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Ambulation recovery after stroke

Niruthikha Mahendran

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Abstract

Most stroke survivors regard successful independent ambulation important. However, ambulation recovery is limited following stroke. Historically, limited availability of objective tools and measures to characterise free-living ambulation recovery has restricted investigation of this outcome after survivors return home. However, commercially available devices, including accelerometers and portable global positioning systems, are now available. Thus, this thesis aimed to characterise free-living ambulation recovery over the first six months after stroke survivors returned home from hospital and determine what factors at discharge contributed to ambulation recovery across this time.

The first study of this thesis investigated the concurrent validity and retest reliability of accelerometers (ActivPAL™ and Sensewear Pro_2 Armband) and global positioning systems (GPS) (Garmin forerunner 405CX) to measure free-living ambulation after stroke. Measures of step counts, time spent walking, energy expenditure, distance and location were taken during walking tasks that impose demands similar to those encountered when walking in the community as well as free-living community ambulation over four days. This study determined that the ActivPAL™ was valid and reliable for measuring ambulation after stroke. The GPS was valid and reliable for all measures except distance, whereas the Sensewear Pro_2 Armband recorded with high error during all walking tests.

The second study aimed to characterise ambulation activity after stroke across the first six months following discharge from hospital and investigate how ambulation activity changed across this time period. Free-living ambulation activity was measured over four days using the ActivPAL™ accelerometer at one, three and six months after stroke survivors left hospital. Measures of volume (daily step counts and time spent walking, sitting/lying, standing and upright), frequency (total number of ambulation bouts; number of bouts and total time spent in short, medium and long duration ambulation bouts) and intensity (number of bouts and total time per day spent in low, moderate and high intensity ambulation bouts) of ambulation activity were collected. This study highlighted that volume of ambulation activity was low across the first six months following hospital discharge, with a majority of ambulation bouts short and low in intensity. Stroke survivors rarely engaged in long duration and high intensity ambulation bouts across the first six months. Daily volume of ambulation activity increased from one month to both three and six months after

discharge from hospital through an increase in medium duration and moderate intensity ambulation only.

The third study aimed to determine what factors at discharge were related to and predicted ambulation activity outcomes over the first six months following hospital discharge in stroke. Factors including age, fatigue, mood, executive function, gait speed, gait endurance, perceived stroke recovery, pre-stroke physical activity, ambulatory self- efficacy and perceived health outcome and status were assessed for their ability to predict volume, frequency and intensity of ambulation activity at one, three and six months after hospital discharge. Gait endurance predicted all outcomes of ambulation activity at one month, and intensity of ambulation at three and six months after discharge from hospital. Beyond one month, pre-stroke activity, age and executive function also contributed to ambulation activity outcomes.

The fourth study explored characteristics of community ambulation across one, three and six months after stroke survivors were discharged from hospital and determined if community ambulation changed over time. Stroke survivors regularly accessed their community, spending most time each day in long duration and moderate intensity ambulation bouts, except at three months, where most time was spent in medium duration bouts. No changes in community ambulation were observed until six months, when stroke survivors spent more time in long duration ambulation bouts.

The final study aimed to determine what factors at discharge predicted community ambulation outcomes at one, three and six months following hospital discharge. Discharge gait endurance best predicted community ambulation at one month after hospital-discharge. However, similar to ambulation activity, beyond one month, age, pre-stroke activity and executive function predicted outcomes. Volume of community ambulation could not be predicted by any factor at discharge after one month.

This thesis concludes that, ambulation activity after stroke is low following discharge from hospital. Improvements in activity are generally realised through increased time spent in medium duration and moderate intensity ambulation bouts, with no change in long duration or high intensity activity over time. Recovery of community ambulation is not observed until months after discharge home. Discharge gait endurance best predicts all ambulation outcomes at one month after hospital discharge. After one month, age, pre-stroke activity and executive function contribute to free-living ambulation outcomes. Increasing gait endurance should be a goal during rehabilitation after stroke. Further, characteristics of stroke survivors who are younger, active prior to stroke and able to initiate and manage multiple tasks should be harnessed during management of free-living ambulation recovery. Further investigation of other factors is required, as not all outcomes were explained by the factors measured in this thesis.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my research higher degree candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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Publications during candidature

<u>Peer-reviewed publications</u>

Submitted for review

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Publications included in this thesis

No publications included.

Contributions by others to the thesis

The PhD candidate was primarily involved in the literature review, design, ethics applications, recruitment, data collection, data analysis and manuscript and thesis preparation for studies 1 to 5. The candidate was also primarily involved in dissemination of research at local and national conferences.

Supervisors Professor Sandra Brauer, and Dr Suzanne Kuys were also involved in study design, data collection and analysis, and review of drafts for manuscript and thesis chapters. They also assisted with funding applications for equipment and conference related travel costs. Professor S Brauer has also assisted with dissemination of study 1 and study 2 findings at international conferences.

Dr Dion Scott has assisted in developing MATLAB programming for device data analysis for studies 2 and 4.

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Statement of parts of the thesis submitted to qualify for the award of another degree

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Keywords

Stroke, ambulation, physical activity, community walking, gait, recovery, rehabilitation

Australian and New Zealand Standard Research Classifications (ANZSRC)

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920403, Disability and Functional Capacity, 40%

Fields of Research (FoR) Classification

1103 Clinical Sciences 80%

1109 Neurosciences 20%

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List of Abbreviations used in the thesis

10MTW	10 metre timed walk test
6MWT	6-minute walk test
AIHW	Australian Institute of Health and Welfare
ANOVA	Analyses of variance
APE	Absolute percentage of error
ASCQ	Ambulatory self-confidence questionnaire
CBRT	Community-based rehabilitation therapy
CI	Confidence interval
DHS	Depression-Happiness scale
EQ-5D	European Quality of Life -5D
FSS	Fatigue severity scale
GPS	Global positioning systems
ICC	Intraclass correlation coefficient
ICF	International classification of functioning and disability
IDEEA	Intelligence device for energy expenditure and physical activity
IQR	Inter-quartile range
LSD	Least significant difference
m	Metre
m/s	Metres/second
MAS	Motor assessment scale
METS	Metabolic Equivalents
min	Minute
MMSE	Mini Mental State Examination
n	Number
NSF	National Stroke Foundation
OR	Odds Ratio
PASE	Physical activity scale for the elderly
PASIPD	Physical activities scale for individuals with physical disabilities
RDTU	Rehabilitation day therapy unit
Resi-TCP	Residential Transitional care program

s	Seconds
SAM	Step activity monitor
SD	Standard deviation
SEM	Standard error of the mean
SIS	Stroke impact scale
SQRT	Square-root
TCP	Transitional care program
TMT	Trail making test
TMTB-A	Trail making test part B minus part A
VAS	Visual analogue scale
WHO	World Health Organisation

Chapter 1

Introduction

This chapter will introduce the reader to the thesis topic. It will present the problem, significance and thesis aims.

1.1. Introduction

Successful recovery of ambulation is an important goal during rehabilitation after stroke (Pound et al., 1998). However following stroke, ambulation recovery can be limited (Jorgensen et al., 1995b). When assessing free-living ambulation recovery, it is useful to consider both ambulation that falls within the activity and participation domains of the International classification of functioning and disability (ICF) (WHO, 2001). In individuals with chronic stroke, low levels of free-living ambulation are observed in both ambulation activity (activity) and community ambulation (participation) (English et al., 2014; Robinson et al., 2011b). However, the process by which such limited recovery occurs is unknown. It is believed that most potential for functional recovery is observed over the first three to six months after stroke (Jang, 2010; Hendriks et al., 2002; Jorgensen et al., 1995b). Yet there is little accurate and objective measurement of ambulation recovery across this time period. In addition, factors that affect ambulation outcomes need further investigation, especially across the first six months of recovery after stroke, when the most change is observed.

Ambulation activity differs from community ambulation, as it is not selective of ambulation that occurs outside the home and yard (Lord et al., 2004). Rather, it is a measure of total ambulation or walking that occurs each day (Manns and Baldwin, 2009; Shaughnessy et al., 2005). Ambulation activity recovery across the subacute phase, that is the first six months after stroke (NSF, 2010; Ronning et al., 1998), requires more investigation. Some stroke survivors demonstrate increased ambulation activity over this time (Askim et al., 2013; Shaughnessy et al., 2005), while others indicate no change in total daily ambulation (Manns and Baldwin, 2009). Understanding changes in ambulation activity and the factors affecting recovery of ambulation activity over the first six months following stroke is essential to resolving the very low levels of ambulation activity observed in individuals with chronic stroke (English et al., 2014; Michael et al., 2005).

Community ambulation, or community walking (Corrigan and McBurney, 2012), has been defined as the ability to independently mobilise outside the home and yard to negotiate uneven terrain, private venues, shopping centres and other public venues (Lord et al., 2004). It is a vital pre-requisite for successful independent community re-integration (Lord and Rochester, 2005) and a key goal for a majority of stroke survivors (Lord et al., 2004). Many stroke survivors do not ambulate within their communities as frequently as healthy adults (Robinson et al., 2011b; van de Port et al., 2008). This is despite regarding it important, and achieving high scores on clinical measures of gait and function (Robinson et al., 2011b; Lord et al., 2004). Studies based in the

United States of America and New Zealand have reported that between 32% (Viosca et al., 2005) and 60% (Lord et al., 2004; Perry et al., 1995) of stroke survivors successfully achieve independent community ambulation (Viosca et al., 2005; Hill et al., 1997; Perry et al., 1995; Keenan et al., 1984). However the process of community ambulation recovery and factors contributing to such poor outcomes after stroke require further investigation.

A major limitation in understanding community ambulation is the absence of an accurate and reliable way of measuring it. Thus far, most studies have used either self-report measures of community ambulation (Robinson et al., 2011a; Robinson et al., 2011b; Lord et al., 2004; Perry et al., 1995); measured total daily walking activity using accelerometers (household and community ambulation combined) (Haeuber et al., 2004); or inferred community ambulation based on performance in clinical outcome measures such as the timed 10m walk test, Functional ambulatory category or Functional independence measure (Hill et al., 1997; Lerner-Frankiel et al., 1986). Unfortunately, these methods do not provide accurate, reliable and detailed information regarding community ambulation after stroke. No cost-effective, reliable and valid tool, which can successfully isolate and measure community ambulation after stroke has been available thus far. However, with advances in technology and increased capabilities of commercially available devices, more accurate and detailed measurement of ambulation is possible.

Also, when measuring ambulation activity or community ambulation, it is important to capture the spread of ambulation across the day (English et al., 2014; Lord et al., 2011). Thus, measurement of not only total volume of ambulation per day, but also the characteristics of ambulation such as ambulation bout frequency, intensity and patterns of ambulation is required (Roos et al., 2012; Lord et al., 2010; Cavanaugh et al., 2007). These considerations for objective tools and measures are required during investigation of free-living ambulation recovery after stroke.

Finally, many clinic-based measures of impairment and activity limitations, including gait endurance (Fulk et al., 2010; Mudge and Stott, 2009), gait speed (van de Port et al., 2008; Lord et al., 2004), balance (Michael et al., 2005) and cardiovascular dynamics (Manns et al., 2010; Michael and Macko, 2007) share moderate to strong relationships with free-living ambulation outcomes after stroke. In addition to impairments and activity limitations, changes in personal (Robinson et al., 2011a) and environmental (Barclay et al., 2014; Donovan et al., 2008) factors such as goals, priorities, values, financial and social supports and relationships over time after stroke are common (Leach et al., 2011) and can affect ambulation outcomes after stroke. However, one measure alone is unable to explain the large variance in free-living ambulation observed in individuals with chronic stroke (Fulk et al., 2010; Michael et al., 2005). This is because both ambulation activity and community ambulation are complex and multi-factorial (Robinson et al., 2011a; Robinson et al., 2011b; Fulk et al., 2010; Lord et al., 2004; Shumway-Cook et al., 2002). However, with the need for efficient rehabilitation services in Australia, an improved awareness of factors at hospital discharge that predict free-living ambulation outcomes after stroke survivors return home is required. Understanding the role of post-stroke impairments, activity limitations, personal and environmental factors at hospital discharge on free-living ambulation outcomes across the subacute phase of stroke recovery, may assist in improved discharge planning and goal setting during post-stroke management. Thus allowing a more efficient service provision and improved ambulation activity and community ambulation outcomes after stroke.

1.2. Thesis aims

The aim of this thesis will be to investigate ambulation recovery following stroke and determine the factors at hospital discharge that predict outcomes across the first six months after stroke survivors return home from hospital.

This will be done through five studies addressing the following research aims:

1. Determine the validity and reliability of accelerometers (ActivPAL™ and Sensewear Pro_2 Armband) and GPS (Garmin Forerunner 405CX) for the purpose of community ambulation measurement after stroke.
2. Characterise ambulation activity and determine if characteristics of ambulation activity change over the first six months following hospital discharge after stroke.
3. Identify factors at discharge that predict ambulation activity outcomes over the first six months following discharge from hospital after stroke.
4. Characterise community ambulation and determine if characteristics of ambulation activity change over the first six months following hospital discharge after stroke.
5. Identify factors at discharge that predict community ambulation outcomes over the first six months following discharge from hospital after stroke.

Hypotheses for these aims will be presented in future chapters and the rationale for these will be developed in the following background chapter.

Chapter 2

Background

Successful ambulation recovery is important following stroke. However, the process of ambulation recovery and the factors that affect outcomes across the first six months after stroke requires further investigation. This chapter will introduce the thesis cohort and the framework that will be used to explain the relationship between factors and ambulation outcomes. It will provide a review of existing literature on ambulation recovery after stroke, and factors that influence outcomes. Further it will discuss in detail the reasoning for thesis methods and new proposed measurement methods.

2.1. Stroke and ambulation

Stroke is a leading cause of disability in Australia (AIHW, 2013). Each year, around 50,000 Australians suffer a stroke, resulting in an annual cost of approximately AU$5 billion to both services and families (Cadilhac et al., 2010; NSF, 2012). In Australia, stroke is the third largest contributor to disease burden, accounting for 4.5% of total burden (AIHW, 2013). Globally, stroke is the 4th leading cause of disability in adults (after conditions including HIV/AIDS, depressive disorders and heart disease), with an annual rate of 16 million first time strokes (Mukherjee and Patil, 2011). Each year, around 46.6 million 'disability-adjusted life years' are lost to stroke around the world (AIHW, 2013). With the ageing population and improved survival rates following stroke (Bennett et al., 2014), it is likely that the number of stroke survivors will double in the next 20 years (Mukherjee 2011; NSF 2012). This has significant implications for burden of health and disease resulting from stroke, and highlights the need to investigate strategies to prevent disability in this group.

Ambulation refers to the task of transporting the body from one place to another through the process of walking (Alguren et al., 2009; Eng and Tang, 2007; Perry et al., 1995). Independent ambulation is an important goal following stroke (Pang et al., 2005; Harris-Love et al., 2004; Pound et al., 1998). Ambulation is often limited on admission to stroke rehabilitation units (Brauer et al., 2008; Buurke et al., 2008). However, most stroke survivors make some improvements across the early intensive inpatient rehabilitation period (Buurke et al., 2008). Following this, recovery of ambulation may be limited (Buurke et al., 2008; Hendriks et al., 2002; Jorgensen et al., 1995b), with many stroke survivors continuing to report disability late after stroke (AIHW, 2013). Ambulation is the primary means of achieving physical activity after stroke (Danielsson et al., 2011; Simpson et al., 2011) and a vital precursor for successful community re-integration (Lord and Rochester, 2005). Poor ambulation recovery can contribute to further functional decline (O'Donnell et al., 2010; Rand et al., 2010; Jacobs et al., 2008), diminished health status (Jacobs et al., 2008) and poor quality of life (Leach et al., 2011; Rand et al., 2010; Carod-Artal et al., 2000; Pound et al., 1998). Investigation of ambulation recovery after stroke and the factors affecting outcomes with consideration of all domains of the International classification of function and disability (ICF) are required.

2.2. An introduction to the ICF

The International classification of function and disability (ICF) provides a standardised language system to describe the multi-dimensional characteristics of function and disability (WHO, 2002). It highlights the complex interaction between the domains of body structures and functions, activity performance, contextual factors (including environment and personal factors) and participation (WHO, 2002). Similarly, it explains the influence of impairments activity limitations, participation restrictions, environment and personal factors on the process of disability (WHO, 2002). Formal definitions of the different domains of the ICF are provided below (see table 2.1) (WHO, 2002).

Table 2.1: Definitions of the ICF domains

Terms	**Definition**
Body structures	The anatomical parts of the body, including organs, limbs and their components
Body functions	The physiological functions of the body systems
Impairments	Any problem in body structures or functions that result in significant deviation or loss
Activity	The execution of a task or action by the individual
Activity limitation	Any difficulty in executing an activity
Participation	The execution of an activity in a life situation
Participation restriction	Limitations, or difficulty in completing an activity in a life situation
Environmental factors	External factors that could include social attitudes, architectural characteristics, legal and social structures as well as climate, terrain and other physical environmental dimensions.
Personal factors	Internal factors which influence an individual's experience of disability, such as gender, age, coping styles, social background, education, profession, past and current experiences, overall behaviour patterns and character.

Ambulation is categorised within the activity domain of the International classification of function, disability and health (d450-d469). A range of factors within each ICF domain can influence ambulation outcomes (see figure 2.1). In this thesis, both ambulation activity (activity domain) and community ambulation (participation domain) will be investigated. Further, the role of factors within ICF domains on ambulation outcomes across the subacute phase of stroke will be investigated.

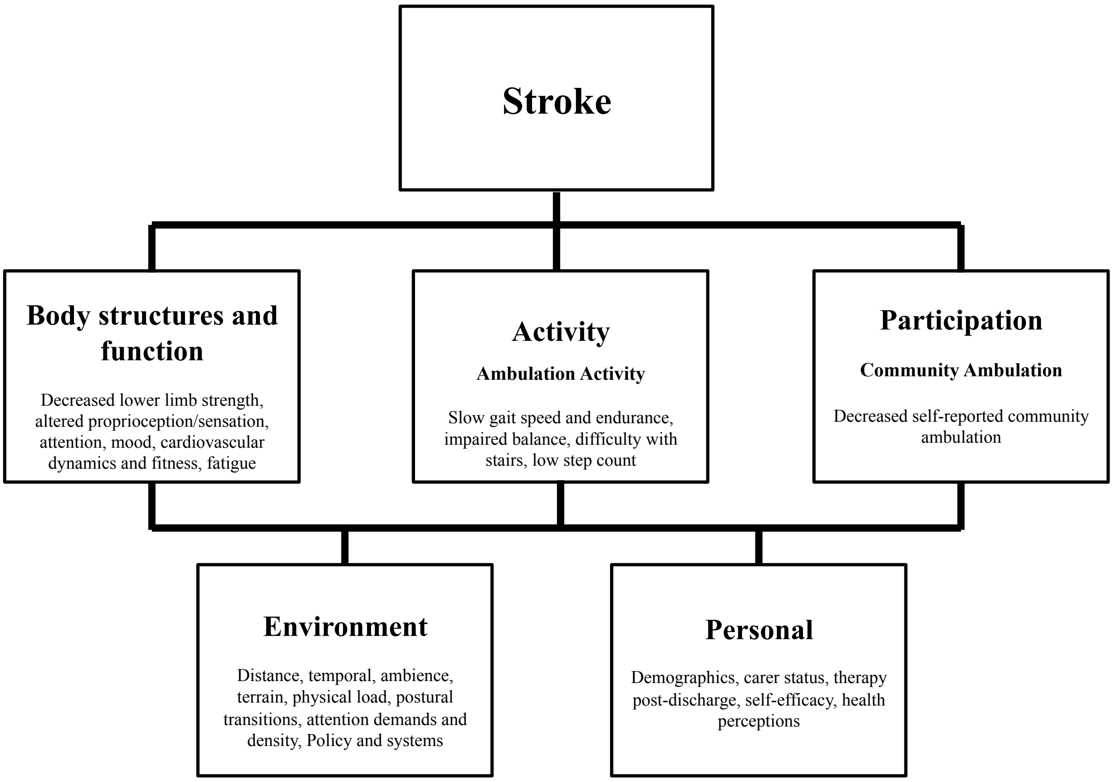

Figure 2.1: Applying the ICF to ambulation recovery

2.3. Ambulation activity

Ambulation activity is a component of physical activity that results from walking (Manns and Baldwin, 2009; Michael and Macko, 2007; Michael et al., 2005; Caspersen et al., 1985). This component of physical activity is beneficial after stroke to improve function and reduce the risk of falls (Billinger et al., 2014), recurrent stroke (Alevizos et al., 2005), cardiovascular disease and mortality (Gordon et al., 2004). Post-stroke changes predispose survivors to low levels of ambulation activity. Such low levels are observed early after stroke during inpatient rehabilitation (Prajapati et al., 2013; West and Bernhardt, 2012; Kuys et al., 2006) and even in those with chronic stroke (English et al., 2014). However, the recovery of ambulation activity across the subacute phase of stroke, especially the first six months of returning home, has received little investigation. Accurate measurement of ambulation activity across this phase and investigation of factors contributing to outcomes are required.

2.3.1. Capturing ambulation activity after stroke – tools for measurement

A number of tools are available for measurement of ambulation activity after stroke. Current measurement tools include direct observation (Sjoholm et al., 2014; West and Bernhardt, 2012; Kuys et al., 2006), self-report questionnaires (Krarup et al., 2007; Washburn et al., 2002; Sallis and Saelens, 2000), pedometers (Macko et al., 2002) and accelerometers. These tools collect measures of ambulation activity duration (Michael et al., 2005), energy expenditure (Rand et al., 2010), steps (Manns et al., 2010; Manns and Baldwin, 2009; Michael and Macko, 2007; Michael et al., 2005), activity bouts (Roos et al., 2012; Manns and Baldwin, 2009; Shaughnessy et al., 2005) and activity counts (Alzahrani et al., 2011). However, consideration of the 'best' tool for ambulation activity measurement after stroke is required.

Direct observation allows for accurate recording of ambulation measures (such as step count) and enables investigators to record interactions and responses within various situations (Shumway-Cook et al., 2002). This tool has often been used to assess activity after stroke within the inpatient setting (Sjoholm et al., 2014; West and Bernhardt, 2012; Kuys et al., 2006). However, direct observation of free-living ambulation can be labour intensive. Further, there is potential for change in activity and participation behaviours with the presence of an observer (Shumway-Cook et al., 2002).

Another common tool for activity measurement is self-report. Self-report tools that have been used with people after stroke include the Physical Activities Scale for Individuals with Physical Disabilities (PASIPD) (Rand et al., 2010; Washburn et al., 2002), the 7-day physical activity recall questionnaire (Zalewski and Dvorak, 2011; Hale et al., 2008) and the Physical Activity Scale for the Elderly (Vahlberg et al., 2013). Self-report tools provide either an overall score of activity, or total energy expenditure based on self-reported activity type, frequency and intensity of activity (Zalewski and Dvorak, 2011; Rand et al., 2010). Such tools are useful for large study samples, as they are cheap and easily administered (Murphy, 2009). However, they are limited in their ability to provide quantitative measures of ambulation, such as step counts, that could be used to characterise activity. Further, self-report questionnaires require sufficient memory recall and receptive communication ability, which are often affected after stroke (Murphy, 2009). Accuracy of self-report tools can also be affected by respondent mood, health status, depression, anxiety and cognition (Murphy, 2009). Stroke survivors have been shown to overestimate activity levels when asked for a verbal report of activity (Zalewski and Dvorak, 2011). Thus, though easily administered, self-report tools often overestimate activity levels after stroke.

More recently, devices have been used to measure activity after stroke. Electronic pedometers are cheap ($10 to $200), portable devices used in healthy populations to measure step counts based on vertical accelerations at the hip when walking (Berlin et al., 2006; Cyarto et al., 2004). However, these devices are invalid against direct observation and unreliable during measurement of post-stroke gait patterns (Fulk et al., 2014; Gebruers et al., 2010; Macko et al., 2002).

Accelerometers are another cost-effective, non-invasive, device-based tool commonly used to measure general physical activity after stroke. They record ‘activity counts’ (units dependent upon the device) based on acceleration detected across various movement planes (e.g. X, Y, Z planes). Accelerometers are classified as ‘uniaxial’, ‘biaxial’ or ‘triaxial’ depending on the number of planes across which they detect acceleration. Uniaxial accelerometers detect acceleration across one plane, biaxial accelerometers detect movement across two planes and triaxial accelerometers detect movement across all three planes. Accelerometers provide a range of objective measures of ambulation activity including step count, activity duration, total activity counts and energy expenditure. Many accelerometers are also deemed valid and reliable for use after stroke. Examples of accelerometers that have been used to measure free-living activity after stroke include the Dynaport mini (Frazer et al., 2013), the Intelligence device for energy expenditure and physical activity (IDEEA) (Alzahrani et al., 2011; Alzahrani et al., 2009; Sakamoto et al., 2008), the Step activity monitor (Fulk et al., 2010; Manns et al., 2010; Manns and Baldwin, 2009; Bowden et al., 2008; Mudge et al., 2007; Michael and Macko, 2007; Michael et al., 2005; Haeuber et al., 2004) (Mudge et al., 2007), the PAL2 (Askim et al., 2014; Askim et al., 2013; Egerton et al., 2006), the Sensewear (Moore et al., 2013; Manns and Haennel, 2012), the Actical (Rand et al., 2010) and the ActivPAL™ (Roos et al., 2012).

Accelerometers provide objective measures of ambulation that can be compared to daily activity recommendations, such as daily step count requirements for health benefits. These devices are also able to provide a simple representation of the spread of ambulation activity across each day, such as number of bouts and time spent in low, moderate and high intensity activity bouts across each day. Accelerometers are unlikely to influence usual ambulation activity behaviours, which is an issue with direct observation tools. Also, unlike self-report tools, accuracy of accelerometer measures is not dependant upon memory recall of stroke survivors. Thus, these appear the best tool for free-living ambulation measurement after stroke.

When considering which accelerometer to use for ambulation activity measurement after stroke, the Step activity monitor (Fulk et al., 2010; Manns and Baldwin, 2009), ActivPAL™ (Taraldsen et al., 2011) and Sensewear Pro_2 Armband (Moore et al., 2012) appear accurate and demonstrate good potential. The Step activity monitor is a biaxial accelerometer that has been commonly used in individuals with chronic stroke (Moore et al., 2013; Manns et al., 2010; Manns and Baldwin, 2009; Bowden et al., 2008; Michael and Macko, 2007; Michael et al., 2005; Haeuber et al., 2004). It is worn above the lateral malleolus of the unaffected leg following stroke (Mudge et al., 2007) and provides daily summaries for measures of step counts as well as activity duration, intensity and bouts (Mudge et al., 2007). Recording frequency can be set manually depending on measurement requirements, to as frequent as three second epochs. The Step activity monitor demonstrates excellent agreement with 3-dimensional gait analysis for measures of step count (Pearson's $r = 0.959$, mean percentage error = -2.6%) (Mudge et al., 2007) and excellent retest reliability for step count (ICC: 0.928 to 0.989) and step-based measures of activity intensity (ICC: 0.830 to 0.985) (Mudge et al., 2008) when worn on the unaffected limb in people with chronic stroke. The Step activity monitor has the highest cost out of these three accelerometers, with initial start up costs of approximately $2000 AUD and per device charges of $600 AUD.

More recently, the ActivPAL™ has been used in individuals with stroke (Roos et al., 2012; Taraldsen et al., 2011). The ActivPAL™ is a uniaxial accelerometer worn on the front of the thigh. The device records electrical signals at a frequency of 10Hz, based on the acceleration resulting from gravity and inclination of the thigh. These signals are then interpreted by proprietary software and classified as postures of sitting, standing or walking (Grant et al. 2010). Based on this information, the device provides real-time measures of step count, activity duration and energy expenditure at 15-second epochs for up to seven days. Real-time data summaries can be further analysed to provide more detailed information regarding characteristics of activity, such as the spread of ambulation throughout the day (Roos et al., 2012). The ActivPAL^{TM} demonstrates excellent agreement with direct observation for measures of time spent in sitting, lying and standing postures (absolute percentage of error = 0%) and postural transitions (absolute percentage error = 0%) in older adults with impaired function, including people with subacute stroke (Taraldsen et al., 2011). It also demonstrates excellent agreement with direct observation for measures of step counts in healthy older adults in both indoor and outdoor environments (absolute percentage of error < 1%) (Grant et al., 2010; Grant et al., 2008) and excellent retest reliability for measures of step counts and time spent walking in healthy young adults (ICC = 0.99, absolute percentage of error < 1%) (Ryan et al., 2006). However, further investigation of the device's accuracy is required at gait speeds below 0.47m/s is required (Taraldsen et al., 2011; Grant et al., 2010; Grant et al., 2008). This device has a start up cost of $750 AUD, with a per device charge of $600 AUD.

The Sensewear Pro$_2$ Armband is a biaxial accelerometer worn on the back of the triceps, and used in individuals with chronic stroke to measure free-living activity (Moore et al., 2013). Information from the accelerometer and multi-sensor derived physiological parameters (e.g. heat flux, skin temperature, galvanic skin response), allow the device to collect measures of step count, time spent walking and energy expenditure (Vanroy et al., 2013). The device provides data at one-minute epochs and can collect for up to 28 days. The Sensewear Pro$_2$ Armband has demonstrated good to excellent agreement for measures of energy expenditure with gold standard methods of measurement (i.e. doubly-labelled water and portable metabolic cart) (ICC: 0.702, Spearman's r = 0.850) in people with chronic stroke (Manns and Haennel, 2012; Moore et al., 2012). However, one more recent study has determined that the accuracy of the device for energy expenditure can be variable (Spearman's r: 0.01 to 0.85) (Vanroy et al., 2013). Further, accuracy around step counts requires further investigation (Manns and Haennel, 2012). It has a start up cost of approximately $240 AUD, and per device cost of approximately $131 AUD.

The ActivPAL^{TM} and Sensewear Pro$_2$ armband provide real-time measures of ambulation activity which can be further analysed to determine how activity is spread across the day (Roos et al., 2012). The ActivPAL^{TM} is also able to distinguish between various postures, such as sit/lying, standing and walking which other devices are unable to measure. This will be useful in measurement of activity and sedentary behaviours after stroke (English et al., 2014). The Sensewear Pro_2 Armband may provide valid measures of energy expenditure based on a combination of accelerometer and physiological parameters. This is different to other accelerometers that only use pre-programmed algorithms for calculation of energy expenditure based on healthy adult populations, with no consideration of physiological parameters. After stroke, energy expenditure during various functional tasks may be different to healthy adults (Chen et al., 2005). Thus, measurement of activity intensity based on physiological parameters indicative of activity intensity may provide accurate measures in this group. Thus, the ActivPAL^{TM} and Sensewear Pro_2 Armband will be considered for use for ambulation activity measurement in this thesis.

2.3.2. Capturing ambulation activity after stroke – measures of ambulation

Traditionally, device-based measures of ambulation activity have included total daily activity after stroke, such as total steps taken per day (Moore et al., 2013; Macko et al., 2005; Michael et al., 2005; Macko et al., 2002; Shaughnessy et al., 2005). However, daily step counts do not provide information regarding the spread of activity and how activity is accumulated across the day (English et al., 2014; Roos et al., 2012; Lord et al., 2010; Manns and Baldwin, 2009). Similar to low activity levels, prolonged periods of sitting also have a negative impact on health (Dunstan et al., 2012). However, interruption of sedentary periods with activity has demonstrated health benefits (English et al., 2014; Dunstan et al., 2012; Healy et al., 2008). Thus, in addition to measuring how much ambulation activity stroke survivors engage in, it is also important to see how ambulation is spread throughout the day. This has led to the development and measurement of 'activity bouts' to add richness to the traditional volume of activity measures (Roos et al., 2012; Lord et al., 2010).

The 'bout' – a measurement unit for activity

The activity bout refers to a period of time during which activity takes place (Roos et al., 2012; Grant et al., 2010; Lord et al., 2010; Manns and Baldwin, 2009; Cavanaugh et al., 2007). It is a measurement unit that has been used to characterise activity in older adults (Grant et al., 2010; Lord et al., 2010; Cavanaugh et al., 2007) and stroke survivors (Frazer et al., 2013; Roos et al., 2012; Manns and Baldwin, 2009). Measurement of bouts is useful as this information can be used to observe how activity and inactivity is spread across the day. For example, it can be used to determine if activity is spread over only one long bout each day, while the remainder of the day is spent inactive, or if activity is spread over several short bursts throughout the day. This information can be used to determine if, and how, activity behaviours can be targeted to improve general health outcomes after stroke (English et al., 2014). In this thesis, ambulation bouts will be used to determine characteristics of ambulation activity following stroke.

Ambulation bouts are usually calculated by applying an algorithm to raw accelerometer data (Roos et al., 2012; Manns and Baldwin, 2009; Cavanaugh et al., 2007). Currently, there are a few definitions of ambulation bouts used in studies of stroke survivors. Differences in definitions of bouts across studies may contribute to the range of ambulation activity outcomes observed after stroke. Thus, definitions of ambulation bouts need careful consideration during study design. Varying definitions for ambulation bouts have possibly resulted from the differences between accelerometer epochs and device measurement abilities. Roos et al. (2012) defined the start of an ambulation bout as any 15-second recoding interval with > six steps and the end of the bout as any 10 second interval within which no steps occurred. In contrast, Manns et al. (2009) defined an ambulation bout beginning when the step count was greater than two steps per minute and ending when no steps were registered. More recently, Frazer et al. (2013) defined ambulation bouts as any period of ambulation of at least 4 seconds in duration. Once ambulation bouts are identified, characteristics such as volume, frequency, intensity and patterns of ambulation activity can be determined (Roos et al., 2012; Lord et al., 2010; Manns and Baldwin, 2009).

When considering which ambulation bout definition to use in this thesis, it is important to consider the accelerometers chosen - the ActivPAL^{TM} and Sensewear Pro_2 Armband. Both accelerometers have different measurement epochs and mechanisms of collecting data. As the ActivPAL^{TM} accelerometer has 15 second measurement epochs, distinguishes between sitting, standing and walking positions and records transitions between various positions, a smaller step range (e.g. > 2 steps) is sufficient to define the start of an ambulation bout. This is because the chance of incidental movements (e.g. sit to stand transition) registering a step on this device is low as these movements are most likely differentiated by the device. The Sensewear Pro_2 Armband has one-minute measurement epochs, and is not able to distinguish between incidental upper limb movements and walking. Thus, if this device is used for free-living ambulation measurement, a larger step range (e.g. > 6 steps) may be required to define the start of an ambulation bout. These will be considered prior to use in measurement of free-living ambulation after stroke.

Measures to characterise ambulation activity

The following section provides a summary and justification for choice of measures (and their definitions) that will be used to characterise ambulation activity in this thesis. This will be followed by a summary of the existing literature reporting on characteristics of ambulation activity after stroke. Thus far, a range of measures has been used to characterise ambulation activity after stroke. These can be grouped into volume, frequency, intensity and patterns (Lord et al., 2011; Cavanaugh et al., 2007).

Volume measures provide a global representation of activity. During ambulation activity measurement after stroke, most common volume measures include total number of steps and duration of walking (Manns and Baldwin, 2009; Michael et al., 2005; Shaughnessy et al., 2005; Haeuber et al., 2004; Macko et al., 2002). Some accelerometers also collect total time spent sitting/lying, standing and upright (for example, the PAL and ActivPAL^{TM}). These measures may be useful in individuals with mobility limitations like stroke survivors, who may find it difficult to ambulate to the level required for health benefits. In this thesis, volume of ambulation activity will be characterised by daily step count and duration of activity (see table 2.2).

Investigation of the spread of activity across the day is also important, as volume measures alone may not provide a full representation of activity behaviours. For example, two stroke survivors may take the same number of steps, but across a different time. One stroke survivor may walk faster, and thus may have a reduced time spent walking, despite a similar volume of steps. This is possible especially after stroke, as walking capacity (e.g. gait speed and gait endurance) may be different for each survivor. Thus, collecting measures such as frequency and intensity of ambulation activity will assist in capturing more detail regarding how total steps and time spent walking are accumulated across the day.

Frequency measures are useful to look at the way in which ambulation activity is spread throughout the day (Orendurff, 2008; Cavanaugh et al., 2007). Measures of frequency of ambulation bouts can discriminate between groups of young and older adults, as well as adults with mobility disability (Cavanaugh et al., 2007). Thus, this measure is regarded a sensitive measure for comparing between individuals with and without free-living activity limitations (Lord et al., 2011; Cavanaugh et al., 2007).

Frequency of ambulation activity after stroke has been characterised by either a) total number and average duration of ambulation bouts per day (Frazer et al., 2013; Manns & Baldwin, 2009) or by b) the total number and time spent in short, medium and long duration bouts (Roos et al., 2012). Measures such as total number and average bout duration can be influenced by the different definitions of 'bouts' used. As discussed above in section 2.3.2, some studies define the start of a bout as a recording interval with > 6 steps (Roos et al., 2012), while others define the start of a bout as a recording interval with > 2 steps (Manns & Baldwin, 2009). A lower step threshold (i.e. 2 steps) for the start of a bout may result in a higher total number of bouts, and thus a shorter average bout duration, than a higher step definition (i.e. 6 steps).

Also measures of average bout duration do not give information regarding the spread of activity across short (< 40 steps), medium (41 to 300 steps) and long (> 300 steps) duration bouts (Roos et al., 2012; Andrews et al., 2010). For example, after stroke, 72-74% of all ambulation bouts may be short in duration, while only 1-2% will be long in duration (Roos et al., 2012). When using the measure of average duration of bouts per day, information regarding long ambulation bouts will be lost, due to the high proportion of short ambulation bouts. However, capturing information regarding the number of and time spent in long duration bouts per day may have implications for health outcomes (Prajapati et al., 2013; Baert et al., 2012; Gordon et al., 2004) and could be targeted during interventions after stroke (Danks et al., 2014). Thus, for this thesis, frequency of ambulation activity will be characterised by the number of and time spent in short (< 40 steps), medium (41 to 300 steps) and long (> 300 steps) duration ambulation bouts per day (Roos et al., 2012; Andrews et al., 2010). These measures have been defined based on step counts required for real-life distances (Roos et al., 2012; Andrews et al., 2010) (see table 2.2).

Intensity measures of activity have previously been determined based on metabolic equivalents (METS) (Moore et al., 2013; Baert et al., 2012; Rand et al., 2010), or step counts per minute after stroke (Manns and Baldwin, 2009; Michael & Macko, 2007). Thus far, low intensity activity has been defined either as ambulation bouts with a step rate of less than 30 steps per minute (Manns and Baldwin, 2009; Michael and Macko, 2007) or activity of less than 3 METS (Baert et al., 2012); moderate intensity activity as an ambulation bout with a step rate of 30 to 79 steps per minute (Manns and Baldwin, 2009; Michael and Macko, 2007) or at 3-6 METS (Baert et al., 2012) and high intensity activity a step rate greater than 79 steps per minute (Manns and Baldwin, 2009; Michael and Macko, 2007) or > 6 METS (Baert et al., 2012).

After stroke, energy expenditure (METS) during usual walking is higher than healthy controls (Chen et al., 2005). Thus, standard algorithms used by current accelerometers for METS measures based on healthy population norms may not be applicable to stroke survivors. There are very few accelerometers that have been validated for measures of METS after stroke. While the Sensewear Pro_2 Armband (chosen for use in this thesis) demonstrated good to excellent agreement with doubly labelled water for total energy expenditure in a small sample of stroke survivors (Moore et al., 2012), accuracy of this device for measures of METS is variable (Vanroy et al., 2013; Moore et al., 2013; Manns and Baldwin, 2009). Further investigation of accelerometers like the Sensewear Pro_2 Armband for accuracy of METS measures is required prior to use during ambulation activity measurement (Vanroy et al., 2013; Moore et al., 2013; Manns and Baldwin, 2009).

Step cadence may also be a feasible measure for ambulation intensity until valid METS measurement for stroke survivors is possible. Step cadence has a strong positive relationship with METS scores in healthy adults (Tudor-Locke et al., 2011b; Tudor-Locke et al., 2011a) and peak oxygen consumption (peak VO_2) in people with chronic stroke (Michael and Macko, 2007). A similar association is anticipated in people with subacute stroke. Two studies of ambulation activity after stroke have used step cadence definitions of low, moderate and high intensity ambulation bouts (Manns and Baldwin, 2009; Michael and Macko, 2007). These definitions of ambulation intensity will be used for this thesis (see table 2.2).

Patterns measures of ambulation have been used to characterise how activity changes across the day and within various locations. Unlike volume, frequency and intensity of ambulation activity, the definition of patterns of ambulation activity has varied considerably across the literature. Rather than formal 'measures', like those for volume, frequency and intensity, patterns of activity have been more related to determining how activity is spread over the observation time and location in studies of stroke survivors. Measures of patterns after stroke have included comparing activity across the morning and afternoon (Frazer et al., 2013), determining the proportion of the day in different bout types (Roos et al., 2012), how activity changes based on location of stroke survivors (Sjoholm et al., 2014) or how activity changes between limited and unlimited community walkers (Roos et al., 2012). In older adults, formal measures including the Gini Index and D_1 index have been used to characterise patterns of activity (Lord et al., 2011). These measures characterise how total activity is accumulated by different activity bouts and the diversity of activity bouts across the day. It is also understood that investigating the characteristics and spread of volume, frequency and intensity of physical activity can also be considered investigating patterns of activity. Thus, in this thesis, ambulation activity will be characterised using measures and definitions of volume, frequency and intensity, with an understanding that overall they contribute to our understanding of the overall pattern of activity across a day or period of community ambulation (see table 2.2).

Table 2.2: Definitions of measures of free-living ambulation used in this thesis

Measure	**Definition**
Volume	
Duration of activity	
Time spent sit/lying	Total time in minutes per day spent sitting/lying
Time spent standing	Total time in minutes per day spent standing
Time spent walking	Total time in minutes per day spent walking
Time spent upright	Total time in minutes spent standing and walking per day
Number of steps	Total number of steps taken per day
Frequency	
Postural transitions	Sum of number of transitions (both sit to stand, and stand to sit)
Bouts (total)	Any recording epoch with ≥ 2 steps to an epoch of no steps
Short duration bout	Ambulation bout with < 40 steps
Medium duration bout	Ambulation bout with 41 to 300 steps
Long duration bout	Ambulation bout with > 300 steps
Intensity	
Number of minutes within each intensity	
Low intensity bout	Ambulation bout with cadence < 30 steps per minute
Moderate intensity bout	Ambulation bout with cadence of 30 to 80 steps per minute
High intensity bout	Ambulation bout with cadence > 80 steps per minute

2.3.3. Ambulation activity after stroke – current findings and limitations

Ambulation activity after stroke is low. Tables 2.3 and 2.4 present a summary of accelerometer-based measures of ambulation activity in individuals with subacute and chronic stroke. Thus far, ambulation activity has mostly been measured through cross-sectional observational studies in individuals with chronic stroke (English et al., 2014). Only a few studies have prospectively investigated ambulation activity recovery across the subacute phase of stroke (i.e. across the first six months after stroke) (Moore et al., 2013; Manns and Baldwin, 2009; Shaughnessy et al., 2005). These few studies present conflicting findings. However, as the subacute phase of stroke is when survivors demonstrate greatest potential for recovery (Jang, 2010; Jorgensen et al., 1995b), understanding how ambulation activity changes over this time is essential to improving ambulation activity outcomes after stroke. Further, in most studies, ambulation activity is characterised by measures of volume alone, which does not provide information on how activity is accumulated throughout the day. Issues with study methods and definitions of measures used to characterise activity could be responsible for the variability observed across studies. The recovery of ambulation activity across the subacute phase into the chronic phase of stroke requires further investigation.

