of appropriate patients, otherwise the usefulness of the intervention is questionable. Therapists further explained that the number of suitable patients for RT-UL may ebb and flow over time. This may result in therapists gradually losing skills and confidence to use RT-UL as part of their routine practice. Undertaking a pre-implementation audit of patient numbers and clinical demographics across a range of time periods should be a foundational part of the implementation process (McCluskey & O'Connor, 2017). Audit results could help determine the initial feasibility of the purchase of an RT-UL device and may even aid in determining the most suitable type of RT-UL device. The range of commercially available RT-UL devices is increasing, and it is important that health administrators and clinicians consider the type of device that will best meet the needs of their patients and staff. Additionally, audit data may help identify strategic times for staff retraining to refresh knowledge and skills and in turn increase confidence to incorporate RT-UL into their routine practice.

Implications for practice and research

An audit of patient admissions should be undertaken prior to RT-UL device acquisition to help ensure the device is suitable to a setting. Training should inform therapists of the efficacy, suitability and safety of RT-UL along with the functionalities of an RT-UL device. Consideration should also be given to the scheduling of

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the use the RT-UL to tackle potential logistical and interdisciplinary challenges. Further research is needed to determine if RT-UL increases the dosage of practice performed by stroke survivors once part of routine clinical practice.

Limitations

This study investigated the perceptions of occupational therapists and physiotherapists within a single rehabilitation facility in Australia and both groups were of a small size. Conclusions from this study are therefore reflective of the participants and their healthcare setting. Transferability of results to the respective professions as a whole should be made with caution. Inclusion of allied health assistants and students may have broadened the findings of this study. However, as neither group was to be involved in the prescription of RT-UL in daily practice these groups were excluded. Finally, the use of the TDF to guide data analysis may have limited identification of other relevant themes. However, this framework enabled a structured and effective process of categorisation and placed the information in a format that is consistent with other studies in the field of implementation science.

Conclusion

Pending implementation of RT-UL into clinical practice was perceived positively by both occupational therapists and physiotherapists. Therapists identified the potential for RT-UL to improve the specificity and dosage of practice performed by stroke survivors, particularly those with severe upper limb impairment. However, further research is needed to determine if the purported amount of RT-UL repetitions and associated improvement in clinical outcomes can be achieved in routine clinical practice when factoring in the various practical challenges for using upper limb robotic devices in the clinical setting.

The availability of a single RT-UL device within a rehabilitation facility may create unique interdisciplinary and scheduling challenges that need to be considered as part of the implementation process. Finally, therapists linked their potential use of RT-UL in routine practice to having the support of a clinical leader, training in use of the robotic device, and the availability of patients who would benefit from its use.

Key Points for Occupational Therapy

- Therapist training in robot-assisted therapy for the upper limb (RT-UL) should include efficacy, device functionality, patient suitability and endorse RT-UL as a safe intervention.
- A single RT-UL device within a workplace may present unique logistical and interdisciplinary challenges.
- Further research is needed to determine if RT-UL can increase dosage of practice in routine practice and repetitions.

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References

Atkins, L., Francis, J., Islam, R., O'Connor, D., Patey, A., Ivers, N., et al. (2017). A guide to using the theoretical domains framework of behaviour change to investigate implementation problems. *Implementation Science*, *12* (1), 77. https://doi.org/10.1186/s13012-017-0605-9.

Barker, R. N., Hayward, K. S., Carson, R. G., Lloyd, D. & Brauer, S. G..(2017). SMART arm training with outcome-triggered electrical stimulation in subacute stroke survivors with severe arm disability: a randomized controlled trial. *Neurorehabilitation & Neural Repair*, *31* (12), 1005–1016. https://doi.org/10.1177/1545968317744276.

Bionik Labs (2017). *Bionik Labs*. Retrieved 29 June 2017, from http://bionikusa.com/

Bradley, E. H., Webster, T. R., Baker, D., Schlesinger, M., Inouye, S. K., Barth, M. C., et al. (2004). Translating research into practice: Speeding the adoption of innovative health care programs. Issue Brief (Commonwwealth, Fund) (724),1–12.

Chen, C. C. & Bode, R. K..(2011). Factors influencing therapists' decision-making in the acceptance of new technology devices in stroke rehabilitation. *American Journal of Physical Medicine & Rehabilitation*, *90* (5), 415–425. https://doi.org/10.1097/PHM.0b013e318214f5d8.

Forsetlund, L., Bjørndal, A., Rashidian, A., Jamtvedt, G., O'Brien, M. A., Wolf, F. M., et al. (2009). Continuing education meetings and workshops: Effects on professional practice and health care outcomes. *Cochrane Database of Systematic Reviews*, *2009* (2), 1–99. https://doi.org/10.1002/14651858.CD003030.pub2

Galea, M. P., Khan, F., Amatya, B., Elmalik, A., Klaic, M. & Abbott, G..(2016). Implementation of a technology-assisted programme to intensify upper limb rehabilitation in neurologically impaired participants: A prospective study. *Journal Of Rehabilitation Medicine*, *48* (6), 522–528. https://doi.org/10.2340/16501977-2087.

Hamilton, C., Lovarini, M., McCluskey, A., Folly de Campos, T. & Hassett, L..(2018). Experiences of therapists using feedback-based technology to improve physical function in rehabilitation settings: a qualitative systematic review. *Disability and Rehabilitation*, *41* (15), 1739–1750. https://doi.org/10.1080/09638288.2018.1446187.

Hamilton, C., McCluskey, A., Hassett, L., Killington, M. & Lovarini, M. (2018). Patient and therapist experiences of using affordable feedback-based technology in rehabilitation: A qualitative study

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nested in a randomized controlled trial. *Clinical Rehabilitation, 32* (9), 1258–1270. https://doi.org/10.1177/0269215518771820.

Hayward, K. S. & Brauer, S. G. (2015). Dose of arm activity training during acute and subacute rehabilitation post stroke: A systematic review of the literature. *Clinical Rehabilitation, 29* (12), 1234–1243. https://doi.org/10.1177/0269215514565395.

Hoffmann, T., Bennett, S. & Mar, C. D.(2017). Embedding evidence-based practice into routine clinical care. In: T. Hoffmann, S. Bennett & C. D. Mar (Eds.), Evidence-based practice across the health professions (3rd ed., pp. 409–427). Chatswood, NSW: Elsevier Health Sciences.

Lang, C. E., Wagner, J. M., Edwards, D. F. & Dromerick, A. W..(2007). Upper extremity use in people with hemiparesis in the first few weeks after stroke. *Journal of Neurological Physical Therapy, 31* (2), 56–63.

McCluskey, A. & O'Connor, D..(2017). Implementing evidence: Closing research–practice gaps. In: T. Hoffmann, S. Bennett & C. D. Mar (Eds.), Evidence-based practice across the health professions (3rd ed., pp. 384–408). Chatswood, Australia: Elsevier Health Sciences.

Mehrholz, J., Pohl, M., Platz, T., Kugler, J. & Elsner, B. (2018). Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke. *Cochrane Database of Systematic Reviews, 2018* (6), 1–155. https://doi.org/10.1002/14651858.CD006876.pub5

Michie, S., Johnston, M., Abraham, C., Lawton, R., Parker, D. & Walker, A..(2005). Making psychological theory useful for implementing evidence based practice: a consensus approach. *Quality and Safety in Health Care, 14* (1), 26–33. https://doi.org/10.1136/qshc.2004.011155.

van Ommeren, A. L., Smulders, L. C., Prange-Lasonder, G. B., Buurke, J. H., Veltink, P. H. & Rietman, J. S. (2018). Assistive technology for the upper extremities after stroke: Systematic review of users' needs. *JMIR Rehabilitation and Assistive Technology, 5* (2), e10510. https://doi.org/10.2196/10510.

Ratnasabapathy, Y., Broad, J., Baskett, J., Pledger, M., Marshall, J. & Bonita, R. (2003). Shoulder pain in people with a stroke: A population-based study. *Clinical Rehabilitation, 17* (3), 304–311.

Smart, A..(2006). A multi-dimensional model of clinical utility. *International Journal for Quality in Health Care, 18* (5), 377–382. https://doi.org/10.1093/intqhc/mzl034.

Stewart, C., McCluskey, A., Ada, L. & Kuys, S. (2017). Structure and feasibility of extra practice during stroke rehabilitation: A systematic scoping review. *Australian Occupational Therapy Journal, 64* (3), 204–217. https://doi.org/10.1111/1440-1630.12351.

Veerbeek, J. M., Langbroek-Amersfoort, A. C., van Wegen, E. E. H., Meskers, C. G. M. & Kwakkel, G. (2016). Effects of robot-assisted therapy for the upper limb after stroke: A systematic review and meta-analysis. *Neurorehabilitation and Neural Repair, 31* (2), 107–121. https://doi.org/10.1177/1545968316666957.

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9.4 Appendix 4 – Publication Study 2

DISABILITY AND REHABILITATION: ASSISTIVE TECHNOLOGY
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ORIGINAL RESEARCH

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Repetitions, duration and intensity of upper limb practice following the implementation of robot assisted therapy with sub-acute stroke survivors: an observational study

Nicholas Flynn, Elspeth Froude, Deirdre Cooke and Suzanne Kuys

School of Allied Health, Australian Catholic University, Banyo, Australia

ABSTRACT

Background: Robot assisted upper limb (UL) therapy has been identified as an intervention with the potential to help improve the amount of practice performed by stroke survivors.
Objectives: This study aimed to measure the amount of UL practice (i.e., repetitions, duration, intensity) performed by subacute stroke survivors, in particular those with severe UL impairment, pre and post implementation of robot assisted upper limb therapy (RT-UL) into an inpatient rehabilitation setting.
Methods: Two observational study phases (pre-RT-UL and post-RT-UL) were undertaken of occupational therapy and physiotherapy sessions performed by subacute stroke survivors. Upper limb tasks observed and recorded in therapy were classified as either impairment-related therapy or activity-related.
Results: In the pre-RT-UL observational phase, 7 subacute stroke survivors were observed across 11 days involving 25 therapy sessions. Post-RT-UL, 12 subacute stroke survivors were observed across 12 days involving 29 therapy sessions. There were no significant differences in characteristics of patients observed in each phase ($p > .05$). The mean difference (95% CI) between pre and post RT-UL for repetitions (reps) (569 (1 to 1136) and intensity (7 (4–11)) reps/min of practice increased for all patients, including those with severe UL impairment (337 (37–638)) reps and 8 (2–14) reps/minute, with the duration of therapy unchanged.
Conclusions: This is the first study to have observed an increase in UL practice with the inclusion of RT-UL as part of routine clinical practice. This increase in practice is considered to be due to RT-UL providing highly supportive and expeditious semi-supervised practice. Notably, RT-UL was able to be implemented within the existing organisational structures with only basic training of therapy staff.