Table 2.3: Ambulation activity in people with subacute stroke – review of the available literature

Author, Date	Sample (size, age)	Device/Measure	Findings	Healthy Control data
Shaughnessy et al., 2005	n = 11 Age: 68 (12.8) years Time post-stroke: unspecified	**Device:** Step activity monitor (SAM) **Time:** at 2-weeks and 3 months post-discharge (measurement period unspecified) **Measures:** *Volume:* Total steps per day at 2-weeks and 3 months	*Volume:* 2-weeks: 1536 (106) steps per day 3-months: 2765 (1677) steps per day **Overall change:** Increased steps at three months from two weeks post-discharge (p<0.001)	
Egerton et al., 2006	n = 41 Age: 68.2 (11.3) years Time post-stroke: 1.5 (0.6) months	**Device:** Miniature pressure transducer **Time:** 7-8 hours ('therapeutic day') **Measures:** *Volume:* time upright *Frequency:* number of postural transitions per hour	*Volume:* 8.3 (8.5)% of day upright, 5 minutes upright per hour *Frequency:* 2.6 (1.7) transitions per hour.	
Manns et al., 2009	n = 10 Age: 66.3 (15) years Time post-stroke: 74.7 (31.1) days	**Device:** SAM **Time:** 2 full days at Pre-discharge, 3 days at both 2 weeks post-discharge and 6 weeks post-discharge **Measures:** *Volume:* volume steps per day, absolute time spent walking per day *Frequency*: number of bouts per day, duration of bouts *Intensity:* frequency of bouts at low, moderate and high intensity	*Volume:* **Pre-discharge:** 5541 (1846) steps per day, 183 (39) minutes per day **2-weeks post-discharge:** 5506 (2197) steps per day, 199 (69) minutes per day **6-weeks post-discharge:** 6195 (2068) steps per day, 229 (65) minutes per day *Frequency*: **Pre-discharge:** 57.6 (15.9) bouts per day 3.3 (0.5) minutes per bout **2-weeks post-discharge:** 57.2 (21.4) bouts per day 3.6 (0.8) minutes per bout **6-weeks post-discharge:** 61.5 (17.9) bouts per day 3.8 (0.7) minutes per bout	

			Intensity: **Pre-discharge:** Low intensity 62.6 (8.6) bouts, Moderate intensity 31.2 (7.4) bouts, High intensity 6.2 (5) bouts per day **2-weeks post-discharge:** Low intensity 68.0 (12.5) bouts, Moderate intensity 24.7 (7.3) bouts, High intensity 7.3 (10.7) bouts per day **6-weeks post-discharge:** Low intensity 68.5 (8.4) bouts, Moderate intensity 26.2 (5.4) bouts, High intensity 5.4 (5.8) bouts per day **Overall change:** No difference in steps per day, number of bouts, or intensity of bouts across time. Significant difference in absolute minutes per day across time and length of bouts (p = 0.030)	
Askim et al., 2013	n = 28 Age: 79 years (SD unspecified) Time post-stroke: 7.5 (3.2) days	**Device:** PAL 2 **Time:** 24hrs at 14 days post-stroke, 1, 3 and 6 months post-stroke **Measures:** *Volume:* total time upright *Frequency:* number of postural transitions	*Volume:* 14 days: 92 (range 11-141) minutes upright 1-month: 146 (range 29-321) minutes upright 3-months: 144 (range 31-248) minutes upright 6-months: 144 (range 66-232) minutes upright *Frequency:* 14 days: 50 (range 16-103) postural transitions 1-month: 63 (range 32 – 103) postural transitions 3-months: 62 (range 35 – 123) postural transitions 6-months: 59 (range 48-89) postural transitions	
Moore et al., 2013	n = 25 Age: 73 (9) years Time post-stroke: unspecified	**Device:** Sensewear Pro$_3$ Armband **Time:** 7 full days at 1-week, 3 and 6-months post-stroke **Self-report:** International Physical activity Questionnaire **Measures:** *Volume:* total energy expenditure, total time in ambulation activity and sedentary, total steps per day *Frequency:* Frequency of breaks in sedentary time	Based on 25 stroke survivors *Volume:* **1-week:** total energy expenditure 1840 (354) kcal, 28 (32) minutes per day in activity, 1383 (43) minutes per day sedentary, 3111 (2290) steps per day **3-months:** total energy expenditure 2100 (447) kcal, 64 (58) minutes per day in activity, 1350 (57) minutes per day sedentary, 5764 (3026) steps per day	Based on 25 healthy controls *Volume:* total energy expenditure 2213 (492) kcal, 98 (63) minutes per day in activity, 1372 (272) minutes per day sedentary, 8726 (3735) steps per day

			6-months: total energy expenditure 2093 (445) kcal, 66 (68) minutes per day in activity, 1355 (72) minutes per day sedentary, 5927 (4091) steps per day *Frequency:* **1-week:** 252 (72) breaks per day **3-months:** 291 (65) breaks per day **6-months:** 282 (62) breaks per day **Overall change:** Total energy expenditure (kcal), time spent active, time spent sedentary and step counts increased from 1-week to 3-months (p <0.01), no change from 3 to 6 months (p > 0.64). Frequency of breaks to sedentary time increased from 1-week to 3-months, but no change from 3 to 6-months	*Frequency:* 341 (64) breaks per day
Sjoholm et al., 2014	n = 104 Age: 70.3 (14.4) years Time post-stroke: 19 (12-34) days	**Device:** None. Direct observation **Time:** 1 min every 10 minutes (across 8 hours, 51-54 observation minutes) **Measures:** *Volume:* total time spent active and sedentary *Patterns:* activity based on ward location and time Measures presented as time in hours per day (proportion of day)	*Volume:* Sedentary (not in activity) for 6.2 hours per day (74%), 2.1 hours per day (25%) in light - mod activity, 1.08 hours per day (13%) in standing per walking activities. *Patterns:* Greatest activity occurs within hallways, greatest activity occurs between 9:30AM and 12:30PM	

Measures are presented as mean (standard deviation) or median (interquartile range) unless otherwise specified.

Table 2.4: Ambulation activity in people with chronic stroke – review of the available literature

Author, Date	Sample (size, age, time post-stroke)	Device/Measure	Findings	Healthy Control data
Michael et al., 2005	n = 50 Age: 65 years (SD unspecified) Time post-stoke: 0.9 years (SD unspecified)	**Device:** Step activity monitor (SAM) **Time:** 2 days, waking hours **Measures:** *Volume:* Total steps per day	*Volume:* 2837 (1503) steps per day	
Michael et al., 2007	n = 79 Age: 65 years (SD unspecified) Time post-stoke: 0.9 years (SD unspecified)	**Device:** SAM **Time:** 2 days, waking hours **Measures:** *Volume:* total steps per day *Intensity:* number of steps at low, mod and high intensity. Intensity measures presented as steps per day (proportion of time per day) at each intensity	*Volume:* 1389 (797) steps per day *Intensity*: 624 steps per day (45% of time per day) in low intensity, 640 steps per day (46% of time per day) in moderate intensity, 83 steps per day (9% of time per day) in high intensity.	
Alzahrani et al., 2009 *	n = 42 Age: 70 (10) years Time post-stoke: 2.8 (1.4) years	**Device:** Intelligent device for energy expenditure and activity (IDEEA) **Time:** 2 days, 10.8hrs per day, 1 week apart **Measures:** *Volume:* total time spent upright, number of 'activity counts'	*Volume:* 230 (115) minutes upright per day, 5656 (4091) activity counts per day	
Mudge et al., 2009	n = 49 Age: 67.4 (12.5) years Time post-stoke: 5.5 (5.1) years	**Device:** SAM **Time:** 3 days, waking hours **Measures:** *Volume:* total steps per day *Intensity:* Total steps at low rate (< 30 steps per minute) Total steps at high rate	*Volume:* 4765 steps per day (range 1225 to 21273 steps) *Intensity:* Low intensity: mean 2334 (565) High intensity: median 655 (0-10590) steps per day	

		(> 60 steps per minute)		
Rand et al., 2009	n = 40 Age: 66.5 (9.6) years Time post-stoke: 2.9 (2.4) years	**Device:** Actical **Time:** 4 days, waking hours **Measures:** *Volume:* Total activity counts (xyz plane) and activity duration	*Volume:* 55,886 (5696) activity counts per day, 1.9 (SD unspecified) hours per day in activity 13 (2) hours inactive (i.e. No counts),	
Fulk et al., 2010	n= 19 Age: 65.7 (11.9) years Time post-stoke: 3.5 (3.0) years	**Device:** SAM **Time:** 7 days, waking hours **Measures:** *Volume:* Total step count per day	*Volume:* 3838.2 (1963) steps per day	13 healthy controls *Volume:* 6294 (1768) steps per day
Manns et al., 2010	n = 10 Age: 54.3 (3.0) years Time post-stoke: 7.5 (8.3) years	**Device:** SAM **Time:** 4 full days **Measures:** *Volume:* Total steps per day *Frequency:* Number of bouts per day, average duration of bouts	*Volume:* Total steps per day*:* 7379 (3107) steps per day *Frequency:* 64 (19) bouts per day Bout duration 4.1 (0.7) minutes per bout	10 healthy controls *Volume:* 14,730 (4522) steps per day *Frequency:* 74 (10.4) bouts per day Bout duration 5.6 (1.6) minutes per bout
Alzahrani et al., 2011 *	n = 42 Age: 70 (10) years Time post-stoke: 2.8 (1.4) years	**Device:** IDEEA **Time:** 2 days, 10.8hours per day (converted to measures per 12hours), 1 week apart **Measures:** *Volume:* total time spent upright (including walking and standing time), total time not upright, ‘activity counts’ (including number of steps and stairs) *Frequency:* transitions	*Volume:* 256 (128) minutes upright: 112 (66) minutes walking; 140 (71) minutes standing; 2 (4) stairs; 1 (1) transitions) 464 (112) minutes not upright 6284 (4546) activity counts: 6083(4443) steps; 138 (337) stairs) *Frequency:* 63 (48) transitions per day	21 healthy controls *Volume:* 292 (97) minutes upright: 103 (32) minutes walking; 175 (68) minutes standing; 13 (8) minutes stairs; 2 (2) minutes transitions 428 (91) minutes not upright 10346 (3590) activity counts: 8966 (3021) steps, 1278 (861) stairs *Frequency:* 103 (86) transitions per day

Roos et al., 2012	n = 51 Age: 63.7 (10.4) years Time post-stoke: 3.4 (3.1) years	**Device:** ActivPAL^{TM} **Time:** 3 days, waking hours **Measures:** *Volume:* Step count per day, total time spent walking per day *Frequency:* Bouts per day, frequency of short, medium and long bouts per day *Patterns:* % of day in short, medium and long bouts **Participant groups:** HHA-LCA: Household ambulator and limited community ambulators ULA: Unlimited community ambulators Healthy: Healthy older adults	*Volume:* HHA-LCA: ≈ 3000 steps, 1 hour per day UCA: ≈ 7000 steps, 2 hours per day *Frequency:* HA-LCA: ≈ 100 bouts, per day (200 short bouts, 70 medium bouts, 2 long bouts) UCA: ≈ 175 bouts per day (350 short bouts, 130 medium bouts, 4 long bouts) *Patterns:* All groups had ≈ 72-74% of all walking over short bouts, ≈ 25% medium bouts, ≈ 1% long bouts	n = 14 healthy older adults Age: 68.9 (6.2) *Volume:* ≈ 11,000 steps, 3 hours per day *Frequency:* ≈ 250 bouts per day (500 short bouts, 170 medium bouts, 6 long bouts) *Patterns:* All groups had ≈ 72-74% of all walking over short bouts, ≈ 25% medium bouts, ≈ 1% long bouts
Frazer et al., 2013	n = 14 Age: 60 (6.0) years Time post-stoke: 3.6 (3.0) years	**Device:** Dynaport mini **Time:** 5 - 7 days, waking hours **Measures:** *Volume:* Total time in activity, standing and sitting, total 'ambulation activity counts' *Frequency:* Number of transitions, number of bouts, duration of bout type *Patterns:* Spread of activity across AM versus PM and between days	*Volume:* 589 (92.8) minutes per day sitting; 115 (61.0) minutes per day standing; 54 (33.0) minutes per day in 'activity' *Frequency:* 197 (109) bouts per day (16 (5) seconds per bout) *Patterns:* Significantly lower time spent standing, in activity in the afternoon and evening than the morning ($p < 0.008$) Significantly fewer bouts and transitions in the afternoon and evening than the morning ($p < 0.002$)	

Measures are presented as mean (standard deviation) or median (interquartile range) unless otherwise specified, * both papers by Alzahrani et al. (2011 and 2009) report on the same study sample.

Volume

Ambulation activity after stroke has been predominantly characterised by the volume of steps taken per day. Volume of ambulation activity has also been characterised by measures of time spent walking (both absolute time spent walking per day and average time spent walking per day) (Frazer et al., 2013; Moore et al., 2013; Roos et al., 2012; Alzahrani et al., 2011; Touillet et al., 2010; Manns and Baldwin, 2009; Sakamoto et al., 2008; Michael and Macko, 2007) and upright (Askim et al., 2013; Egerton et al., 2006) per day. Often, stroke survivors record average daily step counts lower than usual levels for sedentary older adults (5000 steps per day) (Tudor-Locke et al., 2011a) (see tables 2.3 and 2.4). Across the subacute phase of stroke, daily step counts range from 1536 (SD 106) (Shaughnessy et al., 2005) to 6195 (SD 2068) steps (Manns and Baldwin, 2009). Similarly, in individuals with chronic stroke, daily step counts range from 1389 (SD 797) (Michael and Macko, 2007) to 7379 (SD 3107) (Manns et al., 2010). When compared with healthy older adults, stroke survivors (both with subacute and chronic stroke) take up to 33-67% fewer steps per day (Moore et al., 2013; Roos et al., 2012; Alzahrani et al., 2011; Fulk et al., 2010; Manns et al., 2010; Sakamoto et al., 2008).

When looking at time spent walking and upright per day, individuals with subacute stroke spend between 27 minutes (Moore et al., 2013) and 182.6 (SD 38.5) minutes walking and 62.4 to 92 minutes upright within the hospital inpatient setting each day (Sjoholm et al., 2014; Askim et al., 2013; Bernhardt et al., 2004). Following hospital discharge, stroke survivors spend more time walking and in upright positions per day. Average time spent walking per day by individuals with subacute stroke living in the community ranges from 64 (SD 58) minutes (Moore et al., 2013) to 228.8 (SD 65.4) minutes (Manns and Baldwin, 2009) and time spent in upright positions is on average 144 (SD unspecified) minutes per day (Askim et al., 2013). Individuals with chronic stroke spend between 39.8 minutes (Janssen et al., 2010) to 112 minutes (Alzahrani et al., 2011) walking each day and 115 minutes (Frazer et al., 2013) to 230 minutes (Alzahrani et al., 2009) in upright positions. When compared to healthy adults, stroke survivors (both with subacute and chronic stroke) living in the community spend 10-67% less time walking per day (Moore et al., 2013; Roos et al., 2012; Alzahrani et al., 2011) (see tables 2.3 and 2.4).

Consistent findings in studies of volume of ambulation activity across the subacute and chronic phases of stroke recovery are the low volume of activity and large variance in data. Stroke survivors can engage in up to two thirds less volume of activity than healthy controls. Also, as evident in Tables 2.3 and 2.4, standard deviations for daily step count and time spent walking are often greater than half the mean (Moore et al., 2013; Roos et al., 2012; Alzahrani et al., 2011; Fulk et al., 2010; Manns and Baldwin, 2009; Michael and Macko, 2007) reflecting the wide range in ambulation activity levels in this group. This wide range in results could represent the variability in ambulation activity outcomes after stroke, or could also be the result of the range of methods used for ambulation activity measurement after stroke. Studies of ambulation activity after stroke have different sample characteristics (e.g. age, time post-stroke, intervention), measurement periods (e.g., measurement over 24 hour periods versus only during waking hours), follow-up time points (e.g. one month and three months, versus two weeks and six weeks following hospital discharge) participant environments (e.g. hospital versus community) and measurement tools (for example, pedometers versus accelerometers).

Sample characteristics can have an effect on ambulation activity outcomes after stroke. For example, increased age can also contribute to lower activity outcomes (Cavanaugh et al., 2007). Thus, the range of outcomes observed in volume measures after stroke could be due to differences in sample characteristics between studies. Measuring activity during waking hours only (Fulk et al., 2010; Janssen et al., 2010) can result in missing incidental or intentional bouts of ambulation that may occur outside the measurement period. This could explain why some studies, which measure during waking hours (Fulk et al., 2010; Janssen et al., 2010) record lower volume of activity than studies that record across full 24-hour periods (Manns and Baldwin, 2009). Prospective observational studies across the subacute phase which use different baseline and follow-up time points (Moore et al., 2013; Manns and Baldwin, 2009; Shaughnessy et al., 2005) may also result in differences in reported ambulation activity. Also, volume of activity within the hospital setting is lower than in free-living community environments – thus location of activity measurement could also contribute to findings regarding recovery of activity after stroke. Thus, when comparing activity at one week post-stroke (within the inpatient setting) with activity at three months post-stroke (within the community), increased activity is likely (Moore et al., 2013). These issues need consideration when designing future studies of ambulation activity measurement after stroke.

In light of this, though it is evident that overall volume of activity is low after stroke, the recovery of volume of ambulation activity across the subacute phase of stroke requires further investigation. While some studies demonstrate an increase in daily step counts (Shaughnessy et al., 2005) and upright time (Askim et al., 2013) across the subacute phase, others demonstrate no change in overall daily ambulation activity (Manns and Baldwin, 2009). It is possible that differences in study methods and sample characteristics contribute to the range of findings in volume of ambulation activity observed after stroke. Prospective follow-up of the one sample, within their usual living environments, with measurement across full 24 hour periods across a sufficient number of days are required to ensure other participant demographics or measurement methods do not contribute to variation in findings across time points. Further, understanding how volume of ambulation activity is recovered (e.g. spread of activity over the day) is required.

Frequency

Frequency of ambulation activity after stroke has been characterised by measures of ambulation bout duration and frequency. Most ambulation bouts are short in duration after stroke (Roos et al., 2012), regardless of gait speed. However, it is possible that duration of bouts may increase across the subacute phase of stroke (mean bout duration: 3.3 to 3.8 minutes) (Manns and Baldwin, 2009). Though this requires more investigation, as short duration bouts are most commonly observed across the chronic phase of recovery (mean bout duration: 16 seconds to 36 seconds) (Frazer et al., 2013; Roos et al., 2012). Individuals with subacute stroke record a frequency of ambulation bouts ranging from 57 to 62 bouts per day (Manns and Baldwin, 2009), while individuals with chronic stroke record 64 to 197 bouts per day (Frazer et al., 2013; Roos et al., 2012). When compared to healthy adults, individuals with chronic stroke take 30-60% fewer ambulation bouts per day, despite similar bout duration (Roos et al., 2012). Ambulation bout frequency is further reduced in stroke survivors with mobility limitations (Roos et al., 2012). It appears that individuals with subacute stroke may increase bout duration and frequency of ambulation bouts over time, or with functional recovery, however this needs further prospective investigation (Roos et al., 2012).

Issues with study methods similar to those discussed above under volume, and differences in definitions of ambulation ‘bouts’ across studies could cause conflicting results on observed recovery of frequency of ambulation activity after stroke. Differences in ambulation bout definitions have been discussed earlier in section 2.3.2, and will be considered during study design for this thesis. An increase in frequency of ambulation bouts and engagement in long duration bouts would be beneficial to health and function after stroke (Nelson et al., 2007). Across the subacute phase of stroke, survivors may have limitations in pre-stroke activity, roles and responsibilities (Plante et al., 2010a; Desrosiers et al., 2008; Desrosiers et al., 2005a). By the chronic phase, stroke survivors may return to pre-stroke activities, and thus have an increased drive or need to ambulate. Thus, it is likely that stroke survivors will increase the frequency of ambulation activity across this phase, though this has only been investigated in one small sample (n=10) of individuals with subacute stroke until six weeks after hospital discharge (Manns and

Baldwin, 2009). Further accurate, objective measurement, using meaningful definitions of bout duration, over a longer follow-up period is required after stroke.

Intensity

Ambulation activity intensity has been defined across studies of stroke according to the step rate (cadence) or in METS (see section 2.3.2). Regardless, similar findings on the proportion of daily activity taken at low, moderate and high intensity are observed in individuals with subacute and chronic stroke. The majority of ambulation activity undertaken by individuals following stroke is low in intensity. In people with subacute stroke, low intensity ambulation activity comprises 62.6% to 68.5% of all activity (114.3 to 156.7 minutes per day) (Manns and Baldwin, 2009). The remainder of the day is comprised of approximately 25% to 31% of moderate intensity ambulation activity (42 minutes to 59 minutes per day) and 5% to 7% of high in intensity ambulation activity (11 to 15 minutes per day) (Manns and Baldwin, 2009). Little difference is seen in those with chronic stroke who similarly spend 45% to 77% of all ambulation activity (approximately 149 minutes per day) in low intensity, 26% to 46% (approximately 44 minutes per day) in moderate intensity and 1% to 6% of all activity in high intensity activity (3 minutes per day) (Baert et al., 2012; Michael and Macko, 2007). Further, few stroke survivors complete the recommended 30 minutes of continuous or accumulated bouts of >10minutes of moderate intensity activity 3 days per week (Prajapati et al., 2013; Baert et al., 2012; Gordon et al., 2004). Investigation of the changes in intensity of ambulation activity as stroke survivors recover is required. Thus far, intensity of activity across the subacute phase has only been measured until six weeks after stroke (Manns and Baldwin, 2009). However, it is known that recovery after stroke is possible beyond this time point.

2.3.4. Changes in ambulation activity over time

Only three studies have prospectively measured ambulation activity across the subacute phase (first six months) of stroke (Moore et al., 2013; Manns and Baldwin, 2009; Shaughnessy et al., 2005). However, differences in study design and sample characteristics make comparisons across the studies and deriving accurate conclusions on recovery across the subacute phase after stroke difficult (Moore et al., 2013; Manns and Baldwin, 2009; Shaughnessy et al., 2005). Review of these prospective studies is included in section 2.3.3. In summary, from pre-hospital discharge to six weeks post-hospital discharge, stroke survivors demonstrate no improvement in daily volume of steps, even though they spend more absolute minutes walking per day (Manns and Baldwin, 2009). Further, across this early period of recovery, ambulation bouts become longer in duration, but remain similar in intensity over time (Manns and Baldwin, 2009). Across the first three months post-stroke (Moore et al., 2013) or post-hospital discharge (Shaughnessy et al., 2005), stroke survivors increase total daily steps (Moore et al., 2013; Shaughnessy et al., 2005). After three months post-stroke, recovery of ambulation activity may plateau (Moore et al., 2013).

It is difficult to compare results across these three prospective studies of ambulation activity in people with subacute stroke due to differences in baseline and follow-up assessment time points, sample characteristics, devices used, duration of measurement and measures used to characterise ambulation activity. Manns & Baldwin (2009) and Moore et al., (2013) compared pre-hospital discharge with post-hospital discharge time points, while Shaughnessy et al. (2005) compared across two time points after hospital discharge. The change from hospital to free-living environments may also lend towards an observed increase in daily ambulation activity (Sjoholm et al., 2014; Bernhardt et al., 2004). Thus, the improvement in ambulation activity observed by Manns & Baldwin (2009) and Moore et al., (2013) may have resulted from the change in 'free-living' environments. This could also be a reason for the greater change observed in ambulation activity in studies comparing pre-discharge with post-discharge time points (Moore et al., 2013; Manns & Baldwin, 2009), instead of across post-discharge time points (Shaughnessy et al., 2005).

Differences in sample characteristics across the three studies could also contribute to variation in the recovery of ambulation activity observed across the three studies. The studies report findings on stroke survivors of different ages (mean age ranging from 66 years to 73 years), stroke severity and functional ability (Moore et al., 2013; Manns and Baldwin, 2009; Shaughnessy et al., 2005). Age has a negative relationship with daily ambulation activity in healthy adults (Lord et al., 2011; Cavanaugh et al., 2007) and thus, differences in age between the three samples could contribute to variation in observed ambulation activity outcomes. Differences in stroke severity and function between the study samples may also explain the lower number of steps observed in the study by Shaughnessy et al. (2005) when compared to those recorded by Moore et al. (2013) and Manns & Baldwin (2009). Stroke survivors observed in the study by Shaughnessy et al. (2005) were of mild to moderate stroke severity, had a Functional independence measure score of 5.8 out of 14 and mean gait speed of 0.37 m/s. However, the stroke survivors observed in the studies by Moore et al. (2013) and Manns & Baldwin (2009) were of mild stroke severity only, and had higher scores on the Functional independence measure (10.4 out of 14) (Manns & Baldwin, 2009) and mean gait speed (mean gait speed 0.8m/s) (Moore et al., 2013). Increased stroke severity can contribute to poor functional outcomes after stroke (Veerbeek et al., 2011) and scores on clinical measures of function share a positive relationship with ambulation activity (Fulk et al., 2010; van der Port et al., 2008). Thus, these differences in sample characteristics could have also contributed to the difference in observed ambulation activity across the three studies of survivors with subacute stroke.

Finally differences in study design, such as devices used, recording period and measures, across the three prospective studies could have contributed to differences in observed ambulation activity outcomes across the subacute phase of stroke. Two out of the three studies mentioned above used the Step Activity Monitor, worn on the ankle (Manns & Baldwin, 2009; Shaughnessy et al., 2005), while the other used the Sensewear Pro_2 armband, worn on the back of the triceps (Moore et al., 2013). Difference in device position (e.g. ankle versus arm) could contribute to differences in observed ambulation activity (Moore et al., 2013), as the devices assume steps based on different movements. Only one study (Moore et al., 2013) recorded ambulation activity for the minimum recommended period of four days (Murphy, 2009). The other studies either recorded for 2-3 days (Manns & Baldwin, 2009), or did not specify their measurement period (Shaughnessy et al., 2005). Not measuring for the minimum four day period increases the risk of not capturing variability observed in free-living activity measures (Murphy et al., 2009). Also, the study by Manns & Baldwin (2009) had a different recording period across time points, with a longer recording period at two and six weeks after discharge. This could have influenced their findings for 'absolute minutes of activity per day', which significantly increased over the three time points (Manns & Baldwin, 2009).

Spontaneous cortical, motor and ambulation recovery is greatest early after stroke (Hermann and Chopp, 2012; Jang, 2010; Cramer and Riley, 2008; Byl et al., 2003; Hendriks et al., 2002; Jorgensen et al., 1995b; Bonita and Beaglehole, 1988). Greatest improvement in motor function and ambulation is observed in the first month after stroke (Hendriks et al., 2002; Jorgensen et al., 1995a; Jorgensen et al., 1995b) and stroke survivors continue to demonstrate improvements in motor function and ambulation across the first three months from stroke onset (Jang, 2010; Hendriks et al., 2002; Jorgensen et al., 1995a; Jorgensen et al., 1995b; Bonita and Beaglehole, 1988). However, from three to six months, several studies report that stroke survivors may plateau in their recovery of motor function (Jang, 2010; Hendriks et al., 2002; Jorgensen et al., 1995a; Jorgensen et al., 1995b; Bonita and Beaglehole, 1988). Further, after three months, spontaneous neural recovery may be limited (Hermann and Chopp, 2012; Cramer and Riley, 2008; Byl et al., 2003). This phenomenon is not completely understood, with some arguments supporting recovery of motor function after stroke beyond six months (Page et al., 2004). Further, in individuals with chronic stroke (that is, greater than six months post-stroke), cortical reorganisation, recovery of motor function, ambulation and ambulation activity is observed during goal-oriented intervention studies (Danks et al., 2014; Veerbeek et al., 2014; Park et al., 2011; English and Hillier, 2011; Byl et al., 2003). This suggests that recovery of ambulation activity may indeed be possible after three months with the appropriate intervention.

It is known that volume of activity is low during the early phase of stroke, within the inpatient setting (West and Bernhardt., 2010; Bernhardt et al., 2009; Kuys et al., 2006) as well as in community dwelling survivors of chronic stroke (English et al., 2014). However, as discussed in detail above, the process of recovery of ambulation activity across the subacute phase of stroke is not completely understood. As this is the time period during which most cortical (Hermann and Chopp, 2012; Cramer and Riley, 2008; Byl et al., 2003) and functional recovery (Jang, 2010; Jorgensen et al., 1995b) may be observed after stroke, it may also be the most optimal time for intervention to improve ambulation activity. Measurement of ambulation activity after stroke survivors return home is useful to identify how they recover ambulation activity within their usual living environments. Also, similar to healthy adults, characteristics of ambulation activity such as frequency and intensity may provide a better representation of activity across the subacute phase of stroke (Orendurff, 2008; Cavanaugh et al., 2007). Objective, device-based investigation of ambulation activity recovery, using measures that can characterise activity recovery, across a sufficient time period to observe both recovery and potential plateau of activity after stroke, has not yet been completed.

Thus, this thesis will look at the recovery of ambulation activity within free-living environments in one sample of stroke survivors following hospital discharge. It will take into consideration major time points previously identified as significant points at which recovery may change in this group. Time points of one, three and six months will be used as most recovery is observed across the first one month after stroke. Further recovery is observed up until three months, with a potential plateau in recovery between three and six months (Hermann and Chopp, 2012; Cramer and Riley, 2008; Hendriks et al., 2002; Jorgensen et al., 1995b). Valid and reliable accelerometers will be used to measure ambulation activity over the required duration of four full days (Murphy, 2009). Measures that will be used to characterise activity have been previously defined and will be used throughout the thesis to see how characteristics of ambulation activity change over the first six months after stroke survivors return to their home environments.

2.4. Community Ambulation

2.4.1. Defining community ambulation

Community ambulation refers to independent ambulation that occurs outside the home and yard, to include negotiating uneven terrain, private venues, shopping centres and other public venues (Lord et al., 2004). It differs from total daily ambulation activity as it excludes any household-based ambulation. Further, community ambulation falls within the participation domain of the ICF, and is generally associated with a purpose (WHO, 2001). Community ambulation is more complex than household-based ambulation as it incorporates potentially challenging physical environments (Patla and Shumway-Cook, 1999; Robinson et al., 2013) as well as cognitive and physical demands (Robinson et al., 2013; Robinson et al., 2011a; Robinson et al., 2011b; Lord et al., 2010). It is an important pre-requisite for community re-integration (Lord and Rochester, 2005) and regarded by a majority of stroke survivors as a very important goal (Lord et al., 2004).

A number of terms have been used to describe community ambulation in the literature. These include a combination of 'community' or 'outdoor' with; 'ambulation', 'locomotion', 'walking' or 'mobility' (Brown et al., 2010; Lord et al., 2010; Lord and Rochester, 2008; Lord et al., 2006; Shumway-Cook et al., 2005b; Lord et al., 2004; Shumway-Cook et al., 2003; Shumway-Cook et al., 2002; Perry et al., 1995; Lerner-Frankiel et al., 1986). However, regardless of the differences in terms used, studies refer to a similar task. Study methods indicate that participants have to be ambulant (Robinson et al., 2013; Robinson et al., 2011a; Robinson et al., 2011b; Lord et al., 2010; Lord et al., 2004; Shumway-Cook et al., 2002), within their 'community' – a location that is not within the home environment (Robinson et al., 2011a; Robinson et al., 2011b; Lord et al., 2010; Lord et al., 2004; Shumway-Cook et al., 2002). Further, outcome measures include direct observation, or self-report of walking that occurs within respective 'communities' (Robinson et al., 2011a; Robinson et al., 2011b; Lord et al., 2010; Lord et al., 2004; Shumway-Cook et al., 2002; Patla and Shumway-Cook, 1999). In stroke, the term 'community ambulation' and its definition by Lord et al. (2004) are most commonly used. Thus, for the purpose of this thesis, community ambulation will be defined as *'any ambulation that occurs outside the home and yard'* (Lord et al., 2004).

2.4.2. Current *requirements* and *criteria* for community ambulation

It is difficult to define a standard set of requirements for community ambulation applicable to all individuals. Distance, speed and functional requirements for successful community ambulation differ between communities, depending on location (Salbach et al., 2014b; Mudge and Monachino, 2013; Corrigan and McBurney, 2012; Andrews et al., 2010; Robinett and Vondran, 1988) and population density (Robinett and Vondran, 1988). Minimum gait speed requirements for successful independent community ambulation range from 0.8m/s (Hill et al., 1997; Perry et al., 1995) to 1.3m/s (Andrews et al., 2010; Lord and Rochester, 2005; Lord et al., 2004; Robinett and Vondran, 1988; Lerner-Frankiel et al., 1986), while minimum walking distance requirements range from 18m (Salbach et al., 2014b; Robinett and Vondran, 1988) to 677m (Salbach et al., 2014b; Andrews et al., 2010; Hill et al., 1997; Lerner-Frankiel et al., 1986) (see table 2.5). Differences in definitions of gait speed, gait endurance and general functional outcomes for community ambulation between studies (see table 2.5) make it difficult to compare between samples, and generate conclusions regarding community ambulation after stroke. Further, successful, or unsuccessful achievement of defined requirements for independent community ambulation does not guarantee outcomes. One study based in Melbourne, Australia (Hill et al., 1997) reported 40% of stroke survivors achieved independent *outdoor* ambulation, despite only 7% achieving all clinical requirements indicative of independent community ambulation.

Criteria currently used to classify stroke survivors as community ambulant vary across the literature (see table 2.5). A range of clinical measures has been used to classify stroke survivors into categories of community ambulation ability. These include the timed 10m walk (gait speed) (Taylor et al., 2006; Lord et al., 2004; Hill et al., 1997), functional ambulatory category (Hill et al., 1997), functional independence measure (Hill et al., 1997), treadmill test and 6 minute walk test (both as a measure of walking endurance) (Bijleveld-Uitman et al., 2013; Donovan et al., 2008; Lord et al., 2004; Hill et al., 1997) as well as independent negotiation of stairs (Alzahrani et al., 2009; Lerner-Frankiel et al., 1986). Further, within these clinical measures, a range of scores is used when defining criteria for independent community ambulation. Such differences in definitions and clinical measures are reflective of the variety of community locations investigated, as well as the complexity and patient-specific nature of this goal.

Table 2.5: Common definitions and criteria for community ambulation in the literature

Author/ Year	Sample (size, age in years)	Definition of community ambulation/ambulator	Methods and measures used	Criteria
Keenan, Perry & Jordan, 1984	n = 90 stroke survivors Age: 59.4 (13.3) years	Nil definition of community ambulation. *Classification of community ambulator:* Able to ambulate independently on all terrain and negotiate stairs and curbs	**Measure of Community ambulation:** Able to ambulate on all terrain and negotiate stairs and curbs at discharge from rehabilitation **Clinical measures:** *Sensation:* grading of tactile sensation and proprioception (normal, impaired or absent) *Motor function:* resting muscle tone (scale 1-5) *Motor Control:* Lower limb manual muscle tests (grade 1-5) *Sensory integration:* method not specified *Balance reactions:* sitting balance ± external perturbations; anterior + posterior tipping tests in standing.	Based on achievement of functional goals as assessed by physical therapists at discharge**:** *Community ambulators:* able to ambulate independently on all terrain and negotiate stairs and curbs *Limited community ambulators:* independent on all terrain but required supervision/standby assistance on uneven surfaces, stairs or curbs *Household Ambulators:* Supervised on level terrain and minimally assisted with stairs and curbs *Physiologic ambulators:* assisted on level terrain *Non-ambulators:* unable to walk without maximal assistance of more than one person
Lerner-Frankiel, 1986	n = 7 stroke survivors 3 amputees Age: 59.7 (6.6) years	Nil definition of community ambulation provided. *Classification of community ambulator:* Should be able to ambulate a distance sufficient to conduct business in a variety of locations, be able to ascend and descend curbs and cross a street within the time provided by a crossing signal.	**Measures of Community ambulation:** Self-report of independence in community ambulation by participants and treating physiotherapists **Clinical Measures:** *Curb mobility:* ascend/descend 18cm curb *Gait endurance:* walk until fatigue to maximum distance of 600m	Criteria for requirements for community ambulation based on measurements by assessors of community environments (for example, required distances, crosswalk time allocation and curb height) at various locations of interest during community ambulation (supermarket, drugstore, bank, department store within a shopping mall, post office and physicians office). **Distance:** 332m (mean), 33m-600m (range) **Curb Height:** 18-20cm **Velocity:** 79m/min (mean)
Robinett and Vondran	Nil participants.	Used definitions as provided by Lerner-Frankiel et al., 1986.	Assessed 3 communities of varying population sizes: <10,000; 10,000 to 40,000;	**Distance:** min 13m to max 480m *Median distance: 45.5m to 342m* (dependent on population size)

1988		Nil definition of community ambulation provided. *Classification of community ambulator:* Should be able to ambulate a distance sufficient to conduct business in a variety of locations, be able to ascend and descend curbs and cross a street within the time provided by a crossing signal.	>95,000 to evaluate differences in requirements for minimum distance, velocity and curb height for successful community ambulation.	**Velocity:** 30m/min to 82.5m/min *Median Velocities: 44.5m/min to 63.5m/min*(dependent on population size) **Curb height:** 17-18.5cm Greater distance and velocity requirements for urban communities rather than rural.
Perry 1995	n = 147 stroke survivors Age: 55.5 (12.2) years	Nil definition of community ambulation provided. *Classification of community ambulators:* Based on self-report using the walking ability questionnaire. 3 levels of household ambulation and 3 levels of community ambulation (most-limited, least-limited, community walker).	**Measure of community ambulation:** Walking ability questionnaire (developed by authors) **Clinical measures:** *Velocity* using bilateral footswitch stride analyser *Lower limb muscle strength:* functional muscle strength of lower limb flexors and extensors using the Upright Motor Control test (Keenan & Perry, 1984) *Lower limb proprioception:* measured using accuracy of copied lower limb positions on unaffected side by assessors	Velocity unable to distinguish between levels of community ambulation, but able to distinguish between household and community walkers. Combined velocity and strength significantly different between the three groups of community walkers (most, least, and unlimited). *Most-limited community walker:* 24m/min *Least-limited community walker:* 35m/min *Community walker:* 48m/min
Hill et al., 1997	n = 109 stroke survivors Age: 72.9 (10.4) years	Nil definition of community ambulation provided. *Classification of community ambulator:* Based on achievement of criteria including: **FIM>5** (independent gait) **FAC = 6** (negotiate uneven terrain and kerbs) **Velocity ≥ 48m/min** (avg required velocity to cross Melbourne traffic crossing) **Distance:** >500m	**Measure of Community ambulation:** Achievement of functional criteria set by authors **Clinical Measures:** *Functional independence indoors* via the Functional independence measure *Outdoor mobility* via Functional ambulation category Movement recovery via *Motor Assessment Scale (Walking item)* *Gait velocity* via 10MTW *Gait endurance* based on physiotherapist's estimation of distance walked without a rest	Based on requirements for community ambulation as perceived by the authors: **FIM>5** (independent gait) **FAC = 6** (negotiate uneven terrain and kerbs) **Velocity ≥ 48m/min** (avg required velocity to cross Melbourne traffic crossing) **Distance:** >500m

Lord et al., 2004	n = 130 people with subacute stroke Age: 68.8 (11.3) years	**Definition of community ambulation used:** Independent mobility outside the home, which includes the ability to confidently negotiate uneven terrain, private venues, shopping centres and other public venues. *Classification of levels of community ambulation:* 1) not ambulant outside home 2) ambulant as far as the letterbox 3) ambulant in the immediate environment 4) ambulant in a shopping centre and/or places of special interest	**Measure of community ambulation:** Self-reported questionnaire. **Clinical measures:** *Gait velocity* via timed 10m walk test (10MTW) *Indoor and outdoor walking ability:* Functional ambulation category *Functional ambulation:* Rivermead mobility index *Gait endurance* via treadmill walk test up to 300m Compared clinical measures of gait velocity and endurance with self-reported measures of community ambulation difficulty and participation	Based on velocity and distance walked on treadmill *Not ambulant outside the home:* Speed: 30.9m/min Distance: 54.2m *Ambulant to the letterbox:* Speed: 39.6m/min Distance: 93.7m *Ambulant in immediate environment:* Speed: 49.2m/min Distance: 140m *Ambulant in a shopping centre and/or places of special interest:* Speed: 68.6m/min Distance: 220.2m
Andrews et al., 2010	Participant characteristics not reported	Used definition of community ambulation provided by Lord et al. (2004)	Measured distances required to ambulate at 9 community locations as outlined by Lerner-Frankiel et al. (1986). The 9 community locations including: post-office, banks, medical, pharmacy, department store, grocery stores, hardware store, superstore, club warehouse Also measured gait speed requirements at cross-walks within the community.	**Distance:** *Mean distance:* Post office: 52.0 (23.3) metres Bank: 57.1 (20.9) metres Medical: 65.8 (32.2) metres Pharmacy: 206.3 (26.8) metres Department store: 345.9 (69.2) metres Grocery store: 380.6 (86.3) metres Hardware: 565.5 (38.6) metres Superstore: 606.6 (101.2) metres Club warehouse: 676.8 (159.4) metres **Cross-walk speed:** *Mean speed allotted by cross-walk:* 0.49 (0.20) m/s *Mean gait speed used by individuals at cross-walk: 1.32* (0.31) m/s
Brown et al., 2010	n = 19 older adults Age: 76.6	*Used a variation of the definition of community ambulation provided by Lord*	Interviewed participants to determine routine locations visited during community trips to maintain independence. Then measured the	**Distance:** *Essential locations* (including: doctors office/professional building, bank, superstore,

	(5.8) years	*et al. (2004):* Community ambulation: locomotion outdoors that includes activities necessary to live independently, such as visits to the bank, pharmacy, and supermarket.	minimum and maximum walking distances required to ambulate to complete tasks at each community location. Community locations visited by participants: Grocery store (84% of sample), doctor's office (79% of sample), family and friend's homes (79% of sample), religious facilities (74% of sample), supermarket (68% of sample), restaurant (42% of sample), shopping mall (37% of sample), beauty/barbershop (32% of sample), bank (32% of sample) and pharmacy (26% of sample).	pharmacy, grocery store and department store): Mean distance: 38m (minimum) to 609m (maximum) *Locations essential to some* (including: gas station, post office, religious facility and doctor's office in a hospital): Mean distance: 44m (minimum) to 192m (maximum) *Non-essential locations* (including: beauty parlour/barbershop, restaurant, cemetery, senior centre, library, hospital visitation and mall): Mean distance: 18m (minimum) to 1309m (maximum)
Mudge et al., 2013	Nil participants	Nil definition of community ambulation provided.	Assessed 30 supermarkets as well as suburb population size Measured distances required to ambulate for single and two-tasks during community trips. Recorded presence of curbs and pedestrian crossings.	**Distance:** Single-task: *Mean distance:* 393 (113) metres Two-task: *Mean distance:* 871 (276) metres No relationship between single-task trips and population size. Low correlation between two-task trips and population size (r = 0.340) **Curbs:** present at 40% of community locations **Pedestrian crossings:** present at 47% of community locations
Salbach et al., 2013	Nil participants	Nil definition of community ambulation provided.	Synthesised measures from seven studies to determine distance and speed requirements based on population size	**Distance:** *For essential errands:* 20 metres to 381metres *All distances: 16 metres to 677 metres* Smallest distances included: cemeteries and accessing the front and back of the house (16 metres to 19 metres) Largest distances required at hardware stores, superstores and club warehouses (183 metres to 677 metres). **Crosswalk speed:** 0.44m/s to 1.32 m/s Increased distance requirements with larger population size

2.4.3. Community ambulation after stroke – what do we already know?

Unlike ambulation activity, community ambulation following stroke has received minimal accurate device-based measurement. Currently, most studies have collected self-reported levels of community ambulation, or inferred outcomes based on performance during clinical tests of gait and function (see table 2.5). Based on self-report, stroke survivors do not engage in community ambulation as frequently as age-matched healthy adults (Robinson et al., 2011b; van de Port et al., 2008) and a high proportion of survivors report dissatisfaction with their community ambulation outcomes (Robinson et al., 2011a). Studies based in the United States of America and New Zealand report between 32% (Viosca et al., 2005) and 66% (Eng and Tang, 2007; Lord et al., 2004; Hill et al., 1997; Perry et al., 1995) of stroke survivors achieve independent community ambulation.

Only two studies have used device-based measures of community ambulation after stroke (Evans et al., 2012; McCluskey et al., 2012). These studies include a case study of one stroke survivor (Evans et al., 2012) and a study investigating the feasibility and validity of GPS for measurement of outings after stroke (McCluskey et al., 2012). Comparison of outcomes in volume, frequency and intensity of community-based ambulation is difficult. However, lower volume of community ambulation after stroke is implied by self-reported difficulty with returning to pre-stroke community ambulation (Robinson et al., 2011a; Lord and Rochester, 2008; van de Port et al., 2008; Lord et al., 2004) and reduced participation across all domains of life (Adamit et al., 2014; Blomer et al., 2014; van der Zee et al., 2013; Barclay-Goddard et al., 2012). Stroke survivors may reduce the frequency of community ambulation through a decrease in total trips into the community, as well as in the frequency of walking related activities during each community trip (Robinson et al., 2011a; Robinson et al., 2011b; Lord et al., 2004). Though, some stroke survivors report splitting long community trips over multiple shorter trips. This could result in an increase in frequency of community ambulation, though would also indicate that community trips may become shorter after stroke (Lerner-Frankiel et al., 1986). No study has investigated intensity of community-based ambulation after stroke. Further, the recovery of community ambulation – especially the changes over the subacute phase of stroke has not been investigated.