➤ IMPLICATIONS FOR REHABILITATION

- Robotics presents as a viable intervention to increase the amount and intensity of upper limb practice performed by stroke survivors in routine clinical practice
- Robotics were able to be implemented within the existing organisational structures with only basic training of therapy staff

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Robotics; stroke rehabilitation; upper extremity; occupational therapy; physical therapy; implementation

Introduction

Motor recovery in the upper limb (UL) following stroke is largely dependent on a person's ability to engage in practice that is highly repetitive, intensive and task-specific [1]. However, this can be a challenge for therapists to provide in the clinical setting particularly when people have severe UL impairment and independent exercise is difficult or impossible [2]. Previous research into usual UL therapy found people with stroke performed less than 32 UL repetitions per therapy session [2] at an average intensity of one repetition per minute [3]. Stroke survivors themselves have also reported an insufficient amount of UL therapy when in hospital and described limited access to rehabilitative technology, such as robot assisted upper limb therapy (RT-UL) [4].

In essence, RT-UL retraining involves the facilitation of repetitive UL movements with the assistance of an electromechanical device supporting the paretic arm [5]. RT-UL devices (e.g., InMotion2) can purportedly facilitate highly intensive practice, enabling over a thousand movement repetitions in a 60 min session [6] with only minimal input from the therapist [7]. Most importantly, RT-UL has been shown to be effective in improving activities of daily living performance, motor control and strength in the impaired UL [5,8,9].

This potential for RT-UL to increase the amount of practice performed by stroke survivors is encouraging, however, a range of individual and environmental factors can impact the successful implementation of UL best-practice into the clinical setting [10–13]. Factors such as patient motivation, therapist knowledge, attitude and skill, clinical leadership, safety concerns, set up of the device and organisational resources may impact usage of robotic devices in the clinical setting [14–16].

This study aimed to measure the amount of UL practice (i.e., repetitions, duration, intensity) performed by subacute stroke survivors, in particular those with severe UL impairment, pre and post the implementation of RT-UL into an inpatient rehabilitation setting.

Methods

Design

Two separate observational study phases (i.e., pre-RT-UL and post RT-UL) were undertaken of occupational therapy and

CONTACT Nicholas Flynn nick.flynn@acu.edu.au School of Allied Health, Australian Catholic University, 1100 Nudgee Road, Banyo QLD 4014, Australia
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physiotherapy sessions completed by subacute stroke survivors across an entire day in the central gym area. The pre-RT-UL observational phase was conducted between September 2016 and December 2016, prior to the implementation of the InMotion2 into the rehabilitation practice setting. The post-RT-UL observational phase was conducted from September 2018 to February 2019, 20 months after the introduction of the InMotion2 into this clinical setting. A 20-month interval between the pre-RT-UL and post RT-UL phases provided sufficient time for the InMotion2 system to be embedded into routine clinical practice, and, training of all occupational therapy and physiotherapy staff in its use completed. Training involved either individual or small group based practical education sessions led by the senior physiotherapy staff.

Site

The participating rehabilitation facility was located in metropolitan Brisbane, Australia. The facility services 50 rehabilitation beds with approximately 600 rehabilitation admissions per year, of which approximately 30% of patients have a primary diagnosis of stroke. Stroke survivors are typically seen by both occupational therapists and physiotherapists on a daily basis, Monday to Friday. The InMotion2 system was permanently located in the physiotherapy gym area of the rehabilitation unit. Ethical approval for the study was gained from The Prince Charles Hospital Human Research Ethics Committee (HREC) (HREC/16/QPCH/36) and the Australian Catholic University HREC (2016-266 R).

Participants

Subacute stroke survivors (i.e., less than 3 months post event) undergoing UL rehabilitation as part of an inpatient programme were eligible for inclusion in the study. For the post RT-UL observational phase, patients also needed to be engaged in RT-UL as part of their UL rehabilitation programme. Patients were excluded if they had a serious complicating medical illness, pain or a preexisting comorbidity impacting their participation in UL therapy. Severity of UL impairment was determined by patients raw score on the Motor Assessment Scale (MAS) item 6, with a score ≤ 3 categorized as severe UL impairment [17].

Recruitment

The rehabilitation unit was visited on a weekly basis (NF) during both the pre and post RT-UL observation phases. A convenience sample of eligible patients for observation was selected pragmatically based upon patient and staff schedules on the day of each observational research visit. As the study progressed, patient types that were underrepresented in the dataset (e.g., gender and UL severity) were prioritized for observation.

Robot-assisted UL therapy device (InMotion2)

The InMotion2 system (Figure 1) facilitates movement at the shoulder, elbow and hand (with the wrist fixed in neutral or pronation) and intuitively adapts to the person's active movements providing "assist-as-needed exercise guidance" [18]. The InMotion2 system also includes a series of inbuilt evaluative tools that can be used to measure and monitor changes in UL kinematic control and force.

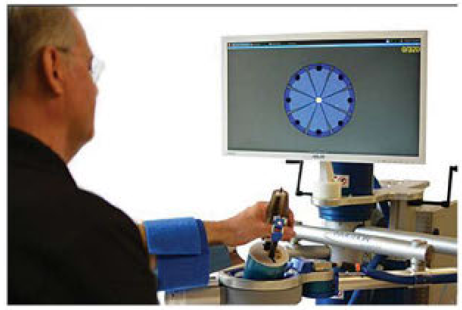

Figure 1. InMotion2 system [18].

Measures

The observational protocol and recording form developed to record repetitions, duration and intensity of UL practice initially involved the review of previous observational studies investigating UL practice for stroke survivors [2,3,17,19,20]. The protocol and recording form subsequently developed were pilot tested and refined during trial observations of patient sessions. Observational data were collected by one investigator (NF) for both observation phases to ensure consistency of recording. Where it was uncertain how to categorise or count a specific task, the activity observed was recorded and consensus reached with the research team.

To enable accurate recording of therapy, only a single patient was observed on each observational day. All occupational therapy and physiotherapy gym-based sessions conducted in that day were observed except where the sole purpose of the session was assessment. Where a patient was observed on more than one day the average dose for both minutes and repetitions was determined across the total number of observation days. During session observations, the investigator aimed to be unobtrusive and not interfere or assist with the therapy session being observed. Time and repetitions were totalled at the end of each session.

UL repetitions were manually counted using a clicker. A single repetition was defined as the patient performing an active or assisted movement of the paretic UL from an initial resting position, through a prescribed motion and then returning to a resting position [19]. A repetition was only counted if considered to be therapeutic, that is, instructed or performed to complete a prescribed therapeutic task. Repetitions also included obvious attempts to perform the prescribed therapy task (whether the patient was successful or not). Movements associated with assessment or that were incidental in nature were not counted. Duration of therapy was measured in minutes using a digital stopwatch. Intensity of UL practice was defined and calculated as the number of UL repetitions performed per minute [3].

UL therapy tasks were categorized as either impairment-related therapy or activity-related based on previously developed coding lists for observing UL practice by stroke survivors [17,20]. Definitions for the categories and the repetitions of UL movements utilised in this study are shown in Table 1. The discipline that provided each UL therapy session, either occupational therapy or physiotherapy, was noted.

Impairment-related therapy involved patients completing tasks to directly address deficits in body function and structure and included active exercise, passive exercise and sensory tasks.

Table 1. Definitions of movements, repetitions and examples for impairment-related and activity-related upper limb task practice.

Category	Definition	Definition of single repetition	Examples
Impairment-related			
Active exercise	Any movement in which the patient attempted or moved the limb through a specific motion	One movement from initial position and back again	Side-lying shoulder flexion/extension
Passive exercise	Any movement of the limb by a therapist or a device, without any effort by the patient	One movement from initial position and back again	Stretches; passive range of patients fingers by therapist
Sensory	Any activity done to receive/enhance somatosensory input	One period of the activity	Weight bearing where one period of bearing weight through the paretic arm was counted as one repetition
Activity-related			
Functional tasks	Any movement that accomplishes/ attempts to accomplish a functional task. For more complex functional tasks movements were recorded as subunits of the whole task.	One completion of the functional task	Reaching for a cup Throwing a beanbag Preparing a cup of coffee (contained subunits) Making a bed (contained subunits)
RT-UL	Any movement that accomplishes/ attempts to accomplish a task presented on the InMotion2 computer monitor.	One movement from initial position and back again as displayed on the computer monitor	Clock game task = starting at the central dot of the clock presented on the computer monitor, reaching out to the presented dot on the outer edge of the clock and then returning to the central dot Pick game = Reaching, grasping, transporting and releasing (with active-assistance from the InMotion2 device) a highlighted dot to designated positions on the computer screen.

Adapted from table in Lang, MacDonald [20]. RT-UL: Robot Assisted UL Therapy.

Activity-related therapy involved patients executing functional tasks either basic or complex. Complex functional task repetitions were recorded as subunits of the whole task. For example, 11 subunit repetitions were counted in observation of a patient using their paretic UL to prepare a cup of coffee including filling kettle with water, carrying the cup, carrying the spoon, opening the coffee jar, putting the lid back on the coffee jar, opening the fridge door, removing the lid from the milk, putting lid on the milk, reopening the fridge door, stirring the coffee and carrying the coffee. RT-UL was categorized under activity-related therapy with the patient required to execute a specific functional task as presented on a computer monitor.

Data analysis

Data are presented descriptively as mean (SD) to describe repetitions, duration of therapy (minutes) and intensity of therapy (repetitions/minute). Types of UL therapy data (activity-related, activity-related without RT-UL, impairment-based, RT-UL alone) are described separately. Between group analysis was undertaken to examine differences between the amount of UL therapy practice pre and post-RT-UL for all subacute stroke survivors. Results for observations of those with severe UL impairment (MAS score ≤ 3) were also examined separately in both pre and post RT-UL. Independent sample *t*-tests (or non-parametric equivalent) were used to compare pre and post RT-UL measures. For categorical data a Chi-square test for independence or Fisher's Exact test were used. All data were analysed using SPSS v. 25 and statistical significance set at <0.05.

Results

Participants

Pre RT-UL, 7 subacute stroke survivors were observed across 11 days, involving 25 therapy sessions (9 occupational therapy sessions; 16 physiotherapy sessions). Post-RT-UL, 12 subacute stroke survivors were observed across 12 days involving 29 therapy sessions (10 occupational therapy sessions; 19 physiotherapy sessions). Fourteen sessions involved RT-UL, 13 of which were led by physiotherapy. RT-UL practice performed by patients required only intermittent input from the treating therapist. There were no significant differences in characteristics of patients observed pre-RT-UL and those observed post RT-UL ($p > .05$). Demographic data and clinical characteristics of patients observed as part of the pre and post RT-UL observations is summarized in Table 2.

Pre RT-UL, 5 subacute stroke survivors with severe UL impairment were observed across 8 days involving 19 sessions (8 occupational therapy sessions; 11 physiotherapy sessions). Post RT-UL, 5 subacute stroke survivors with severe UL impairment were observed across 5 days involving 10 sessions (3 occupational therapy sessions; 7 physiotherapy sessions). Patients with severe UL impairment engaged in 6 sessions that involved RT-UL, all were led by physiotherapy. There were no significant differences in patients' characteristics with severe UL impairment between pre-RT-UL and post RT-UL ($p > .05$) (Table 2).

UL therapy practice for all stroke patients

Table 3 summarizes UL therapy practice (repetitions, duration, intensity) for all patients pre and post RT-UL. Total UL repetitions increased post RT-UL (*p*-value = .01) and there was no change in total UL therapy duration (*p*-value = .38). Intensity of UL practice increased post RT-UL (*p*-value = .001). Activity-related UL repetitions increased post RT-UL (*p*-value = .01) with no change in the duration of activity-related UL therapy time post RT-UL (*p*-value = .55). Intensity of activity-related UL practice increased post RT-UL (*p*-value = .001). There was no difference between pre and post RT-UL for activity-related UL practice without RT-UL and no change in impairment-related practice.

Table 2. Demographics and clinical characteristics of all patients and those with severe upper limb impairment in the pre and post robot-assisted upper limb therapy (RT-UL) observations.

Patient characteristic	All stroke patients ($n = 19$)		Patients with severe upper limb impairment ($n = 10$)	
	Pre RT-UL ($n = 7$)	Post RT-UL ($n = 12$)	Pre RT-UL ($n = 5$)	Post RT-UL ($n = 5$)
Age (years), mean (SD)	68 (11)	68 (15)	67 (13)	61 (19)
Gender, n females (%)	4 (57)	2 (17)	2 (40)	1 (20)
Stroke type, n ischaemic (%)	5 (71)	12 (100)	3 (60)	5 (100)
Paretic arm, n right (%)	4 (57)	5 (42)	3 (60)	1 (20)
Severe UL impairment, $n \leq 3$ MAS Item 6 (%)	5 (71)	5 (42)	5 (100)	5 (100)
Days post stroke at time of observation, mean (SD)	32 (17)	28 (24)	36 (19)	32 (23)
FIM Admission, mean (SD)	65 (31)	89 (22)	69 (36)	75 (21)

FIM: Functional Independence Measure; MAS: Motor Assessment Scale; RT-UL: Robot Assisted UL Therapy.

Table 3. Mean (SD) for type and dosage of Upper Limb (UL) therapy over the day and mean difference (95% CI) between pre and post robot-assisted UL therapy (RT-UL).

UL therapy per day	Pre-RT-UL ($n = 7$)		Post-RT-UL ($n = 12$)		Difference between Pre and Post RT-UL	
	All ($n = 7$)	Severe UL impairment ($n = 5$)	All ($n = 12$)	Severe UL impairment ($n = 5$)	All	Severe UL impairment
Repetitions						
Total	282 (231)	265 (227)	851(682)	602 (183)	569 (1–1136)	337 (37–638)
Activity–related	236 (258)	200 (258)	796 (689)	531 (203)	561 (–16 to 1137)	331 (–81 to 670)
Activity–related without RT–UL	236 (258)	200 (258)	247 (295)	59 (65)	11 (–272 to 295)	–141 (–457 to 176)
Impairment–related	26 (57)	37 (66)	54 (60)	71 (68)	28 (–31 to 87)	34 (–63 to 132)
RT–UL alone	n/a	n/a	549 (428)	472 (175)	n/a	n/a
Minutes						
Total	55 (46)	59 (52)	71 (38)	60 (33)	17 (–24 to 58)	1 (–62 to 65)
Activity–related	48 (50)	50 (58)	60 (38)	42 (21)	12 (–30 to 55)	–8 (–72 to 56)
Activity–related without RT–UL*	48 (50)	50 (58)	31 (25)	13 (16)	–17 (–64 to 30)	–37 (–108 to 34)
Impairment–related	7 (14)	9 (16)	11 (15)	18 (18)	5 (–10 to 19)	9 (–15 to 33)
RT–UL alone	n/a	n/a	29 (17)	29 (11)	n/a	n/a
Intensity (reps/min)						
Total	5 (3)	4 (2)	12 (5)	12 (5)	7 (4–11)	8 (2–14)
Activity–related	4 (3)	2 (2)	13 (4)	14 (4)	9 (5–13)	11 (7–16)
Activity–related without RT–UL*	4 (3)	2 (2)	6 (4)	3 (3)	3 (–2 to 7)	1 (–3 to 4)
Impairment–related	2 (3)	2 (3)	4 (7)	3 (3)	3 (–3 to 9)	0 (–4 to 5)
RT–UL alone	n/a	n/a	18 (4)	16 (3)	n/a	n/a

*Mean and SD remains unchanged due to no RT-UL being available for clinical use pre-RT-UL.

UL therapy practice for stroke patients with severe UL impairment

UL therapy practice for stroke survivors with severe UL impairment pre and post RT-UL is summarized in Table 3. Total UL repetitions for patients with severe UL impairment increased post RT-UL (p-value = .04) but there was no change in the total UL therapy time (p-value = .92). Intensity of UL practice increased post RT-UL (p-value = .009). Activity-related UL repetitions for patients with severe UL did not increase post RT-UL (p-value = .06). There was no change in the duration of activity-related UL therapy post RT-UL (p-value = .92). Intensity of activity-related UL practice increased post RT-UL (p-value = .009). There was no difference between pre and post RT-UL for activity-related UL practice without RT-UL and no change in impairment-related practice.

Discussion

This study aimed to quantify UL practice in terms of repetitions, duration and intensity performed by sub-acute stroke survivors, including those with severe UL impairment, in an inpatient rehabilitative setting pre and post the implementation of RT-UL. We found that UL repetitions and intensity of practice increased for all patients, including those with severe UL impairment, with the duration of therapy unchanged. To our knowledge this is the first study to have observed an increase in UL practice when RT-UL is implemented into routine clinical practice. These findings are noteworthy firstly from the perspective that highly repetitive and intensive UL training is essential for motor recovery [21] and secondly therapists have previously found this difficult to provide to stroke survivors in the clinical setting [2].

We propose the increase in UL practice was the outcome of RT-UL providing a uniquely supportive and efficient form of UL practice that requires minimal input from the therapist. The InMotion2 provided physical assistance at the patient's elbow, wrist and hand and presented up to 80 therapy targets sequentially to the patient on the computer monitor before any therapist involvement was required. Conventionally, UL practice for stroke survivors has involved one-on-one input from the therapist particularly patients with severe UL impairment [2,7]. This can result in periods of downtime or reduced intensity of practice for the patient if they have difficulty completing repetitive UL movement unassisted while the therapist attends to other patients or tasks. Other recommended strategies for extra practice for patients with severe UL impairment such as room-based programmes and UL groups [7] may not be as effective due to the reliance on staff or family. The capacity for semi-supervised practice also distinguishes RT-UL as a potentially cost-effective means of increasing practice levels [22–24].

The idea that RT-UL could potentially replace the role of the therapist [25] or supersede other forms of effective UL rehabilitation was not evident in this study. The amount of UL practice performed separate to RT-UL (i.e., "impairment-related" and "Activity-related without RT-UL") remained unchanged. Patients continued to engage in a broad range of UL tasks with RT-UL being just one of the many interventions used as part of an UL programme. Therapists remained essential throughout the delivery of these programmes particularly to prescribe and grade tasks, provide feedback on performance and facilitate exercise of isolated muscle groups. Therapist involvement, although minimal, was also crucial in the delivery of RT-UL including the identification of appropriate therapeutic protocols, monitoring of fatigue and pain levels and interpretation of evaluative measures.

A stroke survivor's opportunity to engage in effective UL practice can be limited by a range of factors specific to the clinical environment in which they are receiving therapy [10]. These may include attitudes of therapists, organisational structures and availability of resources [14,15]. A number of these factors were identified in focus groups prior to the commencement of this observational study conducted with occupational therapists and physiotherapists at the facility [16]. Therapists acknowledged the potential for RT-UL to increase UL practice but felt this was dependent on having the support of clinical leaders and receiving adequate training in the use of the RT-UL. The availability of a single robotic device was also perceived by therapists as presenting logistical challenges. Despite these perceived challenges, RT-UL was able to be successfully implemented within the existing leadership structure and therapy schedules with only basic training of therapy staff. A potential implication of only a single RT-UL device being available was that RT-UL was almost exclusively prescribed and provided by the physiotherapists, as opposed to the occupational therapists, due in at least part to the InMotion2 being located in the physiotherapy gym area. In addition to this, the capacity for RT-UL to enable semi-supervised practice appeared particularly conducive to the work patterns in the physiotherapy gym area where therapists were frequently responsible for treating two to three patients at one time.

The scope of this study did not extend to investigating the correlation between practice levels and patient UL outcome measures, however, some assumptions can be made. Schneider, Lannin [26] suggest that a 240% increase in practice minutes is needed to reduce activity limitations in stroke survivors. This conclusion being with the assumption that increased therapy minutes results in increased UL repetitions. The implementation of RT-UL saw an increase of more than 200% in UL practice (i.e., 282 reps/day pre-RT-UL to 851 reps/day post RT-UL) for stroke survivors but without an increase in the duration of UL therapy time. Practice performed outside the gym (e.g., independent or family facilitated practice on the ward) was not recorded so it is possible that patients may have undertaken even more practice during an entire day. It appears feasible that the extra practice necessary to reduce activity limitations in stroke survivors could be achieved with the inclusion of RT-UL into routine clinical practice.

Study limitations

There were several limitations to this study. A relatively small sample of convenience was recruited in both observational phases from a single rehabilitation unit located in a metropolitan area. Although statistical conclusions were able to be drawn from data the transferability of these results to the broader rehabilitation context should be done with caution. Patients observed in the pre-implementation phase were not the same as those observed in the post-implementation phase, however, no differences in demographics or clinical characteristics were found between the two groups. Additionally, the scope of the study did not extend to the collection and analysis of patient clinical outcome measures, so no conclusions could be made as to the effect of the increase in practice on patient recovery. Despite the investigator (NF) being vigilant to be unobtrusive and not to interfere or assist with therapy sessions during data collection, it is possible that therapists altered their behaviour when under direct observation.