Reduced participation after stroke may also result in the reduction in community based ambulation. As stroke survivors reduce time spent in activities such as employment, social activities, physical activity and exercise, religious trips, travel, and education; ambulation that occurs outside the home and yard may also reduce (van der Zee et al., 2013; Barclay-Goddard et al., 2012; Desrosiers et al., 2005a). Conversely, reduced ability to walk in the community might limit participation. This is a complex relationship that requires further longitudinal investigation. Ambulation requirements may also vary based on community locations. These may impose challenges for stroke survivors that may result in increased avoidance of difficult community locations (Robinson et al., 2013; Lord et al., 2010; Shumway-Cook et al., 2005a; Shumway-Cook et al., 2002). For example, larger shopping centres may require stroke survivors to ambulate further than a local medical practice (Barclay et al., 2014; Salbach et al., 2014b; Mudge and Monachino, 2013). Similarly, faster gait speeds may be required to cross roads, or navigate crowds at a larger shopping centre than smaller locations such as a medical practice (Salbach et al., 2014b; Andrews et al., 2010). However, while these challenges may result in increased avoidance of community ambulation early after stroke, the purpose associated with certain community locations, such as essential medical appointments, or grocery shopping, may encourage stroke survivors to continue accessing certain community locations after stroke (Barclay et al., 2014; Ahuja et al., 2013; Barnsley et al., 2012). Thus, characteristics of community ambulation after stroke may be dependent upon community locations and purpose of trips outside the home and yard. This would also benefit from further investigation.

Though a range of community ambulation outcomes (e.g. successful attainment of community ambulation, reported difficulty and dissatisfaction or number of community trips) is observed after stroke, stroke survivors consistently demonstrate low levels of community ambulation (Barclay et al., 2014; Robinson et al., 2013; Robinson et al., 2011a; Lord et al., 2004; Robinson et al., 2011b). Further, a majority report limitations even during the chronic phase of their recovery (Barclay et al., 2014; Rosa et al., 2014; van der Zee et al., 2013; Robinson et al., 2011b). Older adults with mobility limitations demonstrate a reduced frequency of community trips per day and have a tendency to avoid community environments (Lord et al., 2010; Shumway-Cook et al., 2005a; Shumway-Cook et al., 2002). Similarly, stroke survivors with new mobility and functional limitations may change community ambulation soon after stroke (Robinson et al., 2013; Robinson et al., 2011a; Robinson et al., 2011b; Lord et al., 2004). However, the process by which this occurs is unknown. There is a need to accurately measure and characterise community ambulation outcomes across the subacute phase of stroke – where survivors demonstrate greatest change and recovery.

2.4.4. Measuring community ambulation

Studies measuring community ambulation after stroke have mostly relied on self-reported outcomes (Robinson et al., 2013; Robinson et al., 2011a; Robinson et al., 2011b; Lord et al., 2004; Lerner-Frankiel et al., 1986), clinic-based measures of function (Hill et al., 1997; Perry et al., 1995; Lerner-Frankiel et al., 1986) or measures of total daily ambulation rather than separating community-based ambulation from household ambulation (Robinson et al., 2011b; Fulk et al., 2010; Mudge and Stott, 2009; Hale et al., 2008). Two studies have used global positioning systems (GPS) to investigate community ambulation after stroke (Evans et al., 2012; McCluskey et al. 2012). These provided information regarding community locations visited, trip frequency and purpose, and distances walked within community locations (Evans et al., 2012; McCluskey et al. 2012). However, investigation of the validity and reliability of GPS for location and measures of ambulation such as step counts, distance walked and time spent walking is required for use in stroke. Accurate measurement of community ambulation post-stroke is required to facilitate conclusions on current levels of community ambulation and patterns associated with locations visited. This information will allow for a better understanding of the reasons for, and processes involved with decreased levels of community ambulation following stroke (Robinson et al., 2011b; Lord et al., 2004).

Tools for community ambulation measurement

A detailed analysis of potential tools for ambulation measurement after stroke is provided above in section 2.3.1. These tools could also be used for community ambulation measurement after stroke. As discussed above, direct observation may not be suited for free-living ambulation measurement (including community ambulation) after stroke. While self-report tools have potential issues with accuracy and capturing quantitative measures of ambulation, activity diaries have demonstrated some potential in providing accurate measures of purpose of community trips (McCluskey et al., 2012). Self-reported measures of purpose of community trips may allow for greater understanding of participation behaviours after stroke (McCluskey et al., 2012). Technical devices, most commonly accelerometers, have more recently been used to obtain measures of general walking activity in a number of adult samples including stroke (Alzahrani et al., 2011; Rand et al., 2010; Mudge et al., 2007; Haeuber et al., 2004; Macko et al., 2002). Accelerometers demonstrate high suitability for free-living ambulation measurement after stroke (see section 2.3.1). However, accelerometers alone are unable to separate ambulation completed out in the community from that performed within the home (Fulk et al., 2010).

Portable Global Positioning Systems (GPS) have increased the potential for accurate measurement of community ambulation and have been used in adult studies of mobility (Cho et al., 2011; Le Faucheur et al., 2008; Le Faucheur et al., 2007) including a case study of one stroke survivor (Evans et al., 2012). GPS devices provide real-time information on speed, time, location and distance travelled during community trips (Evans et al., 2012; McCluskey et al., 2012; Maddison and Ni Mhurchu, 2009; Le Faucheur et al., 2008; Le Faucheur et al., 2007). Information from GPS devices may assist in ascertaining patterns of movement based on environment or location obtained from satellite signals. These devices have demonstrated excellent agreement (94%) with direct observation for number of outings and good agreement (71%) with direct observation for purpose of community trips during measurement of people with stroke (McCluskey et al., 2012). However, they are yet to be validated for measures of time, location and distance for use after stroke. Further, issues including limited battery life, accuracy of data obtained and the requirement of a gold standard for GPS data analysis may limit their use for community ambulation measurement after stroke (Webber and Porter, 2009). Regardless, it has potential to provide isolated measures of community ambulation. Further, the combination of tools (for example accelerometer and GPS) may enhance the quality and accuracy of data obtained during community ambulation measurement to 90% (Cho et al., 2011; Troped et al., 2008). Nonetheless, this requires further investigation with survivors of stroke.

Measures to characterise community ambulation

As device-based measurement of community ambulation is limited, measures of community ambulation that can be captured by devices are not well established. However, as presented above in section 2.3.2, a number of device-based measures of ambulation activity are available. These could also be applied to measurement of community ambulation after stroke. Collecting similar measures during objective device-based measurement of community ambulation will also allow for comparison between community ambulation and total daily ambulation activity to see if characteristics of free-living ambulation change between the two contexts.

In addition to the measures of volume, frequency and intensity of ambulation outlined above (see section 2.3.2.), characteristics specific to community ambulation such as total time spent out in the community, frequency of community trips and purpose of community trips; would be useful to measure after stroke. Total time spent out in the community (a measure of volume) may be useful to capture what proportion of each day is spent out of the home and yard after stroke, and can be measured using devices in this group (Evans et al., 2012). Self-reported frequency of trips into the community is reduced in individuals with chronic stroke when compared to healthy controls (Robinson et al., 2011b). However, this measure of frequency needs accurate measurement, with GPS devices after stroke (Evans et al., 2012; McCluskey et al., 2012). Purpose of community trips is a useful measure to understand the context of community ambulation and capture any changes in participation behaviours (e.g. community reintegration) after stroke. Recovery of these characteristics of community ambulation across the first six months of returning home following stroke is not yet known. It is likely that individuals with subacute stroke would increase time spent in the community and frequency of trips (as well as measures of volume, frequency and intensity of ambulation) as survivors reintegrate into their communities and recommence community walking activities (Chau et al., 2009; Desrosiers et al., 2008; Hartman-Maeir et al., 2007; Desrosiers et al., 2005a; Mayo et al., 2002). Similarly, purpose of trips may also change over time as stroke survivors reintegrate into their communities (Chau et al., 2009; Desrosiers et al., 2008; Desrosiers et al., 2005a). However, understanding how this is recovered across this time after stroke would benefit from further objective measurement, as participation restrictions and dissatisfaction with community ambulation outcomes are reported even in the chronic phase of recovery (Walsh et al., 2014; Chau et al., 2009; Lord et al., 2004).

2.5. Factors affecting ambulation after stroke

It is evident that both ambulation activity and community ambulation are reduced after stroke, thus identifying factors that influence ambulation outcomes after stroke is required. Further, with the pressure for efficient stroke rehabilitation services, identifying factors at hospital discharge that predict free-living ambulation outcomes later after stroke survivors return home are required. Identifying discharge factors will assist in developing a better understanding of what contributes to outcomes early after stroke survivors return home to assist with goal-setting processes and more effective discharge planning. Effective, well-informed discharge planning can lead to more optimal outcomes after stroke survivors return home (NSF, 2010). However, further investigation of factors at hospital discharge that contribute to outcomes after stroke survivors return home is required to inform these processes (NSF, 2010).

No study has yet investigated factors at hospital discharge that predict free-living ambulation outcomes in people with subacute stroke. Thus far, studies have mostly attempted to identify factors that are related to, or predict ambulation activity outcomes in individuals with chronic stroke. Further, ambulation activity has often been characterised by volume measures only, while community ambulation has predominantly been characterised by self-reported independence with community ambulation (Lord et al., 2004) or frequency of trips and walking related activities in the community (Robinson et al., 2013; Robinson et al., 2011a; Robinson et al., 2011b). Consistent among these studies is that no single factor alone can explain the large variance in free-living ambulation outcomes (English et al., 2014; Robinson et al., 2011b; Fulk et al., 2010; Lord et al., 2004).

A number of factors within any of the ICF domains are associated with reduced ambulation activity and community ambulation after stroke (Rosa et al., 2014; Robinson et al., 2013; Rosenberg et al., 2013; Alzahrani et al., 2012; Danielsson et al., 2011; Robinson et al., 2011a; Robinson et al., 2011b; Fulk et al., 2010; Lord et al., 2004; Shumway-Cook et al., 2002). Yet few studies have prospectively investigated a combination of factors within multiple domains of the ICF on free-living ambulation outcomes across the subacute phase of stroke. Identifying factors that affect characteristics (volume, frequency and intensity) of free-living ambulation will enable early intervention to prevent poor outcomes observed after stroke.

2.5.1. Body structures and functions

There is a potential effect of stroke severity, lower limb strength, balance, cardiovascular dynamics, fatigue and mood on ambulation activity and community ambulation outcomes in individuals with chronic stroke. No study has yet prospectively investigated the role of these factors at hospital discharge on free-living ambulation outcomes in individuals with subacute stroke.

Stroke severity

Stroke severity at hospital admission is a significant predictor of functional outcomes at three months after stroke (Veerbeek et al., 2011). It is also related to functional outcomes much later across stroke recovery. Increased stroke severity can result in poor functional recovery (Hakkennes et al., 2011; Veerbeek et al., 2011), a reduced chance of discharge to pre-stroke accommodation (Saxena et al., 2007), increased dependence in both household and community activities and death (Hakkennes et al., 2011; Veerbeek et al., 2011; Saxena et al., 2007; Christensen et al., 2005). While the direct effect of stroke severity on free-living ambulation outcomes has not been determined in individuals with subacute stroke, increased stroke severity has an indirect effect on free-living ambulation outcomes through increased severity of impairments such as muscle strength, cognition impairments, and activity limitations (e.g. balance and walking capacity). Increased stroke severity can also limit stroke survivors ability successfully re-integrate into the community (Walsh et al., 2014). Stroke severity has been well established as a contributing factor to functional outcomes in both survivors of subacute (Veerbeek et al., 2011) and chronic stoke. As the studies of this thesis will concentrate on stroke survivors who are discharged home and able to walk in order to obtain measures, a wide range of severity levels will not be included. Thus, due to the likely limited range of severity levels in the current study population, investigation of this factor on free-living ambulation recovery will not occur in this thesis.

Strength

Loss of muscle strength and control is the most common reported impairment after stroke, affecting anywhere between 50% and 88% of all survivors (Hall et al., 2011; Ng et al., 2005; Jorgensen et al., 1995a). Lower limb muscle strength is not related to total volume of activity in individuals with chronic stroke (Salbach et al., 2013; Fulk et al., 2010). However, improved dorsiflexor and knee extensor strength contributes to an increased frequency of community trips and walking related activities within the community by individuals with chronic stroke (Rosa et al., 2014; Robinson et al., 2011b). Improved lower limb strength at hospital discharge is moderately related to improved walking capacity (i.e. gait endurance and gait speed) (Danielsson et al., 2011; Hall et al., 2011; Patterson et al., 2007) and functional mobility outcomes (OR 2.27, $p = .03$) at follow-up assessments (Eng and Tang, 2007). Further, increased ankle dorsiflexion and knee extensor strength has a positive effect on gait speed and endurance after stroke (Dorsch et al., 2012; Moriello et al., 2011). Faster gait speed, greater gait endurance and higher scores of functional mobility are related to improved free-living ambulation outcomes after stroke (see below) (Fulk et al., 2010; Lord et al., 2004). As a result, improved lower limb muscle strength may indirectly increase free-living ambulation after stroke. While there is a relationship between lower limb muscle strength and measures of community ambulation (Rosa et al., 2014; Robinson et al., 2011b) and walking capacity (Danielsson et al., 2011; Hall et al., 2011; Patterson et al., 2007), investigation of the role of lower limb muscle strength on free-living ambulation outcomes after stroke is beyond the scope of this thesis.

Cardiovascular fitness

Cardiorespiratory fitness, or exercise capacity has been characterised by peak oxygen consumption (VO_2 max) (Baert et al., 2012; Manns et al., 2010; Brooks et al., 2008; Resnick et al., 2008; Michael and Macko, 2007; Michael et al., 2005) and oxygen uptake kinetics (VO_2 on-off kinetics) (Manns et al., 2010; Manns et al., 2009) after stroke. Increased scores in VO_2 max (a score of maximal oxygen consumption) and faster VO_2 on-off kinetics (a score of ability to adapt to change in metabolic demands) indicate improved cardiorespiratory fitness. Stroke survivors demonstrate reduced cardiorespiratory fitness and exercise capacity across all phases of their recovery. Within the first ten days of stroke, peak oxygen uptake, or VO_2 max, can be lower than 50% of healthy age and gender-matched controls (Brooks et al., 2008). While fitness may increase slightly across the first three months following stroke (50% of age and gender-matched controls) (Kelly et al., 2003), fitness is not completely recovered. Individuals with chronic stroke demonstrate 55% to 75% of exercise capacity, and slower time to adapt to changes in metabolic demands than healthy controls (Manns et al., 2010; Brooks et al., 2008; Mackay-Lyons and Makrides, 2002).

Most studies have investigated the direct and indirect effects of cardiorespiratory fitness on activity after stroke rather than on community ambulation. A reduced peak VO_2 after stroke may directly result in reduced total daily steps and intensity of activity in individuals with chronic stroke (Baert et al., 2012; Michael and Macko, 2007), though one study found no relationship (Manns et al., 2009). Peak VO_2 scores are also strongly related to measures of walking capacity (gait speed and gait endurance over six minutes) in individuals with subacute stroke (Kelly et al., 2003). As these measures of walking capacity are strongly related to outcomes in free-living ambulation (Bijleveld-Uitman et al., 2013; Baert et al., 2012; Fulk et al., 2010; Lord et al., 2004), cardiorespiratory fitness may have an indirect effect on the recovery of ambulation activity and community ambulation. Also, a slower ability to adapt to changes in metabolic loads results in lower number of steps per day, a reduced frequency of long duration ambulation bouts and an increased frequency of short ambulation bouts after stroke (Manns and Baldwin, 2009). Reduced cardiovascular fitness is observed early after stroke, and contributes to low activity (Baert et al., 2012; Manns et al., 2010; Brooks et al., 2008). This in turn can continue the deterioration of fitness, and thus further reduce ambulation activity and community ambulation over time after stroke. While the effect of fitness on free-living ambulation outcomes across the subacute phase of recovery of stroke is required, assessment of this factor is regrettably beyond the scope of this thesis.

Fatigue

Fatigue is reported by 39-69.6% of stroke survivors (Duncan et al., 2012; Choi-Kwon and Kim, 2011; Michael and Macko, 2007; Schepers et al., 2006; Glader et al., 2002; van der Werf et al., 2001; Ingles et al., 1999). After stroke, it is often measured through a self-reported presence of fatigue or questionnaires such as the Fatigue severity scale (Lerdal et al., 2009; Michael and Macko, 2007; Shaughnessy et al., 2006; Krupp et al., 1989). Fatigue is a multi-dimensional process involving both biological and psychological elements (Duncan et al., 2012). It is known that stroke survivors have altered cardiovascular dynamics and low cardiorespiratory fitness that impact upon the volume, frequency and intensity of ambulation activity (Baert et al., 2012; Manns et al., 2009; Michael and Macko, 2007).

Self-reported fatigue may influence free-living ambulation recovery after stroke. While one study reported that self-report fatigue does not influence volume of ambulation activity in individuals with chronic stroke (Michael and Macko, 2007), another study observed a relationship between daily steps and fatigue (Robinson et al., 2011a). Self-reported fatigue at hospital-discharge can contribute to decline in general mobility outcomes at one-year follow-up (van de Port et al., 2006). It is suggested that fatigue may lead to decreased ambulation activity through the 'middle range theory of unpleasant symptoms' (Michael et al., 2006). By this theory, stroke survivors reporting fatigue would avoid activities that aggravate the symptom of fatigue (Duncan et al., 2012; Michael et al., 2006). Thus, stroke survivors who experience fatigue will generally avoid ambulation activity and remain inactive. Low activity observed in individuals with chronic stroke may be the result of an early avoidance of activity to minimise symptoms of fatigue.

Self-reported fatigue does not affect the frequency of participation after stroke (van der Zee et al., 2013) and self-reported community ambulation (Robinson et al., 2011a). Most studies investigating the effect of fatigue on community ambulation and participation outcomes have been of individuals with chronic stroke. By this stage, adjustments to community ambulation to reduce the aggravation of fatigue symptoms may have already taken place (Duncan et al., 2012; Michael et al., 2006). The effect of fatigue on the recovery of both ambulation activity and community ambulation across the subacute phase of stroke has not been investigated. The presence of fatigue early after stroke may result in a reduction in community ambulation over time. However this phenomenon requires further investigation.

Executive function

Executive function relates to the ability to plan, monitor and execute complex actions. Impaired executive function is observed in up to one third of stroke survivors (Rasquin et al., 2004), and is even observed in survivors of mild stroke (Adamit et al., 2014). Theoretically, executive function could affect free-living ambulation outcomes after stroke, as it permits adaptation to complex and new environments and also allows allocation of attention during tasks (Royall et al., 2004; Rapport et al., 1993). Impaired executive function may affect the ability of stroke survivors to ambulate and manage additional tasks and environmental challenges encountered within their communities (Donovan et al., 2008; Lord et al., 2006). Further, it is related to a higher risk of falls after stroke (Campbell and Matthews, 2010). Finally, impaired executive function is related to poor performance in measures of balance and gait (Liu-Ambrose et al., 2007; Coppin et al., 2006) including the Berg Balance Scale, 10m timed walk, 6-minute walk test, timed stair climb and the timed up and go – most of which share a strong relationship with daily ambulation activity and community ambulation in individuals with subacute and chronic stroke (Askim et al., 2013; Baert et al., 2012; Fulk et al., 2010; Mudge and Stott, 2009; Michael et al., 2005). Decreased ability to manage new environments and complex tasks (e.g. return to employment), increased fear of falling, impaired balance and limitations of walking capacity can all contribute to a decline in both free-living ambulation activity and community ambulation.

Impairments of executive function after stroke are not related to self-reported activity and participation in individuals with chronic stroke (Viscogliosi et al., 2011; van de Port et al., 2008). However executive function impairments are associated with decreased time spent outdoors (Kerr et al., 2012) and restricted community reintegration (Adamit et al., 2014) after stroke. In older adults, impairment of executive function is a significant predictor of community ambulation (Lord et al., 2010). Further impaired executive function contributes to functional decline in healthy older adults (Coppin et al., 2006). There appears a relationship between executive function impairments and objective measures of free-living ambulation. Further, as discussed above, impaired executive function may affect the ability of stroke survivors to return to all pre-stroke activities, roles and responsibilities (Adamit et al., 2014). However, the recovery of executive function and its effect on ambulation activity and community ambulation requires more investigation after stroke.

Mood

Mood refers to both negative (or depressive) and positive thoughts and emotions (Joseph and Lewis, 1998). Mood disorders are prevalent in the stroke community (White et al., 2008) and can contribute to mobility decline in the first year after stroke (OR .40, $p = 0.00$) (van de Port et al., 2006). Depression is a primary mood disorder experienced by around one third of stroke survivors (Hackett and Pickles, 2014; Hackett and Anderson, 2005). It is significantly associated with reduced self-reported activity and community ambulation after stroke (Rosenberg et al., 2013; Robinson et al., 2011a). Conversely, positive emotion alone is significantly associated with improvements in mobility and functional outcomes at three months following discharge after stroke (Ostir et al., 2008). It is important to assess both positive and negative thoughts and emotions, as both impact free-living ambulation through their association with motivation and energy (Rosenberg et al., 2013).

In individuals with chronic stroke, positive mood is significantly related to increased total steps taken per day ($r = 0.62$) (Baert et al., 2012), time spent upright (including ambulation time) (Alzahrani et al., 2012) and activity counts (including step count) ($r = 0.42 – 0.52$) (Alzahrani et al., 2012). Mood is also a significant predictor of time spent upright and total activity counts in individuals with chronic stroke (Alzahrani et al., 2012). Similarly, stroke survivors with positive mood demonstrate increased walking related activities within the community (Robinson et al., 2011a). Further, survivors of chronic stroke with depression and anxiety report a reduced desire to leave the home (Barclay et al., 2014). However, stroke survivors who ambulate within their community experience positive emotional benefits that may reinforce the benefits of ambulation and encourage further free-living ambulation (Barclay et al., 2014; Robinson et al., 2011a). It is evident that both positive and negative moods can influence the recovery or decline of free-living ambulation after stroke. However, the effect of mood on the recovery of ambulation activity and community ambulation across the subacute phase of stroke needs further investigation.

2.5.2. Activity

Activity limitations after stroke are associated with ambulation outcomes. Clinical measures of balance, functional mobility and walking capacity (gait speed and gait endurance) have demonstrated some associations with activity outcomes after stroke.

Balance

Scores of static balance demonstrate a positive relationship with activity and community ambulation after stroke (Askim et al., 2013; Alzahrani et al., 2012; Robinson et al., 2011b; Schmid et al., 2011; Fulk et al., 2010; Michael et al., 2005). Higher scores of static balance are related to increased time spent upright (including ambulation time) during the first six months of stroke recovery (subacute phase) (Askim et al., 2013). Similarly, in individuals with chronic stroke, improved balance scores are related to greater total number of steps taken per day ($r = 0.54$ – 0.581) (Fulk et al., 2010; Michael et al., 2005). Scores of static balance can explain up to 30% of variance in total step counts in individuals with chronic stroke (Michael et al., 2005). Regarding community ambulation - improved scores in static balance are significantly related to the number of walking related activities that are performed in the community by individuals with chronic stroke (Robinson et al., 2011b). Further, higher scores in balance tests can predict independence with community ambulation six months after stroke (Rosa et al., 2014).

The effect of balance on ambulation activity across the subacute phase of stroke would benefit from investigation. Impaired balance early after stroke may limit a survivor's ability to remain upright and engage in ambulation activity and community ambulation, predisposing them to low levels later during recovery (Askim et al., 2014; Askim et al., 2013). This needs further investigation, but is beyond the scope of this thesis.

Functional Mobility

Functional mobility is often characterised using tests such as the Rivermead mobility index (Baert et al., 2012; Egerton et al., 2006), Barthel Index (Egerton et al., 2006), Continuous scale physical functional performance 10-item test (CF-PFP 10) (Manns et al., 2009), timed stairs ascension (Alzahrani et al., 2009) and the Chedoke-McMaster stroke assessment (Rand et al., 2010). Survivors of subacute stroke who score lower on measures of functional mobility have less frequent transitions in posture within the inpatient setting (Egerton et al., 2006) and engage in lower volume of time upright (Askim et al., 2013) when living in the community. Further, subacute stroke survivors with lower scores of functional mobility report reduced independence with community ambulation (Lord et al., 2004). Also, individuals with chronic stroke who demonstrate limitations in functional mobility have a reduced volume of ambulation activity (Baert et al., 2012; Rand et al., 2010; Alzahrani et al., 2009). No study has investigated the influence of functional mobility over time on ambulation activity and community ambulation outcomes in subacute stroke survivors. Over time, improvements in clinic-based measures of functional mobility may lead to improvements in free-living ambulation after stroke. Investigating the direct effect of such measures are required, but is beyond the scope of this thesis.

Walking capacity

Walking capacity has been characterised through clinical measures of gait speed and endurance after stroke. The most common clinical measures of gait speed and gait endurance are the timed 10-metre walk and six-minute walk tests respectively. Both gait speed and endurance are important in predicting stroke survivor independence in ambulation activity and community ambulation (Barclay et al., 2014; Rosa et al., 2014; Fulk et al., 2010; Lord et al., 2004; Perry et al., 1995; Lerner-Frankiel et al., 1986). Clinical measures of walking capacity provide an indication of stroke survivor's ability to ambulate within some environmental settings and negotiate challenges encountered during free-living ambulation. Gait speeds greater than 0.8m/s and endurance over 300m indicate independence in all conditions within which free-living ambulation may take place (Andrews et al., 2010; Perry et al., 1995; Lerner-Frankiel et al., 1986). No study has prospectively investigated the direct effect of gait speed and endurance on objective measures of ambulation activity and community ambulation in individuals with subacute stroke.

Survivors of subacute stroke who walk at faster gait speeds also spend more time upright within the inpatient setting (Egerton et al., 2006). Indicating that faster gait speeds could also result in increased ambulation activity across this phase. In individuals with chronic stroke, both gait speed and endurance have a significant relationship with volume and intensity of ambulation activity and volume and frequency of community ambulation. Gait speed shares a positive relationship with total daily step counts (Baert et al., 2012; Alzahrani et al., 2011; Fulk et al., 2010; Mudge and Stott, 2009; Michael and Macko, 2007) and time spent upright in individuals with chronic stroke (Baert et al., 2012; Alzahrani et al., 2011). Faster gait speeds are also related to more trips into the community and walking related activities within the community setting after stroke (Robinson et al., 2011b). Stroke survivors report that increased gait speeds allow safe mobilisation within the community as well as an improved ability to keep up with family and friends who accompany them during community trips (Barclay et al., 2014). Early after stroke, limitation in gait speed is a barrier towards community ambulation (Barclay et al., 2014).

Gait endurance has been identified as a strong indicator of ambulation activity outcomes in individuals with chronic stroke (Mudge and Stott, 2009). It also has a positive relationship with total step counts per day ($r = 0.60 – 0.68$) (Alzahrani et al., 2011; Fulk et al., 2010), time spent upright ($r = 0.55$) (Alzahrani et al., 2011) and intensity of ambulation activity in survivors of chronic stroke (Mudge and Stott, 2009). Gait endurance is also a strong predictor of total step counts after stroke (Fulk et al., 2010; Mudge and Stott, 2009), overall self-reported activity (Danielsson et al., 2011) and intensity of activity (Mudge and Stott, 2009). In individuals with chronic stroke, six-minute walk test distance predicts 38-54% of variance in total step counts (Fulk et al., 2010; Mudge and Stott, 2009), 21% of variance in self-reported activity (Danielsson et al., 2011) and 33-54% of intensity of activity (Mudge and Stott, 2009).

There is limited investigation of the direct effect of gait endurance on community ambulation after stroke. However, stroke survivors often report gait endurance as an important component of walking capacity that impacts community ambulation outcomes (Barclay et al., 2014; Combs et al., 2013). Further, improved gait endurance is associated with independence with community ambulation (Bijleveld-Uitman et al., 2013; van de Port et al., 2008). Theoretically, increased gait endurance will allow stroke survivors to ambulate within places of interest within the community (Salbach et al., 2014b; Andrews et al., 2010). Thus, improvements in gait endurance may result in stroke survivors ambulating without restrictions within their community and thus increased community ambulation.

Most often the effect of walking capacity on free-living ambulation has been assessed in cross sectional studies of individuals with chronic stroke (Bijleveld-Uitman et al., 2013; Baert et al., 2012; Alzahrani et al., 2011; Robinson et al., 2011b; Fulk et al., 2010; Mudge and Stott, 2009). Survivors of stroke who have significant limitations in gait speed and endurance may be unable to engage in large volumes of activity, frequent bouts of walking and higher intensity activity (Baert et al., 2012; Alzahrani et al., 2011; Danielsson et al., 2011; Fulk et al., 2010; Mudge and Stott, 2009). Further, limitations in walking capacity may limit stroke survivors' in accessing places of interest within their communities (Salbach et al., 2014b; Shumway-Cook et al., 2005b; Shumway-Cook et al., 2003). This may predispose stroke survivors to low levels of ambulation activity and community ambulation early after stroke. However, this phenomenon, and the role of walking capacity on the recovery of free-living ambulation across the subacute phase of stroke requires prospective investigation.

2.5.3. Environmental factors

Clinical measures of impairment and activity alone are unable to explain all of the large variance observed in ambulation activity outcomes after stroke. As modelled by the ICF, and reflected in self-reported barriers and facilitators to activity and participation by stroke survivors (Nicholson et al., 2013; Simpson et al., 2011; Resnick et al., 2008; Hammel et al., 2006), environmental factors may have an impact on the recovery of free-living ambulation in this group. Stroke survivors report factors that enable and limit ambulation within all five domains of the environment (Barclay et al., 2014; Nicholson et al., 2013; Simpson et al., 2011; Resnick et al., 2008). These include components of the natural and human made physical environment, products and technology (for example mobility aides), supports and relationships (for example carer support), attitudes (for example self-awareness and perceptions of others), as well as services systems and policies (for example access to services). While it is out of the scope of this thesis to investigate the role of all environmental factors on ambulation activity outcomes, it is important to consider these factors. Environmental factors can influence the choices to engage in free-living ambulation (Nicholson et al., 2013; Robinson et al., 2013; Simpson et al., 2011), and thus impact ambulation recovery across the early phase post-stroke.

Physical environment

Frank & Patla (2003) suggested that successful community ambulation was dependent upon the skills and abilities of the individual, the requirements of the task and surrounding environmental challenges. They proposed eight dimensions of the physical environment that could be encountered when walking out of the home and yard (Frank and Patla, 2003; Patla and Shumway-Cook, 1999). These dimensions included distances traversed, time constraints, ambient conditions (light level, weather), terrain conditions, physical load interaction, attentional demands, postural transitions and density of vehicular and human traffic (Frank and Patla, 2003; Patla and Shumway-Cook, 1999). Since their development, these domains have been used to better understand ambulation difficulty in outdoor and community settings in a variety of groups pre-disposed to functional disability (Lamont et al., 2012; Shumway-Cook et al., 2005b; Shumway-Cook et al., 2003; Shumway-Cook et al., 2002). Increased difficulty with ambulating within an environment may lead to increased avoidance of that situation, resulting in further reduction of free-living ambulation (Barclay et al., 2014; Robinson et al., 2013; Lamont et al., 2012; Shumway-Cook et al., 2005b).

Stroke survivors report significantly greater avoidance of walking-related activities within the physical environment when compared to healthy adults (Robinson et al., 2013). The most avoided dimensions include distance, terrain, ambience and physical loads (Robinson et al., 2013; Resnick et al., 2008; Rimmer, 2008; Hammel et al., 2006). Individuals with chronic stroke also report barriers to exercise relating to access to environments where activity can take place safely (Rimmer, 2008; Hammel et al., 2006). Avoidance of community-based locations with challenging environments may lead to a reduction in both ambulation activity and community ambulation (Robinson et al., 2013; Shumway-Cook et al., 2005b).

Further, after stroke, gait speed and endurance can change within different environmental settings, though this change is not consistent across all survivors (Carvalho et al., 2010; Donovan et al., 2008; Taylor et al., 2006). Thus, how stroke survivors ambulate within their environments may also change – thereby affecting characteristics such as frequency and intensity of free-living ambulation (Robinson et al., 2013; Robinson et al., 2011b). Similarly, over time, challenges encountered within the physical environment when ambulating within free-living locations and environments may result in increased avoidance of ambulation, and thus further decline in free-living ambulation over time after stroke. This would benefit from consideration when investigating the recovery of free-living ambulation after stroke.

Other environment

Self-reported barriers and facilitators to activity and participation indicate a number of factors within the environment domain of the ICF could affect ambulation outcomes after stroke. Factors such as the availability of ambulation aides and devices, easy access to environments, availability of rest spots and public washrooms are identified by stroke survivors as products and technologies that allow safe and comfortable ambulation within community locations (Barclay et al., 2014). Social support from family and carers, other stroke survivors and professional and research staff increases stroke survivors' confidence when encountering new challenges and taking risks within the community and commencing new activities (Barclay et al., 2014; Simpson et al., 2011; Resnick et al., 2008). Family and friends also encourage social enjoyment during community trips, thus encouraging increased community ambulation (Barclay et al., 2014).

Self-awareness of activity limitations after stroke can limit stroke survivor confidence when ambulating outside of the home (Barclay et al., 2014). Further, self-consciousness that arises from social perceptions of stroke and disability may also negatively influence free-living ambulation recovery after stroke (Nicholson et al., 2013; Simpson et al., 2011). A lack of awareness by others of post-stroke disability may result in negative experiences when ambulating within the community – thus leading to stroke survivors potentially avoiding these trips later on (Barclay et al., 2014). Within services, systems and policies, poor maintenance of public areas within the community and increased cost of services and facilities lead to a reduced ability to access community locations and engage in activity (Barclay et al., 2014; Nicholson et al., 2013; Simpson et al., 2011). High cost of exercise programs and exercise facilities is a major barrier to general physical activity after stroke (Nicholson et al., 2013; Simpson et al., 2011). However, external services that encourage free-living ambulation can assist in providing external motivation and assist with overcoming reduced self-efficacy surrounding ambulation that is experienced after stroke (Simpson et al., 2011). It is evident that all dimensions of the environment can impact recovery of free-living ambulation after stroke.

2.5.4. Personal factors

Similar to the role of impairments, activity limitations and environment, the role of personal factors on the recovery of ambulation activity and community ambulation across the subacute phase of stroke requires further investigation. Personal factors include those that can influence an individual's experience of disability (WHO, 2001). These can include factors within the individual's life that are not a part of a health condition of health state such as age (Fulk et al., 2010), gender (Robinson et al., 2011a), self-efficacy (Bijleveld-Uitman et al., 2013; Askim et al., 2013; Robinson et al., 2011a), health perception and carer status (Nicholson et al., 2013; Rimmer et al., 2008). They can also include lifestyle, habits, upbringing, coping styles, social background, education, profession, past and current experience, overall behaviour pattern and character style, individual psychological assets and other characteristics (Geyh et al., 2011). Thus far most studies have included cross-sectional investigation of individuals with chronic stroke. The role of personal factors on the recovery of free-living ambulation needs further investigation.

Self-efficacy

There is some contention on whether self-efficacy is best placed within the impairment or personal factors domains of the ICF framework (Robinson et al., 2011a). In this thesis, self-efficacy will be placed within the personal factors domain of the ICF. Theoretically, self-efficacy is a central concept in Social Cognitive Theory (Bandura, 1997) and relates to the confidence or belief that an individual has within himself or herself to successfully complete tasks in their lives (Bandura, 1994). Self-efficacy beliefs are shown to influence how individuals feel, think, motivate themselves and behave in various aspects of their lives (Bandura, 1994). The strength of an individual's self-efficacy is developed through (a) past and concurrent experiences, (b) social models and standards (c) external social persuasion and (d) the individual's natural reaction to stress and negative experiences (Bandura, 1994). It is specific to the individual, their environment and the behaviour or task (Hellstrom et al., 2003; Bandura, 1997). This is more in line with the description of the personal factors domain of the ICF. Further, a recent review of papers discussing personal factors identified self-efficacy as a factor most commonly discussed within the personal factors domain of the ICF (Geyh et al., 2011). Thus, self-efficacy will be placed under the personal factors domain of the ICF in this thesis.

Self-efficacy refers to the confidence that stroke survivors feel around their ability to perform certain activities and behaviours (Bandura, 1977). It can influence the likelihood of an individual initiating certain activities and behaviours (Lee et al., 2008). Decreased balance and falls self-efficacy is often observed after stroke (Schmid et al., 2012). Balance and falls self-efficacy share a strong relationship with total free-living ambulation in individuals with chronic stroke (Robinson et al., 2011a; Michael et al., 2006), with balance self-efficacy sharing a significant relationship with total daily upright time (Askim et al., 2013). Reduced balance and falls self-efficacy is significantly related to reduced community trips and walking related activities in the community (Bijleveld-Uitman et al., 2013; Robinson et al., 2011a). Further, in one study of individuals with chronic stroke, balance self-efficacy had a stronger relationship with total self-reported activity and participation than measures of walking capacity and function (Schmid et al., 2012). Self-efficacy towards exercise has been identified as a major contributor to activity engagement after stroke (Simpson et al., 2011). In older adults, reduced self-efficacy is identified as a major factor contributing to the decline in free-living ambulation observed with age (Lord et al., 2010; Lee et al., 2008). Similarly, reduced ambulation self-efficacy can result in a reduction in both ambulation activity and community ambulation after stroke, and thus influence their recovery early after stroke.

Pre-stroke activity

Most stroke survivors report low levels of activity prior to stoke onset (Ricciardi et al., 2014; Baert et al., 2012; Krarup et al., 2007). Low activity prior to stroke may also contribute to increased severity of stroke (Ricciardi et al., 2014); reduced early re-canalisation (Ricciardi et al., 2014); reduced independence and functional recovery after stroke (Ricciardi et al., 2014; Baert et al., 2012; Stroud et al., 2009; Krarup et al., 2008; Wendel-Vos et al., 2004). These outcomes after stroke could also contribute to reduced ambulation activity and community ambulation after stroke. Pre-stroke activity is a confounding factor when looking at the effect of gait speed and endurance on community ambulation after stroke (Bijleveld-Uitman et al., 2013; van de Port et al., 2008). Further, secondary effects of low activity such as decreased fitness, muscle atrophy, altered blood enzymes and proteins, impaired circulation, high blood pressure, obesity, cardiovascular disease, increased functional dependence and depression may also contribute to further decline in ambulation activity and community ambulation (Billinger et al., 2014; Hamilton et al., 2008; Gordon et al., 2004). The role of pre-stroke activity on ambulation activity and community ambulation recovery after stroke needs further investigation.

Perceived health status and stroke recovery

Perceptions, awareness and knowledge of stroke and outcomes are associated with increased satisfaction and improved activity and participation outcomes after stroke (Eames et al., 2013; Eriksson et al., 2013; Wolf and Koster, 2013; Almborg et al., 2009). Perceptions of health and recovery can improve outcomes by increasing confidence of stroke survivors to make decisions about health care and engage in their recovery (Eriksson et al., 2013; Stein et al., 2003; Mayo et al., 2002). Further perceiving that recovery is sufficient to resume activities may result in returning to pre-stroke activities, roles and responsibilities (Eriksson et al., 2013; Stein et al., 2003; Mayo et al., 2002). Perceiving improved recovery and health status early after stroke may encourage stroke survivors to return to pre-stroke activities and thus increased free-living ambulation over the first six months after stroke. Conversely, poor perceptions of health status and recovery from stroke can result in reduced ambulation activity and community ambulation (Barclay et al., 2014; Robinson et al., 2011a). However it is still unclear if higher perceived recovery and health outcomes are the result of improved activity and participation, or if improved perceptions encourage activity and participation in this group. This would benefit from investigation across the subacute phase of stroke – especially as stroke survivors re-engage in pre-stroke activities, roles and responsibilities.

Stroke survivor demographics

Stroke survivor demographics including age, gender, carer status and post-discharge therapy are associated with outcomes following stroke. Older age demonstrates a trend towards reduced daily step counts ($r = -0.43$, $p = 0.06$) (Fulk et al., 2010) and frequency of community ambulation trips (Robinson et al., 2011b) in individuals with chronic stroke. Further, increased age at time of stroke onset is related to poor outcomes following stroke, with an age greater than 75 indicating worse mobility scores at follow-up assessments (OR 3.71, $p = 0.005$, SEM = 0.47) (Paolucci et al., 2001). Healthy adults demonstrate significant decline in all measures of ambulation activity and community ambulation with increased age (Lord et al., 2010; Cavanaugh et al., 2007). Similarly, age can influence outcomes after stroke.

The presence or absence of a carer has been regularly reported as a factor contributing to choices relating to activity and participation (Nicholson et al., 2013; Rimmer, 2008). Further, the absence of formal therapy at discharge is a significant contributor to reduced mobility outcomes at one year follow-up (OR 3.73, $p <0.001$, SEM - .39) (Paolucci et al., 2001). These factors can also influence recovery of free-living ambulation regardless of post-stroke changes. As greatest recovery after stroke is often observed over the first six months, investigation of the impact of these personal factors on ambulation outcomes in subacute stroke is essential.

Other factors

As modelled by the ICF, a range of factors can influence free-living ambulation outcomes after stroke. Though the above review of potential factors that could affect free-living ambulation outcomes across the subacute phase of stroke includes a number of factors within all domains of the ICF, it is important to acknowledge that it is not an exhaustive list. Other factors such as cognitive impairment (Viscogliosi et al., 2011; van de Port et al., 2006; Tatemichi et al., 1994), incontinence (Thomas et al., 2005), communication difficulty (Plante et al., 2010b) or sentinel events (e.g. return to driving, financial strain, return to work) early following discharge (Nalder et al., 2012a) could also affect free-living ambulation recovery. However, while the potential effect of these factors is acknowledged, investigating all potential factors contributing to free-living ambulation outcomes after stroke is beyond the scope of this thesis.

2.6. Thesis research aims and objectives

Free-living ambulation (including ambulation activity and community ambulation) is low after stroke, with a high proportion of survivors reporting dissatisfaction with outcomes. The importance of improving ambulation activity and community ambulation after stroke is well established, through a positive effect on general health, quality of life and successful return to pre-stroke activity and participation. While a number of cross-sectional studies have attempted to measure free-living ambulation in individuals with chronic stroke, these studies have been limited by issues surrounding measurement tools and measures used to characterise outcomes. Further, limited investigation of free-living ambulation recovery across the subacute phase of stroke – where stroke survivors demonstrate greatest change – has taken place. Also, understanding factors at hospital discharge that predict free-living ambulation after stroke survivors return home is important to ensuring more efficient rehabilitation practices and discharge planning. In light of this, this thesis aims to investigate free-living ambulation recovery across the subacute phase of stroke, and determine the factors at hospital discharge that predict outcomes across the first six months after stroke survivors return home from hospital.

This will be completed across five studies. The first study (Chapter three) will determine if device-based measurement tools are valid and reliable for free-living ambulation measurement after stroke, by assessing the ability of accelerometers and portable GPS devices to measure post-stroke ambulation within various environments and across different tasks.

The next two studies (Chapters four and five) will explore ambulation activity recovery after stroke. Study two (Chapter four) will aim to characterise ambulation activity at one, three and six months using device-based tools that were deemed accurate and reliable in study one (Chapter three). This study will also determine if characteristics of ambulation activity change over the first six months following hospital discharge after stroke. Ambulation activity will be characterised by measures of volume, frequency and intensity that have been previously used in studies of older adults and stroke survivors. Study three (Chapter five) will then identify factors at hospital discharge that predict volume, frequency and intensity of ambulation activity across the first six months after stroke survivor return home.

The following two studies (Chapters six and seven) will explore community ambulation across the subacute phase of stroke. Using accurate device-based tools and measures, Study four (Chapter six) will aim to characterise community ambulation and determine if characteristics of ambulation activity change over the first six months following hospital discharge after stroke. Again, measures of ambulation that have been used with older adults and stroke survivors will be used to characterise community ambulation in this study. This will then be followed by study five, which aims to identify factors at hospital discharge that predict volume, frequency and intensity of community ambulation outcomes over the first six months following return home after stroke.

Finally, Chapter eight of this thesis will present clinical implications and future research directions, strengths and limitations of the thesis and conclusions.

Chapter 3

Study one: Validity and reliability of accelerometers and global positioning systems for community ambulation measurement after stroke

While ambulation activity has been captured using device-based measures after stroke, currently there are no accurate tools available to measure community ambulation in this group. Most measures of community ambulation are based on self-report, which are often associated with high error and are unable to provide objective measures of outcome. With recent developments in technology, commercially available devices demonstrate potential for accurate community ambulation measurement after stroke. This study assesses the validity and reliability of two accelerometers (ActivPAL™ and Sensewear Pro_2 Armband) and a global position system (Garmin GPS) for the purpose of community ambulation measurement after stroke.

Abstract

Purpose: To determine the validity and reliability of ActivPAL™, Sensewear Pro_2 Armband and Garmin GPS for the purpose of community ambulation measurement after stroke.

Methods: Fifteen community-dwelling stroke survivors attended two assessment sessions; completing a six-minute walk, treadmill walking at three speeds, and 200 metre outdoor circuit wearing the devices. Participants then wore devices for four days of free-living community ambulation. Measures collected included step counts, time spent walking, distance, energy expenditure and location. Intraclass correlation coefficients (ICC), Bland-Altman plots and absolute percentage of error (APE) were used to determine validity and reliability.

Results and Discussion: The ActivPAL™ had excellent validity and reliability for all measures (ICC: 0.821-0.999, APE: 0%-11.1%), except at slower speeds where it still had good scores (ICC: 0.654-0.659, APE: 6.5%-11.1%). The Sensewear Pro_2 Armband had missing values for 23% of recordings and high error for all measures. GPS demonstrated excellent validity and reliability for time spent walking and step count (ICC: 0.805-0.999, APE: 0.9%-10%). It had 100% accuracy for location during all walking tasks and 88% of community trips. However, it was not valid or reliable for distance (ICC = -0.139, APE = 23.8%).

Conclusions: The ActivPAL™ and GPS appear valid and reliable to measure community ambulation after stroke, except for distance. Sensewear Pro_2 Armband demonstrated poor validity and reliability when worn on the hemiplegic arm.

3.1. Introduction

Most stroke survivors regard independent ambulation as important during rehabilitation (Robinson et al., 2011a; Lord et al., 2004; Pound et al., 1998). However despite its importance, low levels of ambulation activity are observed after stroke, and only 32 – 66% of stroke survivors achieve successful community ambulation following rehabilitation (Viosca et al., 2005; Lord et al., 2004; Perry et al., 1995). The importance of objectively measuring free-living ambulation (i.e. ambulation activity and community ambulation) after stroke has been highlighted as high scores on clinical measures of gait and function are not always predictive of successful ambulation activity (Alzahrani et al., 2011; Fulk et al., 2010) and community ambulation outcomes (Viosca et al., 2005; Lord et al., 2004; Perry et al., 1995). While ambulation activity has often been characterised by device-based measures after stroke, investigation of community ambulation has been limited by the absence of accurate and reliable measurement tools. Thus far, the majority of studies of community ambulation after stroke have relied on self-report tools (Bijleveld-Uitman et al., 2013; Robinson et al., 2011b; Viosca et al., 2005; Lord et al., 2004; Perry et al., 1995). However, these methods have been deemed inaccurate (Gebruers et al., 2010; Murphy, 2009).

Accelerometers have been used to quantify daily physical activity after stroke through step counts and activity duration (Gebruers et al., 2010). The ActivPAL^{TM} professional is a uniaxial accelerometer worn on the front of the thigh. This accelerometer has demonstrated excellent agreement (i.e. validity) with direct observation for measures of step count and activity duration in healthy young (Dahlgren et al., 2010) and older adults with (Taraldsen et al., 2011) and without (Grant et al., 2008) mobility limitations. It has also demonstrated excellent agreement with direct observations for measures of step counts in outdoor environments in the healthy older adult population (Grant et al., 2008). Further, the device has excellent retest reliability for step count and time spent walking in healthy young adults (Ryan et al., 2006). However, validity and reliability of the ActivPAL^{TM} during measurement of post-stroke gait patterns within outdoor environments, and at slower gait speeds (< 0.47m/s) requires further investigation (Taraldsen et al., 2011).

The Sensewear Pro$_2$ Armband is a biaxial accelerometer, worn on the back of the triceps muscle and infers measures of energy expenditure and step count from arm swing and body temperature (Jakicic et al., 2004). This device has demonstrated good to excellent agreement for measures of energy expenditure in individuals with chronic stroke when compared against indirect calorimetry (Vanroy et al., 2013; Moore et al., 2012; Manns and Haennel, 2012). However, its accuracy for measures of step counts and energy expenditure appears variable, depending on sample characteristics and testing methods (Manns and Haennel, 2012; Moore et al., 2012; Jakicic et al., 2004), thus requiring further investigation in this group (Manns and Haennel, 2012; Moore et al., 2012; Jakicic et al., 2004). Regardless, the ActivPAL™ and Sensewear Pro_2 Armband show potential for providing accurate, objective real-time measures of ambulation after stroke. However, the lack of location information limits their application for community ambulation measurement.

Portable global positioning systems (GPS) provide location data that can complement accelerometer data to isolate measures of community ambulation from total daily ambulation activity (Le Faucheur et al., 2008). Based on satellite information, locations travelled to, physical environment, duration of walking and distances traversed by stroke survivors during community trips can be determined to facilitate a greater understanding of community ambulation. GPS have been reported to be accurate for distance and speed during outdoor walking when compared against direct observation in both healthy adults (Le Faucheur et al., 2007) and individuals with reduced walking ability (Le Faucheur et al., 2008). It also demonstrates potential for use after stroke for community ambulation measurement (Evans et al., 2012; McCluskey et al., 2012). GPS have demonstrated excellent agreement with direct observation for number of community trips in people with chronic stroke, and good agreement with both direct observation and activity diaries for trip purpose (McCluskey et al., 2012). However, validity of the device for measures such as time spent walking, step count and location; and reliability during community ambulation measurement after stroke is unknown. Further, issues with limited battery life, accuracy of readings within indoor and dense environments and the lack of gold standards for data analysis in stroke samples requires further investigation (Webber and Porter, 2009).

Thus, the aim of this study was to determine the concurrent validity and retest reliability of the ActivPAL™, Sensewear Pro_2 Armband and GPS during walking tasks that impose demands similar to those encountered during community ambulation, as well as concurrent validity of the devices during free-living community ambulation after stroke. It was hypothesised that these devices would be valid and reliable during walking tasks that impose demands similar to those encountered during community ambulation. Also, it was hypothesised that these devices would be valid during free-living community ambulation measurement after stroke.

3.2. Methods

This is a cross-sectional observational study. Concurrent validity was determined when walking within a clinical setting, and over four days of usual free-living community ambulation. During clinic-based walking tasks, measures collected from devices (step count, time spent walking, distance and location) were compared with direct observation. Measures of time spent walking and location collected from devices during free-living community ambulation were compared against an activity diary.

Retest reliability was determined by comparing measures collected from devices (step count, time spent walking, METS, location and distance) during clinic-based walking tasks between two test occasions. Institutional ethics at the University of Queensland approved the study (see Appendix 1). This study was conducted in accordance with the Declaration of Helsinki.

3.2.1. Participants

Sixteen individuals with chronic stroke were recruited through community-based stroke groups and outpatient rehabilitation clinics in Brisbane, Australia. Participants were included if they: (1) were community-dwelling, (2) independently mobile and (3) diagnosed with a unilateral stroke at least six months prior.

Individuals were excluded if they: (1) scored less than 24/30 on the Mini-Mental State Examination (Folstein et al., 1975), or (2) suffered any neurological or medical conditions other than stroke that limited home and community-based ambulation function (e.g. Parkinson's disease, severe osteoarthritis). All participants provided informed consent.

3.2.2. Procedures

Participants were recruited through attendance at community stroke groups and with the assistance of physiotherapists at an outpatient rehabilitation clinic. Investigators presented information on the study and requirements at stroke group meetings to potential participants and provided written information with contact details of the primary investigator. Stroke survivors who were interested to participate, or wanted further information either provided their contact details, or contacted the primary investigator at a convenient time. Physiotherapists at the University of Queensland Neurological, Ageing and Balance clinic also assisted with recruitment by providing potential stroke survivors with information regarding the study and contact details of the principal investigator. Interested participants who contacted the principal investigator were screened for eligibility. If eligible, participants were booked in for an assessment session at the University of Queensland, St Lucia, Brisbane.

Participants attended two sessions (initial and retest assessment) one week apart. This timeframe was chosen to allow sufficient time to ensure measurements were independent between sessions and is a common clinical reassessment timeframe.

Participants donned the three devices (ActivPAL™, Sensewear Pro_2 Armband, Garmin Forerunner sports watch + footpod) and completed three walking tasks: a 6-minute walk test, a treadmill walk test and a 200m outdoor circuit. The three walking tests were chosen to assess the ability of the devices to accurately and reliably measure post-stroke gait over an extended period of time (6-minute walk test), at various gait speeds (treadmill test), and across a number of physical environmental conditions (outdoor circuit). The order of the walking tests was randomised between participants, but remained the same within the individual for the retest session. Standardised instructions were given to all participants. Participants were able to use gait aids if needed and a registered physiotherapist and research assistant were beside participants at all times for safety.

Walking tasks

The 6-minute walk test (Enright, 2003) was completed along an indoor, 34m quiet corridor. The treadmill task was completed on a flat incline. Speed settings began at 0.27 m/s and were gradually increased to each participant's self-selected slow, comfortable and fast speeds. Self-selected speed was chosen over pre-set speeds, as treadmill walking was deemed potentially challenging after stroke (Brouwer et al., 2009; Bayat et al., 2005). Data were recorded for one minute at each speed when the participant had achieved a steady state of walking. The outdoor circuit was 200m in length and participants completed this at their comfortable pace. It included physical environmental challenges such as walking up a ramp (23.3 m, incline 1:19), ascending two steps with bilateral rails, walking along a busy footpath (7.6 m), traversing grass terrain (22.2 m), descending seven steps with bilateral rails, crossing a road without designated traffic signals (7.1 m) and negotiating curbs. Data were collected by both the ActivPAL™ and Sensewear Pro_2

Armband accelerometers for all walking tasks. GPS data were only collected during the outdoor circuit, as GPS satellite reception was only available outdoors. Investigators measured time spent walking using a calibrated stopwatch, number of steps using a step counter and distance using a trundle wheel. Investigators also documented location.

Free-living community ambulation

Community ambulation was measured over a four-day period as it has previously been determined that this time period was reflective of usual activity (Murphy, 2009). During this four-day period, participants affixed both the accelerometers on waking in the morning, and the GPS device during any community trip. Community trips were defined as any trip that was outside the home and yard (Lord et al., 2004). Participants also recorded information of their community ambulation via an activity diary (see Appendix 2).

3.2.3. Devices

Two accelerometers were used in this study, the ActivPAL^{TM} (PAL Technologies Ltd©, Glasgow, UK) and Sensewear Pro$_2$ Armband (Bodymedia Inc., Pittsburgh, PA) (see figure 3.1). The ActivPAL^{TM} (PAL Technologies Ltd©, Glasgow, UK), a uniaxial accelerometer, records at a frequency of 10Hz, and provides measures at 15-second epoch (Dahlgren et al., 2010). It was affixed on the middle of the non-paretic thigh (Dahlgren et al., 2010). Measures collected included number of steps, time spent walking and energy expenditure (METS).

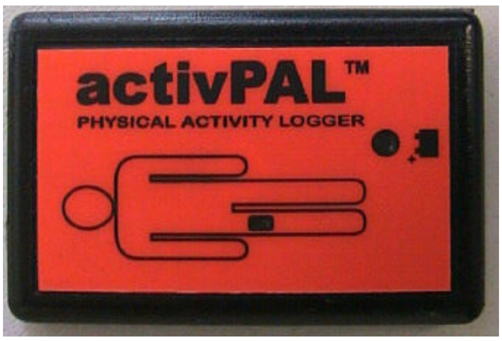

Figure 3.1: The ActivPAL^{TM}

The Sensewear Pro$_2$ Armband (Bodymedia Inc., Pittsburgh, PA) is a biaxial accelerometer, which records measures at one minute intervals. It was worn over the triceps muscle of the hemiplegic arm to allow independent use, as this would be required during free-living community ambulation measurement (Almeida et al., 2011; Jakicic et al., 2004). The Sensewear Pro$_2$ Armband provided measures of number of steps, time spent walking and energy expenditure (METS) (see figure 3.2.).

Figure 3.2: The Sensewear Pro$_2$ Armband

The Garmin Forerunner 405CX (Garmin Ltd., Olathe, Kan) is a GPS enabled sports watch. For this study, the Garmin footpod accessory was also used (see figure 3.3). Data and graphs obtained from the Garminconnect website (www.garminconnect.com.au) provided overall trip summaries which were used to determine measures. The GPS watch provided measures of steps, time spent walking, distances traversed and location.

Figure 3.3: Garmin Forerunner 405CX and Garmin footpod

3.2.4. Data Analysis

Concurrent validity for step count, time spent walking, distance and location during walking tasks (all measures) and free-living community ambulation (time and location only) was determined using intraclass correlation coefficients ($ICC_{3,1}$), with a 95% confidence interval (Rankin and Stokes, 1998). Retest reliability for step count, time spent walking, METS, distance and location during walking tests was determined using intraclass correlation coefficients ($ICC_{2,1}$), with a 95% confidence interval. Guidelines outlined by Rankin and Stokes (1998) were used to describe concurrent validity and retest reliability scores. Coefficients of 0.80 – 1.0 were interpreted as excellent; 0.60-0.79 as good; 0.4-0.59 as fair and 0.10-0.39 as poor (Rankin and Stokes, 1998).

Analyses of variance (ANOVA) were used to determine if there was a difference between device and directly observed measures for validity, as well as between device measures across the two assessment sessions for reliability.

Bland-Altman plots (Bland and Altman, 1986) were used to visually quantify the mean differences and upper and lower limits of agreement (mean difference +/- (1.96 x SD)). Absolute percentage error (APE) was also calculated using the formula (absolute mean difference/mean) x 100. SPSS v. 21.0 (SPSS Inc., Chicago, IL) was used for all analyses and a p-value of $p < 0.05$ was used.

3.3. Results

3.3.1. Participants

One participant (male, age: 64 years) required assistance during the outdoor circuit and scored lower in the measure of ambulation recovery (MAS item 5 score: 3 out of 6) than the remainder of the sample. Thus, fifteen participants with mean age 63.4 years (SD 8.3) and seven years post-stroke were used for the final analysis (see table 3.1). Fifty-three percent of the sample were male and sixty-seven percent had a left hemiplegia. Four participants (26.7%) used a unilateral gait aide during all walking tasks.

Table 3.1: Characteristics of participants

Descriptive measure	Sample (n = 15)
Age (years)	63.4 (8.3)
Gender (n, % males)	8, 53.3%
Hemiparetic side	
Left (n,%)	9, 66.7%
Time since stroke (years)	7.3 (5.6)
Walking aid (n, %)	
Nil	11, 74.3%
Unilateral gait aid	4, 26.7%
6MWT distance (m)	390.9 (125.3)
MAS Item 5 (score /6)	
5	4, 26.7%
6	11, 74.3%

Data is presented as mean (SD) or number, %
6MWT: six minute walk test; MAS: Motor Assessment Scale

3.3.2.Validity

Table 3.2 shows the mean (SD), ICC scores, 95% confidence intervals and the absolute percentage of error for measures of step counts, time spent walking and distance used to assess validity of devices. No trend in error was observed on Bland-Altman plots for measures collected both during walking tasks and free-living community ambulation (see figure 3.4).

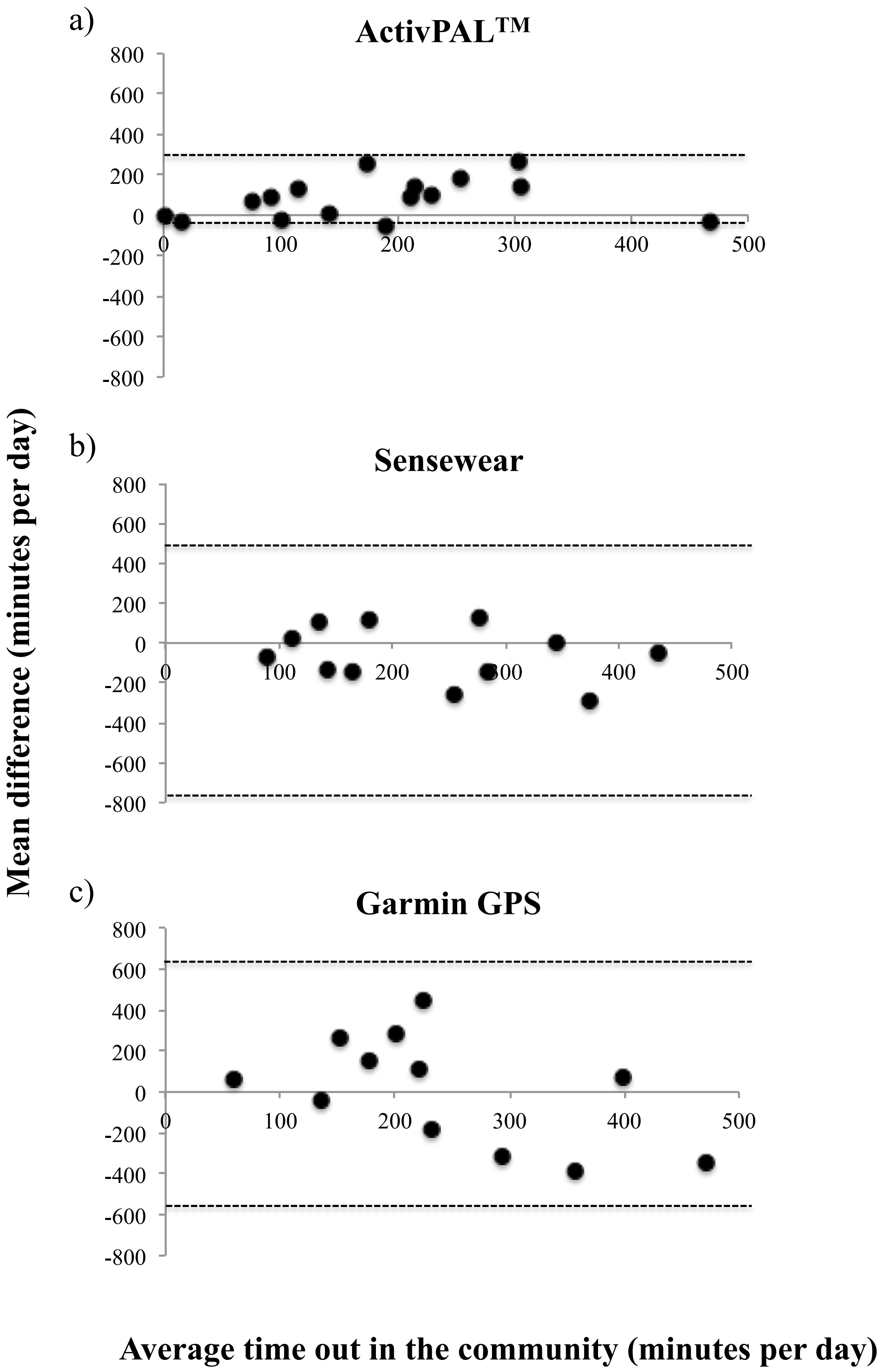

Figure 3.4: Bland-Altman plots for time spent walking during 4-day community ambulation measurement for (a) ActivPAL^{TM}, (b) Sensewear Pro_2 Armband and (c) Garmin GPS watch

Table 3.2: Comparison of measures between direct observation and the three devices across walking tests and during the 4-day community ambulation measurement period (validity)

Task	Comparison	Observed mean (SD)	Device Mean (SD)	APE	ICC	95% Confidence Interval (ICC)
6-minute walk test						
Steps (n)	ActivPAL™	648.6 (90.0)	638.9 (89.1)	1.6%	0.994	0.982 to 0.998
	Sensewear	646.5 (93.3	518.8 (135.9)	21.9%	N/A	N/A
Time (s)	ActivPAL™	360 (0)	360.1 (1.5)	0.3 %	-	-
Treadmill task (Slow)						
Steps	ActivPAL™	73.0 (13.8)	65.1 (18.6)	11.4%	0.718	0.343 to 0.895
	Sensewear	74.5 (13.3)	37.3 (36.6)	66.8%	N/A	N/A
Time (s)	ActivPAL™	60.0 (0)	59.3 (2.5)	1.1%	-	-
Treadmill task (Comfortable)						
Steps (n)	ActivPAL™	84.9 (16.0)	78.0 (21.4)	8.4%	0.758	0.419 to 0.912
	Sensewear	86.1 (17.0)	45.1 (42.2)	62.5%	N/A	N/A
Time (s)	ActivPAL™	60.0 (0)	58.1 (7.1)	3.2%	-	-
Treadmill task (Fast)						
Steps	ActivPAL™	94.7 (18.9)	90.4 (23.7)	5.6%	0.855	0.622 to 0.949
	Sensewear	94.7 (20.2)	55.0 (43.8)	53.1%	N/A	N/A
Time (s)	ActivPAL™	60.0 (0)	58.2 (6.8)	3.1%	-	-
Outdoor circuit						
Steps (n)	ActivPAL™	380.9 (69.6	376.8 (69.4)	1.5%	0.992	0.976 to 0.997
	Sensewear	380.6 (73.6	253.5 (79.4)	40.1%	N/A	N/A
	GPS	368.3 (60.3	381.0 (66.4)	4.1%	0.986	0.951 to 0.996
Time (s)	ActivPAL™	227.6 (58.2	221.6 (56.5)	3.1%	0.997	0.990 to 0.999
	GPS	236.7 (66.2	237.8 (68.7)	0.9%	0.999	0.997 to 1.000
Distance (m)	GPS	211.5 (5.4	205.1 (34.8)	11.4%	0.120	-0.401 to 0.582
4-day community ambulation						
Time (min)	ActivPAL™	236.5 (132.2)	147.0 (117.4)	54.5%	0.681	0.290 to 0.883
	Sensewear	249.8 (123.3)	392.3 (409.5)	80.7%	N/A	N/A
	GPS	249.4 (122.2)	238.6 (221.7)	91.2%	-0.185	-0.625 to 0.344

APE: absolute percentage error, ICC: intra-class correlation coefficient, 95% CI (ICC): 95% confidence interval for intra-class correlation coefficient, Sensewear: Sensewear Pro_2 Armband, N/A: not applicable, as the Sensewear data did not have a normal distribution for ICC statistics.

The ActivPAL™ demonstrated excellent agreement with direct observation for all measures of time spent walking (ICC: ≥ 0.997, APE: 0.3% to 3.0%) and most measures of step count during walking tasks (ICC: 0.855 to 0.994, APE: 1.5% to 5.6%). Good agreement with direct observation was observed for step counts during comfortable (ICC = 0.758, APE = 8.4%) and slow (ICC = 0.718, APE = 11.4%) treadmill walk speeds. The mean (SD) self-selected slow, comfortable and fast treadmill speeds were 0.31 (0.11) m/s, 0.42 (0.17) m/s and 0.54 (0.25) m/s respectively.

The Sensewear Pro_2 Armband failed to collect any data for 21% of all walking tasks. When data was detected, a bimodal distribution was found (that is, it recorded either very few steps or hundreds of steps) and thus statistical assumptions for ICCs were not met. The Sensewear Pro_2 Armband demonstrated a high APE for measures of step count during all walking tasks (APE ranging from 21.9% to 66.8%).

The Garmin GPS watch showed excellent agreement with direct observation for measures of step count (ICC = 0.986, APE = 4.1%) and time spent walking during the outdoor circuit (ICC = 0.999, APE = 0.9%). It accurately identified the location of start and stop points during the outdoor circuit for all participants. However, maps on the Garminconnect website demonstrated that the Garmin GPS was not consistently accurate for the exact route taken by participants. Further, the GPS device demonstrated poor agreement with direct observation for distance (ICC = 0.120, APE = 11.4%).

During free-living community ambulation measurement, the ActivPAL^{TM} demonstrated good (ICC = 0.681) and GPS poor (ICC = -0.185) agreement with the activity diary for time spent walking across the four-day period. However, all devices had a high APE (54.5% to 91.2%) for all measures. The GPS device collected accurate information on location of the community trip for 88% of recordings.

3.3.3. Reliability

Table 3.3 shows the mean (SD), ICC scores, 95% confidence intervals and the absolute percentage of error for measures of step counts, time spent walking, METS and distance for all devices across the two assessment sessions. No trends were observed on Bland-Altman plots for reliability measures collected during walking tasks.

Table 3.3: Comparison of measures at the two assessments during walking tasks (reliability)

Measure	Device	Assessment 1 Mean (SD)	Assessment 2 Mean (SD)	APE	ICC	95% CI (ICC)
6 - minute walk						
Steps (n)	Observation	638.2 (120.8)	640.4 (117.9)	3.0%	0.974	(0.926 to 0.991)
	ActivPAL™	622.0 (127.5)	626.4 (126.7)	3.2%	0.977	(0.930 to 0.993)
	Sensewear	486.4 (226.2)	492.5 (232.9)	34.5%	N/A	N/A
Time (s)	Observation	360.0 (0.0)	360 (0.0)	0.0%	-	-
	ActivPAL™	355.9 (14.6)	356.5 (12.2)	0.2%	0.981	(0.942 to 0.994)
METS	ActivPAL™	0.379 (0.046)	0.369 (0.044)	2.6%	0.928	(0.791 to 0.976)
	Sensewear	23.3 (7.9)	25.8 (4.0)	23.1%	N/A	N/A
Treadmill task (Slow)						
Steps (n)	Observation	72.5 (16.3)	68.5 (18.5)	9.4%	0.589	(0.130 to 0.840)
	ActivPAL™	65.0 (18.9)	62.5 (20.3)	11.1%	0.894	(0.703 to 0.965)
	Sensewear	41.3 (39.7)	37.4 (38.3)	2.2%	N/A	N/A
Time (s)	Observation	60.0 (0.0)	60.0 (0.0)	0.0%	-	-
	ActivPAL™	59.3 (2.5)	59.0 (2.1)	1.6%	0.659	(-0.193 to 0.736)
METS	ActivPAL™	0.047 (0.007)	0.046 (0.007)	6.7%	0.821	(0.530 to 0.939)
	Sensewear	21.2 (10.8)	17.9 (6.8)	17.8%	N/A	N/A
Treadmill task (Comfortable)						
Steps (n)	Observation	85.7 (17.1)	85.9 (14.5)	6.8%	0.879	(0.666 to 0.959)
	ActivPAL™	85.1 (17.7)	83.1 (17.4)	5.4%	0.659	(0.194 to 0.882)
	Sensewear	61.6 (42.2)	64.1 (36.9)	15.5%	N/A	N/A
Time (s)	Observation	60.0 (0.0)	60.0 (0.0)	0.0%	-	-
	ActivPAL™	56.2 (9.3)	60.0 (0.0)	6.5%	-	-
METS	ActivPAL™	0.051 (0.010)	0.052 (0.006)	6.7%	0.654	(0.187 to 0.880)
	Sensewear	17.7 (6.5)	16.9 (4.2)	24.1%	N/A	N/A
Treadmill task (Fast)						
Steps (n)	Observation	96.1 (19.1)	95.6 (19.7)	4.8%	0.951	(0.855 to 0.984)
	ActivPAL™	90.9 (24.3)	93.2 (21.2)	6.2%	0.902	(0.712 to 0.969)
	Sensewear	69.5 (42.6)	73.1 (45.0)	16.3%	N/A	N/A
Time (s)	Observation	60.0 (0.0)	60.0 (0.0)	0.0%	-	-
	ActivPAL™	58.1 (7.0)	60.0 (0.0)	3.3%	-	-
METS	ActivPAL™	0.056 (0.009)	0.057 (0.008)	3.2%	0.912	(0.737 to 0.972)
	Sensewear	21.3 (6.8)	19.0 (6.3)	26.8%	N/A	N/A
Outdoor circuit						
Steps (n)	Observation	395.9 (75.4)	387.0 (78.2)	4.8%	0.960	(0.881 to 0.987)
	ActivPAL™	372.1 (70.0)	374.3 (82.6)	2.7%	0.874	(0.639 to 0.960)
	Sensewear	240.2 (94.2)	268.9 (81.7)	38.5%	N/A	N/A
	GPS	385.3 (101.4)	392.5 (112.7)	8.4%	0.805	(0.478 to 0.936)
Time (s)	Observation	273.9 (160.9)	274.9 (194.7)	7.8%	0.971	(0.916 to 0.990)
	ActivPAL™	254.4 (119.1)	272.2 (204.8)	6.6%	0.828	(0.527 to 0.944)
	GPS	273.7 (156.4)	271.5 (188.2)	10.7%	0.970	(0.916 to 0.989)
METS	ActivPAL™	0.246 (0.082)	0.240 (0.086)	4.3%	0.991	(0.971 to 0.997)
	Sensewear	19.9 (6.1)	22.1 (7.4)	20.3%	N/A	N/A
Distance (m)	Observation	211.7 (4.4)	212.1 (7.8)	1.8%	0.376	(-0.150 to 0.736)
	GPS	219.8 (24.5)	210.5 (56.4)	23.8%	-0.139	(-0.582 to 0.367)

APE: Absolute percentage error, ICC: intraclass correlation coefficient, 95% CI: 95% Confidence interval for ICC scores, METS: Metabolic equivalents, N/A: not applicable, as the Sensewear data did not have a normal distribution for ICC statistics

The ActivPAL^{TM} demonstrated excellent retest reliability for most measures of step count (ICC: 0.874 to 0.977, APE: 2.7% to 11.1%), time spent walking (ICC: 0.828 to 0.999, APE: 0% to 6.6%) and METS (ICC: 0.821 to 0.991, APE: 2.6% to 6.7%). It had good reliability for step counts and METS during comfortable treadmill speeds (ICC: 0.654 to 0.659, APE: 5.4% to 6.7%) and time spent walking during the slow treadmill speed (ICC: 0.659, APE: 1.6%).

The Sensewear Pro_2 Armband had missing values for 25% of recordings and did not satisfy the statistical assumptions for ICC calculations due to a bimodal distribution. Further, the Sensewear Pro_2 Armband data had a high absolute error across all but one test situation (average of 22% error, range 2.2% to 38.5%).

The Garmin GPS demonstrated excellent retest reliability for step counts (ICC = 0.805, APE = 8.4%), and time spent walking (ICC = 0.970, APE = 10.7%). However, it demonstrated poor reliability for distance (ICC: -0.139, APE: 23.8%). Observation of maps on the garminconnect website demonstrated that the GPS watch recorded the same start and stop locations between test sessions for all participants, though map routes recorded differed between test occasions for each participant.

3.4. Discussion

This study investigated the concurrent validity and retest reliability of the ActivPAL^{TM}, the Sensewear Pro_2 Armband and Garmin GPS for the purpose of community ambulation measurement in individuals with chronic stroke. The study demonstrates that the ActivPAL^{TM} is a valid and reliable accelerometer for this purpose. The Garmin GPS is valid and reliable for step count, time spent walking and location, but requires further investigation for measurement of distance. The Sensewear Pro_2 armband appears to have poor concurrent validity and is unreliable for free-living community ambulation measurement after stroke.

Walking tasks

The ActivPAL^{TM} demonstrated good to excellent validity and reliability for all measures in people with stroke, similar to earlier studies in healthy adults (Grant et al., 2008; Ryan et al., 2006). Measures were most accurate for walking speeds at least >0.42 m/s, which enable stroke survivors some ability to walk in the community (Lord et al., 2004; Perry et al., 1995). Highest absolute error (although only modest) was demonstrated during self-selected slow and comfortable treadmill speed conditions. These slower gait speeds may have altered gait kinematics (Wagenaar and Beek, 1992), resulting in insufficient thigh acceleration to register an activity recording by the ActivPAL^{TM} for some steps. Undercounting of steps by the ActivPAL^{TM} at similar slow speeds (< 0.47m/s) has previously been reported (Taraldsen et al., 2011). Alternatively, the higher error may be due to a short data collection time. Measures in the current and previous study (Taraldsen et al., 2011) were collected over a one-minute interval and five-metre distance respectively. Other studies that have employed longer measurement periods have reported excellent validity and reliability of ActivPAL^{TM} with absolute error below 1.1% (Grant et al., 2008; Ryan et al., 2006). Future studies investigating optimal algorithms when walking at gait speeds below 0.42 m/s and the minimum measurement period or number of steps needed for reliable measures when walking at slow speeds are warranted.

The current study found that the Sensewear Pro$_2$ Armband was not valid or reliable for independent community ambulation measurement after stroke when worn on the affected arm. This device underestimated step counts during all test situations and recorded with high absolute error regardless of environment or gait speed. While some studies have found this device accurate after stroke (Manns and Haennel, 2012; Moore et al., 2012), others report it is less accurate (Vanroy et al., 2013), and inaccurate when worn on the hemiplegic arm (Manns and Haennel, 2012). The placement of the Sensewear Pro$_2$ Armband on the hemiplegic arm during this study may have contributed to its high absolute error. Current device algorithms have been developed based on assessment of young and middle aged healthy adults, with limited incorporation of other groups with conditions such as obesity and heart disease, and none based on post-stroke testing (Andre et al., 2006). Modified algorithms to detect steps at lower amplitudes of arm swing after stroke (Keenan et al., 1984) and slower gait speeds, while incorporating post-stroke cardiovascular dynamics needs investigation prior to using the Sensewear Pro$_2$ Armband for community ambulation measurement after stroke.

The Garmin GPS demonstrated excellent validity and reliability for all measures except distance. Accurate location information during all outdoor walking tests suggests it could provide data to assist with the separation of ambulation activity measured within the home, from that completed within the community. In earlier studies, GPS accuracy improved with distance in adults with reduced walking ability (Le Faucheur et al., 2008). The circuit used in the current study was limited to a shorter distance (200 m) than previously studied (2000 m) (Le Faucheur et al., 2007) due to anticipated functional limitations of stroke survivors. This shorter distance is likely to have contributed to the lower validity and reliability reported here. In addition, GPS is more accurate in open environments (Webber and Porter, 2009). Though the route calculated by the GPS (obtained from the garminconnect.com website) was slightly different between each test occasion, the start and stop points were consistently accurate and reliable across all participants. The start and stop points of the outdoor circuit were in open environments, but early during the circuit participants walked between two buildings. This may have caused a satellite interruption, and thus the differences in map routes recorded for each test occasion, and resulting poor validity and reliability of distance measures. The effect of environment density on GPS accuracy and reliability requires more investigation (Le Faucheur et al., 2008).

Free-living community ambulation

All three devices demonstrated high error during the four-day community ambulation measurement. This was due, at least in part, to inaccuracies associated with completion of the activity diary. Though self-report questionnaires and diaries have been used to measure ambulation activity (Rand et al., 2010) and community ambulation (Lord et al., 2004) after stroke, reliance upon memory recall, and the potential influence of social desirability (Sallis and Saelens, 2000) can influence accuracy. However, the activity diary provided additional valuable information. It provided information such as issues with the devices, problems encountered during the trips, and purpose for each community trip assisted with data analysis, as well as providing additional useful information on context and motivation for community ambulation. Such information can be used to provide extra contextual information about community ambulation to complement objective measures collected by devices (McCluskey et al., 2012).

This study is limited by its small sample size (n=15), however the sample did include a mix of age, gender and gait ability. Further documentation of limb function using a standardised measure may have been useful to determine whether validity and reliability were related to functional ability of the participants. Assessment of the devices at set treadmill speeds similar to earlier studies may have provided a more consistent methodological approach to assess the effect of gait speed on device accuracy and reliability. However, as not all participants could achieve treadmill speeds identified in earlier treadmill protocols (0.9 m/s to 1.78 m/s), slower gait speeds were allowed in this study.

The study used set tasks rather than free-living community ambulation to assess validity and reliability of the ActivPAL^{TM}, Sensewear Pro$_2$ Armband and GPS. This was to ensure the variability of the devices, rather than the participants, was measured. Whilst it would be ideal to investigate the retest reliability of the devices during free-living community ambulation, a longer test period is required (i.e. several days for one session) as individuals are likely to change their routine from day to day, and high within-subject variability is likely to influence the strength of results.

During the four-day community ambulation measurement, participants had to remember to wear the devices before each trip and complete the diary after every trip. While the ActivPAL™ and Sensewear Pro_2 Armband did not require any additional set-up, the GPS had to be manually started and stopped for each trip recording. Some participants reported difficulty in manipulating the small buttons and touch-sensitive bezel on the GPS watch with their unimpaired limb. Failure to don the device correctly accounted for most incorrect recordings during free-living community ambulation measurement in this study. In addition to this, the 7-8 hour battery life on the GPS was a limiting factor for one participant, who worked outside of home for approximately 12 hours each weekday. Other studies have also recognised the disadvantage of using portable GPS devices in multi-day studies, as frequent recharging of these units increases burden on participation and decreases compliance (Webber and Porter, 2009; Rodriguez et al., 2005). Future research could be directed at modifying sporting GPS watches with easier function and longer battery life or sourcing alternate devices such as smart phones (Albert et al., 2012).

3.5. Conclusions

The ActivPAL™ and the Garmin GPS watch are valid in people with stroke for measures of time spent walking, step count and location (GPS only) collected across tasks that are reflective of community ambulation. The ActivPAL™ is a reliable accelerometer for measurement of step count, time spent walking and METS in people with stroke for the purpose of community ambulation. The Garmin GPS can be accurately and reliably used to complement the ActivPAL™ for information on location, but further investigation is required for exact routes taken and distances ambulated, especially in dense urban areas and during short walking trips. The Sensewear Pro_2 Armband recorded with error too high for clinical use when worn on the hemiplegic arm to allow independent use during free-living community ambulation measurement after stroke.

Chapter 4

Study two: Exploring ambulation recovery following stroke – longitudinal measurement of ambulation activity following hospital discharge.

From existing literature, we know that ambulation activity in individuals with chronic stroke is low. However, the way in which this occurs is unknown. Across the subacute phase of stroke, where most recovery is observed, characteristics of ambulation activity have great potential to improve. However from preliminary studies, it appears that this may not always be the case, and further investigation of ambulation activity recovery across the subacute phase of stroke is required. Using the accelerometer found to be valid and reliable in Study one (Chapter 3), this study aims to accurately capture ambulation activity across the first six months following hospital discharge after stroke. Further, using measures to characterise activity (volume, frequency and intensity), this study will investigate any changes over time following hospital discharge.

Abstract

Purpose: To characterise ambulation activity and investigate how ambulation activity changes over one, three and six months after hospital discharge post-stroke.

Methods: 36 subacute stroke survivors (age: 71.0 SD 13.6 years, 69.5% male) were followed up at 1-month, 3-months and 6-months post-discharge from hospital into the community. Measures of ambulation activity were collected over four days and included *volume* (time spent lying/sitting, standing, upright and walking and step count), *frequency* (number of and time spent in short: <40 steps, medium: 40-300 steps and long:>300 steps ambulation bouts) and *intensity* (number and time spent in low: <30 steps/minute, moderate: 30-80 steps/minute and high:>80 steps/minute ambulation bouts) per day. Linear mixed effects modelling was used to determine changes over time.

Results: Stroke survivors demonstrated high variability in daily ambulation activity at all time points. The majority of each day was spent in sitting/lying positions (approximately 19 to 20 hours per day). Total step counts across all time points were below required levels for health benefits (mean 4452 SD 3430). While most ambulation bouts were of short duration and low intensity, most time was spent in moderate intensity ambulation each day across all time points. When examining changes over time (after adjustment for age and discharge gait speed) volume of steps and time spent walking increased from one month to three and six months. The number of and time spent in medium ambulation bouts did not change from one to three months but increased from one to six months. Further, from one month, time spent in moderate intensity ambulation increased at three and six months. No change was observed for any other measures.

Conclusions: Stroke survivors increased the volume of ambulation activity from one month by increasing medium duration and moderate intensity ambulation. No changes are observed in long duration bouts or high intensity ambulation. Stroke survivors would benefit from interventions to encourage long duration and high intensity bouts of ambulation for health benefits.

4.1. Introduction

Ambulation activity, or walking activity, is known to have beneficial effects on physiological, psychological, sensorimotor, strength, endurance and functional recovery after stroke (Gordon et al., 2004). However, by the time stroke survivors reach a chronic phase, they commonly adopt a sedentary pattern of activity (English et al., 2014). These activity patterns contribute to further activity limitations and are likely to perpetuate a cycle of disability in this group. Further, vascular changes following stroke (Billinger et al., 2014; Manns and Baldwin, 2009), reduced fitness (Kelly et al., 2003) and increased energy costs of walking (Ganley et al., 2008; Platts et al., 2006; Chen et al., 2005) can adversely affect free-living ambulation outcomes (Manns and Baldwin, 2009). As a result, ambulation activity levels are low in individuals with chronic stroke (Roos et al., 2012; Michael et al., 2005). However, the process by which this occurs across the subacute phase of stroke recovery is not understood.

Traditionally, ambulation activity after stroke has been characterised by measures of volume. Volume of ambulation activity in people with chronic stroke has been measured using accelerometers and pedometers through total daily step counts (Moore et al., 2013; Fulk et al., 2010; Manns and Baldwin, 2009; Mudge and Stott, 2009; Rand et al., 2009; Resnick et al., 2008; Michael and Macko, 2007; Michael et al., 2006; Michael et al., 2005; Haeuber et al., 2004; Katoh et al., 2002), with some studies also looking at activity duration (Askim et al., 2013; Baert et al., 2012; Alzahrani et al., 2011; Rand et al., 2009; Mudge et al., 2007) and daily energy expenditure (Moore et al., 2013; Haeuber et al., 2004; Katoh et al., 2002). Step counts have been recorded ranging from 1389 to 7379 steps/day in people with stroke; indicating that daily activity after stroke is below that required for general health benefits in older adults (Manns and Baldwin, 2009; Michael and Macko, 2007).

Few studies have investigated changes in ambulation activity over the first six months following stroke. Those that have measured ambulation activity in subacute stroke survivors report conflicting findings. No change in daily step counts was observed over six weeks following stroke in a small group of individuals with subacute stroke (Manns and Baldwin, 2009). In contrast, improvements of approximately 80% in daily step count by three months following hospital discharge has been observed (Moore et al., 2013; Shaughnessy et al., 2005), with limited increase in daily ambulation activity after this time point (Moore et al., 2013). Differences in study findings may be due to the range of study methods used, including choice of devices, baseline and follow-up time points and measures used to characterise activity.

Further, there is a need to capture changes in characteristics other than just volume of ambulation activity across the first six months after stroke. Such characteristics, including frequency, intensity and patterns of ambulation have been investigated in other groups by measuring ‘ambulation activity bouts’ (Roos et al., 2012; Lord et al., 2011; Cavanaugh et al., 2007). Measurement of characteristics of ambulation activity through bouts will provide more information regarding how stroke survivors recover ambulation activity than traditional daily volume measures alone (Lord et al., 2011; Cavanaugh et al., 2007). Ambulation activity recovery after stroke needs further investigation, with characterisation using measures that capture volume, frequency and intensity of ambulation activity over time. This will assist in understanding ambulation activity behaviours that may contribute to the low ambulation activity observed in individuals with chronic stroke.

Thus, the primary aim of this study was to characterise ambulation activity after stroke at one, three and six months following discharge from hospital. It was hypothesised that volume, frequency and intensity of ambulation activity would be similarly low across all time points. The second aim of this study was to investigate how ambulation activity in stroke survivors changes across the first six months following discharge from hospital. It was hypothesised that volume of ambulation activity (daily step counts, total time spent walking), frequency of ambulation activity bouts and intensity of ambulation activity would increase from one to three months and plateau by six months after hospital discharge.

4.2. Methods

This was a prospective, longitudinal observational study of subacute stroke survivors following discharge from either an acute stroke unit or inpatient rehabilitation ward at The Prince Charles Hospital, Brisbane, Australia. Participants were recruited within one week prior to discharge, and followed up at one month, three months and six months after hospital discharge. Institutional ethics committees at The Prince Charles Hospital and University of Queensland approved the study (see Appendices 3 and 4). This study was conducted in accordance with the Declaration of Helsinki.

4.2.1. Participants

A total of 42 stroke survivors were recruited from the acute stroke and rehabilitation units at The Prince Charles Hospital, Brisbane, Australia. Participants were included if they (1) were diagnosed with a stroke within the past 4 months confirmed with imaging, (2) were aged > 18 years and (3) were discharged into the community to live alone or with a carer or spouse within the Brisbane metropolitan region.

Individuals were excluded if they: (1) had a diagnosis of another neurological condition (e.g. Parkinson's disease) or co-morbidities that limited ambulation prior to stroke, or during their hospital admission, (2) had any unstable medical condition, (3) chest pain, heart attacks, angioplasty or heart surgery in the previous three months, (4) skin allergies to adhesive tape, (5) were discharged to a residential aged care facility, (6) moderate to severe expressive of receptive communication difficulties (based on speech therapist assessment) or (7) scored < 24/30 on the Mini Mental State Examination (MMSE) (Folstein et al., 1975).