Conclusions

This study observed an increase in UL repetitions and intensity of practice by sub-acute inpatient stroke survivors, including those with severe UL impairment, following the implementation of RT-UL into routine clinical practice. Notably, this increase in practice was achieved without an increase in the time spent in therapy by patients. Further pragmatic studies involving the use of RT-UL in routine clinical practice with larger sample sizes are needed to support the generalisation of these results.

Patient consent

Ethical approval for the study was gained from The Prince Charles Hospital Human Research Ethics Committee (HREC) (HREC/16/QPCH/36) and the Australian Catholic University HREC (2016-266R). The research programme was approved as low risk and a waiver of consent was granted for the observational surveys.

Health & safety

All mandatory health and safety procedures have been complied with in the course of conducting any experimental work reported in this paper.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Nicholas Flynn http://orcid.org/0000-0001-5282-9695
Elspeth Froude http://orcid.org/0000-0002-6863-2317
Deirdre Cooke http://orcid.org/0000-0003-0920-2031
Suzanne Kuys http://orcid.org/0000-0002-6263-4223

References

[1] Arya KN, Pandian S, Verma R, et al. Movement therapy induced neural reorganization and motor recovery in stroke: a review. J Bodyw Mov Ther. 2011;15(4):528–537.

[2] Hayward KS, Brauer SG. Dose of arm activity training during acute and subacute rehabilitation post stroke: a systematic review of the literature. Clin Rehabil. 2015;29(12):1234–1243.

[3] Kimberley TJ, Samargia S, Moore LG, et al. Comparison of amounts and types of practice during rehabilitation for traumatic brain injury and stroke. J Rehabil Res Dev. 2010;47(9):851–861.

[4] Hughes A-M, Burridge JH, Demain SH, et al. Translation of evidence-based assistive technologies into stroke rehabilitation: users' perceptions of the barriers and opportunities. BMC Health Serv Res. 2014;14:124.

[5] Veerbeek JM, Langbroek-Amersfoort AC, van Wegen EEH, et al. Effects of robot-assisted therapy for the upper limb after stroke. Neurorehabil Neural Repair. 2017;31(2):107–121.

[6] Conroy SS, Whitall J, Dipietro L, et al. Effect of gravity on robot-assisted motor training after chronic stroke: a

randomized trial. Arch Phys Med Rehabil. 2011;92(11): 1754–1761.

[7] Stewart C, McCluskey A, Ada L, et al. Structure and feasibility of extra practice during stroke rehabilitation: a systematic scoping review. Aust Occup Ther J. 2017;64(3):204–217.

[8] Mehrholz J, Pohl M, Platz T, et al. Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke. Cochrane Database Syst Rev. 2015;2015(11):CD006876.

[9] Rodgers H, Bosomworth H, Krebs HI, et al. Robot assisted training for the upper limb after stroke (RATULS): a multicentre randomised controlled trial. The Lancet. 2019; 394(10192):51–62.

[10] Jolliffe L, Hoffmann T, Lannin NA. Increasing the uptake of stroke upper limb guideline recommendations with occupational therapists and physiotherapists. A qualitative study using the Theoretical Domains Framework. Aust Occup Ther J. 2019;66(5):603–616.

[11] Bayley MT, Hurdowar A, Richards CL, et al. Barriers to implementation of stroke rehabilitation evidence: findings from a multi-site pilot project. Disabil Rehabil. 2012;34(19): 1633–1638.

[12] McCluskey A, Vratsistas-Curto A, Schurr K. Barriers and enablers to implementing multiple stroke guideline recommendations: a qualitative study. BMC Health Serv Res. 2013;13(1):323–323.

[13] Mudge S, Hart A, Murugan S, et al. What influences the implementation of the New Zealand stroke guidelines for physiotherapists and occupational therapists? Disabil Rehabil. 2017:39(5):511–518.

[14] van Ommeren AL, Smulders LC, Prange-Lasonder GB, et al. Assistive technology for the upper extremities after stroke: systematic review of users' needs. JMIR Rehabil Assist Technol. 2018;5(2):e10510.

[15] Atkins L, Francis J, Islam R, et al. A guide to using the Theoretical Domains Framework of behaviour change to investigate implementation problems. Implement Sci. 2017; 12(1):77.

[16] Flynn N, Kuys S, Froude E, et al. Introducing robotic upper limb training into routine clinical practice for stroke survivors: perceptions of occupational therapists and physiotherapists. Aust Occup Ther J. 2019;66(4):530–538.

[17] Hayward KS, Barker RN, Wiseman AH, et al. Dose and content of training provided to stroke survivors with severe upper limb disability undertaking inpatient rehabilitation: an observational study. Brain Impairment. 2013;14(3): 392–405.

[18] Bionik Labs. Bionik Labs. 2017; [cited 2017 Jun 29]; Available from: http://bionikusa.com/.

[19] Lang CE, MacDonald JR, Gnip C. Counting repetitions: an observational study of outpatient therapy for people with hemiparesis post-stroke. J Neurol Phys Ther. 2007;31(1): 3–10.

[20] Lang CE, Macdonald JR, Reisman DS, et al. Observation of amounts of movement practice provided during stroke rehabilitation. Arch Phys Med Rehabil. 2009;90(10): 1692–1698.

[21] Kleim JA, Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res. 2008;51(1):S225–S239.

[22] Hesse S, Heß A, Werner C C, et al. Effect on arm function and cost of robot-assisted group therapy in subacute patients with stroke and a moderately to severely affected arm: a randomized controlled trial. Clin Rehabil. 2014;28(7): 637–647.

[23] Masiero S, Armani M, Ferlini G, et al. Randomized trial of a robotic assistive device for the upper extremity during early inpatient stroke rehabilitation. Neurorehabil Neural Repair. 2014;28(4):377–386.

[24] Wagner TH, Lo AC, Peduzzi P, et al. An economic analysis of robot-assisted therapy for long-term upper-limb impairment after stroke. Stroke. 2011;42(9):2630–2632.

[25] Laffont I, Bakhti K, Coroian F, et al. Innovative technologies applied to sensorimotor rehabilitation after stroke. Ann Phys Rehabil Med. 2014;57(8):543–551.

[26] Schneider EJ, Lannin NA, Ada L, et al. Increasing the amount of usual rehabilitation improves activity after stroke: a systematic review. J Physiother. 2016;62(4): 182–187.

9.5 Appendix 5 – Publication Study 3

DISABILITY AND REHABILITATION
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ORIGINAL ARTICLE

Check for updates

The sustainability of upper limb robotic therapy for stroke survivors in an inpatient rehabilitation setting

Nicholas Flynn[a], Elspeth Froude[a], Deirdre Cooke[b], Jessica Dennis[c] and Suzanne Kuys[a]

[a]Australian Catholic University, Brisbane, Australia; [b]Mater Private Hospital Rehabilitation Unit, Australian Catholic University, Brisbane, Australia; [c]Brighton Rehabilitation Unit, Australian Catholic University, Brisbane, Australia

ABSTRACT

Purpose: To investigate the sustainability of Robot-assisted upper limb therapy (RT-UL) as part of routine occupational therapy and physiotherapy clinical practice.

Methods: Two separate audits, 12 months apart, of RT-UL computer data records were undertaken to determine sustainability in a subacute rehabilitation unit. Records of the two audits were compared in terms of the number of early subacute stroke survivors using RT-UL, the number of RT-UL sessions, duration of RT-UL sessions, and disciplines prescribing RT-UL.

Results: During Audit 1 58% ($n = 18$) of stroke survivors received RT-UL compared to 50% ($n = 7$) in Audit 2. The total number of RT-UL sessions reduced between audits (148 *vs.* 36 sessions) reflecting the overall reduction in admission rates for stroke survivors. There was no significant difference between audits in the average number of RT-UL sessions per patient ($p = 0.203$) nor the length of sessions ($p = 0.762$). Patients engaged in active therapy more than three-quarters of the time when on the robotic device. Physiotherapists were the primary prescribers of RT-UL when compared to occupational therapists.

Conclusions: RT-UL was in continued and regular use with stroke survivors 2 years after initial implementation within an inpatient rehabilitation setting. RT-UL practice was intensive and used routinely with patients.

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Robotics; stroke rehabilitation; upper extremity; occupational therapy; physical therapy; implementation

➤ IMPLICATIONS FOR REHABILITATION

- RT-UL is a sustainable and intensive intervention for stroke survivors within an inpatient rehabilitative setting.
- The cost-benefits of RT-UL should be evaluated from the perspective of the whole rehabilitation service not just at an individual patient level.
- RT-UL may be considered a "bridging" form of UL practice for those with more limited active UL movement until there is sufficient UL movement and power for more complex real-world task-specific practice.

Introduction

Robot-assisted upper limb therapy (RT-UL) is an emerging technology in the field of rehabilitation and is globally recognised as part of best practice for stroke survivors with upper limb deficits [1,2]. RT-UL is effective in improving motor control and strength in the upper limb (UL) following stroke [3–5]. Despite this growing body of evidence, little is understood as to how these devices are implemented and used clinically and in particular the sustainability of RT-UL as part of routine practice.

Sustainability, as it relates to the implementation of a specific health intervention, involves the continued use of an intervention over a period of years to achieve desired health outcomes [6]. Although a vital domain within implementation science, sustainability has been largely under-investigated for many health interventions [7]. The sustainability of RT-UL in practice is important when considering the potential benefits of RT-UL for patients, particularly those with severe upper limb impairment [2]. There is also a significant financial outlay associated with the procurement and implementation of these robotic devices. However, no studies have directly investigated the sustainability of RT-UL in practice.

To measure sustainability there is a need to objectively record (i.e., audit) the use of the intervention as part of daily practice [6]. RT-UL usage in this study will be considered from the perspective of the number and characteristics of stroke survivors using RT-UL in routine practice, duration of RT-UL use in UL programs, and types of RT-UL activities used. A better understanding of these variables across a prolonged timeframe will create a picture of the long-term viability of RT-UL in a clinical practice setting. Ultimately this knowledge will enhance therapists' and health administrators' decision-making around the acquisition and implementation of RT-UL in their specific clinical setting.

Methods

Design

Two separate audits were undertaken to measure the sustainability of the InMotion2 device as a routine intervention for early

CONTACT Nicholas Flynn nick.flynn@acu.edu.au School of Allied Health, Australian Catholic University, 1100 Nudgee Road, Banyo, 4014, QLD, Australia
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subacute stroke survivors (i.e., <3 months post-stroke) at an Australian rehabilitation unit. Audit 1 was conducted between September 2017 and December 2017 and Audit 2 was between September 2018 and December 2018.

Site

The participating rehabilitation facility was located in metropolitan Brisbane, Australia. The facility services 42 rehabilitation beds with ~600 rehabilitation admissions per year, of which ~30% of patients have a primary diagnosis of stroke. Stroke survivors are typically seen by both occupational therapists and physiotherapists daily, Monday to Friday. The InMotion2 device was permanently located in the physiotherapy gym area of the rehabilitation unit. Ethical approval was gained from the rehabilitation unit's human research ethics committee.

Participants

All early subacute stroke survivors admitted to this inpatient rehabilitation unit during the audit periods were eligible for inclusion in this study.

Robot-assisted UL therapy device (InMotion2)

The InMotion2 is a robotic device that facilitates movement at the shoulder and elbow with an additional hand component if required. The device intuitively adapts to the person's active movements providing "assist-as-needed exercise guidance" during use [8]. The InMotion2 device includes a series of inbuilt evaluative tools that can be used to measure and monitor changes in UL kinematic control and force. Users of this device complete a therapist-selected, pre-programmed treatment protocol with therapy tasks presented on an adjoining computer screen. In addition to the standardised treatment protocol users can also complete additional therapeutic games (including "maze," "pong," and "squeegee") on the device.

Procedure

Initial implementation of the InMotion2 device into clinical use at the participating rehabilitation unit occurred in November 2016. Audit 1 commenced in September 2017, 10 months post the initial implementation period with the InMotion2 deemed having been sufficiently embedded in usual practice for both occupational therapists and physiotherapists by that time. During this 10-month implementation period, the InMotion2 had been tested, trialled, and made operational, that is, it was routinely being initiated and delivered as part of patients' upper limb rehabilitation programs. Additionally, both therapy disciplines had received training sessions that involved either individual or small group-based practical education sessions led by a senior physiotherapist. The second audit was conducted two years post-initial implementation. This timing of the audits was in line with previous recommendations that sustainability is measured across multiple points in time [7] and span a period of two or more years from "initial implementation" (i.e., when the intervention is first introduced into practice) [9].

During both audit periods, investigators visited the rehabilitation unit weekly and liaised with therapy staff to identify patients meeting the inclusion criteria. Once identified, patient demographics and clinical outcome measures were gathered from the medical records for all stroke survivors admitted to the unit during the audit periods, whether they used or did not use the RT-UL during their inpatient rehabilitation stay. Clinical outcome measures recorded by the treating therapist included patients' Functional Independence Measure (FIM) score on admission and Motor Assessment Scale (MAS) Item 6 on admission. The FIM is a measure of disability scored out of 126; a higher score relates to a greater level of independence [10]. The FIM has been previously shown to have excellent reliability (inter-rater 0.94; test–retest 0.93) and validity in measuring disability [11]. The severity of upper limb impairment was determined using the MAS Item 6 score. The MAS is a motor assessment tool encompassing both upper and lower limb function [12]. Item 6 is a measure of upper arm function scored on a seven-point scale, from zero indicating no functional recovery to six indicating good functional recovery [12]. Patient performance on Item 6 of the MAS has been used previously as a measure of upper limb severity for stroke survivors [13].

The RT-UL usage data was collected for those patients who had commenced use of the robotic device as part of their upper limb program during inpatient rehabilitation. RT-UL usage data were extracted from the InMotion2 computer. When the patient's admission extended beyond the audit period, RT-UL usage data continued to be collected to record the total amount of usage by a patient across their admission.

Measures

Sustainability was measured by comparing InMotion2 usage data across the two audit periods. Data was collected in terms of the number of early subacute stroke survivors who used the InMotion2, the number of InMotion2 sessions completed by each individual patient during their admission, and the amount of time the InMotion2 was used by each patient. The amount of RT-UL time was measured in relation to each session and across the patient's admission. Time on the InMotion2 was then further considered in terms of active RT-UL use, rest periods, evaluative tasks, and hand module use. Active RT-UL included the time in which the patient was actively engaged in completing an initiated task on the InMotion2. Active RT-UL was interspersed with rest periods where the patient remained seated at, or attached to, the device but was not actively engaged in completing an initiated protocol or a therapeutic game. Patients completed evaluative tasks on the InMotion2 for the purpose of objectively measuring and monitoring changes in UL kinematic control and force. A hand module was available to be attached to the InMotion2 to enable patients to perform grasp/release movements in combination with reach. Finally, data were collected in relation to the discipline of the prescribing therapist (i.e., occupational therapy and physiotherapy) for each InMotion2 session including student therapists.

Data analysis

Descriptive statistics including mean and standard deviations were used to report the number of RT-UL sessions completed by each patient in each audit period. The usage data is described separately in terms of patients, sessions, and duration (minutes) for each audit and total. Comparisons between the first and second audit periods were completed to analyse the sustainability of InMotion2. Independent sample *t*-tests (or non-parametric equivalent) were used to compare audit RT-UL measures. Categorical data were analysed using a Chi-square test for independence or Fisher's Exact test. All data were analysed using SPSS v. 25 and statistical significance set at <0.05.

Results

Participants

During Audit 1, 31 stroke survivors were admitted to the unit, 18 received RT-UL (58%) and during Audit 2, 14 stroke survivors were admitted and seven received RT-UL (50%). Across both audits, stroke survivors provided with RT-UL had significantly lower scores on MAS Item 6 (p-value = 0.0002) and had a longer length of stay in rehabilitation than those who did not receive RT-UL (p-value = 0.002).

In Audit 2, patients in RT-UL had significantly higher admission FIM (p-value = 0.007) and MAS Item 6 scores (p-value = 0.04) than those participating in RT-UL in audit 1 as well as shorter length of stay in inpatient rehabilitation (p-value = 0.02). There were no differences between audits in the demographics and clinical characteristics of non-RT-UL users. Demographic data and clinical characteristics of stroke survivors included in both audits are summarised in Table 1.

Sustainability

Tables 2, 3 summarise RT-UL usage in both audit periods. A total of 148 RT-UL sessions were conducted across Audit 1 and 36 RT-UL sessions during Audit 2. The total number of RT-UL sessions reduced between audits, coincided with an overall reduction in the number of early sub-acute stroke survivors admitted to the rehabilitation unit. There was no significant difference in the average number of RT-UL sessions per patient nor the length of the sessions between Audits 1 and 2. Distribution of RT-UL usage with respect to active therapy and rest time per session remained unchanged, and the hand module was utilised commensurately across both audit periods. The number of sessions involving evaluative tasks also remained the same across both audits. In Audit 1, RT-UL sessions were initiated by both physiotherapists and occupational therapists, including students from each of the disciplines. In Audit 2, RT-UL sessions were only initiated by physiotherapists with no sessions initiated by occupational therapists or students of either discipline.

Overall usage patterns

Across both audit periods patients engaged in a total of 184 RT-UL sessions for a duration of 123 h, with >75% of this time involving active therapy time. The RT-UL users on average participated in nine RT-UL sessions per admission for an average of 38 min/

Table 1. Demographic data and clinical characteristics of early stroke survivors (upper limb robotic users and non-robotic users) across both audit periods.

	Audit 1		Audit 2		Total	
Patient characteristics	Robotic users (N = 18)	Robotic non-users (N = 13)	Robotic users (N = 7)	Robotic non-users (N = 7)	Robotic users (N = 25)	Robotic non-users (N = 20)
Age, years, mean (95% CI)	67 (63–72)	71 (64–78)	68 (53–83)	73 (57–89)	67 (63–72)	72 (65–79)
Gender, female, n (%)	8 (44%)	6 (46%)	0 (0)	3 (43%)	8 (32%)	9 (45%)
Stroke type, ischaemic, n (%)	16 (89%)	11 (85%)	7 (100%)	5 (71%)	23 (92%)	16 (80%)
Hemiparetic arm, n (%), right	10 (56%)	6 (46%)	4 (57%)	6 (86%)	14 (56%)	12 (60%)
MAS Item 6 admission score, mean (range)	1.2 (0–2)	4.3 (3–6)	2.6 (1–4)	4.7 (3–7)	1.6 (1–2)	4.4 (3–5)
Days in rehab, mean (95% CI)	65 (42–88)	18 (17–39)	33 (8–59)	29 (19–39)	56 (38–74)	28 (21–35)
Admission FIM score, mean (range)	54 (42–66)	78 (64–92)	88 (68–107)	69 (47–91)	64 (52–75)	75 (64–85)

FIM: functional independence measure; MAS: Motor Assessment Scale.

Table 2. Clinical use of upper limb robotic therapy by early subacute stroke survivors across both audit periods.

Robotic usage	Audit 1 (n = 18)	Audit 2 (n = 7)	Total (n = 25)
Patients			
Utilised evaluative capacity of robotic	18 (100%)	6 (86%)	24 (96%)
Utilised hand module of robotic	4 (22%)	2 (29%)	5 (20%)
Sessions			
Total	148	36	184
Involving evaluative capacity of robotic	30 (22%)	8 (22%)	38 (21%)
Involving hand component of robotic	27 (18%)	5 (14%)	32 (17%)
Physiotherapist initiated	112 (76%)	36 (100%)	148 (80%)
Physiotherapy student initiated	8 (5%)	0 (0)	8 (4%)
Occupational therapist initiated	26 (18%)	0 (0)	26 (14%)
Occupational therapy student initiated	2 (1%)	0 (0)	2 (1%)
Minutes			
Total	5966	1432	7398
Active robotic use	4569 (77%)	1116 (78%)	5685 (77%)
Use of evaluative capacity	555 (9%)	105 (7%)	660 (9%)
Rest time while seated at robotic device	842 (14%)	210 (15%)	1052 (14%)

Table 3. Clinical use of upper limb robotic therapy by early subacute stroke survivors for the whole of admission.

Robotic usage	Audit 1 (n = 18)	Audit 2 (n = 7)	Total (n = 25)	Mean differences (95% CI)
Sessions				
Per patient (95% CI)	11 (7–14)	7 (1–13)	9 (7–12)	Not applicable
Per patient involving evaluation (95% CI)	2 (2–2)	2 (1–3)	2 (1–2)	Not applicable
Minutes				
Mean per admission (SD)	429 (372)	239 (202)	376 (340)	190 (−120–499)
Mean per session (SD)	38 (12)	38 (8)	38 (11)	0 (−11–10)
Mean active-RT-UL per session (SD)	26 (11)	28 (7)	27 (10)	1 (−11–8)
Mean rest time per session (SD)	5 (5)	6 (3)	5 (4)	−1 (−5–3)

session, with minimal rest time during each session (i.e., 5 min/session). Patients using RT-UL completed the evaluative tasks on average twice during their admission, and almost a quarter of patients utilised the hand module as part of their therapy.