4.2.2. Procedures

Participants were identified through bi-weekly screening of stroke unit admission lists and weekly attendance at the hospital acute stroke meeting. Further information to assist with screening of stroke survivors was obtained through discussion with treating physiotherapists. Eligible participants were approached by a member of the research team and given a verbal summary of the study's aims, procedures and expectations. Potential participants were provided with a participant information sheet. Stroke survivors were provided with sufficient time to consider the research project and discuss it with their family, treating therapists and carers. All participants provided signed written informed consent prior to data collection commencing.

Participants were recruited and assessed during their last week prior to discharge from hospital. Demographic and routine clinical discharge measures of walking capacity were collected from hospital medical charts and therapist notes to characterise the sample. Participants were contacted for follow-up appointments at one, three and six months following discharge via a phone call from the principal investigator. Follow-up appointments at The Prince Charles Hospital were made at a time convenient to participants. During this appointment, an accelerometer, the ActivPAL™ was applied for measurement of ambulation activity.

The ActivPAL™ accelerometer was worn by participants for 4-days. This period has been deemed sufficient for measurement of habitual activity (Murphy, 2009). The ActivPAL™ was encased in a water-proof casing and affixed to the skin in the middle of the front thigh of the non-hemiparetic leg with a low irritant sticker (hypafix). This allowed for a complete four x 24-hour period of measurement. Participants were provided with written instructions on how to manage the device and warnings about any potential skin irritation.

The ActivPAL™

The ActivPAL™ professional physical activity monitor (PAL Technologies Ltd©, Glasgow, UK) is a small (53 x 35 x 7mm) and light (21g) uniaxial accelerometer. It produces a signal related to inclination of the thigh, which helps to determine step count, cadence, and changes in position. It provides data in 15-second intervals. The ActivPAL™ has been deemed valid and reliable in healthy (Dahlgren et al., 2010; Grant et al., 2010; Ryan et al., 2006) and functionally impaired adults (Taraldsen et al., 2011; Ryan et al., 2006). The device was determined valid and reliable in a sample of stroke survivors for the purpose of community ambulation measurement in stroke (see Chapter 3). Validity for measurement of ambulation activity was assumed as the ActivPAL™ was able to accurately capture measures of ambulation after stroke, and has also successfully captured similar activity bout (Lord et al., 2011) and daily activity measures in individuals with chronic stroke (Roos et al., 2012).

4.2.3 Measures of ambulation activity

Measures of ambulation activity were categorised according to volume, frequency and intensity. A unit of measurement, the *'ambulation bout'* was defined as any 15-second data epoch with at least 2 steps (Lord et al., 2011; Cavanaugh et al., 2007). This definition was chosen based on previous studies using ambulation bouts after stroke, and with consideration of the ability of the ActivPAL to distinguish walking from various other positions (e.g. sitting, standing) (Roos et al., 2012; Manns and Baldwin, 2009). The ambulation bout unit was used to assist in defining measures of ambulation. Characteristics of ambulation activity were calculated by a MATLAB program using definitions previously used to explore activity in older adults (Lord et al. 2011), and both individuals with subacute (Manns and Baldwin, 2009) and chronic stroke (Roos et al. 2012).

Volume of ambulation activity was determined using measures of total number of steps per day and total time in minutes per day spent sitting/lying, standing, walking, standing and in upright positions.

Frequency of ambulation activity was determined using total number of bouts and time in minutes spent at each ambulation bout duration (short, medium and long) (Roos et al., 2012; Manns et al. 2009). Ambulation activity bout duration was defined as – short: any bout with < 40 steps; medium: any bout with 41-300 steps; and long: any bout with > 300 steps based on a previous study of chronic stroke survivors (Roos et al. 2012).

Intensity of ambulation activity was determined based on the number of bouts and daily time spent in ambulation activity bouts of low, moderate and high intensity (Manns et al. 2009). Ambulation activity bout intensity definitions used in a previous study of subacute stroke survivors (Manns & Baldwin, 2009) were used in this study and included – low: any bout with a cadence of < 30 steps/minute; moderate: any bout with a cadence of 30-80 steps/minute; and high: any bout with a cadence of > 80 steps/minute.

Participant data were downloaded from ActivPAL™ devices using PAL software. A customised MATLAB (Mathsworks, Natick, MA) program was developed using algorithms written based on definitions used previously in the literature to calculate daily ambulation activity bouts, duration of ambulation bouts and intensity of ambulation bouts (Roos et al., 2012, Manns et al., 2009), with averages per day used in analysis.

4.2.4. Data analysis

Data were screened for normality using Shapiro-wilk statistics, histograms and normality plots. When variables did not meet assumptions of normality, ambulation activity data were transformed using the square root/log transformation (positive skew), or reverse square root/log function (negative skew) as recommended by Tabachnick et al. (2001). The sample was characterised by calculating means, standard deviations and ranges for all continuous variables (for example, age, time post-stroke, gait speed) and frequency for all categorical data (for example, gender, side of stroke, discharge destination).

To address the first aim, descriptive statistics were completed for all volume, frequency and intensity measures for all time points. To address the second aim, linear mixed effects models were used to test for changes in activity across the one, three and six month time points. Models were adjusted for age and discharge gait speed. Age has been recognised as a significant predictor of functional recovery after stroke (Veerbeek et al., 2011), and was thus deemed a potential factor to influence activity over time. Gait speed has also been identified as a predictor of free-living activity in chronic stroke (Fulk and Echternach, 2008) and thus could also contribute to change in activity over time. To determine differences in characteristics between included participants and dropouts, a Mann-Whitney U test was used for non-parametric data and ANOVAs for parametric data. Significance was set at $p < 0.05$ and SPSS 21.0 was used for all statistical calculations.

4.3. Results

4.3.1. Participants

Forty-two participants were recruited from all patients admitted into the stroke rehabilitation and acute stroke units at The Prince Charles Hospital. 225 potential stroke survivors were screened for eligibility from 14th February 2012 to the 8th February 2014. Main documented reasons for exclusion were dependence with mobility on discharge (9%), refusal to participate (7.6%), discharge to residential aged care facilities (7.1%), cardiac surgery/events within three months prior to hospital discharge (5.7%) and cognitive impairment (5.2%). Other reasons for exclusion included participant discharge prior to recruitment, absence of imaging to confirm diagnosis of stroke, pre-existing conditions affecting community ambulation prior to stroke (arthritis, Parkinson's disease), non-English speaking background (thus affecting ability to provide informed consent), discharge to a location outside of Brisbane, moderate to severe aphasia affecting assessment and palliation/death. From recruitment, eight participants withdrew from the study, four participants were lost to follow-up and two participants were unable to attend assessments due to hospital admissions for other medical reasons. Figure 4.1 outlines the flow of participants through the study.

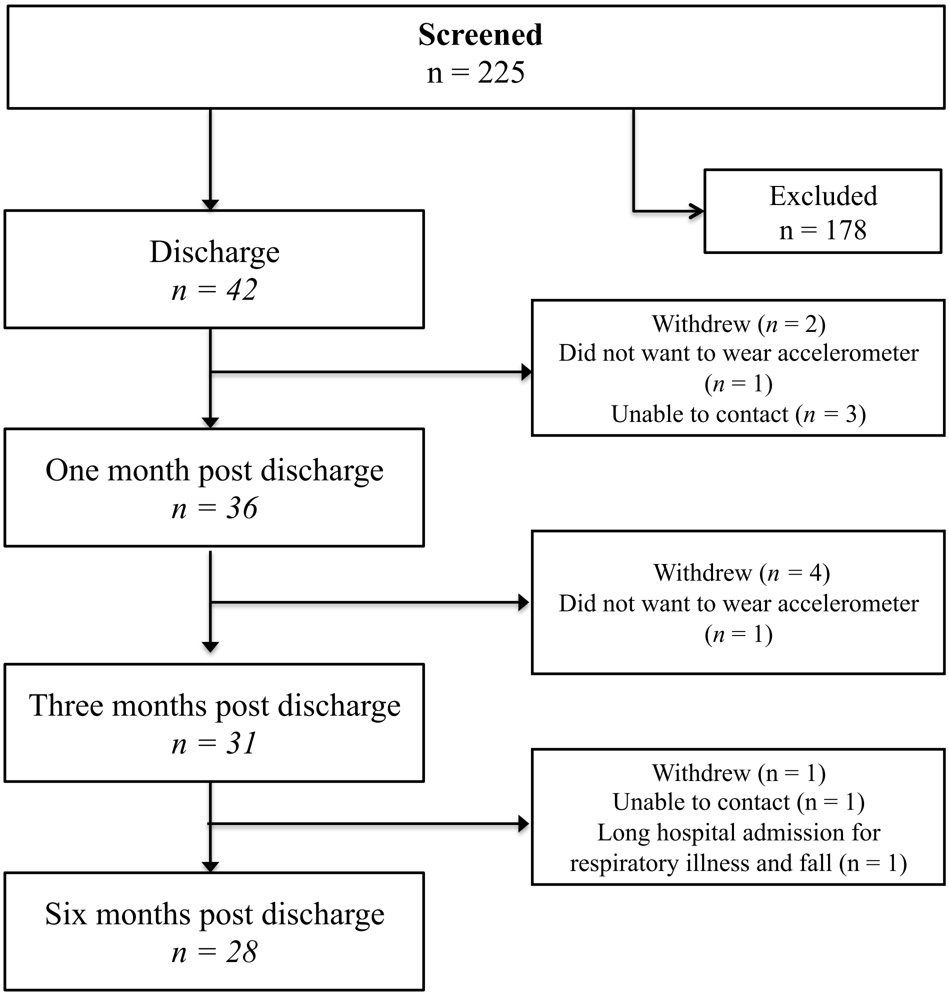

Figure 4.1: Flow of participants through the study.

Thirty-six participants were included in the final analysis. There was no significant difference between characteristics of participants who were included in the analysis and those who withdrew or were lost to follow-up ($p \geq 0.063$) at all time points, except for a greater number of females withdrawing at the one-month follow-up time point ($Z = - 2.598$, $p = 0.030$).

Participant characteristics are reported in table 4.1. Participants included in the analysis had a mean age of 71.0 years (SD 13.6), 69.5% of the sample was male, and the average inpatient stay was 24.0 (SD 21.3) days. A majority of stroke survivors demonstrated right hemiplegia (58.3%), with the remainder having no (22.2%), left (16.7%) or bilateral hemiplegia (2.8%) at discharge (n = 36). Approximately half (55.6%) of participants were discharged home with community follow-up. One participant received residential transitional care for six weeks, fifteen participants continued rehabilitative therapy with a community-based program, and four participants were discharged with a community-based program at either a local rehabilitation centre, or The Prince Charles Hospital.

Table 4.1: Characteristics (presented as mean (SD) or n, %) of stroke survivors at 1, 3 and 6-months after hospital discharge

	1-month n = 36	**3-months** n = 29	**6-months** n=28
Demographics			
Age (years)	71.0 (13.6)	73.0 (13.3)	71.1 (14.7)
Length of stay in rehabilitation (days)	24.0 (21.3)	21.5 (14.4)	23.4 (23.6)
Gender (n, % males)	25, 69.5	21, 72.4	21, 75.0
Hemiplegia (n, %)			
Nil	8, 22.2	5, 17.2	6, 21.4
Left	6, 16.7	6, 20.7	5, 17.9
Right	21, 58.3	17, 58.6	16, 57.1
Bilateral	1, 2.8	1, 3.4	1, 3.6
Aphasia (n, % with)	10, 27.8	7, 24.1	6, 21.4
Carer (n, % with)	18, 50.0	14, 48.3	14, 50.0
Therapy on discharge (n, %)			
Nil	16, 44.4	12, 41.4	13, 46.4
RDTU	4, 11.1	3, 10.3	3, 10.7
CBRT/TCP	15, 41.7	13, 44.7	11, 39.3
Resi-TCP	1, 2.8	1, 3.4	1, 3.6
Functional Measures			
10MTW (m/s)	0.99 (0.4)	1.06 (0.4)	1.07 (0.4)
6MWT (m)	362.8 (167.8)	370.4 (161.2)	395.8 (167.6)

RDTU: Rehabilitation day therapy unit, CBRT: Community based rehabilitation therapy, TCP: Transitional care program, Resi-TCP: Residential transitional care program, 10MTW: Timed 10 metre walk (comfortable pace), 6MWT: 6-minute walk test

The means and SD for gait speed (10MTW) and gait endurance (6MWT) at each follow-up time point are provided in Table 4.1. Participants demonstrated a similar large range for all measures of gait speed and endurance at all time points (one month: 10MTW range 0.14 to 1.76 m/s, 6MWT range 55.0 to 680.0 m, three months: 10MTW range 0.37 to 1.64 m/s, 6MWT range 90.0 to 640 m and 6 months: 10MTW range 0.45 to 1.67 m/s, 6MWT range 90.0 to 750.0 m). No differences were observed in demographic and functional measures across all time points ($p \geq 0.96$).

4.3.2. Characteristics of ambulation activity

Measures of ambulation activity are presented in table 4.2. Mean change in ambulation measures following transformation and adjustment for age and discharge walking capacity across one, three and six months are shown in table 4.3. Stroke survivors demonstrated a range in all measures of activity.

Table 4.2: Mean (SD) and range of volume, frequency, and intensity measures of ambulation activity at 1, 3 and 6-months post discharge

	1-month		**3-months**		**6-months**	
	mean (SD)	**range**	**mean (SD)**	**range**	**mean (SD)**	**range**
Volume						
Step count (counts)*	4452 (3430)	148 – 17687	4623 (2735)	1096 – 10766	4946 (3732)	450 – 15317
Time spent walking (min) *	59.8 (39)	4.5 – 200.4	63.4 (33)	18.2 – 134.4	63.4 (42)	9.4 – 177.5
Time spent standing (min)	183.6 (97)	33.6 – 562.2	191.9 (72)	96.9 – 353.5	188.5 (68)	76.7 – 363.7
Time spent sitting/lying (min) ^	1182.3 (130)	795.7 – 1376.5	1184.5 (90)	997.3 – 1300.7	1188.1 (92)	942.8 – 1330.0
Time spent upright (min)	243.4 (118.9)	45.0 – 644.3	255.2 (90.8)	139.3 – 442.7	251.9 (92.4)	110.0 – 497.2
Frequency						
Frequency of bouts	142.0 (65.1)	21.8 – 323.0	151.4 (59.6)	66.3 – 288.3	141.6 (60.8)	46.8 – 307.8
Frequency of short bouts ^	120.1 (56)	21.3 – 303.0	126.4 (46)	59.9 – 231.7	116.3 (47)	40.8 – 247.8
Frequency of medium bouts *	20.1 (15)	0.0 – 59.0	23.2 (16)	3.3 – 55.3	23.4 (16)	1.8 – 62.0
Frequency of long bouts	1.8 (3)	0.0 – 13.0	1.5 (2)	0.0 – 6.3	1.9 (2)	0.0 – 9.0
Time in short bouts (min) ^	54.6 (26)	11.3 – 129.5	58.3 (22)	24.0 – 114.2	52.6 (23)	14.3 – 121.4
Time in medium bouts (min) *	33.3 (25)	0.0 – 100.6	39.4 (28)	6.7 – 102.3	38.4 (28)	2.5 – 112.0
Time in long bouts	16.3 (24)	0.0 – 119.5	13.9 (15)	0.0 – 55.4	17.4 (25)	0.0 – 103.1
Intensity						
Frequency of low intensity bouts	81.4 (42)	18.3 – 232.5	83.4 (31)	34.3 – 157.3	74.3 (33)	24.5 – 177.0
Frequency of moderate intensity bouts *	63.2 (35)	5.3 – 142.8	64.7 (33)	15.0 – 144.3	63.2 (35)	5.3 – 142.8
Frequency of high intensity bouts	3.4 (3)	0 – 13.8	3.2 (3)	0.0 – 13.0	4.1 (4)	0.0 – 12.5
Time in low intensity bouts (min)	39.4 (21)	9.3 – 102.6	41.4 (18)	14.0 – 79.1	36.6 (19)	10.5 – 92.9
Time in moderate intensity bouts (min)*	51.4 (37)	0.1 – 169.6	60.4 (34)	15.0 – 139.5	55.6 (36)	6.5 – 154.7
Time in high intensity (min)	13. 5 (18)	0.0 – 79.5	9.9 (14)	0 – 48.9	16.3 (24)	0 – 96.9

All values are given as mean (SD) per day, time is given in minutes/day, and frequency is given as counts/day. * indicates that time has a significant effect on change in activity over one, three and six months when adjusted for age and discharge walking speed ($p < 0.05$), ^ indicates that there is a trend towards time having an effect on change in activity measures over one, three and six months when adjusted for age and discharge walking speed (p = 0.05 – 0.099).

Volume

As seen in Table 4.2 and Figure 4.2, stroke survivors took on average 4500 to 5000 steps per day, with a range of 148 to 17,686 at the three time points post discharge from hospital. A majority of their day was spent in sitting/lying positions (~19 hours), spending just around one hour walking (ranging from 10 minutes to 3 hours, see figure 4.2) and 4 hours in upright positions (ranging from approximately 2 to 8 hours) on average per day. The proportion of time each day in lying/sitting versus standing versus walking at one, three and six months is illustrated in Figure 4.3.

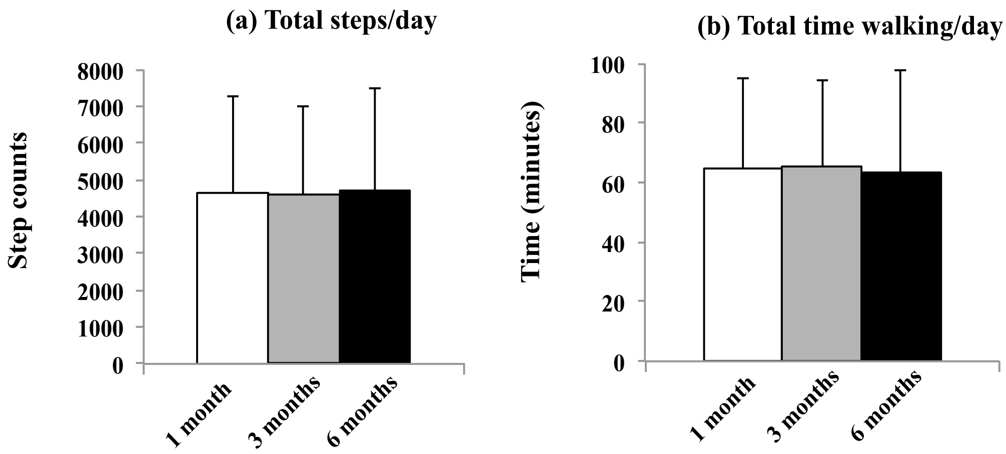

Figure 4.2: Measures of volume of ambulation activity, including (a) total steps/day and (b) time spent walking per day at 1, 3 and 6-months post discharge from hospital.

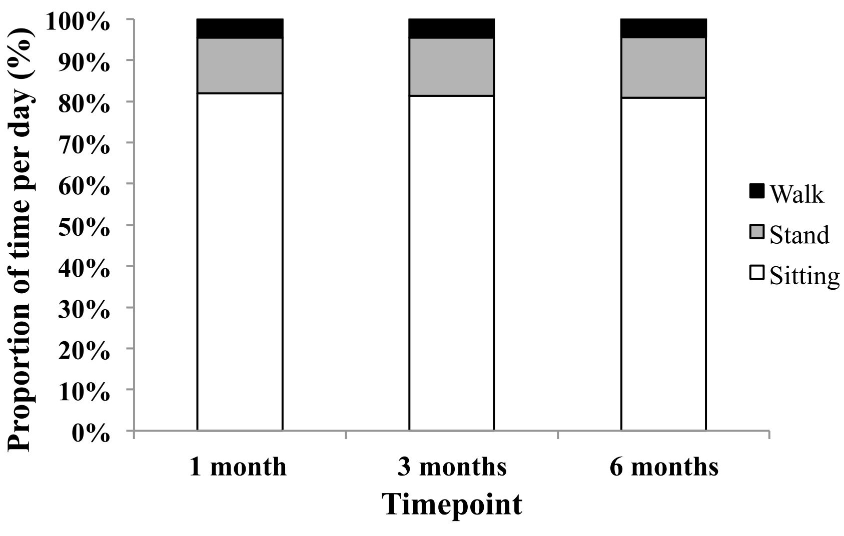

Figure 4.3: Proportion of each day spent walking, standing and sitting/lying at 1,3 and 6-months post discharge.

Frequency

Ambulation activity was spread across an average of 142 to 151 bouts per day as seen in Figure 4.4 and detailed in Table 4.2. A majority of ambulation bouts (85%) were short (<40 steps) in duration (~120 bouts per day) across all time points, with less than a third of total bouts being of medium duration (40-300 steps) (~20 bouts per day) and only 1-2 long bouts of more than 300 steps each day (see figure 4.4). At all time points, around 13.9% of stroke survivors did not engage in any long ambulation bouts across the four days. Total time spent in short ambulation bouts per day comprised approximately 50% of daily walking activity (52.6 SD 23 minutes to 54.6 SD 26 minutes), medium duration bouts comprised 32.0% to 35.4% (33.3 SD 25 minutes to 39.4 SD 28 minutes) and long duration bouts comprised 12.5% to 16.1% (13.9 SD 15 minutes to 17.4 SD 25 minutes) of daily walking activity (see figure 4.5).

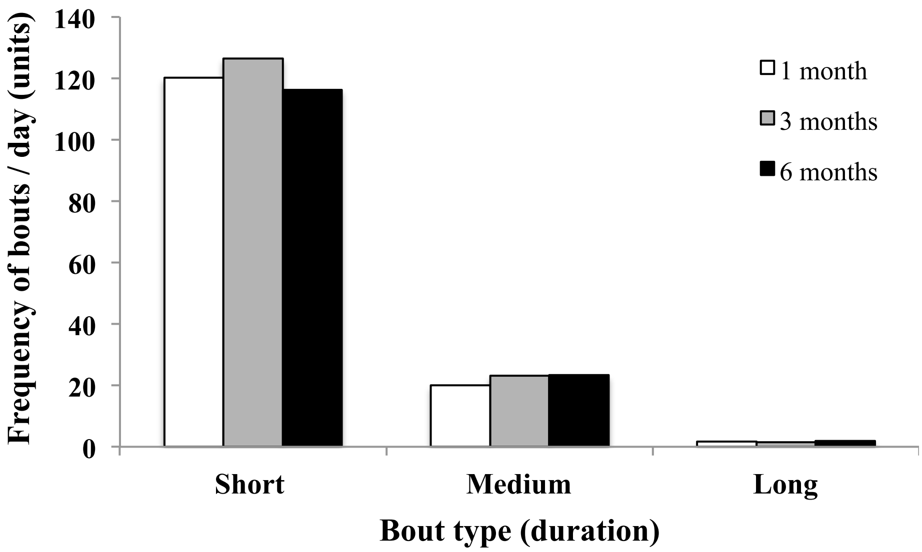

Figure 4.4: Frequency of activity bouts of short (< 40 steps), medium (40-300 steps) and long (> 300 steps) duration at 1, 3 and 6-months post discharge.

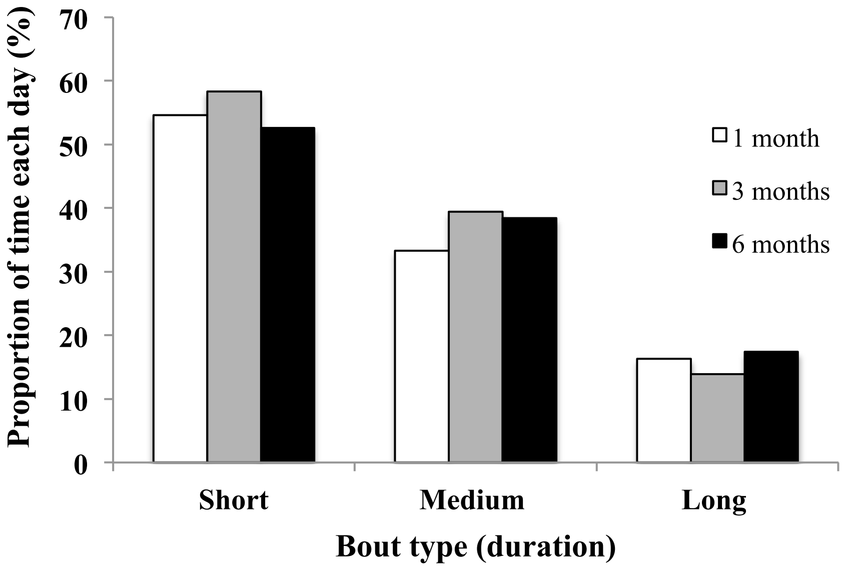

Figure 4.5: Proportion of time per day at each ambulation bout duration: short (<40 steps), medium (40-300 steps) and long (>300 steps) at 1,3 and 6-months post discharge.

Intensity

Most ambulation bouts (74.3 SD 33 bouts to 83.4 SD 31 bouts per day) were low in intensity (< 30 steps / minute) as seen in figure 4.6, but most time was spent walking at a moderate intensity (48.8% to 54.1% in moderate intensity versus 33.7% to 37.4% in low intensity activity) (see figure 4.7). Least time was spent in high intensity (> 80 steps more minute) ambulation bouts across all three time points (8.9% to 15.0% of total daily walking).

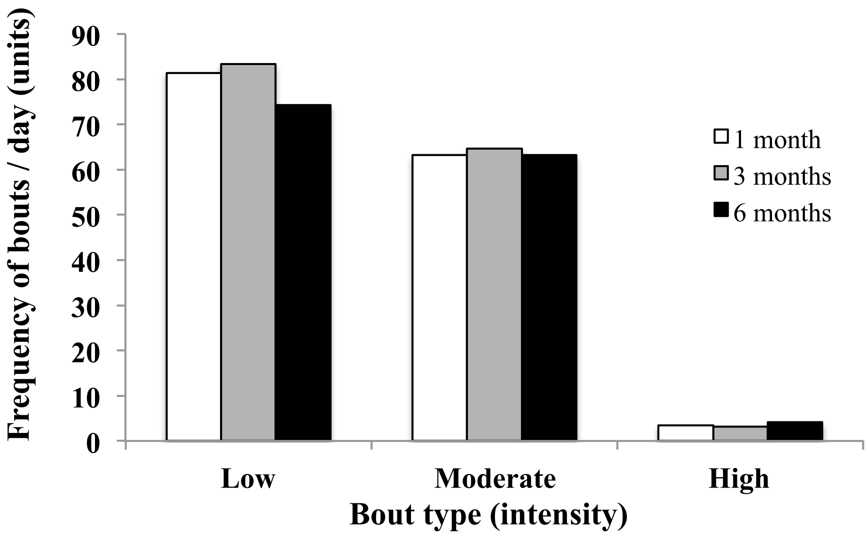

Figure 4.6: Frequency of bouts per day at low (<30 steps/minute), moderate (30-80 steps/minute) and high intensity (>80 steps/minute) at 1,3 and 6-months post discharge.

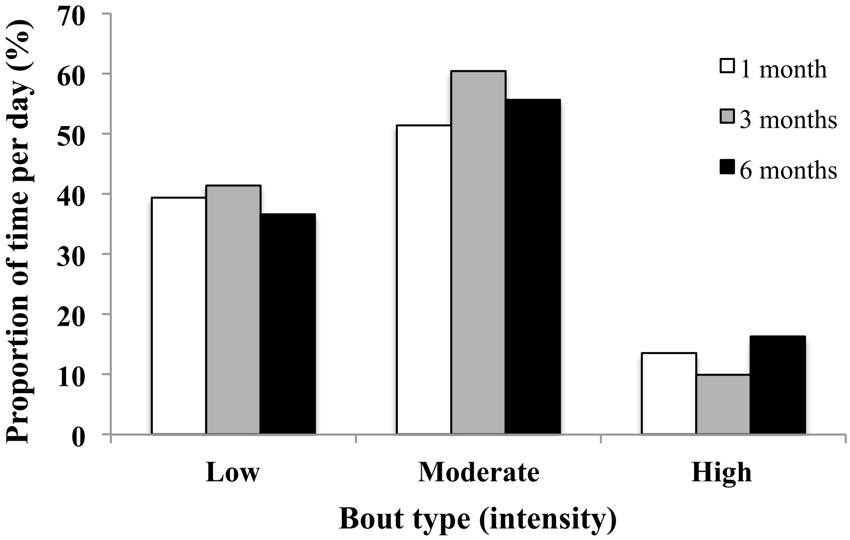

Figure 4.7: Proportion of time per day at each ambulation bout intensity: low (<30 steps/min), moderate (30-80 steps/min) and high (>80 steps/min) at 1,3 and 6-months post discharge.

4.3.3. Changes in ambulation activity across one, three and six months

Volume

When adjusted for age and gait speed at discharge, stroke survivors demonstrated increased daily step counts from one month to both three and six months following discharge from hospital (see table 4.3 for transformed data). Time spent walking per day also significantly increased from one month to three and six months after discharge from hospital. There was an overall trend (overall change: $p = 0.051$) towards an increase in time spent sitting from one to three months ($p = 0.063$) and increase in time spent sitting from one to six months ($p = 0.014$). No significant change was observed for total time spent sitting/lying, standing or in upright positions over time.

Increased age had a negative effect on the rate of recovery of daily step counts and time spent walking from one month to three and six months ($p = 0.038$ and 0.033 respectively). Discharge gait speed did not influence recovery of volume of ambulation activity over the six months.

Table 4.3: Changes in ambulation activity across 1, 3 and 6-months, adjusted for age and gait speed at discharge from hospital (values are transformed and adjusted for age and discharge gait speed)

		Month 1 to month 3			Month 1 to month 6		
	Overall change (p-value)	**Mean change**	**95% confidence interval**	**p-value [a]**	**Mean change**	**95% confidence interval**	**p-value [a]**
Volume							
Step count [b] *	0.041	88.2	17.9 to 158.5	0.016	113.5	32.6 to 194.5	0.008
Time spent walking [b] *	0.020	10.5	2.4 to 18.6	0.013	13.3	4.0 to 22.7	0.007
Time spent standing [b]	0.247	8.7	-8.0 to 678.6	0.295	13.8	-3.2 to 30.9	0.108
Time spent sitting/lying [c] ^	0.051	18.3	-1.0 to 37.6	0.063	24.9	5.3 to 44.5	0.014
Time spent upright [b]	0.091	13.5	-3.8 to 30.9	0.122	19.5	1.8 to 37.2	0.032
Frequency							
Number of bouts [e] ^	0.085	242.8	-87.9 to 573.4	0.144	357.9	39.4 to 676.5	0.029
Number of short bouts [b] ^	0.057	10.5	-1.6 to 22.5	0.087	14.8	2.8 to 26.9	0.017
Number of medium bouts [b] *	0.010	2.9	-3.3 to 9.1	0.347	8.7	1.7 to 15.7	0.017
Number of long bouts [b]	0.119	3.5	-0.1 to 7.0	0.053	3.4	-0.3 to 7.2	0.067
Time in short bouts [b] ^	0.052	7.5	-0.8 to 15.8	0.074	10.8	2.3 to 19.3	0.015
Time in medium bouts [b] *	0.013	4.0	-4.6 to 12.6	0.345	12.6	2.8 to 22.4	0.013
Time in long bouts [d]	0.521	0.9	-1.9 to 3.7	0.505	-0.6	-2.4 to 1.2	0.464
Intensity							
Number of low intensity bouts [b]	0.201	8.7	-2.5 to 19.9	0.122	9.2	-1.1 to 19.5	0.078
Number of moderate intensity bouts [e]	0.119	86.6	-51.4 to 224.6	0.208	178.5	5.3 to 351.6	0.044
Number of high intensity bouts [b]	0.154	4.7	-0.2 to 9.6	0.059	4.7	-0.6 to 9.9	0.080
Time in low intensity bouts [b]	0.158	7.2	-1.2 to 15.6	0.089	7.1	-0.7 to 14.9	0.073
Time in moderate intensity [b] *	0.014	12.8	4.3 to 21.3	0.005	16.2	4.7 to 27.7	0.007
Time in high intensity bouts [b]	0.392	2.8	-6.0 to 11.6	0.522	4.8	-2.4 to 11.9	0.178

[a] LSD pairwise significance. [b] SQRT transformed result, [c] reverse SQRT transformed result, [d] log transformed result, [e] untransformed results, * indicates that time has a significant effect on activity measures ($p < 0.05$), ^ indicates that time trends to affect activity measures ($p < 0.1$).

Frequency

Over time, most improvement in frequency of ambulation occurred between one and six months, with no significant differences observed in frequency of ambulation activity between one and three months after hospital discharge ($p > 0.053$). There was a significant increase in frequency of and total time spent in medium duration bouts (40 – 300 steps) per day from one to six months after hospital discharge ($p < 0.017$) (see Table 4.3). There was a trend towards increased total number of ambulation bouts per day from one month to six months when adjusted for age and discharge walking speed (overall change: $p < 0.085$). Further, there was also a trend towards increased frequency ($p = 0.057$) and duration ($p = 0.052$) of time spent in short (<40 steps) walking bouts from one month after hospital discharge. There was no change in frequency and time spent in long ambulation bouts (> 300 steps) over time when adjusted for age and discharge walking speed. Age had a negative effect on recovery of time spent in short and medium duration bouts ($p < 0.042$). Discharge walking speed had no effect on recovery of ambulation activity frequency.

Intensity

Characteristics of intensity of ambulation bouts did not change over time except for time spent in moderate intensity ambulation bouts. Stroke survivors increased daily time spent in moderate intensity ambulation activity from one month to both three ($p = 0.005$) and six months ($p = 0.007$). There was no change in the number of ambulation bouts at low, moderate or high intensity over time. No change was also observed in total time spent in low and high intensity ambulation bouts over one, three and six months after discharge ($p > 0.073$). Increased age had a significant negative effect only on recovery of total time spent in moderate intensity activity ($p = 0.036$). Discharge walking speed did not affect change in intensity of ambulation bouts over time.

4.4. Discussion

This study is the first to measure ambulation activity across six months following hospital discharge after stroke. Stroke survivors demonstrate a large range in all measures of ambulation activity across the first six months after hospital discharge, but overall, total daily ambulation activity is low. Further, most ambulation bouts are short in duration and low in intensity each day. Findings indicate that when adjusted for age and discharge gait speed, volume of steps and time spent walking per day increases from one month following hospital discharge. Further, the results demonstrate that majority of improvements in ambulation activity are spread across medium duration bouts (40 – 300 steps), and moderate intensity bouts (30 – 80 steps/minute). Stroke survivors demonstrate no increase in short or long ambulation bouts (> 300 steps) and low or high intensity ambulation bouts (>80 steps/minute) over time. Finally, age appeared to have a negative effect on recovery of ambulation activity over one, three and six months following hospital discharge.

All average activity measures demonstrated great variation across all time points, which is consistent with literature in both subacute (Manns and Baldwin, 2009; Shaughnessy et al., 2005) and chronic stroke survivors (English et al., 2014). Volume measures indicate that the current study sample was engaging in ambulation activity similar to sedentary older adults (Tudor-Locke et al., 2008) and below required levels for health benefits (Tudor-Locke et al., 2011c). Though by six months, average daily step counts were close to the minimum 5000 steps required for health benefits (Tudor-Locke et al., 2011). The majority of ambulation bouts were short (less than 40 steps) (85%) and low in intensity (< 30 steps/minute) (56%). However, most time was spent in moderate intensity activity (30-80 steps/minute) at all time points. Increased time in moderate intensity walking is a more favourable outcome than a greater proportion of the day in low intensity ambulation (Billinger et al., 2014).

Stroke survivors increased daily ambulation activity by increasing the number of and time spent in medium duration bouts (40 – 300 steps) and moderate intensity bouts (< 30 – 80steps/minute). In healthy adults, recommendations for daily activity suggest a minimum of 30 minutes of moderate intensity activity per day, spread across bouts of at least 10 minutes in duration, with a range of 75 to 150 minutes per week in ‘vigorous’ or high intensity activity (WHO, 2010). Though stroke survivors spent around an hour per day in moderate intensity ambulation activity at all time points, this was most likely accumulated through short bouts (< 40 steps) of walking. Thus, this sample may not have reaped health benefits associated with moderate intensity ambulation.

Further, while any improvement in daily activity is positive, the low engagement in long duration and high intensity ambulation and the limited improvement in these characteristics of ambulation activity is concerning. Despite spending an average of 14 to 17 minutes in long bouts and 10 to 16 minutes in high intensity bouts of walking per day, there was a high frequency of no recordings of long duration and high intensity bouts across the four-day measurement period. Such a low engagement in long and high intensity walking bouts, and no change over the six months suggests that low engagement in these bout types commences early after hospital discharge, with no improvements over time. This has serious health implications for a group at risk of cardio-metabolic disorders and recurrent stroke (Gordon et al., 2004).

This study contributes to the range of findings on ambulation recovery across the subacute phase of stroke. While one previous study reported no increase in volume of steps over the first six weeks after hospital discharge (Manns and Baldwin, 2009), the current study agrees with others in that the volume of activity showed improvement over time (Moore et al., 2013; Shaughnessy et al., 2005). However, in the current study, it appears that a greater improvement in ambulation activity is observed between one and six months than between one and three months after discharge. This is different to previous reports of a plateau in volume of ambulation activity at six months when compared to one week post-stroke measures of activity (Moore et al., 2013). However, further study would be required to confirm if stroke survivors have potential to continue to increase daily ambulation activity beyond six months of hospital discharge.

Though the results of this study are similar to one study of survivors of subacute stroke reporting increased step counts from one to three months after discharge (Shaughnessy et al., 2005), there were slight differences to other studies, despite synonymous definitions (Moore et al., 2013; Manns and Baldwin, 2009). One earlier study reported no increase in daily step counts from three to six months, while the current study found greatest increase in measures of ambulation activity at six months when adjusted for age and discharge gait speed. Though the current sample had lower steps than earlier studies, ambulation activity was spread over more than double the frequency of ambulation bouts at all time points (Manns and Baldwin, 2009). This could have been due to differences in baseline and follow-up timeframes (Manns and Baldwin, 2009). Further, though previous studies have not reported any change over six weeks in intensity of ambulation, this study demonstrated an increase in moderate intensity ambulation, especially between one and six months. This could be due to the longer timeframe over which data was recorded.

Variations in activity outcomes in individuals with subacute stroke may be due to the differences in sample characteristics, location and study design. The current sample was on average older than previous subacute stroke groups (66 SD 15 years versus 71 SD 14 years) (Manns and Baldwin, 2009). The effect of increased age on reduced activity has been reported in earlier studies in healthy adults (Tudor-Locke et al., 2011c), and as such, similar trends could be expected after stroke. Differences in location (Canada versus USA versus Australia) could have also resulted in dissimilarities in daily ambulation activity, due to differences in health guidelines, health service provision, lifestyles and physical environments. Further, across all studies of activity in subacute stroke, a range of assessment time points are used. Some studies compare pre-discharge to post-discharge activity outcomes, and a range of follow-up timeframes are used (from six weeks to six months). This study's design would not have captured any changes in ambulation activity that could occur as stroke survivors accommodate to their return home from hospital, as the first follow-up time point was at one month (as opposed to pre-discharge and two weeks post-discharge time points) (Manns and Baldwin, 2009; Shaughnessy et al., 2005).

There are a few limitations to this study, including the small sample size and large proportion of stroke survivors who dropped out from discharge to six months (30%). While there were no significant differences in sample characteristics between participants who continued through the study and those who dropped out, there was a greater drop out of female participants by the one month follow-up. Further, some data was lost due to various reasons including, planned surgeries n = 1, refusing to wear the accelerometer n = 1, travel commitments n = 1, hospital admissions following falls n = 1, difficulty with contacting participants n = 1 and corrupt accelerometer data n = 2. The mixed effects modelling procedure assisted in accounting for such missing data points, as it did not exclude cases where there were missing values, but should still be interpreted with caution.

Definitions of ambulation bouts and intensity used in the current study were derived from earlier studies (Roos et al., 2012; Manns and Baldwin, 2009). However, these have not yet been validated in stroke. In healthy adults, it is known that cadence is strongly related to activity intensity (r=0.94) (Tudor-Locke et al., 2011b), and a cadence of 100 steps/minute is regarded as high intensity. This cadence value may not apply to stroke survivors (due to altered cardiovascular dynamics and cost of hemiplegic gait patterns) (Manns et al., 2010; Brooks et al., 2008; Mackay-Lyons and Makrides, 2002). Also, it is possible that some stroke survivors may not be able to achieve a step cadence > 80 steps per minute, but will still be walking at a high metabolic intensity. The relationship between walking cadence and metabolic load after stroke needs validation before it can be concluded that cadence is a true measure of intensity activity in this group.

4.5. Conclusions

In conclusion, subacute stroke survivors demonstrate low levels of ambulation activity after hospital discharge. A majority of ambulation bouts are short in duration and low in intensity after discharge. Stroke survivors demonstrate an increase in volume of steps and time spent walking; frequency and time spent in medium duration ambulation bouts; and time spent in moderate intensity walking over time from one to six months after hospital discharge. However, there are no improvements in long bouts and higher intensity ambulation activity. In future, it would be beneficial to investigate factors contributing to outcomes in ambulation activity after hospital discharge. Further, it would be useful to identify strategies to increase early engagement in longer bouts of walking and higher intensity ambulation to improve health outcomes after stroke.

Chapter 5

Study three: Factors predictive of ambulation activity after stroke

From Chapter Four, we know that daily volume of ambulation activity improves over the first six months following hospital discharge after stroke. However, most of this takes place through increasing the time spent in short ambulation bouts and low to moderate intensity ambulation activity. There are no improvements in beneficial activity behaviours, such as long ambulation bouts and high intensity ambulation. The purpose of this chapter is to identify what factors at discharge from hospital predict ambulation activity outcomes in the first six months after stroke survivors return home from hospital. Identifying these factors will assist in goal setting and discharge planning during rehabilitation of stroke survivors. Thus, stroke survivors can potentially be well set up to improve daily ambulation activity over time, as well as increase time in longer duration and higher intensity ambulation bouts. This will encourage better general health and functional outcomes for this group.

Abstract

Purpose: To identify factors at hospital discharge which predict ambulation activity outcomes across the first six months following discharge from hospital after stroke.

Methods: Thirty-six (36) subacute stroke survivors (age: 71.0 SD 10.4 years, 69.4% male) were recruited at hospital discharge. Clinical measures of walking capacity (10-metre walk test and six-minute walk test), and factors related to ambulation recovery after stroke (fatigue, mood, executive function, pre-stroke activity, ambulation self-efficacy, perceived health status and stroke recovery) were collected. Stroke survivors were followed up at 1,3 and 6-months after hospital discharge. At each follow-up stroke survivor ambulation activity was measured over four days by the ActivPAL^{TM} accelerometer. Measures of ambulation activity included volume (step count per day), frequency (time per day in long ambulation bouts: >300 steps) and intensity (time per day in high intensity ambulation bouts: cadence > 80 steps/minute). Three to four strongest correlated factors were entered into a step-wise regression to identify which factor predicted ambulation activity outcomes.

Results: At one month, gait endurance alone predicted all of volume ($R^2 = 0.29$, $F = 9.87$, $p = 0.004$), frequency ($R^2 = 0.29$, $F = 9.69$, $p = 0.005$) and intensity ($R^2 = 0.46$, $F = 20.28$, $p < 0.001$) of ambulation activity. At three months, both discharge gait endurance and pre-stroke activity predicted volume ($R^2 = 0.46$, $F = 9.48$, $p = 0.001$) and intensity ($R^2 = 0.61$, $F = 17.5$, $p < 0.001$), and pre-stroke activity predicted frequency ($R^2 = 0.31$, $F = 10.190$, $p = 0.004$) of ambulation activity. At six months, age alone predicted volume ($R^2 = 0.35$, $F = 11.78$, $p = 0.002$) and frequency ($R^2 = 0.34$, $F = 11.34$, $p = 0.003$), while pre-stroke activity, discharge 6-minute walk distance, and executive function together predicted intensity of ambulation activity ($R^2 = 0.79$, $F = 25.32$, $p < 0.001$).

Conclusions: Gait endurance contributes to ambulation activity outcomes at one, three and six months following hospital discharge after stroke, in particular intensity. After one month, other factors such as pre-stroke activity, age and executive function contribute to ambulation activity outcomes over time. At six months following hospital discharge, stroke related impairments may not affect ambulation activity outcomes, but rather age related decline. Post-stroke interventions should encourage improvement in gait endurance, executive function and positive ambulation activity behaviours.