Discussion

This study found that RT-UL was a sustainable intervention, in continued and regular use with stroke survivors 2 years after initial implementation within an inpatient rehabilitation setting. These findings are noteworthy firstly from the viewpoint of RT-UL being part of best-practice in the rehabilitation of the upper limb following stroke as well as the significant expense involved in acquiring and implementing RT-UL.

Technology abandonment is a commonly encountered problem for health services [14]. Reasons for this are unclear and likely complex involving a range of patient, staff, technical, financial, and governance issues [14]. Despite this, there is a scarcity of research directly exploring the sustainability of health technologies [15] with much of the research having focused on initial implementation [14]. In the case of RT-UL technology, clinical practice implementation has remained largely unaddressed with the majority of research undertaken involving clinical efficacy trials [3]. To our knowledge, this is the first study to investigate the sustainability of RT-UL in routine clinical practice.

The key drivers for the sustainability of RT-UL in this particular study relate to complementary studies conducted at this same unit when the RT-UL was initially acquired [16,17]. The first of these studies, an observational study, found a significant increase in the amount of UL practice for stroke survivors following the implementation of the InMotion2 [16]. This increase in practice was attributed to the supportive and efficient form of practice provided by the robotic device and providing the opportunity for semi-supervised or independent practice by the patients. This is positive from the perspective that the provision of unsupervised practice is important for increasing overall practice levels but is often not able to be implemented in the rehabilitation setting [18].

Another apparent driver for clinical uptake of the RT-UL was highlighted in focus groups with the therapists run before the implementation of the device at the participating facility [17] where it was expressed that there would be accountability to senior management to use the Inmotion2 due to the large number of funds outlaid to acquire the device. Interestingly, therapists also foresaw that the usage patterns of the RT-UL would be strongly dependent on admission rates of stroke survivors [17]. This is a valuable finding when considering the cost-benefits of RT-UL. Previous studies have analysed the cost-benefits of RT-UL at an individual patient level [5,19], whereas the current study highlights the importance of also looking at the financial viability of RT-UL from the perspective of the whole rehabilitation service.

In addition to the question of sustainability, the current study provided several insights into the use of RT-UL more broadly. Of note was stroke survivors prescribed RT-UL had a greater level of upper limb impairment and overall disability than those who were not prescribed RT-UL. This pattern of prescription is consistent with clinical guidelines which advise that RT-UL may be most appropriate for those stroke survivors with dense hemiplegia [2]. Typically, stroke survivors with more severe UL impairment are largely dependent upon the therapist for physical assistance to engage in meaningful practice [13]. As detailed above, RT-UL offers these stroke survivors an opportunity for independent or semi-supervised intensive UL practice. Conversely, stroke survivors with less impaired UL were underrepresented in the group prescribed RT-UL. With greater levels of UL movement and power, the priority for these patients would likely be on more complex and real-world object usage for task-specific practice [20].

The intensity of practice is important for upper limb recovery for stroke survivors [21]. In this study, RT-UL was identified to be an intensive form of UL practice with patients engaged in active therapy more than three-quarters of the time when on the robotic device. In a comparative study, patients participating in a Graded Repetitive Arm Supplementary Program (GRASP), also an adjunct UL intervention for stroke survivors, engaged in active UL practice only 64% of their session [22]. This high level of intensity from RT-UL practice is a notable finding from the perspective that the efficacy of RT-UL, as seen in clinical trials, has been primarily attributed to this intensity of practice [3]. It is, therefore, encouraging that this intensity of practice was evident within a real-world clinical setting where human and organisational variables are also influencing patient RT-UL practice.

UL practice involving computer games has previously been considered a form of "pre-functional" training as opposed to task-orientated practice [20]. Task-orientated practice should involve the direct practice of activities of daily living [20]. This potential limitation of RT-UL may in part explain the inconclusiveness within the literature as to whether RT-UL improves outcomes at an activity and participatory level. Mehrholz et al. [3] in their systematic review concluded that RT-UL may improve stroke survivors' capacity to engage in activities of daily living whereas Veerbeek et al. [4], in a systematic review drawing from a similar pool of studies, alternatively concluded that RT-UL did not significantly improve activities of daily living. Overall, RT-UL could be considered a "bridging" intervention, facilitating a basic form of movement practice until there is sufficient UL strength and power to advance to more complex and real-world task-specific practice.

Therapists in the current study routinely used the evaluative tools of the InMotion2 which involved the detailed measurement of UL kinematic control and force. On average stroke survivors underwent RT-UL evaluation twice during their program, typically at the beginning and end of the rehabilitation stay. Evaluative reports were produced by the InMotion2 computer and included graphical representations of the stroke survivors' UL performance in relation to UL acceleration, speed, accuracy, and movement coordination. Stroke survivors have previously identified that feedback on performance from rehabilitative technology is important and may enhance motivation for therapy and practice [23]. This would seem particularly important where robotic evaluative measures can detect and display very subtle improvements or change both in quality and degree of movement for stroke survivors [24]. Such changes may fail to be detected or be poorly represented through less sensitive or commonly used clinical outcome measures.

The InMotion2 is one of only a few robotic devices that has an optional hand module that can be used to facilitate hand movements in combination with shoulder and elbow movements. However, the hand module was used only a quarter of the time with patients in this study. This is notable from the perspective that recovery of hand function is crucial to independence in a range of activities of daily living [25,26]. The hand module is a relatively new addition to the InMotion2 device and the limited use seen in this study may be reflective of the unique technical challenges associated with the design of robotic hand componentry for stroke survivors [27]. Therapists also may have had limited knowledge of how to use and apply the hand module or simply did not feel the patient had sufficient hand function to effectively use the module. The exact reasons for the limited use of the hand module are not clear and merit further exploration (e.g., interviewing of prescribing therapists and patients) to potentially improve the design and functionality of the device.

Finally, physiotherapists were found to be the primary prescribers of RT-UL at the rehabilitation unit when compared to their occupational therapy colleagues. This could be attributed to the fact that there was only a single robotic device available and the device was located in the physiotherapy area of the gym. In the pre-implementation focus groups, therapists had highlighted that the availability of only a single device may create unique logistical challenges relating to location and interdisciplinary use [17]. Additionally, this may be reflective of differences between disciplines in the focus of UL therapy, with occupational therapists potentially prioritising the practice of specific activities of daily living over the use of RT-UL. Again, exploration of therapists' experiences through interviews or focus groups would provide insight into how each discipline approaches and values the use of RT-UL as part of their UL rehabilitation programs for stroke survivors.

Study limitations

There were several limitations to this study. This study investigated the use of RT-UL within a single rehabilitation facility in Australia and conclusions from this study are therefore reflective of this healthcare setting. Transferability of results to healthcare settings more broadly should be made with caution. Despite the investigator (NF) being vigilant to be unobtrusive and not to interfere with the decision-making of the therapist in relation to the use of RT-UL during data collection, it is possible that therapists altered their behaviour in response to the audits being conducted. Finally, this study did not extend to the collection and analysis of UL outcome measures, so no conclusions could be made as to the impact on UL recovery or outcomes for these particular individuals, the appropriateness of the timing of RT-UL commencement, or cessation for individual stroke survivors.

Conclusions

This study found that RT-UL is a sustainable intervention for stroke survivors within an inpatient rehabilitative setting. Stroke survivors with severe UL impairment were more likely to be prescribed RT-UL, however, use of the optional hand module was limited. Further research is needed to explore the clinical reasoning behind the prescription of RT-UL by therapists and the most effective time to incorporate RT-UL along the rehabilitative continuum for stroke survivors.

Ethical approval

Ethical approval for the study was gained from The Prince Charles Hospital Human Research Ethics Committee (HREC) (HREC/16/QPCH/36) and the Australian Catholic University HREC (2016-266R). The research programme was approved as low risk and a waiver of consent was granted for the audits.

Disclosure statement

All authors declare that there were no conflicts of interest in this study.

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Health and safety

All mandatory health and safety procedures have been complied with in the course of conducting any experimental work reported in this paper.

ORCID

Nicholas Flynn http://orcid.org/0000-0001-5282-9695
Elspeth Froude http://orcid.org/0000-0002-6863-2317
Deirdre Cooke http://orcid.org/0000-0003-0920-2031
Suzanne Kuys http://orcid.org/0000-0002-6263-4223

References

[1] Stroke Foundation. Clinical guidelines for stroke management 2017; 2017 [cited 2018 Jun 11]. Available from: https://informme.org.au/en/Guidelines/Clinical-Guidelines-for-Stroke-Management-2017

[2] Teasell R, Cotoi A, Chow J, et al. Stroke rehabilitation clinicians handbook; 2020 [cited 2020]. Available from: http://www.ebrsr.com/

[3] Mehrholz J, Pohl M, Platz T, et al. Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke. Cochrane Database Syst Rev. 2018;9(9):CD006876.

[4] Veerbeek JM, Langbroek-Amersfoort AC, van Wegen EEH, et al. Effects of robot-assisted therapy for the upper limb after stroke. Neurorehabil Neural Repair. 2017;31(2):107–121.

[5] Rodgers H, Bosomworth H, Krebs HI, et al. Robot assisted training for the upper limb after stroke (RATULS): a multicentre randomised controlled trial. Lancet. 2019;394(10192):51–62.

[6] McCluskey A, O'Connor D. Implementing evidence: closing research–practice gaps. In: Hoffmann T, Bennett S, Mar CD, editors. Evidence-based practice across the health professions. 3rd ed. Chatswood: Elsevier Health Sciences; 2017. p. 384–408.

[7] Shelton RC, Lee M. Sustaining evidence-based interventions and policies: recent innovations and future directions in implementation science. Am J Public Health. 2019;109(S2):S132–S134.

[8] Bionik Labs. Bionik Labs; 2017 [cited 2017 Jun 29]. Available from: http://bionikusa.com/

[9] Wiltsey Stirman S, Kimberly J, Cook N, et al. The sustainability of new programs and innovations: a review of the empirical literature and recommendations for future research. Implementation Sci. 2012;7(1):17.

[10] Keith RA, Granger CV, Hamilton BB, et al. The functional independence measure: a new tool for rehabilitation. Adv Clin Rehabil. 1987;1:6–18.

[11] Radomski MV, Latham CAT. Occupational therapy for physical dysfunction. 7th ed. Philadelphia (PA): Wolters Kluwer Health; 2014.

[12] Carr JH, Shepherd RB, Nordholm L, et al. Investigation of a new motor assessment scale for stroke patients. Phys Ther. 1985;65(2):175–180.