5.1. Introduction

Ambulation activity after stroke is low. However, the process of ambulation recovery over time following stroke and predictive factors is unclear. During the subacute phase of stroke, stroke survivors display the greatest potential for improvement in functional outcomes (Jang, 2010; Carod-Artal et al., 2000; Jorgensen et al., 1995b). Further, experiences such as sentinel events, or mismatched expectations of recovery that can occur early after stroke survivors return home from hospital can change expectations of outcome and engagement in walking related activities if not sufficiently supported (Ahuja et al., 2013; Barnsley et al., 2012; Nalder et al., 2012a; Nalder et al., 2012b). Thus, this immediate phase post hospital discharge is important to target during recovery to ensure optimal outcomes later after stroke. Understanding factors at hospital discharge that predict ambulation activity outcomes later after stroke survivors return home can also assist in better informing decisions during discharge planning to encourage healthy activity behaviours early after stroke.

A number of cross-sectional studies have identified factors within various domains of the ICF that predict general function and volume of ambulation activity (i.e. daily step count) in individuals with chronic stroke. While a number of factors are related to ambulation activity outcomes in individuals with chronic stroke (Askim et al., 2013; Alzahrani et al., 2012; Fulk et al., 2010; Manns et al., 2010; Alzahrani et al., 2009; Michael et al., 2005), the influence of these on outcomes across the subacute phase need further investigation. It is still unknown if impairments, activity limitations or personal factors at the end of inpatient rehabilitation (when stroke survivors are 'ready for home') predict actual ambulation activity outcomes later on. Assessment of the ability of these factors at hospital discharge to predict ambulation activity outcomes across the subacute phase of recovery after stroke is clinically useful. This will enable better discharge planning and goal-setting processes during inpatient rehabilitation.

In individuals with chronic stroke, impairments such as self-reported fatigue (Michael et al., 2006), mood disorders and impaired executive function are associated with lower step counts (Alzahrani et al., 2012; Baert et al., 2012; Michael and Macko, 2007; van de Port et al., 2006) and limited functional recovery (Adamit et al., 2014; Liu-Ambrose et al., 2007; van de Port et al., 2006). Within the ICF activity domain, increased walking capacity (gait speed and gait endurance) has been reported to have a positive effect on volume of activity in individuals with chronic stroke (Baert et al. 2012, Alzahrani et al. 2011, Fulk 2010, Mudge et al. 2009, Michael et al. 2007), with gait endurance considered a strong predictor of volume of steps per day in this group (Fulk et al. 2010, Mudge et al. 2009). Post-stroke impairments and activity limitations can influence whether or not stroke survivors are able to resume ambulation activity after hospital discharge – thus these may influence how much ambulation activity stroke survivors engage in early after their return home. Also, identifying if such impairments and activity limitations at hospital discharge predict ambulation activity across the first six months of returning home, will assist in determining post-stroke changes to target during rehabilitation to increase ambulation activity after discharge.

The important role of participant characteristics and personal factors on re-engagement in pre-stroke activities has been highlighted across the literature. Participant demographics such as female gender (Carod-artal et al. 2007), older age (Fulk et al., 2010; Paolucci et al., 2001), the absence of carer support (Nicholson et al. 2012) and not receiving therapy post hospital discharge (Paolucci et al. 2001) are associated with poor outcomes in the chronic phase of stroke. Also, physical activity in the week prior to stroke has a strong relationship with stroke risk, severity and resulting disability and as such can contribute to ambulation activity outcomes over the first six months following hospital discharge. Perceptions of health and recovery can improve ambulation outcomes by increasing confidence of stroke survivors to make the decision to re-engage in walking activities after going home (Eriksson et al., 2013; Barnsley et al., 2012; Stein et al., 2003; Mayo et al., 2002). However, investigation of the association between these factors at hospital discharge and device-based measures of ambulation activity across the first six months after returning home is required.

In light of this, this study aimed to determine what factors at discharge are related to and predict accelerometer measured ambulation activity outcomes (volume, frequency and intensity) over the first six months following hospital discharge after stroke. It was hypothesised that stroke survivors with lower levels of fatigue, who were younger and had higher scores of mood, executive function, walking capacity, self-efficacy, pre-stroke activity and perceived health status and stroke recovery at hospital discharge would have increased volume, frequency and intensity of ambulation activity outcomes at one, three and six months after returning home.

5.2. Methods

This study followed a prospective, longitudinal observational repeated measures design, and the recruitment of participants is the same as detailed in Chapter 4. Stroke survivors were recruited from acute stroke and rehabilitation units at The Prince Charles Hospital, Brisbane, Australia during their last week of admission prior to discharge. Participants were followed up at one, three and six months after their discharge date. Institutional ethics committees at The Prince Charles Hospital and University of Queensland approved the study (see Appendices 3 and 4). This study was conducted in accordance with the Declaration of Helsinki.

5.2.1. Participants

A total of 42 stroke survivors were recruited. Participants were included if they (1) presented with a stroke within the past 4 months, (2) were aged > 18 years and (3) were discharged into the community to live alone or with a carer or spouse.

Individuals were excluded if they: (1) had a diagnosis of another neurological condition (e.g. Parkinson's disease) or co-morbidities that limited ambulation prior to stroke, or during their hospital admission, (2) had any unstable medical condition, (3) chest pain, heart attacks, angioplasty or heart surgery in the previous three months, (4) skin allergies to adhesive tape, (5) were discharged to a residential aged care facility, (6) moderate to severe expressive of receptive communication difficulties (based on speech therapist assessment) or (7) scored < 24/30 on the Mini Mental State Examination (MMSE) (Folstein et al., 1975).

5.2.2. Procedures

Consenting participants attended four assessments at The Prince Charles Hospital day therapy rehabilitation gym. These included a discharge assessment within the final week prior to hospital discharge, and then three follow-up assessments at one month, three months and six months following hospital discharge. These follow-up time points were chosen based on existing literature on functional recovery and ambulation activity after stroke. Greatest functional recovery occurs in the first few months following stroke (Hendriks et al., 2002), with most gains occurring by the first month (Duncan et al., 2000) and typically, very limited spontaneous recovery occurring after six months (Jang, 2010; Duncan et al., 2000; Jorgensen et al., 1995a; Jorgensen et al., 1995b; Bonita and Beaglehole, 1988). Ambulation activity literature also suggests continual increase in daily steps to three months following stroke, with limited improvements following this (Moore et al., 2013). Thus, ambulation activity outcomes at one, three and six months following discharge were investigated.

At the discharge assessment, general demographic and clinical information such as age, gender, time since stroke onset, medical co-morbidities, medications, side and site of the lesion premorbid mobility, premorbid residential status, discharge destination, social and community provided supports on discharge (e.g. Bluecare, Meals on Wheels) and length of stay were collected. Clinical outcome measures of walking capacity routinely collected by therapists and additional questionnaire responses were collected (see below).

At one month, three months and six months follow-ups, measures of ambulation activity were collected over four days by an accelerometer, the ActivPAL^{TM}.

5.2.3. Factors at discharge

Potential factors contributing to ambulation activity were determined based on existing research in individuals with chronic stroke. Factors were collected during the final week prior to discharge from hospital.

Body structure and functions

Measures of body structure and function included self-reported fatigue, mood and executive function.

Fatigue was measured using the seven-item Fatigue severity scale (FSS-7) (Krupp et al., 1989). This scale has seven statements relating to the effect of fatigue on daily function along with a seven point Likert scale (1 to 7) to indicate strength of participant disagreement/agreement with each statement. The FSS-7 has been used in studies with stroke survivors, and has demonstrated good psychometric properties in this group (Lerdal et al., 2009).

Mood was measured using the Depression-Happiness scale (DHS) (Joseph and Lewis, 1998). The DHS is a 25-item self-report scale which assesses a range of thoughts, feelings and bodily experiences associated with depression and happiness. It has 13 items relating to negative thoughts, feelings and bodily experiences and 12 items relating to positive thoughts, feelings and bodily experiences. Each item is rated on a four-point scale referring to frequency of each item, 'never', 'rarely', 'sometimes' and 'often'. Scoring of negative items are: never (3), rarely (2), sometimes (1) and often (0), and of positive items are: never (0), rarely (1), sometimes (2) and often (3). Summation of individual item scores gives a total score out of 75, with a higher score indicating a higher frequency of positive thoughts, feelings and bodily experiences, and thus a positive mood. The DHS has not been validated after stroke, but it has been used previously with stroke survivors, where it predicted outcomes in total time on feet (regression coefficient: 8.2, R^2: 0.19, $p < 0.01$) in individuals with chronic stroke (Alzahrani et al., 2012).

Executive function was assessed using the Trail making test (TMT) (Reitan, 1958). The TMT is a neuropsychological assessment tool which is a sensitive indicator of brain damage (Reitan, 1958). It is a measure of the speed of mental processing, sequence alternation, cognitive flexibility, visual search, motor performance and executive function. The test has two parts (A and B). TMT-A requires participants to draw a continuous line connecting 25 encircled numbers in consecutive order (e.g. 1-2-3-4-5-6 etc.). TMT-B requires participants to draw a continuous line connecting encircled numbers (1-13) and letters (A-L) while alternating between them (e.g. 1-A-2-B-3-C etc.). The TMT has not been validated in stroke samples, but normative values and guidelines for use are available for the traumatic brain injury population (Perianez et al., 2007) and healthy older adults (Tombaugh, 2004). The score for executive function was given by subtracting the total TMT-A time from the TMT-B time (in seconds) (TMTB-A) (Coppin et al., 2006; Corrigan and Hinkeldey, 1987). The trail-making test, has a range of scoring options, however, the TMTB-A is a score useful for individuals with stroke as it removes the effect of change in speed of movement on time scores. This makes it easier for comparison with normative values (Arbuthnott and Frank, 2000).

Activity (walking capacity)

Measures of *walking capacity* included self-selected gait speed over ten metres (Vos-Vromans et al., 2005) and gait endurance over 6 minutes (Enright, 2003; Pohl et al., 2002).

Self-selected gait speed was measured using the timed 10m-walk test (10MTW). This was completed along an uncluttered, open 14 m corridor at the outpatient rehabilitation gym. Participants were instructed to walk along the corridor at their comfortable pace, and timing commenced at 2 metres, and stopped at 12 metres. Participants were allowed to use their own mobility aides, and a therapist accompanied them during the test. The 10MTW is a valid measure of gait speed and walking ability in the stroke population (Fulk and Echternach, 2008; Vos-Vromans et al., 2005).

Gait endurance was measured during the Six-minute walk test (6MWT) (Enright, 2003; Pohl et al., 2002). This test was completed along a quiet, uncluttered and open 30m corridor within the hospital. Participants were instructed to 'walk as far as possible for six minutes' up and down the corridor. Participants were given updates on time remaining at minute intervals and provided with standardised encouragement at each minute, (e.g. 'one minute remaining, do your best') (Enright, 2003; Pohl et al., 2002). Distance walked was measured in metres at the end of the six minutes and used as the measure of gait endurance. Participants were permitted to use their mobility aides and were accompanied by a therapist at all times. Rests were allowed if required during the test. The six-minute walk test is a valid and reliable measure of gait endurance in individuals with stroke (Pohl et al., 2001).

Personal factors

Personal factors included age, pre-stroke activity (Washburn et al., 1993), ambulation self-efficacy (Asano et al., 2007) perceived stroke recovery (Duncan et al., 2003) and perceived health outcome and status (Shaw et al., 2005).

Pre-stroke activity was assessed using the Physical activity scale for the elderly (PASE) (Washburn et al., 1993). The scale assesses physical activity over one week. It includes activities relating to leisure, paid and unpaid work, walking outside the home, housework, lawn/yard work, home repairs, gardening, caring for others, muscle strengthening exercises and light, moderate and strenuous sports and recreation activity. Frequency of engagement in each activity (seldom: 1-2days/week, sometimes: 3-4 days/week, often: 5-7 days/week) and approximate duration per day (<1 hour, 1-2 hours, 2-4 hours or > 4 hours) was collected. The final PASE score was calculated by multiplying the amount of time in each activity (hours/week) or participation (yes/no) in each activity by an empirically derived item weight, which was then summated. PASE scores have been validated in elderly samples, and are associated with measures of energy expenditure by doubly labelled water, and demographic health status characteristics (Washburn et al., 1993). The scale has also been used in a number of studies as a measure of physical activity after stroke (Danielsson et al., 2011; Krarup et al., 2008; Krarup et al., 2007).

Ambulation self-efficacy was measured using the Ambulatory self-confidence questionnaire (ASCQ) (Asano et al., 2007). The ASCQ is a 22-item test to assess confidence when ambulating in different environmental conditions, by providing a score out of 10 for each item. A score of 0 indicates no confidence and a score of 10 indicates complete confidence in the respective condition. The scores are then averaged to give an overall score out of 10.

Perceived stroke recovery was assessed using the Stroke impact scale (SIS) version 3.0 (Carod-Artal et al., 2008; Duncan et al., 2003). The SIS is a 59-item questionnaire that assesses stroke outcome in the domains of strength, hand function, mobility, activities and instrumental activities of daily living, memory and thinking, communication, emotion and social participation, as well as a vertical visual analogue scale (VAS) score of perception of recovery following stroke. Each item is scored from 0 to 5 to indicate recovery in each domain. For example in strength, a score of 0 indicates 'no strength', and a score of 5 indicates 'a lot of strength'. Individual item scores are summated to give a total score out of 295. The VAS score of perception of recovery is from 0 to 100 percent, with 100 percent indicating full recovery, and 0 percent indicating no recovery from stroke (Danielsson et al., 2011).

Perceived health outcome and status was determined using the European Quality of Life -5D (EQ-5D) (Shaw et al., 2005). It assesses five dimensions of health outcome, including mobility, self-care, usual activities, pain/discomfort and anxiety and depression. Each dimension is scored out of 3 (1: no problems at all, 2: some problems, 3: extreme problems). A 20cm vertical VAS (0 to 100 percent) is used for participants to specify perceived health status. A score of zero indicates the participant perceives that they are in the worst health state imaginable, and a score of 100 indicates the participant perceives they are in the best health state imaginable (Shaw et al., 2005).

5.2.4. Measures of ambulation activity

At each follow-up assessment, participants donned the ActivPAL^{TM} for four days, as detailed in section 4.2.2 of this thesis. Outcomes in ambulation activity were divided into volume, frequency and intensity to characterise ambulation activity. Outcome of volume of activity was number of steps per day, frequency was total time per day in long ambulation bouts (> 300 steps) and intensity was total time per day spent in high intensity ambulation bouts (> 80steps per minutes). An 'ambulation bout' was defined as any 15second data interval with ≥ 2 steps. These outcome measures were chosen as they have previously been used as measures of volume, frequency and intensity of activity after stroke (Roos et al., 2012; Manns and Baldwin, 2009; Shaughnessy et al., 2005). Further, health benefits are associated with longer bouts of walking and higher intensity activity (Pang et al., 2013; Roos et al., 2012). Thus, capturing which factors predict outcomes in long duration and high intensity outcomes after stroke is clinically useful.

5.2.5. Data Analysis

Averages were calculated for all factors and measures of ambulation activity. Data were inspected for assumptions of step-wise multiple regression. Data were screened for normality using Shapiro-wilk statistics, histograms and Q-Q plots. When variables did not meet assumptions of normality, data were transformed using the square root (positive skew), or reverse square root function (negative skew) (Tabachnick and Fidell, 2001). All ambulation activity measures required transformation, and were square root transformed. All other assumptions for regression were met.

Spearman's correlations of all independent factors (impairment, activity and personal) with raw ambulation activity outcomes (volume, frequency and intensity) were completed, as this data were not normally distributed and many variables were categorical. The top three to four measures from different domains that were significantly correlated with ambulation activity at each time points individually were identified and entered into a step-wise regression model. Three to four measures were chosen to ensure sufficient power for prediction with a sample size of n=36. This was based on the literature around the ratio of subjects to variables during multiple regression analysis, where a commonly cited rule of thumb of at least 10 subjects per variable is reported (Nunnally, 1978). Three individual stepwise multiple regression models were created to identify which factors at discharge predicted ambulation activity volume, frequency and intensity at one, three and six months following hospital discharge. Any post-hoc comparisons between groups were completed using Mann-Whitney U for non-parametric data. Significance was set at $p < 0.05$. SPSS 21.0 was used for all statistical calculations.

5.2. Results

5.3.1. Participants

Forty-two participants were recruited at hospital discharge with six withdrawing by the one month follow-up assessment. Thus, 36 stroke survivors were included in the final analysis. Sample characteristics are reported in table 5.1. No differences were observed in demographic and functional measures over time. The sample had a mean age of 71.0 (13.7) years, and 69.4% were male at discharge. Over half of participants were discharged with allied health therapy and half of the sample had carer support. No differences were observed in factors at discharge or measures of ambulation activity between those who received therapy versus did not receive therapy and those with versus without carer support.

Table 5.1: Characteristics (presented as mean (SD) or n, %) of stroke survivors (n = 36) at discharge

Characteristic	n = 36
Age (years)	71.0 (13.7)
Hospital length of stay (days)	24.0 (21.3)
Gender (n, % males)	25, 69.4
Hemiplegia (n, %)	
Nil	8, 19.5
Left	6, 16.7
Right	21, 58.3
Bilateral	1, 2.8
Aphasia (n, % with)	10, 27.8
Carer (n, % with)	18, 50.0
DC Therapy (n, %)	
Nil	16, 44.4
RDTU	4, 11.1
CBRT/TCP	15, 41.7
RESI-TCP	1, 2.8

DC Therapy: Therapy received following discharge, RDTU: Rehabilitation day therapy unit, CBRT: Community based rehabilitation therapy, TCP: Transitional care program, RESI-TCP: Residential care based transitional care program.

5.3.2. Factors at discharge related to ambulation activity at one, three and six months

Tables 5.2 presents the mean, standard deviation; and median, interquartile ranges for the independent factors assessed at discharge from hospital included in the correlation analysis.

Table 5.2: Mean (SD)/median and range/IQR of the independent factors for the stroke survivors (n = 36) at discharge from hospital

Factor	**Mean (SD)/ Median**	**Range/ IQR**
Age *(years)*	71.0 (13.7)	39 - 91
FSS *(score out of 7)*	3.6	1.6 – 4.4
DHS *(score out of 75)*	58.0	47.8 – 66.0
TMTB-A *(seconds)*	111.3 (142.4)	- 434.0 – 436.0
Gait speed *(m/s)*	1.0 (0.4)	(0.1 – 1.7)
6MWT *(distance in metres)*	327.4 (145.7)	47.0 – 544.0
PASE *(score)*	175.9 (111.0)	8.6 – 375.6
ASCQ *(score out of 10)*	8.6	6.4 – 9.5
EQ-5D *(score out of 15)*	7.0	6.0 – 8.0
EQ-5D (VAS) *(%)*	72.2 (22.0)	10 – 100
SIS total *(score out of 295)*	253.0	221.0 – 265.0

FSS: Fatigue severity scale (score out of 7), DHS: Depression and Happiness Scale (score out of 75), TMT: Trail making test B – Trail making test A (in seconds), PASE: Physical activity scale for the elderly (max score undefined), ASCQ: Ambulatory self-confidence questionnaire (score out of 10), EQ-5D: European quality of life instrument (score out of 15), EQ-5D (VAS): European quality of life instrument health state (%), SIS – total: Stroke Impact Scale total score, IQR: Inter-quartile range.

Table 5.3 presents the means, standard deviations and range of the raw, untransformed ambulation activity measures. Stroke survivors took an average of 4500 steps per day across the six months. Participants spent 14 to 17 minutes per day in long duration ambulation bouts (>300 steps) and 10 to 16 minutes per day in high intensity (> 80 steps per minute) across the six months. High variability was observed in all measures of ambulation activity (see table 5.3).

Table 5.3: Ambulation activity measures at 1, 3 and 6-months post discharge

	1-month (n = 36)		**3-months (n = 29)**		**6-months (n = 28)**	
	mean (SD)	**range**	**mean (SD)**	**range**	**mean (SD)**	**range**
Volume Number of steps	4452 (3430)	148 – 17687	4623 (2735)	1096 – 10766	4946 (3732)	450 – 15317
Frequency Time per day in Long bouts	16.3 (23.6)	0.0 – 119.5	13.9 (15.0)	0.0 – 55.4	17.4 (24.9)	0.0 – 103.1
Intensity Time in High intensity	13.5 (17.9)	0.0 – 79.5	9.9 (13.6)	0.0 – 48.8	16.3 (24.4)	0.0 – 96.9

All measures are reported as mean (SD) (standard deviation).

Table 5.4 presents the Spearman's correlation coefficients and p-values between discharge factors and measures of ambulation activity at the three follow-up time points. All measures of ambulation activity at one month were significantly correlated with discharge fatigue severity, gait speed, gait endurance, ambulation self-efficacy, and perceived health outcome. Ambulation activity at three months was significantly related to discharge walking speed, gait endurance, pre-stroke activity and age. Six month ambulation activity was significantly related to discharge gait speed, gait endurance, executive function, pre-stoke physical activity and age.

Table 5.4: Relationship between independent factors at discharge and measures of volume, frequency and intensity of activity at 1, 3 and 6-months following hospital discharge, Spearman's R (p). Significant correlations are in bold.

	1-month			**3-months**			**6-months**		
Factor	*Volume of steps*	*Long bouts*	*High intensity bouts*	*Volume of steps*	*Long bouts*	*High intensity bouts*	*Volume of steps*	*Long bouts*	*High intensity bouts*
Age	0.136 (0.450)	0.034 (0.851)	0.024 (0.892)	**-0.431 (0.020)**	**-0.454 (0.013)**	**-0.446 (0.015)**	**-0.590 (0.001)**	**-0.583 (0.001)**	**-0.499 (0.007)**
FSS	**- 0.387 (0.026)**	**-0.504 (0.003)**	**-0.534 (0.001)**	-0.114 (0.563)	-0.167 0.395)	-0.123 (0.532)	-0.063 (0.756)	-0.184 (0.360)	-0.217 (0.277)
DHS	0.239 (0.187)	0.254 (0.161)	0.295 (0.101)	0.161 (0.412)	0.306 (0.113)	0.207 (0.292)	-0.148 (0.462)	0.012 (0.954)	0.124 (0.536)
TMT	- 0.265 (0.143)	-0.285 (0.114)	-0.307 (0.088)	- 0.226 (0.249)	-0.159 (0.418)	-0.185 (0.345)	-0.355 (0.069)	**-0.418 (0.030)**	**-0.539 (0.004)**
10MTW	**0.543 (0.003)**	**0.516 (0.005)**	**0.621 (0.000)**	**0.411 (0.037)**	0.237 (0.243)	**0.605 (0.001)**	**0.405 (0.045)**	**0.482 (0.015)**	**0.569 (0.003)**
6MWT	**0.556 (0.003)**	**0.530 (0.005)**	**0.674 (0.000)**	**0.552 (0.004)**	0.335 (0.102)	**0.669 (0.000)**	**0.467 (0.021)**	**0.503 (0.012)**	**0.651 (0.001)**
PASE	0.002 (0.993)	0.026 (0.886)	0.065 (0.720)	**0.467 (0.011)**	**0.542 (0.002)**	**0.433 (0.019)**	**0.447 (0.017)**	**0.411 (0.030)**	**0.506 (0.006)**
ASCQ	**0.466 (0.007)**	**0.409 (0.020)**	**0.537 (0.002)**	0.171 (0.385)	0.133 (0.500)	0.264 (0.174)	0.138 (0.492)	0.249 (0.210)	**0.408 (0.035)**
EQ-5D	**-0.529 (0.002)**	**-0.478 (0.006)**	**-0.618 (0.000)**	-0.244 (0.211)	-0.232 (0.235)	-0.334 (0.082)	-0.194 (0.333)	-0.213 (0.286)	**-0.408 (0.035)**
EQ-5D (VAS)	-0.102 (0.579)	-0.196 (0.283)	-0.153 (0.402)	0.057 (0.774)	-0.026 (0.897)	0.133 (0.566)	-0.214 (0.284)	-0.123 (0.541)	-0.119 (0.553)
SIS total	**0.369 (0.049)**	0.354 (0.060)	**0.412 (0.026)**	0.125 (0.552)	0.156 (0.457)	0.188 (0.369)	-0.025 (0.907)	0.131 (0.534)	0.255 (0.218)

FSS: Fatigue severity scale, DHS: Depression and happiness scale, TMT: Trail-making test, 10MTW: 10 m timed walked test, 6MWT: Six-minute walk test, PASE: Physical activity scale for the elderly, ASCQ: Ambulatory self-confidence questionnaire. EQ-5D: Euroqol-5D, EQ-5D (VAS: Euroquol-5D visual analogue scale.

5.3.3. Predictors of ambulation activity

Discharge gait speed and gait endurance were strongly correlated ($r = 0.876$, $p < 0.001$), and thus to meet assumptions of collinearity for regression analysis, only one measure was chosen for final regression. Gait endurance had a stronger correlation to all ambulation activity measures than gait speed and thus, only gait endurance was used in the final factor list at each time point. Factors included in the step-wise multiple regression analysis for one month ambulation activity included: gait endurance, ambulation self-efficacy, fatigue severity and perceived health outcome ($r = 0.369$ to 0.674). Factors chosen for 3-months ambulation activity included: gait endurance, age and pre-stroke activity ($r = 0.431$ to 0.669); and at 6-months: gait endurance, age, pre-stroke activity and executive function ($r = 0.418$ to 0.651).

At one month, gait endurance (6MWT distance) alone predicted 29% to 46% of variance in all measures of ambulation activity (volume $R^2 = 0.291$, frequency $R^2 = 0.288$ and intensity $R^2 = 0.458$) (see table 5.5). Ambulation self-efficacy, fatigue severity and perceived health outcome did not significantly contribute to models at one month. Gait endurance and pre-stroke activity together predicted 46% of volume and 61% of intensity of ambulation activity per day. Pre-stroke activity alone predicted 31% of variance in frequency of ambulation activity. Age did not significantly contribute to any model at three months. At six months, age alone predicted 35% of variance in volume of steps per day and 34% of variance in time spent in long ambulation bouts. A combination of pre-stroke activity, discharge gait endurance and executive function predicted up to 79% of time spent in high intensity ambulation bouts at six months. No other factors at discharge were included into regression analysis at six months.

Table 5.5: Stepwise regression analysis for prediction of volume, frequency and intensity of ambulation activity at 1, 3 and 6-months following hospital discharge (transformed measures of ambulation activity)

	Predictors	R^2	R^2 Adjusted	Coefficient B (unstandardised)	95%CI for B	Coefficient β (standardised)	Significance
One month							
Volume	6MWT	0.291	0.262	0.091	0.031 – 0.151	0.540	0.004
Frequency	6MWT	0.288	0.258	0.009	0.003 – 0.016	0.536	0.005
Intensity	6MWT	0.458	0.435	0.011	0.006 – 0.016	0.677	0.000
Three months							
Volume	6MWT +	0.463	0.414	0.064	0.019 – 0.110	0.465	0.007
	PASE			0.085	0.025 – 0.144	0.465	0.007
Frequency	PASE	0.307	0.277	0.011	0.004 – 0.018	0.554	0.004
Intensity	6MWT +	0.614	0.579	0.009	0.005 – 0.013	0.604	0.000
	PASE			0.009	0.003 – 0.014	0.459	0.002
Six months							
Volume	Age	0.349	0.319	-1.125	-1.806 – - 0.445	-0.590	0.002
Frequency	Age	0.340	0.310	-0.115	-0.186 – -0.044	-0.583	0.003
Intensity	6MWT +	0.792	0.760	0.010	0.008 – 0.019	0.545	0.000
	PASE +			0.013	0.006 – 0.014	0.530	0.000
	TMTB-A			-0.009	-0.013 – -0.005	-0.458	0.000

Factors excluded at 1-month: ambulation self-efficacy, fatigue and perceived health outcome, at 3-months: age and at 6-months: nil.
CI: Confidence interval, 6MWT: Six-minute walk test, PASE: Physical activity scale for the elderly, TMTB-A: Trail making test part B time – part A time (seconds).

5.4. Discussion

This is the first study to investigate the ability of factors at discharge to predict ambulation activity outcomes within the first six months after discharge from hospital following stroke. Overall, factors at discharge were able to predict between 29% and 79% of the variance of ambulation activity at one, three and six months after discharge. This study found that different factors best predicted ambulation activity at one, three and six months. Furthermore, this varied depending on the ambulation characteristic studied, with ambulation intensity at all time points best able to be predicted from discharge factors. Gait endurance at discharge measured with the 6MWT was the best predictor of ambulation activity, particularly in the first month of returning home. After this time point, age, pre-stroke activity and executive function also predicted ambulation activity outcomes. The results of this study are consistent with previous research findings, demonstrating that ambulation activity outcomes are not easily predicted by one factor alone, but a range of demographics and clinical measures that are individual to each stroke survivor (Alzahrani et al., 2011; Fulk et al., 2010; Mudge et al., 2009).

Discharge gait endurance is able to predict the recovery of ambulation activity after hospital discharge, especially intensity. A similar relationship has been found in people with chronic stroke (Alzahrani et al., 2012; Fulk et al., 2010; Alzahrani et al., 2009; Mudge and Stott, 2009); with gait endurance identified as a significant predictor of volume of steps and time spent in low and high intensity activity (approximately 45 to 50% of variance) (Fulk et al., 2010; Mudge and Stott, 2009). In this study, gait endurance had a strong relationship with intensity of activity at all three time points and contributed to the prediction of all intensity measures. Further when considered with other factors gait endurance is still a strong predictor of outcome. This further highlights the importance of assessing gait endurance and incorporating treatments that encourage gait endurance during rehabilitation.

While gait endurance alone predicted ambulation activity at one month, other factors including pre-stroke activity, age and executive function contributed to ambulation activity observed beyond this time point. In the current study, pre-stroke activity was a significant predictor of ambulation activity at both three and six months post discharge. Higher levels of pre-stroke activity are related to better functional outcomes (Stroud et al., 2009), improved fitness (Baert et al., 2012) and healthier blood sugar and protein composition (Ricciardi et al., 2014) after stroke. Further, individuals who were active prior to stroke are more likely to feel confident with returning to activity after returning home (Ahuja et al., 2013; Barnsley et al., 2012). Also, at one month after discharge, stroke survivors may not return to all pre-stroke activities, roles and responsibilities (Roth and Lovell, 2014). However from three months after discharge, they may begin returning to activities similar to what they were doing prior to stroke onset (Kong and Lee, 2014; Roth and Lovell, 2014; Demain et al., 2006). Thus, ambulation activity beyond three months after discharge may be related to activity behaviours prior to stroke. The low levels of ambulation activity observed across the subacute and chronic phases of stroke may be the result of poor activity behaviours prior to stroke onset. Thus, perhaps there is a need for rehabilitation to also include interventions to encourage beneficial activity behaviours (e.g. step counts > 8000 to 10,000 steps per day, minimum time in long duration and high intensity ambulation for health benefits).

Age has been reported as a significant predictor of functional outcome after stroke (Veerbeek et al., 2011). In the current study, age was the strongest predictor of volume and frequency of activity at six months. Previous observation of healthy older adults has also demonstrated a reduction in daily step counts, frequency of ambulation activity bouts and ambulation intensity with increased age (Lord et al., 2011; Cavanaugh et al., 2007). Further, after stroke, it is believed that stroke recovery could begin to plateau after six months (Moore et al., 2013; Jorgensen et al., 1995). Thus in people with stroke able to walk, age-related considerations may contribute more to ambulation activity outcomes rather than post-stroke impairments and limitations at six months following hospital discharge. This would benefit from further investigation.

In the current study, executive function also contributed to the prediction of intensity of activity at six months. There are no normative values for stroke survivor performance in the trail-making test (TMTB-A), despite earlier use with stroke survivors (van de Port et al., 2006; Hochstenbach et al., 2003). However, the current sample performed worse than older adults with mild cognitive impairment (TMTB-A mean test scores = 87.9 seconds) and similar to individuals with Alzheimer's disease (TMTB-A mean test scores = 123.7 seconds) (Ashendorf et al., 2008). This suggests that the current sample had some level of executive function impairment at discharge which could have influenced their engagement in activities requiring complex cognitive processes, such as return to work, community ambulation and managing physical environments. Executive function has also been shown to improve uptake of exercise training programs and improved activity at longitudinal follow-up (Best et al., 2014). Further, impaired executive function is associated with reduced gait speed in healthy adults with non-amnestic cognitive impairment (Doi et al., 2014). As a result, the current sample may have experienced gait changes resulting from impaired executive function, affecting measures of ambulation intensity (based on step rate). Executive function impairments can result in reduced ambulation activity by a reduction in reintegration in pre-stroke lifestyles, poor retention of advice and strategies to improve activity (Best et al., 2014) or reduced gait speed and cadence (Doi et al., 2014). It would be beneficial to assess this impairment during stroke rehabilitation.

The current study also found little or no relationship with ambulation activity for discharge mood, fatigue, self-perceived health outcome and status, ambulation self-efficacy, as well as perceived stroke recovery. This finding could be due to the majority of the current sample not reporting any impairment or difficulty within these factors. Also, though the study identified significant predictors of ambulation activity across the first six months of returning home, factors could not predict all variance in these outcomes. Thus, investigation of the effect of other factors on ambulation outcomes is required. Qualitative investigation of how factors influence stroke survivors' choices to return to walking related activities after hospital discharge, and the barriers and facilitators encountered during this process would also be useful.

It is important to consider the limitations of the current study. The study had a small sample (n=36) and high rate of dropouts (22%) by six months. However, there were no significant differences between those included and excluded in the final analysis, and despite the low numbers, significant correlations and prediction models were found. The study targeted stroke survivors who were mostly able to walk at discharge who returned home, thus findings may not be generalizable to survivors who are functionally dependent. Also, though definitions of ambulation bouts and intensity were used in earlier studies of stroke survivors, the measure of activity intensity has not yet been validated in people with stroke and is needed. Also, the influence of volume and type of therapy on outcomes was not investigated in this study. Though there were no differences in scores for individuals who received therapy after discharge and those who did not receive therapy on post-hoc testing, the influence of volume and type of therapy after hospital discharge on ambulation activity outcomes would be useful.

5.5. Conclusions

Gait endurance appears to be a useful predictor of ambulation activity in stroke survivors, particularly in the first month post hospital discharge. Other factors such as age, pre-stroke activity and executive function appear to be important for predicting ambulation activity after this time point. Assessment of executive function and interventions targeting gait endurance and positive activity behaviours during post-stroke rehabilitation may contribute to improved ambulation activity outcomes after hospital discharge. Follow-up of stroke survivors at six months after hospital discharge may be warranted, as discharge measures of post-stroke impairments and activity limitations alone do not contribute to outcomes. Thus after six months, other factors are likely to influence recovery.

Chapter 6

Study four: Exploring community ambulation after stroke – longitudinal measurement of community ambulation following hospital discharge.

Community ambulation is regarded a very important goal during rehabilitation post-stroke. Regardless, stroke survivors report low levels of ambulation within their community, and high levels of dissatisfaction with outcomes in this goal. Thus far, community ambulation after stroke has only been measured through self-report. Lack of accurate measurement tools has limited understanding of community ambulation and how stroke survivors recover this after hospital discharge. The purpose of this chapter is to objectively measure and characterise community ambulation after stroke using accurate tools assessed in Chapter 3, and determine how these change over the first six months following hospital discharge.

Abstract

Purpose: To characterise community ambulation and determine if characteristics of community ambulation change across the first six months following discharge from hospital after stroke.

Methods: 34 subacute stroke survivors (mean age 71.6 SD 13.8 years, 70.6% male) were assessed at 1, 3 and 6-months after hospital discharge. Community ambulation was measured over four days using the ActivPAL™ accelerometer, Garmin Forerunner 910XT GPS and activity diary. Volume (daily step count, time spent in the community, time spent lying/sitting, standing, walking and upright), frequency (total number of trips, number of bouts and volume of time spent in short, medium, long duration bouts) and intensity (number of bouts and time spent at low, moderate, high intensity bouts) of ambulation bouts were calculated. Linear mixed effects modelling determined community ambulation changes over time. Proportion of trips, time spent in the community and steps per day per trip type (work, social, recreation, essential and religious) were calculated. Cross-tabulation was used to determine if number of trip types changed over the six months.

Results: At one-month post discharge, participants took on average one trip per day, spending137 (SD 113) minutes in their community, taking on average 1859 (SD 1880) steps and walking 21.3 (SD 20.1) minutes per day. Most community ambulation was spread across long duration (11.3 to 14.1 minutes per day) and moderate intensity (14.0 to 16.1 minutes per day) ambulation bouts. Least time was spent in short and low intensity ambulation bouts. When adjusted for age and discharge gait speed, there was no change in community ambulation characteristics except for number of and time spent in long ambulation bouts over time ($p < 0.027$). Most trips into the community were for essential roles and errands. There was no significant change in trip type across 1, 3 and 6-months ($p > 0.302$).

Conclusions: Stroke survivors access their community regularly following hospital discharge. Total volume and intensity of community ambulation after stroke remains unchanged over the first six months following hospital discharge, though long duration ambulation bouts appear to increase. Review of stroke survivors at six months following hospital discharge is required to assess community ambulation outcomes, as this is when change may first be observed.

6.1. Introduction

Returning to independent ambulation outside the home and yard, or community ambulation, is regularly reported as a key goal by a majority of stroke survivors (Lord et al. 2004). However despite its importance, only 32-66% of stroke survivors achieve this following rehabilitation (Viosca et al. 2005, Lord et al. 2004, Pound et al. 1998, Perry et al. 1995). Individuals with chronic stroke report a reduced frequency of community trips and walking related activities within the community when compared to healthy adults (Robinson et al., 2011b). Further, many stroke survivors report dissatisfaction in this outcome (Robinson et al. 2011a), with high scores on clinical measures of gait and function not ensuring successful community ambulation outcomes after hospital discharge (Robinson et al., 2011b; Fulk et al. 2010; Lord et al. 2004). Community ambulation may require higher level cognitive processing and functional ability to manage additional tasks and complex environments (Elbers et al., 2013; Robinson et al., 2011b; Lord et al., 2010). It is regarded a vital precursor to successful community re-integration – the end-point of rehabilitation following stroke (Lord and Rochester, 2005). Any limitations in this outcome could contribute to further disability and poor health outcomes (Leach et al., 2011; Rand et al., 2010; Jacobs et al., 2008; Lord et al., 2004).

To date, community ambulation after stroke has been measured most often through self-report diaries and questionnaires (Bijleveld-Uitman et al., 2013; Robinson et al., 2011a; Robinson et al., 2011b; Lord et al., 2004). However self-report is limited by accurate recall (Murphy, 2009). Furthermore self-report tools are unable to provide objective measures of community ambulation; such as step count, time spent walking, energy expenditure and characteristics of ambulation (e.g. ambulation bouts). Recently, devices such as accelerometers (Mudge et al., 2007) and global positioning systems (Jayaraman et al., 2014; Evans et al., 2012; McCluskey et al., 2012; Kerr et al., 2012; Shoval et al., 2008) have shown potential for measurement of free-living ambulation in individuals with mobility limitations. Accelerometers have been used with stroke survivors to measure physical activity through step count (Roos et al., 2012; Mudge and Stott, 2009; Michael and Macko, 2007; Michael et al., 2005; Shaughnessy et al., 2005), activity duration (Askim et al., 2013; Alzahrani et al., 2011) and energy expenditure (Moore et al., 2013; Manns and Haennel, 2012; Moore et al., 2012). Global position systems have been used in groups with mobility limitations, including stroke, to investigate life space, components of outdoor mobility (Jayaraman et al., 2014; Kerr et al., 2012; Le Faucheur et al., 2008) and frequency and purpose of community trips (Evans et al., 2012; McCluskey et al., 2012; Jayaraman et al., 2014). Chapter three of this thesis revealed that in combination, accelerometers and global positioning devices allow for the separation of ambulation that occurs outside the home and yard from total daily ambulation activity.

Longitudinal measurement of community ambulation in subacute stroke is important, as this period of recovery is often associated with changes in stroke related impairments (Jang, 2010; Van Wijk et al., 2006), activity limitations (Jang, 2010; Patterson et al., 2010; Buurke et al., 2008; van de Port et al., 2006; Paolucci et al., 2001), personal factors, perceptions, priorities and attitudes (Eilertsen et al., 2010; Carod-Artal et al., 2009; Stein et al., 2003). These can lead to difficulty with or changes in characteristics of ambulation and behaviours within the community, such as trip duration, steps taken, frequency of trips into the community, locations visited and physical environmental dimensions encountered (Robinson et al., 2013; Robinson et al., 2011b; Fulk et al., 2010; Lord et al., 2004). In groups with mobility difficulty, changes in the ability to participate in community activities (including community ambulation) can lead to increased avoidance (Shumway-cook et al. 2002), which can contribute to further decline in community ambulation. Survivors of chronic stroke who report avoiding physical environments within the community report a reduced frequency of trips and walking related activities into the community than those who do not avoid their physical environments (Robinson et al., 2013). This suggests that difficulty with community ambulation may lead to further avoidance, reduction in community ambulation and thus increased disability after stroke. However to date, the recovery of community ambulation has not been measured from hospital discharge after stroke. Measuring this will enable a better understanding of the process of recovery of community ambulation after stroke, especially across the phase of their recovery where greatest change is demonstrated.

Thus the aims of this study were to 1) characterise community ambulation across 1, 3 and 6-months following hospital discharge after stroke and 2) determine if characteristics of and purpose for community ambulation changed over the first six months following hospital discharge. It was hypothesised that volume, frequency and intensity of ambulation in the community would improve over the first six months following hospital discharge. Further, it was hypothesised that stroke survivors would engage in more community ambulation for social and recreational purposes over time.

6.2. Methods

This study followed a prospective longitudinal observational design. Participants were recruited within one week of discharge, and followed up at one month, three months and six months after their discharge date. Institutional ethics committees at The Prince Charles Hospital and University of Queensland approved the study (see Appendices 3 and 4). This study was conducted in accordance with the Declaration of Helsinki.

6.2.1. Participants

A sample of 42 stroke survivors was recruited from acute stroke and rehabilitation units at The Prince Charles Hospital in Brisbane, Australia. Participants were included if they (1) presented with a stroke within the past 4 months, (2) aged > 18 years and (3) were discharged into the community to live alone or with a carer or spouse.

Individuals were excluded if they: (1) had a diagnosis of another neurological condition (e.g. Parkinson's disease) or co-morbidities that limited ambulation prior to stroke, or during their hospital admission, (2) had any unstable medical condition, (3) chest pain, heart attacks, angioplasty or heart surgery in the previous three months, (4) skin allergies to adhesive tape, (5) were discharged to a residential aged care facility, (6) moderate to severe expressive of receptive communication difficulties (based on speech therapist assessment) or (7) scored < 24/30 on the Mini Mental State Examination (MMSE) (Folstein et al., 1975).

6.2.2. Procedures

Potential participants were identified through regular screening of ward lists, attendance at weekly acute stroke unit meetings and discussion with treating therapists. Eligible participants were provided with written and verbal information on the study and allowed sufficient time to discuss the study with family, carers, and treating health professionals. All participants provided signed informed consent.

Participants attended four assessments. These occurred at: (1) one week prior to discharge from hospital, (2) one month following discharge, (3) three months following discharge and (4) six months following discharge. At the discharge assessment, general clinical information, demographics and measures of gait and function were collected from medical records and the participant.

Participants were contacted by phone to attend a follow-up appointment at one, three and six months following hospital discharge. At each follow-up appointment, participants were fitted with an accelerometer, the ActivPAL™. They were also provided with a Garmin GPS device and activity diary (see Appendix 2). The ActivPAL™ was worn continuously for a four-day period. The GPS was switched on by the participant at the commencement of any trip 'outside the home and yard' (Lord et al. 2004), and switched off whenever participants returned home. In addition, participants also documented details of the time spent in the community, location and purpose of community trips via the activity diary (see Appendix 2). A four-day measurement period was deemed sufficient as this has been reported as sufficient to capture usual activity patterns (Murphy, 2009). Following the four-day measurement period, an investigator telephoned participants to arrange a suitable time to pick-up the devices and diary.

ActivPAL™

The ActivPAL™ professional physical activity monitor (PAL Technologies Ltd©, Glasgow, UK) is a small (53 x 35 x 7mm) and light (21g) uniaxial accelerometer. The device provides measures step counts, activity duration (sitting/lying, standing and walking), postural transitions and energy expenditure at 15 second epochs. This device was deemed valid and reliable in a sample of chronic stroke survivors during both indoor and outdoor ambulation, and at various gait speeds above 0.42m/s (see Chapter 3). The ActivPAL™ was encased in a water-proof covering and then affixed to the skin in the middle of the front thigh with a low irritant sticker (hypafix) to allow the device to be worn for the full four-day period.