[13] Hayward KS, Barker RN, Wiseman AH, et al. Dose and content of training provided to stroke survivors with severe upper limb disability undertaking inpatient rehabilitation: an observational study. Brain Impairment. 2013;14(3):392–405.

[14] Greenhalgh T, Wherton J, Papoutsi C, et al. Beyond adoption: a new framework for theorizing and evaluating nonadoption, abandonment, and challenges to the scale-up, spread, and sustainability of health and care technologies. J Med Internet Res. 2017;19(11):e367.

[15] Nadalin Penno L, Davies B, Graham ID, et al. Identifying relevant concepts and factors for the sustainability of evidence-based practices within acute care contexts: a systematic review and theory analysis of selected sustainability frameworks. Implement Sci. 2019;14(1):108.

[16] Flynn N, Froude E, Cooke D, et al. Repetitions, duration and intensity of upper limb practice following the implementation of robot assisted therapy with sub-acute stroke survivors: an observational study. Disabil Rehabil Assist Technol. 2020. DOI:10.1080/17483107.2020.1807621.

[17] Flynn N, Kuys S, Froude E, et al. Introducing robotic upper limb training into routine clinical practice for stroke survivors: perceptions of occupational therapists and physiotherapists. Aust Occup Ther J. 2019;66(4):530–538.

[18] Stewart C, McCluskey A, Ada L, et al. Structure and feasibility of extra practice during stroke rehabilitation: a systematic scoping review. Aust Occup Ther J. 2017;64(3):204–217.

[19] Imms C, Wallen M, Laver K. Robot assisted upper limb therapy combined with upper limb rehabilitation was at least as effective on a range of outcomes, and cost less to deliver, as an equal dose of upper limb rehabilitation alone for people with stroke. Aust Occup Ther J. 2015;62(1):74–76.

[20] French B, Thomas LH, Coupe J, et al. Repetitive task training for improving functional ability after stroke. Cochrane Database Syst Rev. 2016;(11):CD006073.

[21] Kwakkel G. Impact of intensity of practice after stroke: issues for consideration. Disabil Rehabil. 2006;28(13–14):823–830.

[22] Connell LA, McMahon NE, Simpson LA, et al. Investigating measures of intensity during a structured upper limb exercise program in stroke rehabilitation: an exploratory study. Arch Phys Med Rehabil. 2014;95(12):2410–2419.

[23] Nasr N, Leon B, Mountain G, et al. The experience of living with stroke and using technology: opportunities to engage and co-design with end users. Disabil Rehabil Assist Technol. 2016;11(8):653–660.

[24] Dipietro L, Krebs HI, Fasoli SE, et al. Submovement changes characterize generalization of motor recovery after stroke. Cortex. 2009;45(3):318–324.

[25] Kim D. The effects of hand strength on upper extremity function and activities of daily living in stroke patients, with a focus on right hemiplegia. J Phys Ther Sci. 2016;28(9):2565–2567.

[26] Faria-Fortini I, Michaelsen SM, Cassiano JG, et al. Upper extremity function in stroke subjects: relationships between the international classification of functioning, disability, and health domains. J Hand Ther. 2011;24(3):257–265.

[27] Aggogeri F, Mikolajczyk T, O'Kane J. Robotics for rehabilitation of hand movement in stroke survivors. Adv Mech Eng. 2019;11(4):168781401984192.

9.6 Appendix 6 - Protocol for Study 2 observation study

Patient information & outcome measures form

- Demographic data and clinical outcome measures will look to be collected for **all newly admitted** neurological patients less than 3 months post event, with upper limb impairment, who are receiving upper limb therapy as part of their rehabilitative program, over the age of 18 years and able to understand simple instructions.
- The exclusion criteria will be patients with a serious complicating medical illness.
- These patients will be identified by the therapy staff (or study investigators).
- Study investigators will complete the Post-*Introduction Participant Information & Outcome Measure Form* (see below) from the medical chart and therapist assessment forms.

Clinical practice observations of usual therapy sessions

- The clinical practice audit will look to quantify the amount of upper limb therapy time and number of upper limb repetitions performed in gym-based therapy sessions in which a key focus is the retraining of the affected upper limb.
- A group of convenience from the subacute neurological patients (identified above) will be observed.
- This will be done through the observation of therapy sessions conducted either by the occupational therapist, physiotherapist, allied health assistant or therapy student.
- Study investigators will conduct the audit and will be unobtrusive, not interfere or assist with the therapy session and be able to observe and hear the therapy session.
- The patients to be observed by the study investigators will be identified by therapy staff or study investigators.
- The *Study 2 observation study recording form* (see below) will be used by the study investigators to record their observations of the gym-based therapy sessions.
    - For each session, record the patient ID code (retrieved from aforementioned *Pre-Introduction Participant Information & Outcome Measure Form*), session number, treating therapist and their discipline, date of therapy session, activity category, start & end of each individual activity, number of upper limb

movement repetitions performed in that activity and other details of the activity.

- The time (i.e. 24 hour) will be noted at the commencement of the session, cessation of an individual activity and at the cessation of the session.
    - Commencement of session – Collection of patient by the treating therapist with the patient having been brought from the ward or the preceding therapy session
    - Cessation of Session – Farewell/concluding statement by treating therapy staff member
- *For all categories, repetitions will only be counted if the movement or activity is considered therapeutic* – that is, instructed or performed for the purpose of therapy. Therefore within sessions that are being observed do not record movement or activity associated with assessment or that are incidental in nature.
- Use 'other' to record any activities not specified or if unsure. If unsure if the activity was therapeutic, then record as therapeutic.
- Do not record the following therapy sessions: initial or discharge evaluation therapy sessions, sessions that are primarily focused towards addressing non-motor issues (e.g. cognitive/perceptual) or equipment prescription (e.g. wheelchair or fabrication of a splint).
- Repetitions to include obvious attempts at movement by the patients (whether or not they are successful).
- Where possible, the observer will look to distinguish between time devoted to set-up versus when the actual therapy task is commenced. Commencement of the therapy task will be defined as when the patient first initiates the initial movement of the exercise or functional task having been instructed and/or presented with the therapeutic equipment.
- Where the patient is observed to be resting while therapist is setting up the task the time will be categorised a "set up"

Category Definitions

Category	Definition	Definition of a Single Repetition	Example
Passive Exercise (PE)	Any movement of the limb by a therapist or a device, without any effort by the patient	One movement from initial position and back again	Stretches, splinting, positioning, ES
Active Exercise (AE)	Any movement in which the patient attempted or moved the limb through a specific motion. (Assistance to obtain the last 25% of the range of motion is acknowledged as active).	One movement from initial position and back again	Side-lying shoulder flexion/extension Wrist flexion/extension seated at desk EMG-ES Active movement with use of skateboard or rollers (and straw used to provide feedback)
Functional Task (FT)	Any movement that accomplishes/attempts to accomplish a functional task. Where applicable movements are to be recorded as subunits of the whole task.	One completion of the functional task	Reaching for a cone Throwing a beanbag Whole task: Buttering a slice of bread with following subunits counted as movements: • Collecting bread from bag • Picking up knife • Removing lid from butter container • Spreading butter on bread (counting each spreading movement) 1.
Robotic Task (RT)	Participation in a therapy game (not evaluation) on the InMotion	One movement in accordance with the InMotion repetition definition (dependent on task)	Clock, squeegee, pong. Also noting of planar and planar hand tasks.
Sensory	Any activity done to receive/enhance somatosensory input	One period of the activity	Weight bearing where one period of bearing weight through the affected arm was counted as one repetition, massage of the upper limb
Rest Break (RB)	Patient is not engaged in an identifiable therapeutic activity	N/A	Seated in wheelchair or lying supine on plinth between activities
Fine motor	Tasks or exercises that primarily involve movement(s) of the hand and wrist	N/A	Screwing on a bolt Threading beads

Gross Motor	Tasks or exercises that clearly incorporate both movement of the elbow and shoulder as well as the hand and wrist	N/A	Reaching for a cone Throwing a sandbag
Set-up (SU)	Therapist is engaged in the preparation of the gym environment and/or the patient to facilitate an upper limb therapy task	N/A	Transferring patient onto plinth from wheelchair Instructing and demonstrating the proposed therapy task Collecting cones from storage area Applying FES device to patient's upper limb
Other (O)	Any activities not specified under the categories above	N/A	Assessment, Education, Mobility retraining, Balance retraining, set up of LL tasks

Functional Task Definitions

All tasks include counting of attempts at these subunits (including attempts at the subunits of complex functional tasks).

Functional Task	Description	Definition of a Single Repetition (Subunits)
Drawing (FM)	Patient seated drawing or practicing handwriting. Not possible to accurately count in subunits or individual movements	Whole task counted as one repetition (with emphasis on quantifying the time spent on the task)
Bead threading (FM)	Patient seated threading individual beads onto plastic thread or removing the beads from the plastic thread (note this is a different task to the "bead along wire" defined below)	Each bead threaded counted as one repetition Each bead(or group of beads) removed in one movement counted as one repetition (This is a separate repetition to the bead being threaded on)

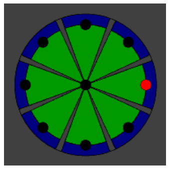
Screwing/Unscrewing bolts (FM)	Patient seated at table screwing and unscrewing different sized bolts.	Each bolt screwed on (or attempt to be screwed) counted as one repetition Each bolt unscrewed (or attempted to be unscrewed) counted as one repetition NB: Individual movements in applying the screws were NOT counted as repetitions.
Throwing sandbags (GM)	Sandbags picked up and thrown into the bucket	Each sandbag thrown at bucket as one repetition
Transporting balls/sandbags(GM)	Transporting balls/sandbags between two buckets (while standing or sitting)	Ball/sandbag passed from one bucket to the next counted as one repetition
Tongs and blocks (GM)	Blocks picked up from the box and placed on table (or into another box) using tongs (or hand)	Each block picked up and placed on the table (successful or attempted) counted as one repetition
Colour tension pegs (GM)	Individual pegs of various tensions are individually squeezed and placed (or removed) from a pole (vertical or horizontal) (IM001 Session 5 1114)	Each peg placed on pole (or removed) counted as one repetition
Pressing clicker (FM)	Client presses the "clicker" with the affected hand to count stands	Each click counted as one repetition (e.g. done when counting sit to stands)
Blocks and Box	Lifting of individual blocks and placing them over the divider into the opposing box. Or another box task was lifting a block out of bucket and placing it on the table (IM003 Session 2 0945).	Each block picked up and placed over the divide or onto the table is one repetition
Screwing/unscrewing jar	Collecting jar/container from shelf and then attempting unscrewing or screwing of jar and placing jar back on shelf. (This task can also involve just the screwing and unscrewing of jar while seated without the collection from the shelf with the same subunits applying)	Subunits or one counted repetition would include : • Unscrewing the jar (including where the affected hand is stabilising the jar as opposed to grasping the jar) = 1 repetition • Screwing the jar (including where the affected hand is stabilising the jar as opposed to grasping the jar) = 1 repetition

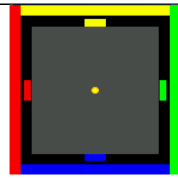
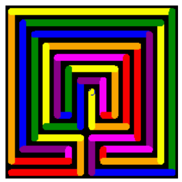
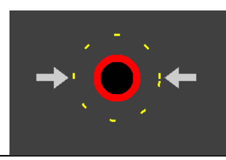
		• Collecting the jar from the shelf (including where the affected hand is stabilising the jar as opposed to grasping the jar) = 1 repetition • Repositioning the jar back onto the shelf (including where the affected hand is stabilising the jar as opposed to grasping the jar) = 1 repetition
Blue Bilateral Incline Board	Push up slide handle on blue incline board with either the affected hand or using both hands	One repetition is where the slide handle is pushed up and then brought back down to its original starting position
Bead along wire	Bead is threaded along wire frame. (Different activity to bead threading listed above)	One repetition is when the bead is moved from its starting position, on one side of the apparatus, to the other side. An attempt can be counted when the hand notably drops to the table from the bead (OR the bead is released and drops back to its original starting position) and then a new repetition is started when the patient re-grasps the bead to complete the transportation to the final position on the other side of the apparatus.
Rings over loop	Coloured rings are threaded over the semi-circle pipe apparatus	One repetition is when the ring is moved from its starting position, on one side of the apparatus, to the other side. An attempt can be counted when the ring is released and drops back to its original starting position and then a new repletion is started when the patient re-grasps the ring to complete the transportation to the final position on the other side of the apparatus.
Rings between poles	Transporting rings between two separate poles (while standing or sitting)	One repetition is when the ring is transported from one pole to the next
Cups and shelf	Patient grasp cup from tabletop and places on shelf in front (or collects from cup form shelf and places back on the table)	One repetition is when the cup is grasped, transported to the shelf and released on the shelf. Alternatively a repetition is also counted when the cup is re-grasped, transported from off the shelf and released on the table.
Rolling theraputty	Rolling of theraputty with affected hand.	1 repetition is the rolling of theraputty ball into one long piece (i.e. ready to be cut)
Cutting theraputty	Cutting of theraputty into singular pieces with knife and fork.	1 repetition is one piece of theraputty cut (also includes attempts at cutting where patient is attempting to cut but momentarily rests knife
Making coffee	Patient prepares cup of coffee in the OT kitchen area.	

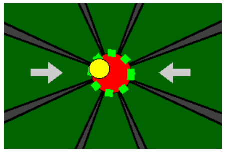
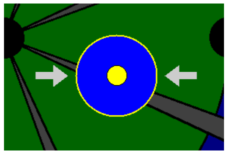
		and fork (but may not let go of knife and fork) and then again reattempts to cut the theraputty)
Washing Up	Washing up of dishes in OT kitchen area.	Subunits that were included in "Making coffee" were those that involved the use of the "affected" hand (note that the affected hand was not always used in each step of the task). The following subunits were counted as one repetition: • Filling kettle with water • Carrying cup • Carrying spoon • Open coffee jar • Putting lid back on coffee jar • Open sugar satchel • Open fridge door • Open milk bottle (counted if affected hand is used as a stabiliser) • Stirring coffee (with affected hand) The subunits needed to involve the use of the affected hand to be counted as a repetition.
Squeezing peg	Coloured tension peg is squeezed as a grip or pinch strength exercise.	Subunits that were included in "Washing Up" were those that involved the use of the "affected" hand (note that the affected hand was not always used in each step of the task). The following subunits were counted as one repetition: • Washing up cup (or spoon or plate) in sink (count each item washed as distinct single repetitions) • Rinsing cup (or spoon or plate) in sink (count each item washed as distinct single repetitions) • Turn on tap • Turned off tap • Position tea towel 1 repetition will involve each squeeze of the peg by the affected hand or fingers.

Donning/doffing shoes (FM)	Patient seated donning/doffing shoe. Not possible to accurately count in subunits or individual movements (IM004 Session 1 – 0926 & 1013)	Whole task counted as one repetition (with emphasis on quantifying the time spent on the task)
Theraputty squeeze exercise	Patient is asked to simply squeeze the theraputty	1 period of squeezing (even if there are multiple contractions of the grasp) = 1 rep
Cutting up of theraputty	Cutting up theraputty with knife and fork	Each piece cut being 1 repetition (with rolling and moulding of theraputty and handling of cutlery included in this repetition*)
Breaking theraputty rings exercise	Patient prepares a theraputty ring and then breaks it apart with fingers of affected hand	Each breaking of the ring apart with fingers = 1 rep (with rolling and moulding of theraputty included in this repetition)
Pulling apart theraputty exercise	This involves the patient moulding the theraputty into a long piece and then pulling the piece apart.	Each piece pulled apart = 1 repetition (with rolling and moulding of theraputty included in this repetition)
Pinching theraputty with fingers	This involves the patient completing a series of pinches along the length of a piece of theraputty	Each piece pinched (along the entire length) = 1 repetition (with rolling and moulding of theraputty included in this one repetition)

InMotion Definitions of Practice

Functional Task	Description	Definition of a Single Repetition (Subunits)
Reaching clock tasks	Patient starts at the central point of the clock and extends out to the presented dot at the 8 points around the circle. Always returning to the central dot after reaching each dot. 	1 repetition involves starting at the central dot of the clock, reaching out to the presented dot on the outer edge of the clock and then returning to central dot (i.e. includes out and in)
Playback clock task	Patient is required to remain statically positioned in the central circle and resist the force applied by the robot	1 repetition involves each application of the forces as indicated in the top right-hand corner of the screen (occurs 16 times per game)
Squeegee task	Patient is required to wipe the entire picture clean and involves multiple movements 	1 repetition is where the patient has completed wiping the entire picture (or attempted this). Individual movements are not counted.
Pong	Patient is required to move the bar to repel the moving dot.	1 repetition is where the patient repels the dot.

		
Cretan Square Maze	Patient is required to move from point to point through the square maze. 	1 repetition is where the patient moves to the presented point in the maze.
Race	Patient is required to guide the dot through a series of gates. 	1 repetition is where the patient moves through a single gate.
Grasp Adaptive	Patient is required to grasp the flashing dot with use of the hand module 	1 repetition is each grasp and release of the highlighted dot

Reach Adaptive	Patient is required to reach to a highlighted dot and “grasp/release” the dot using the hand module before then returning to “grasp/release” the centre dot again. 	1 repetition involves both the reach and grasp of the highlighted dot on the outer of the clock and ALSO returning to grasp the central dot
Pick Adaptive	Patient is required to reach to a highlighted dot and “grasp (pick up)” the dot using the hand module and then “releasing” dot again at the designated point on the clock. 	1 repetition involves both the reach and grasp of the highlighted dot on the outer of the clock and ALSO returning to grasp the central dot

9.7 Appendix 7 - Study 2 observation study recording form

Patient ID Code: ___________ Date of Therapy Session: ___________ Session No.:___________ Therapist's Name (OT/PT):

Activity Category (RT, PE, AE, FT, S, RB, SU, O)	Start Time of Activity		End Time of Activity	No. Reps	Finer Motor (FM) /Gross Motor (GM)	Aids Used (ES, Mirror Box)	Comments: (e.g. active assisted, type of whole functional task, definition of subunit for functional task, involvement of OT/PTA/Carer)
	Total Number of Repetitions: Start of Session Time: ___________ End of Session Time: ___________ Total Time of Session: ___________						

9.8 Appendix 8 - The Theoretical Domains Framework with definitions and component constructs

1. Knowledge (An awareness of the existence of something)	Knowledge (including knowledge of condition/scientific rationale) Procedural knowledge Knowledge of task environment
2. Skills (An ability or proficiency acquired through practice)	Skills Skills development Competence Ability Interpersonal skills Practice Skill assessment
3. Social/professional role and identity (A coherent set of behaviours and displayed personal qualities of an individual in a social or work setting)	Professional identity Professional role Social identity Identity Professional boundaries Professional confidence Group identity Leadership Organisational commitment
4. Beliefs about capabilities (Acceptance of the truth, reality or validity about an ability, talent or facility that a person can put to constructive use)	Self-confidence Perceived competence Self-efficacy Perceived behavioural control Beliefs Self-esteem Empowerment Professional confidence
5. Optimism (The confidence that things will happen for the best or that desired goals will be attained)	Optimism Pessimism Unrealistic optimism Identity
6. Beliefs about Consequences (Acceptance of the truth, reality, or validity about outcomes of a behaviour in a given situation)	Beliefs Outcome expectancies Characteristics of outcome expectancies Anticipated regret

	Consequents
7. Reinforcement (Increasing the probability of a response by arranging a dependent relationship, or contingency, between the response and a given stimulus)	Rewards (proximal/distal, valued/not valued, probable/improbable) Incentives Punishment Consequents Reinforcement Contingencies Sanctions
8. Intentions (A conscious decision to perform a behaviour or a resolve to act in a certain way)	Stability of intentions Stages of change model Transtheoretical model and stages of change
9. Goals (Mental representations of outcomes or end states that an individual wants to achieve)	Goals (distal/proximal) Goal priority Goal/target setting Goals (autonomous/controlled) Action planning Implementation intention
10. Memory, attention and decision processes (The ability to retain information, focus selectively on aspects of the environment and choose between two or more alternatives)	Memory Attention Attention control Decision making Cognitive overload/tiredness
11. Environmental context and resources (Any circumstance of a person's situation or environment that discourages or encourages the development of skills and abilities, independence, social competence and adaptive behaviour)	Environmental stressors Resources/material resources Organisational culture/climate Salient events/critical incidents Person × environment interaction Barriers and facilitators
12. Social influences (Those interpersonal processes that can cause individuals to change their thoughts, feelings, or behaviours)	Social pressure Social norms Group conformity Social comparisons Group norms Social support

	Power Intergroup conflict Alienation Group identity Modelling
13. Emotion (A complex reaction pattern, involving experiential, behavioural, and physiological elements, by which the individual attempts to deal with a personally significant matter or event)	Fear Anxiety Affect Stress Depression Positive/negative affect Burn-out
14. Behavioural regulation (Anything aimed at managing or changing objectively observed or measured actions)	Self-monitoring Breaking habit Action planning

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