Garmin Forerunner 910XT

The Garmin Forerunner 910XT (Garmin Ltd., Olathe, Kan) is a GPS enabled sports watch. It measures 54mm x 61mm x 15mm in size and weighs approximately 72g (see figure 6.1). The Garmin Forerunner 910XT has a battery life of up to 20 hours and records at a frequency of 2.4 GHz. The device measures location, distance, pace, elevation and calorie counts. The Garmin GPS system (Garmin Forerunner 405CX) was deemed valid and reliable for location and duration of trips in a sample of chronic stroke survivors (see Chapter 3). The earlier GPS device (Garmin Forerunner 405CX) assessed in study one of this thesis was replaced by the Garmin Forerunner 910XT as this device was deemed easier to use (i.e. no touch sensitive bezel, larger buttons and screen) (see figure 3.1). However, operating systems between the two devices were the same. In the current study, participants wore the device on the wrist of their affected arm, to ensure easy manipulation of the device. Data and graphs obtained from the Garminconnect website (www.garminconnect.com.au) provided overall trip summaries which were used to identify locations and time spent out of the home and yard.

Figure 6.1: The Garmin Forerunner 910XT.

Activity diary

In addition to the ActivPAL™ and Garmin Forerunner 910XT, participants completed a diary that detailed trip time, location, estimated time spent walking, transport choice, purpose of community trips and any issues encountered during trips. The diary was used during GPS and accelerometer data cleaning and analysis and to obtain purpose of trips into the community (see Appendix 2).

Participants were provided with written information about both devices, warnings about any potential skin irritation from hypafix taping and a contact number if any issues arose during the four-day measurement period.

6.2.3. Measures of community ambulation

Measures of community ambulation were obtained using a combination of ActivPAL^{TM} accelerometer measures of ambulation with maps and summary data obtained from the Garminconnect website and the activity diary. Garminconnect and activity diary data were consulted to determine start and stop times for each community trip, locations visited and purpose of trips. These were then entered into an Excel spreadsheet used by a MATLAB program to analyse subsets of the ActivPAL^{TM} data respective to each trip taken into the community. Thus community ambulation measures were isolated from total daily ambulation accelerometer measures.

Measures of ambulation within the community included volume, frequency and intensity of ambulation. These were chosen, as no guidelines currently exist for characterising accelerometer and GPS measures of community ambulation after stroke. Further, these measures have previously been used to characterise ambulation activity in older adults (Lord et al., 2011) as well as individuals with subacute (Manns & Baldwin, 2009; see Chapter 4 in this thesis) and chronic stroke (Roos et al., 2012). An *'ambulation bout'* is a measurement unit used to characterise ambulation (Lord et al., 2011; Cavanaugh et al., 2007). In this study, the ambulation bout is defined as any 15-second data interval with at least 2 steps. All activity bout definitions for frequency and intensity were based on those previously used in stroke (Roos et al., 2012; Manns & Baldwin et al., 2009).

Volume of community ambulation was determined using ActivPAL^{TM} measures of total number of steps and total time in minutes spent sitting/lying, standing, walking and upright in the community per day. In addition, total time spent out in the community per day was collected.

Frequency of community ambulation was determined using total number of ambulation bouts and total time in minutes taken at each ambulation bout duration (Manns & Baldwin, 2009). Bout durations were defined as – short: any bout with < 40 steps; medium: any bout with 41-300 steps; and long: any bout with > 300 steps (Roos et al. 2012). The number of trips per day into the community was also measured (Robinson et al., 2011b).

Intensity of ambulation within the community was determined based on the number of ambulation activity bouts of low, moderate and high intensity as well as total time in minutes spent at each intensity (Manns & Baldwin, 2009). Bout intensity was defined as – low: any bout with a cadence of < 30 steps/minute; moderate: any bout with a cadence of 30-80 steps/minute; and high: any bout with a cadence of > 80 steps/minute (Manns & Baldwin, 2009).

Trip type was defined based on participant reported purpose for each community trip. Purpose of trips obtained from activity diaries were categorised based on the participation section of the Stroke Impact Scale (version 3.0). The participation domain of the Stroke Impact Scale has often been used as a measure of participation after stroke (Danielsson et al., 2011; Lord and Rochester, 2005). The eight categories within this domain were grouped to give a final set of five trip types. These included: 1) work, 2) social, 3) recreation (combination of quiet and active recreation), 4) essential errands and roles (combination of family and friend roles and additional essential errands such as shopping trips and medical appointments) and 5) religious and spiritual. Questions relating to control of life (question 7), or ability to help others (question 8) were not deemed a 'purpose' to go out into the community alone and were thus excluded from the final grouping. Trips reported by stroke survivors that did not clearly fit one category (such as those with multiple purpose) were discussed within the primary research team. Consensus on final categorisation was reached based on further perusal of GPS maps and accelerometer data.

6.2.4. Data Analysis

Data were screened for normality using Shapiro-wilk statistics, histograms and normality plots. ANOVA and Mann-Whitney U tests were completed to identify any differences in demographics and functional measures between participants included and excluded in the final analysis. All measures of community ambulation were positively skewed, and were thus square root transformed.

Means, standard deviation and range for all measures of volume, frequency and intensity were calculated to characterise community ambulation at one, three and six months following hospital discharge. Linear mixed effects modelling was used to test for differences in measures across the three time points. Measures of community ambulation were adjusted for age and discharge gait speed. Age has been recognised as a significant predictor of functional recovery after stroke (Bijleveld-Uitman et al., 2013; Veerbeek et al., 2011; Mackay-Lyons and Makrides, 2002), and was thus deemed a potential confounding factor in recovery of community ambulation over time. Gait speed has also been identified as a predictor of activity and community ambulation in individuals with chronic stroke (Fulk et al., 2008; Lord et al., 2004) and thus was considered a potential contributor to changes in community ambulation in the current study.

Proportion of trips taken, total time in the community and total steps in the community for each trip type across the three time points was calculated. Cross-tabulation and Kruskal-wallis testing was used to check for change in frequency of community trips by trip type. Significance was set for $p < 0.05$. SPSS 21.0 was used for all statistical calculations.

6.3. Results

6.3.1. Participants

A total of forty-two participants were recruited from 225 potential stroke survivors at discharge from stroke rehabilitation and acute stroke units from 14th February 2012 to the 8th February 2014. Reasons for exclusion included dependence with mobility on discharge (9%), refusal to participate (7.6%), discharge to residential aged care facilities (7.1%), cardiac surgery/events within three months of hospital discharge (5.7%) and cognitive impairment (5.2%). Other reasons for exclusion included participant discharge prior to recruitment, absence of imaging to confirm diagnosis of stroke, pre-existing conditions affecting community ambulation prior to stroke (arthritis, Parkinson's disease), an inability to provide informed consent (e.g. non-English speaking background), discharge to a location outside of Brisbane, moderate to severe aphasia affecting assessment and palliation/death (see figure 6.2).

From recruitment at hospital discharge to the first community ambulation measurement follow-up, three participants withdrew from the study, two participants could not be contacted, two participants had no GPS and diary recordings at all three time points and one participant did not want to wear devices. Thus thirty-four participants were included in the final analysis (see figure 6.2).

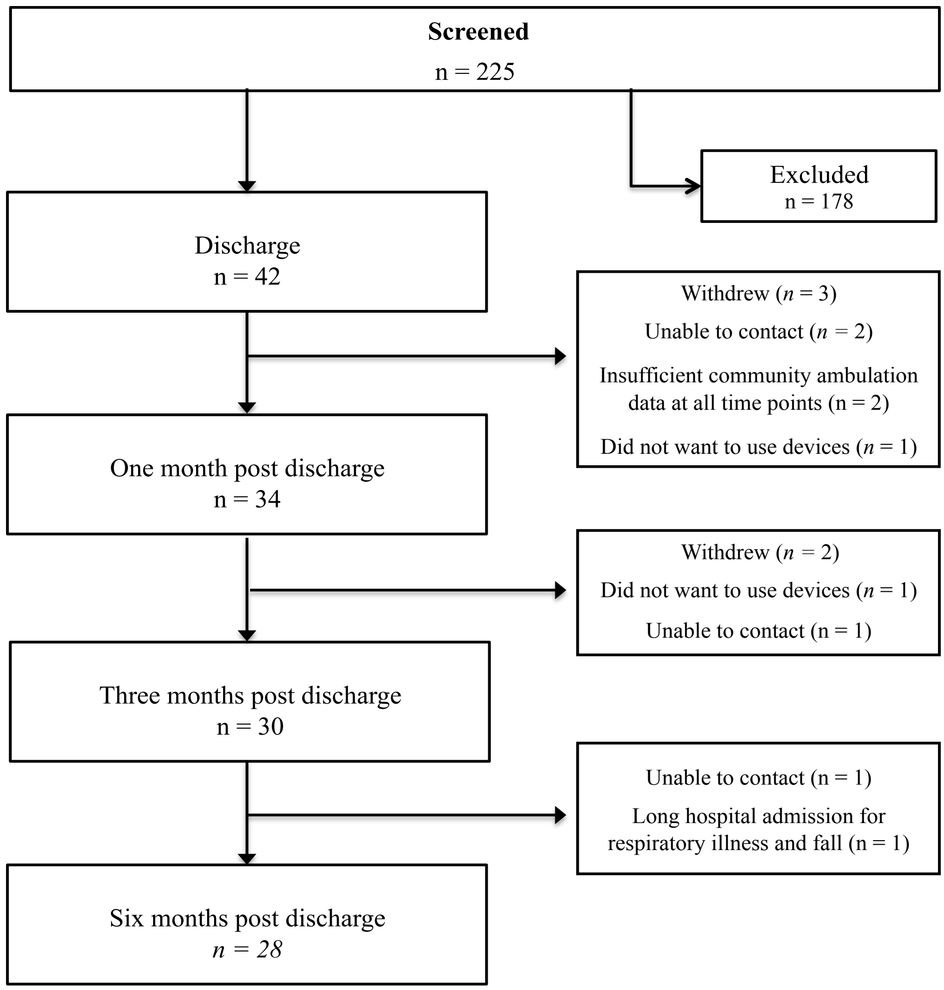

Figure 6.2: Flow of participants through study.

From the one month time point, two participants declined further participation, two participants could not be contacted, one participant could not attend an assessment due to hospital admission and one participant did not want to wear devices. There were no differences between participants included and excluded from the initial measurement time point ($p \geq 0.067$) except for number of days in rehabilitation at three months. Individuals who were lost to follow up at three months had a longer rehabilitation stay (53 SD 51 days) than those included (21 SD 15 days) ($F = 7.847$, $p = 0.009$). Purpose of trip was not reported for 5.8% of total ambulation trips recorded across the three time points and 14% of total GPS/diary recordings of community ambulation were missing across all time points.

Participant characteristics are available in table 6.1. Participants included in the final analysis (n = 34) had a mean age of 71.6 (SD 13.8) years and 70.6% were male. A majority of stroke survivors (58.8%) presented with right-sided hemiplegia, with 20.6% having no hemiplegia, 17.6% with left-sided hemiplegia and 2.9 % with bilateral hemiplegia. Approximately half of participants received therapy following discharge. Therapy mostly included physiotherapy (72% of the sample), but some participants also received speech therapy only (10.5%) and occupational therapy only (5.3%) after hospital discharge. Nine participants demonstrated aphasia during their inpatient stay. Discharge gait speed and gait endurance indicated that most of the sample met criteria for independent community ambulation (Perry et al., 1995).

Table 6.1: Sample Characteristics

	1 Month n = 34	**3 Months** n = 30	**6 Months** n= 28
Demographics			
Age (years)	71.6 (13.8)	72.3 (13.3)	71.5 (13.4)
Rehab stay (days)	23.6 (21.3)	20.6 (14.6)	20.7 (15.1)
Gender (n, % males)	24, 70.6	22, 73.3	21, 75.0
Hemiplegia (n, %)			
Nil	7, 20.6	6, 20.0	6, 21.4
Left	6, 17.6	6, 20.0	5, 17.9
Right	20, 58.8	17, 56.7	16, 57.1
Bilateral	1, 2.9	1, 3.3	1, 3.6
Aphasia (n, % with)	9, 26.5	7, 23.3	6, 21.4
Carer (n, % with)	16, 47.1	14, 46.7	14, 50.0
Employment (n, %)	0, 0%	2, 17%	4, 33%
DC Therapy (n, %)			
Nil	16, 47.1	14, 46.7	14, 50.0
RDTU	4, 11.8	3, 10.0	3, 10.7
CBRT/TCP	13, 38.3	12, 40.0	10, 35.7
RESI-TCP	1, 2.9	1, 3.3	1, 3.6
Measures of walking capacity			
10MTW (m/s)	1.0 (0.4)	1.02 (0.4)	1.02 (0.4)
6MWT (m)	334.7 (139.7)	333.3 (142.2)	332.3 (145.3)

Employment: n, % out of 12 participants working prior to stroke who returned to work post-stroke, DC Therapy: Therapy received following discharge, RDTU: Rehabilitation day therapy unit, CBRT: Community based rehabilitation therapy, TCP: Transitional care program, Resi-TCP: Residential transitional care program, 10MTW: Timed 10metre walk (comfortable pace), 6MWT: 6-minute walk test.

6.3.2 Characteristics of community ambulation

Participants recorded a total of 325 trips across the three time points. All participants ambulated within the community once across the four-day measurement period except for one participant at one month (see figure 6.3). Approximately 30-40% of stroke survivors ambulated within their community every day (4 of 4 days) during the measurement period at one, three and six months. Volume, frequency and intensity of daily community ambulation across one, three and six months are reported in Table 6.2.

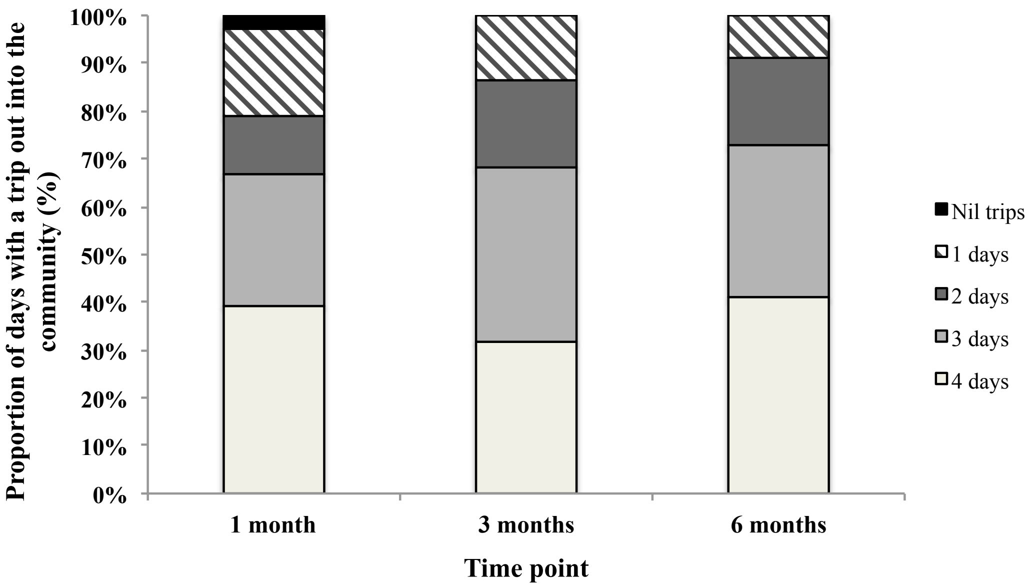

Figure 6.3: Proportion of days with a trip out into the community at one, three and six months

Table 6.2: Mean (SD) and range of volume, frequency and intensity of community ambulation per day at 1, 3 and 6-months following hospital discharge (raw scores, untransformed and unadjusted)

	1-month		**3-months**		**6-months**	
	mean (SD)	**range**	**mean (SD)**	**range**	**mean (SD)**	**range**
Volume						
Step count, counts	1859 (1880)	0 - 6361	1700 (1380)	115 - 4867	2298 (2605)	0 – 10495
Time spent out in community, minutes	137.0 (113.2)	0.0 – 465.6	120.0 (66.9)	13.6 – 297.9	176.9 (148.8)	0.0 – 614.7
Time spent sitting/lying, minutes	84.8 (84.1)	0.0 – 346.1	70.9 (43.1)	0.4 – 177.1	115.6 (116.8)	0.0 – 442.0
Time spent standing, minutes	30.9 (29.2)	0.0 – 122.5	29.0 (21.7)	2.1 – 79.0	35.7 (28.2)	0.0 – 114.8
Time spent walking, minutes	21.3 (20.1)	0.0 – 65.8	20.1 (14.7)	1.8 – 51.4	25.5 (26.6)	0 – 110.0
Time spent upright, minutes	52.2 (45.6)	0.0 – 188.3	49.1 (31.5)	8.3 – 120.8	61.2 (50.0)	0.0 – 172.7
Frequency						
Total number of trips, counts	1.2 (0.8)	0.0 – 3.0	1.1 (0.7)	0.3 – 2.8	1.1 (0.6)	0.3 – 2.3
Number of bouts, counts	23.8 (20.9)	0.0 – 71.0	24.2 (17.6)	1.8 – 67.0	27.8 (22.6)	0.0 – 77.8
Number of short bouts, counts	16.3 (15.4)	0.0 – 52.5	16.8 (13.6)	1.0 – 43.8	19.0 (16.2)	0.0 – 57.6
Number of medium bouts, counts	6.3 (5.6)	0.0 – 25.6	6.4 (5.5)	0.0 – 23.7	7.3 (6.9)	0.0 – 29.0
Number of long bouts, counts *	1.1 (1.5)	0.0 – 5.8	1.0 (1.2)	0.0 – 4.8	1.5 (1.8)	0.0 – 7.0
Duration of time in short bouts, minutes	7.4 (7.1)	0.0 – 26.0	7.8 (6.6)	0.6 – 23.7	8.5 (7.3)	0.0 – 26.8
Duration of time in medium bouts, minutes	10.6 (9.6)	0.0 – 41.8	11.0 (9.3)	0.0 – 42.1	11.9 (12.2)	0.0 – 56.4
Duration of time in long bouts, minutes *	11.3 (14.9)	0.0 – 48.0	9.5 (11.2)	0.0 – 36.4	14.1 (21.3)	0.0 – 84.4
Intensity						
Number of low intensity bouts, counts	10.1 (9.4)	0.0 – 33.3	11.2 (10.5)	0.8 – 39.8	11.1 (9.9)	0.0 – 71.6
Number of moderate intensity bouts, counts	11.9 (11.2)	0.0 – 41.4	11.3 (8.7)	0.3 – 37.0	14.3 (13.2)	0.0 – 50.5
Number of high intensity bouts, counts	1.7 (1.9)	0.0 – 7.0	1.7 (1.9)	0.0 – 6.5	2.4 (2.6)	0.0 – 8.8
Duration of time in low intensity bouts, minutes	4.9 (4.6)	0.0 – 14.3	5.9 (6.1)	0.4 – 24.7	5.3 (4.7)	0.0 – 18.2
Duration of time in moderate intensity bouts, minutes	14.0 (12.9)	0.0 – 53.1	14.7 (12.2)	0.2 – 46.2	16.1 (15.9)	0.0 – 71.6
Duration of time in high intensity, minutes	10.3 (13.8)	0.0 – 41.0	7.8 (10.7)	0.0 – 37.6	13.2 (21.2)	0.0 – 80.8

* indicates that time has a significant effect on change in measure of community ambulation over one, three and six months when adjusted for age and discharge gait speed ($p < 0.05$).

Volume

Participants took around 1700 to 2300 steps per day in the community across one, three and six months following hospital discharge. Daily step counts ranged from 0 to 10,495 steps across the three time points. Participants spent on average 2-3 hours per day out in the community (range between 0 and 10 hours per day across the three time points). Most time in the community was spent in sitting positions (1-2 hours per day), with limited change in the proportion of time each day in each of sit/lying, standing and walking positions over time (see figures 6.4 and 6.5). Participants spent 20-25 minutes walking in the community per day (ranging from 0-2 hours per day), and were upright for approximately one hour (see figure 6.5).

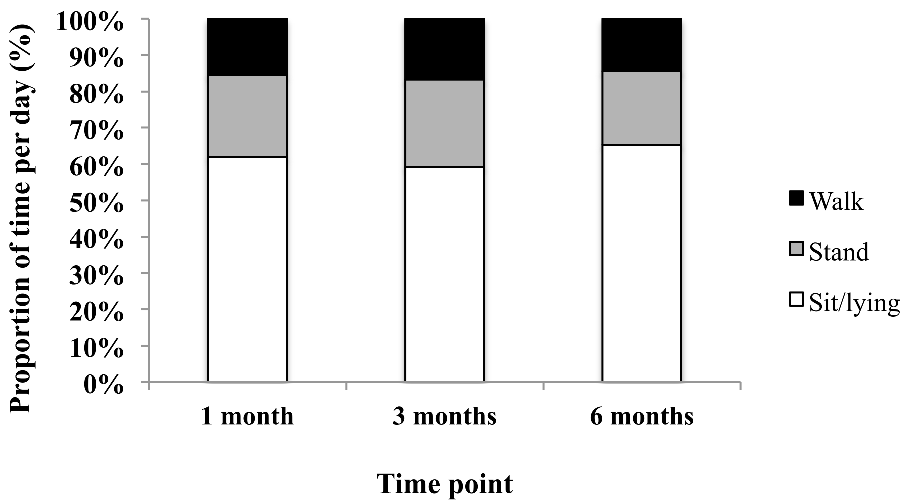

Figure 6.4: Proportion of time in the community in sit/lying, standing and walking positions

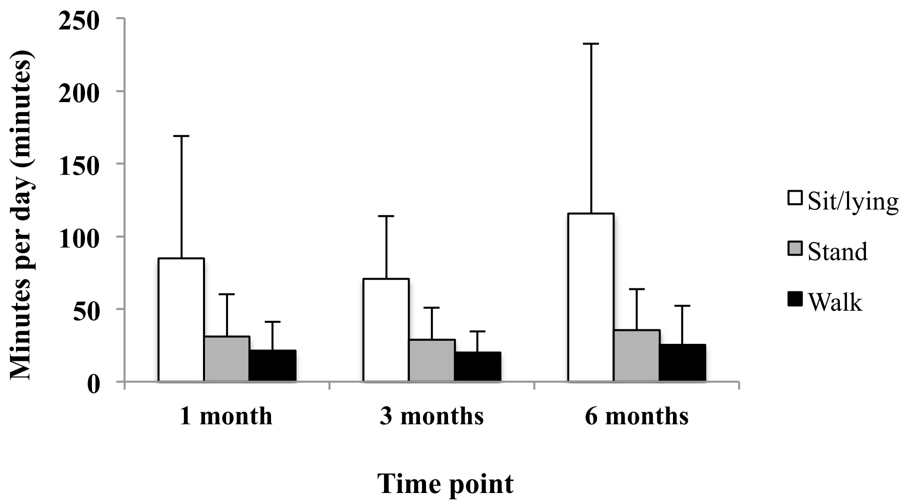

Figure 6.5: Time spent per day in the community in sit/lying, standing and walking positions

Frequency

Participants took on average, one trip into the community per day. Community ambulation was spread across 23 to 28 ambulation bouts, with a daily range of 0 to 78 bouts across one, three and six months. Short ambulation bouts (< 40 steps) were most frequent at all three time points (see figure 6.6). However, most time was spent in long ambulation bouts (>300 steps) at one and six months and in medium ambulation bouts (40-300 steps) at three months (see figure 6.7).

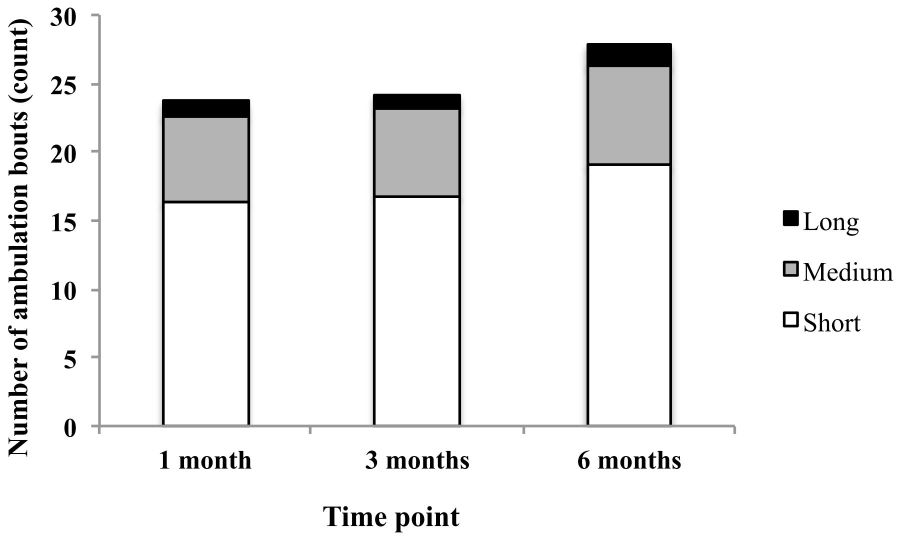

Figure 6.6: Number of short (<40 steps), medium (40-300 steps) and long (>300 steps) ambulation bouts at 1, 3 and 6-months after hospital discharge.

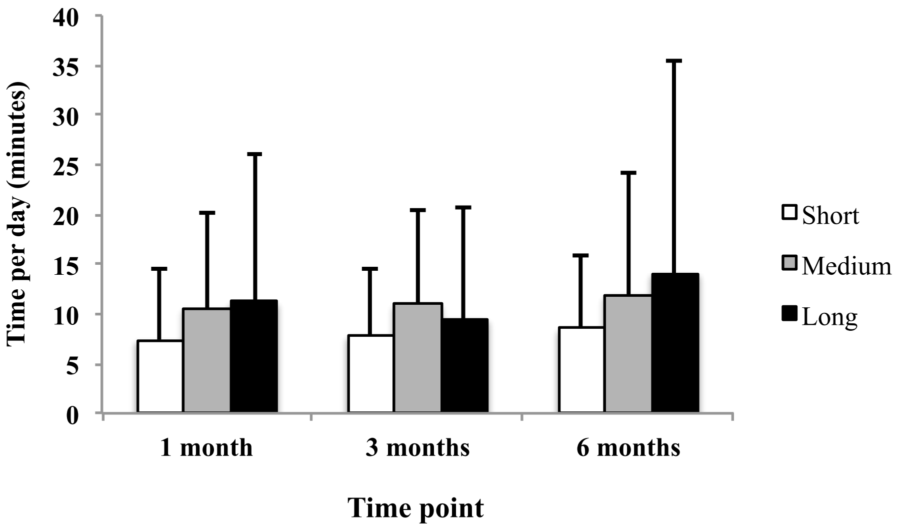

Figure 6.7: Total time per day spent in short (<40 steps), medium (40-300 steps) and long (>300 steps) ambulation bouts at 1, 3 and 6-months after hospital discharge.

Intensity

Most ambulation bouts and time walking (14-16 minutes per day) in the community were moderate (30-80 steps/minute) in intensity (see figures 6.8, 6.9 and see table 6.2). Least time (approximately five minutes) was spent in low intensity community ambulation (< 30 steps/minute), despite similar numbers of ambulation bouts per day as moderate intensity ambulation. Only 1-2 bouts per day were high intensity (>80 steps/minute) at all time points. Daily time spent in high intensity community ambulation ranged from 7.8 to13.2 minutes per day.

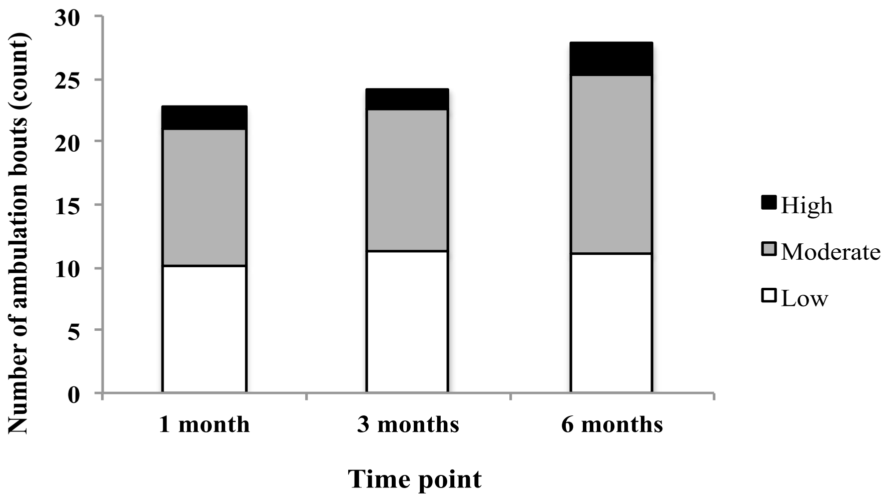

Figure 6.8: Number of low (< 30 steps/minute), moderate (30-80 steps/minute) and high (>80 steps/minute) intensity ambulation bouts at 1, 3 and 6-months after hospital discharge.

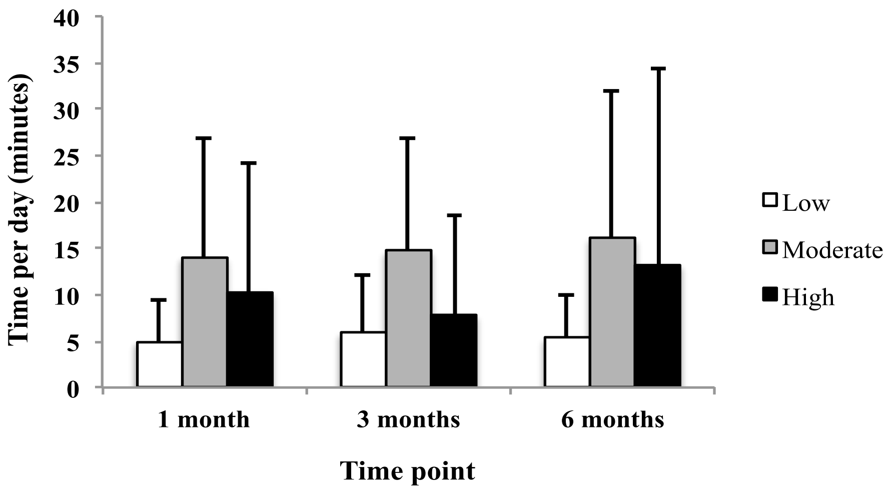

Figure 6.9: Total time per day spent in low (< 30 steps/minute), moderate (30-80 steps/minute) and high (>80 steps/minute) intensity ambulation bouts at 1, 3 and 6-months after hospital discharge.

Characteristics of ambulation trips by trip type

Figure 6.9 displays the proportion of trips taken for each trip type. Most trips and time spent in the community were associated with essential roles and errands at one, three and six months following hospital discharge (see figures 6.10 and 6.11). At one month, most steps were also taken for essential roles and errands (see figure 6.12). However, by three months, most steps were taken during recreational activities (45.5% at three months and 46.8% at six months), with proportion of time and steps taken for essential errands and tasks dropping by around 15% at six months (see figures 6.11 and 6.12). Number of trips and time spent out in the community for the purpose of work increased at six months only, with stroke survivors engaging in no work related trips at three months. Stroke survivors demonstrated a decreased proportion of trips, time and steps in social trips over time, but this was likely due to increases in other trip types. There also appeared to be a minimal change in the trips for the purpose of religious and spiritual practices (< 5%).

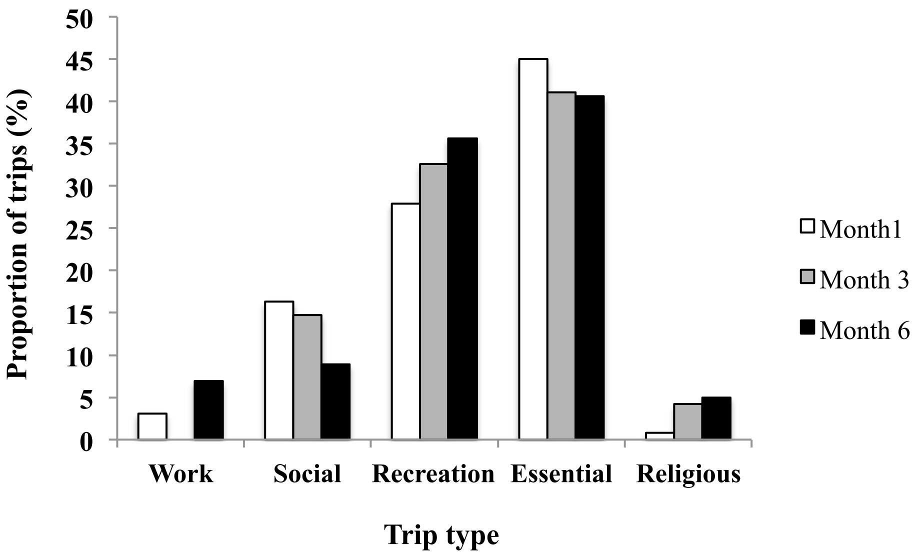

Figure 6.10: Proportion of trips taken for each purpose at 1, 3 and 6-months.

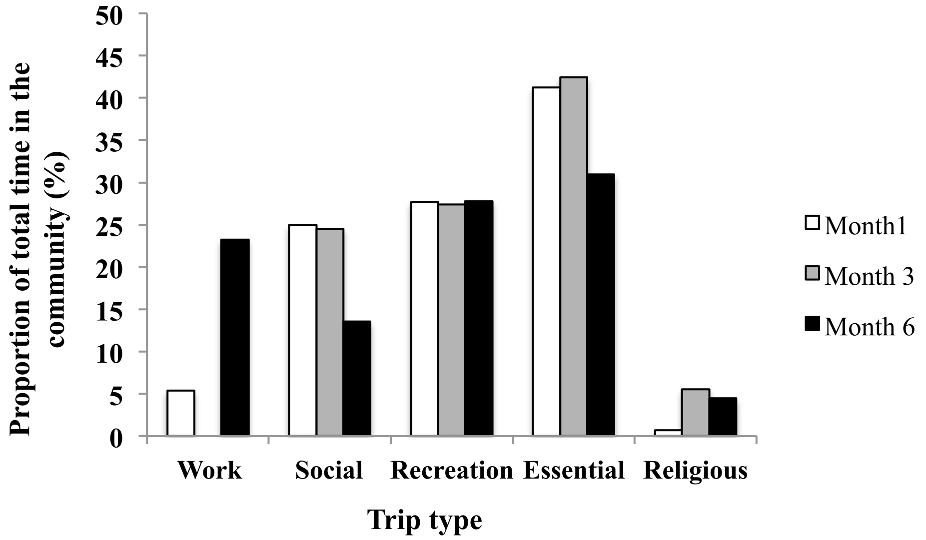

Figure 6.11: Proportion of time spent in the community for each trip type at 1, 3 and 6-months.

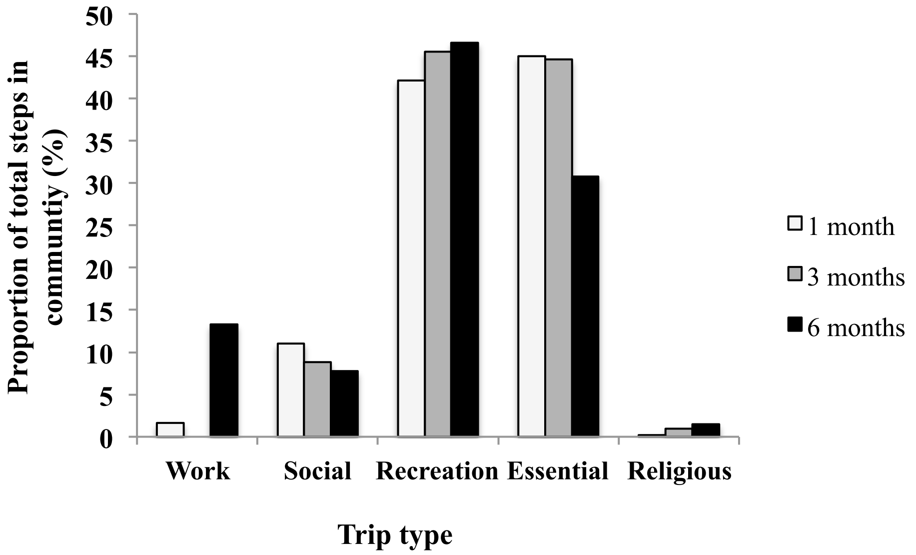

Figure 6.12: Proportion of steps taken in the community for each trip type.

6.3.3. Changes in community ambulation across one, three and six months

Changes in community ambulation over the three time points adjusted for age and discharge gait speed are presented in Table 6.3. There were no changes in volume and intensity of community ambulation across one, three and six months following hospital discharge (see table 6.3). Frequency of community ambulation changed through an increased frequency of long ambulation bouts and time spent in long ambulation bouts at six months following hospital discharge (see table 6.3). There was also a trend towards an increase in total time spent in medium duration ambulation bouts over the six months. The number of bouts and total time spent in short ambulation bouts did not demonstrate any change over time.

Age had a significant effect on some measures of community ambulation (*volume:* time spent in the community, sitting, standing, and upright; *frequency:* time and frequency of short duration bouts; *intensity:* time and frequency of low intensity, time spent in high intensity ambulation). However, it did not influence change observed in time and frequency of medium and long duration ambulation bouts over time. The frequency of community trips for each trip type did not change over the six months ($p > 0.302$).

Table 6.3: Changes in community ambulation across 1, 3 and 6-months, adjusted for age and gait speed at discharge from hospital (values are transformed and adjusted for age and discharge gait speed)

		Month 1 to month 3			**Month 1 to month 6**		
	Overall change (p-value)	**Mean change**	**95% confidence interval**	**p-value [a]**	**Mean change**	**95% confidence interval**	**p-value [a]**
Volume							
Step count	0.140	19.1	-78.7 to 116.8	0.688	116.0	1.2 to 230.7	0.048
Time spent out in community	0.534	11.3	-14.2 to 36.8	0.366	12.7	-27.9 to 53.3	0.524
Time spent sitting/lying	0.639	10.4	-12.7 to 33.5	0.353	-0.5	-39.9 to 38.8	0.978
Time spent standing	0.544	4.6	-12.9 to 22.2	0.590	9.5	-8.6 to 27.7	0.290
Time spent walking	0.146	1.8	-8.9 to 12.5	0.731	12.7	0.0 to 25.3	0.050
Time spent upright	0.351	4.0	-14.7 to 22.7	0.664	15.6	-6.1 to 37.2	0.151
Frequency							
Total number of trips	0.820	0.6	-1.5 to 2.7	0.583	0.3	-1.4 to 2.0	0.686
Number of bouts	0.365	8.2	-6.2 to 22.5	0.247	8.0	-8.4 to 24.4	0.323
Number of short bouts	0.481	7.1	-5.7 to 20.0	0.262	4.2	-10.1 to 18.4	0.552
Number of medium bouts	0.140	4.9	-3.6 to 13.4	0.245	8.4	-1.1 to 17.9	0.080
Number of long bouts *	0.013	-0.2	-3.6 to 3.3	0.914	4.7	1.7 to 7.7	0.003
Duration of time in short bouts	0.506	4.7	-4.2 to 13.5	0.287	3.0	-6.5 to 12.5	0.522
Duration of time in medium bouts ^	0.089	6.8	-4.2 to 17.8	0.210	12.1	-0.1 to 24.4	0.052
Duration of time in long bouts *	0.028	0.3	-10.3 to 10.8	0.957	13.1	3.5 to 22.7	0.010
Intensity							
Number of low intensity bouts	0.743	4.1	-7.2 to 15.4	0.460	1.8	-9.3 to 12.9	0.742
Number of moderate intensity bouts	0.248	6.4	-4.7 to 17.5	0.244	8.7	-4.3 to 21.6	0.179
Number of high intensity bouts	0.263	1.5	-2.8 to 5.8	0.482	3.7	-0.7 to 7.2	0.104
Duration of time in low intensity bouts	0.519	4.4	-3.8 to 12.5	0.277	2.1	-5.5 to 9.7	0.579
Duration of time in moderate intensity *	0.207	6.5	-7.3 to 20.3	0.340	11.0	-2.6 to 24.6	0.108
Duration of time in high intensity bouts	0.110	3.3	-8.9 to 15.5	0.580	10.1	0.6 to 19.7	0.038

All measures are square root transformed and adjusted for age and discharge gait speed. * indicates significant effect of time on measures (overall change p-value < 0.05), ^ indicates trend towards time having an effect on measures (overall change p-value: 0.05 to 0.99).

6.4. Discussion

This study is the first to prospectively characterise community ambulation across the subacute phase of stroke using device-based measures. It was demonstrated that across this phase, stroke survivors who were independent with walking at discharge regularly access their community, and increase their frequency of long bouts (> 300 steps) and time spent in long ambulation bouts per day at 6 months after discharge from hospital. There was however no change in total volume and intensity of community ambulation over time and the purpose for community ambulation remained the same across one, three and six months following hospital discharge.

Stroke survivors accessed their community on average once a day. This frequency of trips was similar to a study that explored community ambulation using self-report methods in individuals with chronic stroke (mean age: 68 years, 1.1 trips per day) (Robinson et al., 2011b). However, in this study of people with chronic stroke, frequency of trips was significantly lower than healthy controls (mean age: 68.6 years), who took 1.8 trips per day ($p < 0.001$) (Robinson et al., 2011b). It is possible that reduced frequency of community trips may begin early after hospital discharge, with little change over the first six months in individuals with stroke. This may contribute to decreased community ambulation in this group. Regardless, it is difficult to compare the current study's findings to earlier studies of community ambulation after stroke, as outcomes are based on self-report measures.

There was no change in the total time spent in the community, frequency of trips per day, as well as volume and intensity of ambulation across the first six months following hospital discharge. Further, there was no change in the purpose of trips over time as hypothesised. This was despite half of the current sample receiving community-based therapy following hospital discharge; half of the sample having carer support and anticipated functional improvements over the three time points (Robinson et al., 2011b; Wood et al., 2010; Desrosiers et al., 2008; Page et al., 2004). Perhaps the recovery of community ambulation occurs later after hospital discharge, as observed by the change in long ambulation bouts only observed at six months after stroke survivors returned home. Reasons for these observations would benefit from further investigation.

It is important to note the significant improvement in the number of bouts and time spent in long ambulation bouts from one month to six months after hospital discharge. No significant differences were observed between one and three months. This was interesting as most functional improvement (Eilertsen et al., 2010; Buurke et al., 2008; Van Wijk et al., 2006; van de Port et al., 2006; Stein et al., 2003; Paolucci et al., 2001) and participation recovery (Desrosiers et al., 2008; Desrosiers et al., 2005a) was expected across the first three months following stroke. Further, post-discharge therapy services received by the sample often ceased by three months. Factors that affect choices around returning to community based activities and roles may assist in understanding this time frame and change in characteristics observed.

The improvement in community ambulation at six months supports an emerging theory regarding community re-integration after stroke (Wood et al., 2010). By this theory, return to community-based activities, roles and responsibilities, and thus community ambulation, may not happen until well after discharge home (Wood et al., 2010). Recovery of community based activities, and thus community ambulation is proposed to be reliant upon successful transitioning between a series of goals: (1) gaining physical function, (2) establishing independence, (3) adjusting expectations and (4) physical capacity to engage in meaningful roles. (Wood et al., 2010). It may take a few months, to over a year to adjust and manage expectations around what activities, roles and responsibilities stroke survivors can return to (Wood et al., 2010; Jones et al., 2009). Unsuccessful adjustment of expectations can affect motivation to continue with pre-stroke community activities, or cessation of activities, as stroke survivors believe that it is an unreasonable goal (Ahuja et al., 2013; Sarre et al., 2014; Wood et al., 2010). This process is specific to both the individual and the community goal (Sarre et al., 2014; Wood et al., 2010). The role of this process on community ambulation recovery may be gleaned through future qualitative research exploring choices and motivation to reintegrate into the community.

Most of the current study sample left the home and yard to engage in 'essential roles and errands' at all time points. These often included essential roles such as spousal and parental duties, as well as shopping, therapy appointments and medical visits. From early after hospital discharge, stroke survivors in the current study spent most time out in the community for this purpose, with limited change in the proportion of time, steps and trips. Even late after stroke, recovery of social, leisure and recreational roles may be restricted (Walsh et al., 2014; Hartman-Maeir et al., 2007; Desrosiers et al., 2005a; Mayo et al., 2002). Community trips that are 'essential' may be a task or duty that cannot be avoided. As such, even if ambulation difficulty is encountered during these community trips, stroke survivors may adapt behaviours to ensure safety. For example, stroke survivors in the current study reported visiting small local shopping centres, rather than large centres and timing trips at off-peak times to increase confidence and safety. Choices around community ambulation may be made early after hospital discharge, and routines established early to improve safety and independence may be maintained over time.

Comparing volume, frequency and intensity of community ambulation with total daily ambulation activity (see Chapter 4) is useful to identify what proportion of daily ambulation occurs outside the home across the subacute phase of stroke. Stroke survivors took 37% to 47% of daily steps and spent 31% to 40% of their total walking time (see section 4.3, table 4.2) in the community. A majority (70-80%) of all daily long duration and high intensity ambulation bouts were taken within the community. Healthy older adults who report frequent outdoor activity also have more accelerometer-derived minutes of moderate to vigorous intensity activity than individuals who report frequent activity indoors only ($p < 0.05$) (Kerr et al., 2012). Further, the high proportion of long duration and high intensity ambulation bouts in the community is not surprising, as distance and speed requirements are often higher for community environments than for household-based ambulation (Salbach et al., 2014a; Andrews et al., 2010; Brown et al., 2010; Lord et al., 2004; Perry et al., 1995). In urban communities, distance requirements can range from 6 m (medical facility) to 677 m (department store) (Salbach et al., 2014b; Dennett et al., 2012). Similarly, gait speed requirements can range from 0.44 m/s to 1.32 m/s (Salbach et al., 2014b). The definitions of long duration (>300 steps) and high intensity (> 80 steps/minute) ambulation bouts used in this study may roughly equate to distances greater than 165 metres and gait speeds greater than 0.73 m/s (assuming a step length of 0.55 metres after stroke) (von Schroeder et al., 1995). Within the community, it is likely that these distances and speeds will be encountered (Salbach et al., 2014b; Andrews et al., 2010; Lerner-Frankiel et al., 1986).

One limitation of the current study is the small study sample used (n = 28 to 34 across time points). Further, the current sample was chosen to include stroke survivors who were ambulant within their communities prior to stroke and independent with walking at hospital-discharge, thus findings are limited to be generalised to this group. Also, participants with cognitive impairment and those discharged to assisted living facilities were excluded. Thus, results of this study are not reflective of these stroke survivors. Also, while devices demonstrated potential for measurement of community ambulation over four days, GPS still requires stroke survivors to start and stop recordings and charge the device daily. Further, as the device is small, restricted upper limb function and fine motor ability can impact manipulation of the device. This could increase difficulty with use of the device for stroke survivors and poor engagement during measurement over multiple days. The GPS device was also unable to provide measures of trip purpose or context. Thus, self-report tools such as activity diaries should be considered during participation outcomes such as community ambulation as this information can be collected via this tool. Since the development of this study, further advances in GPS technology have been made (e.g. improved smartphone technology), and further consideration of simple devices that can measure location over 24 hour periods would be ideal for community ambulation measurement after stroke. In future, measurement of outcome within one-week of hospital-discharge would also be beneficial as adaptations to participation behaviours may have already taken place by one month. This may have contributed to the realisation of no change in overall volume measures.

6.5. Conclusions

Stroke survivors access their community regularly following hospital discharge. Changes in community ambulation across the first six months after hospital discharge are only observed at six months, through increased time and frequency spent in long duration ambulation bouts. Total volume and intensity of community ambulation after stroke remains unchanged over the first six months following hospital discharge, as does the purpose of community trips. It would be beneficial to investigate factors that contribute to community ambulation outcomes early after stroke, as limited recovery is observed across the first six months of returning home. Also, it may be important to consider follow-up of stroke survivors at six months after hospital discharge, as change in community ambulation may only be first observed at this time point.

Chapter 7

Study five: Factors predicting community ambulation after stroke

From Chapter 6, we know that there is limited change in overall community-based ambulation following discharge from hospital in people with subacute stroke. However, time and frequency of long ambulation bouts do increase by six months following discharge. This study explores factors at hospital discharge that predict outcomes in community ambulation over the first six months after returning home. Identifying factors that contribute to community ambulation is useful as there is limited improvement in this outcome across the subacute phase of stroke, and walking-related activities in the community and satisfaction with community ambulation outcomes are low even in the chronic phase. Understanding these potential factors will assist in identifying strategies for those at risk of difficulty with community ambulation prior to hospital discharge after stroke.

Abstract

Purpose: To determine what factors at discharge predict community ambulation outcomes at one, three and six months following hospital discharge.

Methods: 30 subacute stroke survivors (age: 73.0 SD 12.9 years, 66.7% male) were assessed one-week prior to hospital discharge and followed up at one, three and six months later. At discharge, clinical and demographic information was collected, including fatigue, mood, executive function, gait speed, gait endurance, perceived stroke recovery, ambulation self-efficacy, pre-stroke activity and perceived health outcomes. At one, three and six months, community ambulation (volume, frequency and intensity) was measured over four days using the ActivPAL™ accelerometer, Garmin GPS and an activity diary. Correlations were completed between all factors and measures of community ambulation. Significantly related factors were entered into a stepwise linear regression model.

Results: All measures of community ambulation at one month were predicted by gait endurance alone (28.8% to 37.7% of variance, $p < 0.007$), except for frequency of trips into the community, which was predicted by both gait endurance and age (39.9% of variance, $p = 0.044$). At three and six months, volume of community ambulation was not predicted by any measure at discharge. At three months, age predicted 33.6% of variance in frequency of trips ($p = 0.005$), and a combination of gait endurance, executive function and pre-stroke activity predicted 82.3% of variance in time spent in high intensity ambulation bouts. At six months, 18.9% of frequency of trips and 22.2% of time spent in long ambulation bouts was predicted by pre-stroke activity and age respectively. Intensity of ambulation was predicted by both gait endurance and executive function (38.9% of variance).

Conclusions: Walking endurance at discharge alone predicts community ambulation at one month following hospital discharge. Volume of community ambulation cannot be predicted after one month of returning home by factors used in this study. At three and six months, frequency of ambulation is predicted by age and pre-stroke activity while walking endurance is predictive of intensity of community ambulation across the first six months following hospital discharge.

7.1. Introduction

Stroke is the leading cause of disability in Australia (AIHW, 2012). Even late after stroke, participation in community-based activities is restricted (Blomer et al., 2014; Walsh et al., 2014; Barnsley et al., 2012). A vital pre-requisite to successful community reintegration is independence with ambulation outside the home and yard – known as community ambulation (Robinson et al., 2011b; Lord et al., 2004). Community ambulation is considered a very important or essential goal by a majority of stroke survivors (Lord et al. 2004). However, community ambulation is often reduced after stroke and high dissatisfaction with outcomes are reported (Barnsley et al., 2012; Lord et al., 2004; Robinson et al., 2011a; Robinson et al., 2011b). Chapter 6 of this thesis identified that recovery of community ambulation is low across the first six months following hospital discharge. This was contrary to expectations. In order to understand the recovery of community ambulation after stroke and improve discharge planning and support, there is a need to understand factors that contribute to outcomes in this goal after hospital discharge.

Thus far, only a few studies have investigated the factors contributing to community ambulation outcomes after stroke. Further, these have mostly been assessed using self-report measures of community ambulation, such as self-reported successful achievement of independent community ambulation (Bijleveld-Uitman et al., 2013; van de Port et al., 2008), categorisation of community ambulation (e.g. not ambulant outside home, or ambulant to the letter box, immediate environment or a shopping centre etc.) (Lord et al., 2004), or frequency of trips and walking related activities in the community (Robinson et al., 2013; Robsinson et al., 2011a; Robinson et al., 2011b). However, as reported earlier in this thesis (section 2.3.1 and Chapter 3), self-report tools are limited in their ability to accurately represent free-living community ambulation after stroke. Also, in Chapter 3 of this thesis, it is evident that commercially available devices can be used to collect accurate objective measures of community ambulation. These objective measures will allow for a more accurate characterisation of community ambulation.

Determining the ability of factors at discharge from hospital to predict community ambulation outcomes across the subacute phase of stroke is important. Assessment and management of factors that could influence successful reintegration into the community (including community ambulation) is not consistently a priority for rehabilitation professionals during inpatient post-stroke care (Robison et al., 2009; Korner-Bitensky et al., 2008). Not addressing necessary factors during rehabilitation could result in stroke survivors being under-prepared for community-based activities and thus result in negative experiences early after returning home (Walsh et al., 2014; Ahuja et al., 2013; Barnsley et al., 2012; Nalder et al., 2012). Such negative experiences early after discharge can influence whether stroke survivors successfully recommence community ambulation (Barnsley et al., 2012) and may lead to avoidance of community based activities (Robinson et al., 2013; Nalder et al., 2012; Shumway-cook et al., 2005). Identifying factors at hospital discharge that predict community ambulation later will allow for improved awareness of factors that may require attention during post-stroke rehabilitation to improve outcomes after discharge home.

Thus far, a range of factors have been identified to influence community ambulation after stroke. Impairments of fatigue and mood can reduce motivation and drive to ambulate within communities and thus result in fewer walking related activities during community trips (Bijleveld-Uitman et al., 2013; Robinson et al., 2011a; Andrews et al., 2010; Lord et al., 2010). Impaired executive function has a negative impact on successful community reintegration across the subacute phase of stroke recovery (Adamit et al., 2014). However its effect on community ambulation outcomes after stroke are not known.

Higher scores on clinic-based measures of walking capacity, including gait speed and gait endurance are associated with positive self-reported community ambulation outcomes after stroke (Barclay et al., 2014; Bijleveld-Uitman et al., 2013; Robinson et al., 2011b; Lord et al., 2004). Often both gait speed and endurance are used to define minimal requirements for successful community ambulation, though these vary across community locations (Salbach et al., 2014b; Mudge and Monachino, 2013; Andrews et al., 2010; Brown et al., 2010; Lerner-Frankiel et al., 1986). However, even stroke survivors unable to meet minimum gait speed and endurance requirements regularly access their communities (Robinson et al., 2011b; Lord et al., 2004), while conversely, others who meet minimal requirements of walking capacity report limitations in community ambulation after hospital discharge (Robinson et al, 2011b; Lord et al., 2004). The relationship between measures of walking capacity at hospital discharge and accurate device-based measures of community ambulation across the first six months when stroke survivors are potentially resuming community activities is required.

A range of personal factors may also contribute to community ambulation recovery following stroke. Demographics such as increased age (Fulk et al., 2010; Chau et al., 2009; Paolucci et al., 2001), the absence of carer support (Nicholson et al. 2012), and not receiving therapy post hospital discharge (Paolucci et al., 2001) are associated with poor community ambulation and participation outcomes in the chronic phase of stroke recovery (Walsh et al., 2014; Mayo et al., 2002). Further, a number of factors that improve stroke survivor confidence with resuming pre-stroke community activities have a significant impact on driving desire to return to the community (Ahuja et al., 2013; Barnsley et al., 2012). For example, increased self-efficacy in balance and falls (Barnsley et al., 2012; Robinson et al., 2011a), greater perceived recovery from stroke (Eriksson et al., 2013; Wolf and Koster, 2013) and previous engagement in walking activities outside the home (Barnsely et al., 2012) enable the stroke survivor to feel more confident in their ability to resume familiar activities and roles within known locations of the community. Thus scores in these factors at hospital discharge may be a useful way of identifying stroke survivors at risk of poor community ambulation outcomes once returning home. However, this relationship needs further investigation across the early post-discharge phase after stroke.

Thus this study aimed to determine what factors at discharge predict community ambulation outcomes at one, three and six months following hospital discharge. It was hypothesised that factors such as mood, fatigue, executive function, gait speed, gait endurance, age, ambulation self-efficacy and pre-stroke activity behaviours will be related to and predict outcomes in community ambulation at one, three and six months after hospital discharge post-stroke.

7.2. Methods

This is a prospective prediction study, using repeated measures at one, three and six months following discharge from hospital. Participants were recruited one week prior to hospital discharge. Measures collected at discharge were investigated for their ability to predict community ambulation outcomes at the three follow-up time points. Both hospital and institutional ethics committees approved the study (see Appendices 3 and 4). This study was conducted in accordance with the Declaration of Helsinki.

7.2.1. Participants

Participant screening methods are reported in Chapter 6, section 6.2.1. Prior to discharge, 42 stroke survivors were recruited from both the acute stroke and rehabilitation units at The Prince Charles Hospital in Brisbane, Australia. Participants were included if they (1) were diagnosed with a stroke within the past 4 months confirmed with imaging, (2) were aged > 18 years and (3) were discharged into the community to live alone or with a carer or spouse within the Brisbane metropolitan region.

Individuals were excluded if they: (1) had a diagnosis of another neurological condition (e.g. Parkinson's disease) or co-morbidities that limited ambulation prior to stroke, or during their hospital admission, (2) had any unstable medical condition, (3) chest pain, heart attacks, angioplasty or heart surgery in the previous three months, (4) skin allergies to adhesive tape, (5) were discharged to a residential aged care facility, (6) moderate to severe expressive of receptive communication difficulties (based on speech therapist assessment) or (7) scored < 24/30 on the Mini Mental State Examination (MMSE) (Folstein et al., 1975).

7.2.2. Procedures

Participants attended four assessment sessions. The first occurred within one week prior to discharge from hospital, and the remainder at one, three and six months following hospital discharge. Potential factors affecting community ambulation were collected at discharge. Demographic and clinical information were also collected from medical records.

At one, three and six month assessments, participants wore an accelerometer, the ActivPAL^{TM} and a Garmin GPS device (Garmin Forerunner 910XT) for four days. The ActivPAL^{TM} was worn continuously for the four-day period. The GPS was switched on during any trip 'outside the home and yard' (Lord et al. 2004). During these four days, participants also documented details of community trips via an activity diary (see Appendix 2). A measurement period of four days was chosen as this has been reported sufficient to capture usual activity patterns (Murphy, 2009). Details of devices can be found in Chapter 6, section 6.2.2.

7.2.3. Factors at discharge

Measures collected at discharge have previously been described in Chapter 5, section 5.2.3. These included demographics (age), fatigue (Fatigue severity scale) (Krupp et al., 1989), mood (Happiness and depression scale) (Joseph and Lewis, 1998), executive function (Trail-making test) (Reitan, 1958), gait speed (Timed 10m-walk test) (Vos-Vromans et al., 2005), gait endurance (Six-minute walk test) (Pohl et al., 2002), perceived stroke recovery (Stroke impact scale) (Duncan et al., 2003), pre-stroke activity (Physical activity scale for the elderly) (Washburn et al., 1993), ambulation self- efficacy (ambulatory self-confidence questionnaire) (Asano et al., 2007) and perceived health outcome and status (EQ-5D) (Shaw et al., 2005).

7.2.4. Measures of community ambulation

Measures of community ambulation were obtained using a combination of the ActivPAL™, Garmin Forerunner 910XT and activity diary. The ActivPAL™ collected measures of ambulation. Location of trips as well as start and stop times for each community trip were obtained from the Garmin Forerunner 910XT via trip summaries on the Garminconnect website and activity diary. Using the GPS start and stop times and location data, accelerometer measures of ambulation that occurred outside the home and yard were isolated from daily ambulation activity. A MATLAB program was developed to derive measures used to characterise community ambulation per day.

Measures of *volume*, *frequency*, and *intensity* of community ambulation were developed based on earlier research on activity in older adults (Lord et al., 2011) and after stroke (Roos et al., 2012; Manns et al., 2009). *Volume* of community ambulation was characterised by total steps taken in the community per day and total time in the community per day. *Frequency* of community ambulation was characterised by total trips per day into the community and total time per day spent in long ambulation bouts. *Intensity* of community ambulation was characterised by time spent in high intensity ambulation. These measures of ambulation were chosen based on previous studies of ambulation recovery and based on theory of health benefits associated with characteristics of walking. Volume of steps is a common measure of free-living ambulation after stroke (Haeuber et al., 2008). Time spent in long duration and high intensity bouts have potential health benefits and are thus a useful measure to investigate (Billinger et al., 2014; Pang et al., 2013; Roos et al., 2012). Both time spent out in the community and total trips per day were also considered a useful measure of engagement in community ambulation. It is known that frequency of participation behaviours and walking related activities in the community is reduced after stroke, and thus these measures were also included (Blomer et al., 2014; Robinson et al., 2011b).

7.2.5. Data Analysis

Descriptive analyses were calculated for all demographics, factors and measures of community ambulation at one, three and six months. ANOVAs and Mann-Whitney U tests were used to determine if there were any differences between included participants and those who dropped out from the study across the three time points.

Data were inspected for assumptions of step-wise multiple regression and screened for normality using Shapiro-wilk statistics, histograms and Q-Q plots. If assumptions for normality were not met, data were transformed (Tabachnick et al., 2001). All community ambulation measures required transformation, and were thus square root transformed in accordance with Tabachnick et al. (2001). All other assumptions for regression were met.

Spearman's correlations of all independent factors (age, fatigue, mood, executive function, gait speed, gait endurance, pre-stroke activity, ambulation self-efficacy, perceived stroke recovery and perceived health outcome and status) with community ambulation measures were completed. The highest two to four factors that were significantly correlated with ambulation activity at each time point were entered into a step-wise regression model. A maximum of two to four factors were chosen to be included into models to ensure sufficient power for prediction despite a small sample ($n = 30$). This was based on the literature around the ratio of subjects to variables during multiple regression analysis, where a commonly cited rule of thumb of at least 10 subjects per variable is reported (Nunally, 1978). Individual stepwise multiple regression models were created to identify which factors at discharge predicted volume, frequency and intensity of community ambulation at one, three and six months following hospital discharge. Significance was set at $p < 0.05$, and SPSS 21.0 was used for all statistical calculations.

7.3. Results

7.3.1. Participants

Sample characteristics for participants included in the final analysis at each time point are reported in Table 7.1. At hospital discharge, 42 participants were recruited. Figure 7.1 demonstrates the flow of participants and reasons for missing data through the study. From discharge to the final six-month follow-up, 14 participants were lost to follow-up. Further, complications with use of the GPS device (e.g. participant mistakes with start and stop buttons, not saving data and forgetting to take devices on community trips), corruption of one GPS watch and poor uptake by some participants resulted in missing community ambulation data. Thus, at one-month (n=30), eight participants had withdrawn from the study, and four participants had no GPS recordings for this time point. At three months (n=22), four participants were lost to follow-up, and a further four participants had missing GPS data for this time point. By six months (n = 25), two participants were lost to follow-up and three participants had missing GPS recordings for this time point.

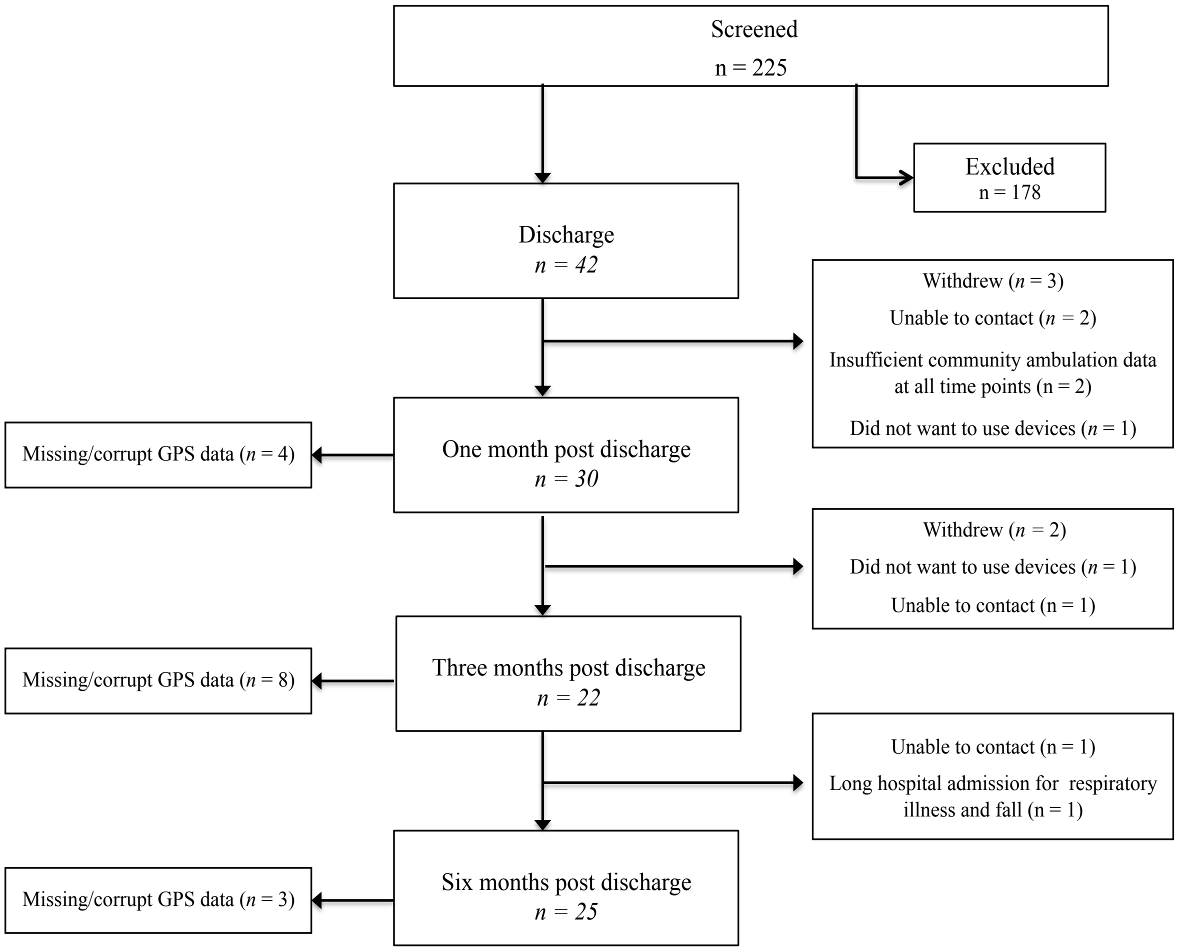

Figure 7.1: Flow of participants and data loss through the study.

Participants (n = 30) had a mean age of 73.0 (SD 12.9) years, two thirds of the sample were male and half the sample present with right hemiplegia. Approximately half the sample had therapy and carer support following hospital discharge at this time point. There were no significant differences between participants who were included (one month n = 30, three months n = 22, six months n = 25) and excluded from analysis across the time points, except for age at one month (F = 4.716, p = 0.036). Participants who were included in the final analysis for this time point were older in age than those who were lost to follow-up or had no GPS recordings (mean age: 68.0 SD 17.9 years).

Table 7.1: Characteristics (presented as mean (SD) or n, %) of stroke survivors at 1, 3 and 6-months after hospital discharge

Characteristic	**Month 1** n = 30	**Month 3** n = 22	**Month 6** n = 25
Age (years)	73.0 (12.9)	71.5 (13.7)	70.4 (13.3)
Hospital length of stay (days)	22.4 (21.1)	19.3 (13.4)	20.4 (15.0)
Gender (n, % males)	20, 66.7	16, 72.7	20, 80.0
Hemiplegia (n, %)			
Nil	7, 23.3	4, 18.2	5, 20.0
Left	6, 20.0	4, 18.2	4, 16.0
Right	16, 53.3	13, 59.1	15, 60.0
Bilateral	1, 3.3	1, 4.5	1, 4.0
Aphasia (n, % with)	7, 23.3	5, 22.7	6, 24.0
Carer (n, % with)	14, 46.7	13, 59.1	13, 52.0
DC Therapy (n, %)			
Nil	14, 46.7	10, 45.5	11, 44.0
RDTU	3, 10.0	3, 13.6	3, 12.0
CBRT/TCP	15, 43.4	9, 40.9	10, 40.0
RESI-TCP	0, 0.0	0, 0.0	1, 4.0

DC Therapy: Therapy received following discharge, RDTU: Rehabilitation day therapy unit, CBRT: Community based rehabilitation therapy, TCP: Transitional care program, RESI-TCP: Residential care based transitional care program

Table 7.2 presents the means and standard deviation, or median and inter-quartile ranges for factors as measured prior to discharge from hospital. There were no significant differences in scores for factors between included participants and those who dropped out at each time point except for age (as mentioned above). The majority of the sample reported no impairments of fatigue or mood. On average, participants performed well in the test of executive function, having a difference of 102 - 114 seconds between Trail-making tests part A and B. Walking capacity was good for stroke, with a mean gait speed of 1.0 (SD 0.4) m/s and gait endurance as measured with the 6MWT of 327.4 (SD 145.7) metres. Average PASE scores for the current sample were also slightly higher than previously reported (158 to 175) (Danielsson et al., 2012) and most participants reported high ambulation self-efficacy at the three time points (average 8.2 out of 10). Finally, median health outcome scores were 7 out of 15 at all time points, health status approximated 70%, and perceived stroke recovery was high as indicated by an average SIS score of 248 / 295.

7.3.2. Characteristics of community ambulation

Characteristics of community ambulation per day in the categories of volume, frequency and intensity, are presented in Table 7.3. From one to three months after stroke, participants took an average of 1700 to 2300 steps across each day with a variation of approximately 2000 steps between subjects. They took on average one trip per day into the community where they spent an average of two to three hours per day. Participants spent approximately 10 to 15 minutes per day in long ambulation bouts, and 8 to 13 minutes per day in high intensity ambulation bouts.

Table 7.2: Mean (SD)/median and range/IQR of the independent factors for stroke survivors (n = 30) at 1, 3 and 6-months following discharge from hospital

	1-month (n = 30)		3-months (n = 22)		6-months (n = 25)	
Factor	**mean (SD)/ median**	**range/ IQR**	**mean (SD)/ median**	**range/ IQR**	**mean (SD)/ median**	**range/ IQR**
Age (years)	73.0 (12.9)	39 - 91	71.5 (13.7)	39 – 90	70.4 (13.3)	39 – 91
FSS (score out of 7)	3.5	1.5 – 4.2	3.7	1.2 – 4.9	3.5	1.4 – 4.4
DHS (score out of 75)	59.0	49.5– 69.0	60.0	49.0 – 69.5	58.5	46.3 – 64.0
TMTB-A (s)	102.9 (146.8)	- 434.0 – 436.0	102.3 (80.7)	-51.0 – 306.0	113.7 (95.4)	-51.0 – 383.1
Gait speed (m/s)	1.0 (0.4)	(0.1 – 1.7)	1.1 (0.4)	0.3 – 1.7	1.1 (0.4)	0.3 – 1.7
6MWT (distance in metres)	327.4 (145.7)	47.0 – 544.0	347.6 (146.8)	80.0 – 544.0	342.3 (147.1)	70.0 – 544.0
PASE (score)	158.2 (104.0)	8.6 – 375.6	160.4 (108.8)	8.6 – 375.6	175.3 (108.9)	8.6 – 375.6
ASCQ (score /10)	8.6	7.0 – 9.5	8.4	6.4 – 9.5	7.5	5.7 – 9.5
EQ-5D (score out of 15)	7.0	5.5 – 7.0	7.0	6.0 – 7.5	7.0	6.0 – 8.8
EQ-5D (VAS) (%)	73.1 (21.5)	10 – 100.0	70.4 (23.9)	10.0 – 100.0	68.7 (24.3)	10.0 – 100.0
SIS total (score out of 295)	253.0	222.0 – 265.0	248.0	221.0 – 265.0	242.5	217.0 – 267.0

FSS: Fatigue severity scale, DHS: Depression and Happiness Scale, TMT: Trail making test B – Trail making test A, PASE: Physical activity scale for the elderly, ASCQ: Ambulatory self-confidence questionnaire, EQ-5D: European quality of life instrument, EQ-5D (VAS): European quality of life instrument health state, SIS – total: Stroke Impact Scale total score, IQR: Inter-quartile range.

Table 7.3: Community ambulation measures at 1, 3 and 6-months following hospital discharge

	1-month		3-months		6-months	
	mean (SD)	**range**	**mean (SD)**	**range**	**mean (SD)**	**range**
Volume						
Number of steps	1859 (1880)	0 - 6361	1700 (1380)	115 - 4867	2298 (2605)	0 – 10495
Total time in community	137.0 (113.2)	0.0 – 465.6	120.0 (66.9)	13.6 – 297.9	176.9 (148.8)	0.0 – 614.7
Frequency						
Number of community trips	1.2 (0.8)	0.0 – 3.0	1.1 (0.7)	0.3 – 2.8	1.1 (0.6)	0.3 – 2.3
Time per day in long bouts	11.3 (14.9)	0.0 – 48.0	9.5 (11.2)	0.0 – 36.4	14.1 (21.3)	0.0 – 84.4
Intensity						
Time in high intensity	10.3 (13.8)	0.0 – 41.0	7.8 (10.7)	0.0 – 37.6	13.2 (21.2)	0.0 – 80.8

All measures are reported as mean SD (standard deviation).

7.3.3. Factors related to community ambulation at one, three and six months

Table 7.4 presents the results of the correlation analyses between discharge factors and community ambulation at one, three and six months after discharge. At one month, all measures of community ambulation were most strongly related to walking capacity (r = 0.524 to 0.710). Volume of community ambulation was also significantly related to age, pre-stroke activity and ambulation self-efficacy. Frequency of ambulation at one month was also related to age, and pre-stroke physical activity, but was also now related to executive function rather than ambulation self-efficacy. Similar to frequency, intensity of activity was also significantly related to executive function, but was now also moderately correlated with fatigue and perceived health outcome.

After one month, total time spent in the community was not significantly related to any factor at discharge. Volume of steps was now only related to executive function. Frequency of community ambulation was related to both executive function and age. Similarly, intensity of community ambulation at three months was related to age and executive function, but was also related to walking capacity and pre-stroke activity.

At six months, total time in the community and frequency of trips was not related to any discharge factor. Volume of steps in the community at six months was related only to age and gait endurance. Frequency of ambulation in the community was also related to age and gait endurance, but now also related to executive function. Intensity of ambulation in the community was again related to both measures of walking capacity (as at one and three months) as well as executive function and perceived health.

Table 7.4: Relationship between independent factors at discharge and measures of volume, frequency and intensity of community ambulation at 1, 3 and 6-months following hospital discharge, Spearman's *r* (p). Significant correlations are in bold.

	Factors										
	Age	FSS	DHS	TMT	10MTW	6MWT	PASE	ASCQ	EQ-5D	EQ-5D (VAS)	SIS TOTAL
One month											
Volume											
Steps	-0.317	-0.324	0.066	-0.336	**0.710**	**0.657**	0.346	**0.413**	0.258	-0.258	0.291
	(0.088)	(0.080)	(0.733)	(0.070)	**(0.000)**	**(0.000)**	(0.061)	**(0.026)**	(0.177)	(0.177)	(0.140)
Time	**- 0.449**	-0.019	-0.042	0.000	**0.565**	**0.637**	**0.422**	**0.422**	-0.360	0.012	0.166
	(0.013)	(0.922)	(0.828)	(0.999)	**(0.003)**	**(0.001)**	**(0.020)**	**(0.023)**	(0.055)	(0.952)	(0.408)
Frequency											
Trips	**-0.493**	-0.276	0.175	**-0.358**	**0.656**	**0.524**	**0.477**	0.334	-0.339	-0.061	0.192
	(0.004)	(0.126)	(0.347)	**(0.044)**	**(0.000)**	**(0.006)**	**(0.005)**	(0.066)	(0.062)	(0.746)	(0.328)
Long bouts	-0.305	- 0.359	0.089	-0.257	**0.579**	**0.600**	0.089	0.289	-0.243	-0.257	0.239
	(0.101)	(0.052)	(0.645)	(0.170)	**(0.002)**	**(0.002)**	(0.164)	(0.128)	(0.204)	(0.178)	(0.231)
Intensity	-0.309	**-0.386**	0.120	**-0.369**	**0.619**	**0.630**	0.357	0.350	**-0.380**	-0.218	0.252
	(0.096)	**(0.035)**	(0.535)	**(0.045)**	**(0.001)**	**(0.001)**	(0.053)	(0.062)	**(0.042)**	(0.255)	(0.205)
Three months											
Volume											
Steps	-0.269	-0.274	0.233	**-0.555**	0.182	0.455	0.390	0.309	-0.326	0.094	0.451
	(0.226)	(0.229)	(0.309)	**(0.009)**	(0.456)	(0.058)	(0.073)	(0.173)	(0.149)	(0.686)	(0.053)
Time	-0.343	-0.071	-0.068	0.029	0.094	0.282	0.329	0.276	-0.165	0.217	0.313
	(0.118)	(0.760)	(0.769)	(0.902)	(0.702)	(0.257)	(0.135)	(0.225)	(0.475)	(0.345)	(0.192)
Frequency											
Trips	**-0.476**	0.010	-0.204	-0.174	0.185	0.330	0.390	0.169	0.071	-0.186	0.287
	(0.025)	(0.967)	(0.376)	(0.450)	(0.448)	(0.182)	(0.073)	(0.463)	(0.761)	(0.419)	(0.233)
Long bouts	-0.122	-0.259	0.319	**-0.482**	0.054	0.270	0.320	0.164	-0.239	0.013	0.343
	(0.589)	(0.257)	(0.159)	**(0.027)**	(0.827)	(0.279)	(0.147)	(0.479)	(0.296)	(0.955)	(0.151)
Intensity	**-0.493**	-0.180	0.129	**-0.538**	**0.482**	**0.614**	**0.568**	0.288	-0.331	0.205	0.255
	(0.020)	(0.436)	(0.578)	**(0.012)**	**(0.037)**	**(0.037)**	**(0.006)**	(0.206)	(0.142)	(0.373)	(0.293)

Six months											
Volume											
Steps	**-0.405**	-0.112	-0.061	-0.411	0.367	**0.497**	0.315	0.254	-0.281	-0.216	0.133
	(0.045)	(0.603)	(0.777)	(0.046)	(0.093)	**(0.022)**	(0.126)	(0.232)	(0.183)	(0.310)	(0.556)
Time	-0.240	0.226	-0.049	-0.136	-0.028	0.092	0.258	-0.195	-0.015	-0.179	-0.050
	(0.249)	(0.288)	(0.820)	(0.527)	(0.901)	(0.691)	(0.214)	(0.360)	(0.945)	(0.403)	(0.824)
Frequency											
Trips	-0.231	-0.035	0.122	-0.292	0.126	0.128	0.394	0.167	-0.199	-0.121	0.339
	(0.302)	(0.881)	(0.599)	(0.199)	(0.596)	(0.602)	(0.069)	(0.470)	(0.387)	(0.600)	(0.144)
Long bouts	**-0.500**	-0.210	-0.048	**-0.412**	0.423	**0.477**	0.376	0.272	-0.254	-0.214	0.137
	(0.011)	(0.326)	(0.825)	**(0.045)**	(0.050)	**(0.029)**	(0.064)	(0.199)	(0.232)	(0.316)	(0.543)
Intensity	-0.383	-0.171	0.041	**-0.528**	**0.443**	**0.560**	0.379	0.402	**-0.435**	-0.231	0.268
	(0.059)	(0.424)	(0.850)	**(0.008)**	**(0.039)**	**(0.008)**	(0.062)	(0.052)	**(0.033)**	(0.278)	(0.229)

7.3.4. Predictors of community ambulation

Separate stepwise linear regression models were constructed for the volume, frequency and intensity of community ambulation at one, three and six months. Factors to be entered into step-wise linear regression models were based on the strength of the bivariate correlations, with the factor most strongly correlated chosen to be entered if a theoretical construct had more than one significant correlation (e.g. only one measure of walking capacity was chosen). Results of the regression analyses are presented in Table 7.5.

At one month, gait endurance (6MWT distance) alone best predicted 29% to 36% of variance in volume of steps ($F = 13.34$, $p = 0.001$), total time in the community ($F = 12.47$, $p = 0.002$) and total time spent in long duration ($F = 8.88$, $p = 0.007$) and high intensity ($F= 11.12$, $p = 0.003$) ambulation bouts within the community (volume $R^2 = 0.362$ to 0.377, frequency $R^2 = 0.288$ and intensity $R^2 = 0.336$) (see table 7.5). Age and gait endurance together predicted 40% of the number of trips taken into the community at one month ($R^2 = 0.399$, $F = 7.63$, $p = 0.003$). Ambulation self-efficacy did not contribute to any model at one month.

At three months no factor at hospital discharge predicted volume of steps, time spent out in the community and time spent in long duration ambulation bouts. Age alone predicted up to 34% of the number of trips taken into the community at three months ($F = 8.09$, $P = 0.012$). All of gait endurance, executive function and pre-stroke physical activity measured at discharge predicted up to 82% of time spent in high intensity ambulation bouts at three months ($F = 21.76$, $p < 0.001$). No other factors were entered into stepwise regression models at three months.

At six months, no factor at hospital discharge predicted volume of community ambulation. At this time point, 19% of the number of trips into the community was predicted by pre-stroke activity alone ($F = 4.66$, $p = 0.043$), and 22% of time spent in long ambulation bouts was predicted by age alone ($F = 5.419$, $p = 0.031$). Executive function at hospital discharge did not contribute to any model predicting measures of frequency of community ambulation at six months. Intensity of community ambulation was predicted by executive function and gait endurance at discharge ($F = 5.73$, $p = 0.012$). Perceived health outcome did not contribute to intensity of community ambulation at six months.

Table 7.5: Stepwise regression analysis for prediction of volume, frequency and intensity of community ambulation at 1, 3 and 6-months following hospital discharge (transformed community ambulation measures)

	Predictors	**R^2**	**R^2 Adjusted**	**Coefficient B (unstandardised)**	**95%CI for B**	**Coefficient β (standardised)**	**Significance**
One month							
Volume							
Steps	6MWT	0.377	0.349	0.094	0.041 to 0.147	0.614	0.001
Time	6MWT	0.362	0.333	0.020	0.008 to 0.032	0.602	0.002
Frequency							
Trips	6MWT +	0.399	0.347	0.002	0.001 to 0.004	0.451	0.012
	Age			-0.017	-0.033 to 0.000	- 0.353	0.044
Long bouts	6MWT	0.288	0.255	0.008	0.003 to 0.014	0.536	0.007
Intensity	6MWT	0.336	0.305	0.009	0.003 to 0.015	0.579	0.003
Three months							
Volume							
Steps	Nil factors at discharge predict outcome						
Time	Nil factors at discharge predict outcome						
Frequency							
Trips	Age	0.336	0.302	-0.024	-0.039 to -0.008	-0.579	0.005
Long bouts	Nil factors at discharge predict outcome						
Intensity	6MWT +	0.823	0.786	0.008	0.004 to 0.011	0.551	0.000
	TMTB-A +			-0.007	-0.010 to -0.004	-0.500	0.001
	PASE			0.009	0.004 to 0.014	0.465	0.001
Six months							
Volume							
Steps	Nil factors at discharge predict outcome						
Time	Nil factors at discharge predict outcome						
Frequency							
Trips	PASE	0.189	0.148	0.002	0.000 to 0.005	0.435	0.043
Long bouts	Age	0.222	0.181	-0.076	-0.145 to -0.008	-0.471	0.031
Intensity	6MWT +	0.389	0.321	0.008	0.001 to 0.015	0.457	0.023
	TMTB-A			-0.008	-0.015 to -0.001	-0.446	0.026

6MWT: Six-minute walk test, PASE: Physical activity questionnaire for the elderly, TMTB-A: Trail-making test B-A

7.4. Discussion

This is the first study to investigate factors at discharge from hospital that predict device-based measures of community ambulation at one, three and six months following discharge in individuals with stroke. Gait endurance at discharge predicted 29-38% of all community ambulation outcomes at one month. Additionally, gait endurance contributed to the prediction of intensity of community ambulation at all three time points, though after one month, other factors such as executive function and pre-stroke activity also contributed. Age and pre-stroke activity predict the number of trips into the community and the total time where individuals walked for longer periods in the community at three and six months following hospital discharge. In contrast, volume of community ambulation could not be predicted after one month by any factor at discharge. Further, discharge scores of mood, fatigue, ambulation self-efficacy, perceived health outcome and stroke recovery did not contribute to the prediction of community ambulation across the first six months following hospital discharge.

Discharge gait endurance measured using the 6-minute walk test consistently contributed to predicting community ambulation during the first six months following discharge from hospital. This is the first study to highlight the potential for gait endurance at discharge to predict objective measures of community ambulation after stroke. Currently, gait speed is used more often to predict community ambulation (Robinson et al., 2010; van der Port et al., 2008; Lord et al., 2004) and classify stroke survivors into ambulation categories (Lord et al. 2004; Perry et al., 1995). While the importance of increased gait endurance for successful community ambulation has been highlighted (Barclay et al., 2014; Salbach et al., 2014; Mudge et al., 2013; Andrews et al., 2010; Lernier-Frankiel et al., 1986), only two studies have investigated gait endurance as a potential predictor of community ambulation after stroke (Bijleveld-Uitman et al., 2013; Lord et al., 2004).

Gait endurance has also been shown to be a significant predictor of ambulation activity in people with chronic stroke. Gait endurance assessed over six minutes has been reported to predict total number of steps (Fulk et al., 2010) and intensity of ambulation activity (Mudge et al., 2009) within both home and community settings after stroke. Additionally in Chapter 5, gait endurance at discharge prospectively predicted ambulation activity outcomes at one, three and six months after hospital discharge. The association between gait endurance and self-reported community ambulation (Bijleveld-Uitman et al., 2013; Lord et al., 2004) may be dependent on the way it is measured. Gait endurance measured over six-minutes can predict independence and device-based outcomes in community ambulation, while gait endurance measured on a treadmill up to a maximum of 300m (with no time limit) does not predict community ambulation after stroke (Lord et al., 2004). The 6-minute walk test is a measure of cardiovascular endurance and fitness but in stroke survivors, distance walked is influenced by motor and balance impairments (Pohl et al., 2002).

Improved performance in this test could suggest that stroke survivors could walk longer distances and thus access more places of interest within the community (Salbach et al., 2014; Andrews et al., 2010; Lerner-Frankiel et al., 1986). Further, longer distances walked over six minutes would also indicate that stroke survivors are also able to walk faster for this time period. Thus, this might explain the current study's finding that stroke survivors were able to engage in more higher intensity ambulation bouts across the first six months of returning home.

After one month following hospital discharge, gait endurance alone did not predict community ambulation. Instead, age, executive function and pre-stroke activity also contributed to prediction of the frequency and intensity of community ambulation. These findings are similar to the factors predicting daily ambulation activity after stroke (see Chapter 5). The similarity between predictors of frequency and intensity of ambulation activity and community ambulation is not surprising, as in the current study cohort, most long bouts (69 – 81%) and high intensity ambulation (76 – 81%) were performed within the community (see Chapters 4 and 6 for comparison).

It is possible that community ambulation at three and six months after returning home may be related to factors other than post-stroke impairments and activity limitations. Most functional improvements after stroke are believed to occur across the first three months (Jorgensen et al., 1995b). Beyond three months, both clinic-based measures of function and free-living ambulation activity after stroke have been reported to plateau (Moore et al., 2013; Hendricks et al., 2002; Jorgensen et al., 1995b). Thus, recovery of community ambulation beyond this time may be independent of post-stroke changes. This is also reflected in the different predictors of community ambulation observed between one month and both three and six months in this study. Also, factors at discharge predicted 19-82% of community ambulation outcomes, suggesting that a range of other factors not included in this study are likely to contribute to community ambulation outcomes after stroke.

Age has previously been shown to be a significant predictor of functional outcomes after stroke (Veerbeek et al., 2011). In the current study, increased age predicted reduced frequency of community ambulation across all time points. Increased age has also been associated with decreased daily levels of free-living ambulation in healthy adults (Lord et al., 2011; Lord et al., 2010; Cavanaugh et al., 2007) and reduced likelihood of returning to pre-stroke participation at three and six months after hospital discharge (Desrosiers et al., 2008). As adults age, there is a reduced drive to get up and ambulate (Cavanaugh et al., 2007), which may also be a reason for reduced frequency of ambulation within the community with increased age. Also, age-related changes such as more co-morbidities, lack of social support, unemployment, reduced strength, decreased gait speed, mood disorders, cognitive impairment, and inability to drive could also influence participation after stroke (Fairhall et al., 2014). Thus, age-related changes may contribute to community ambulation outcomes after stroke.

Increased pre-stroke activity predicts increased time in high intensity community ambulation and frequency of trips out into the community at six months. This could be due to the association between pre-stroke activity and improved functional status and independence following stroke (Ricciardi et al., 2014; Stroud et al., 2009; Krarup et al., 2008). Also, stroke survivors who regularly walked within their communities prior to stroke, may feel more comfortable with returning to these activities after returning home, despite not being confident with walking outdoors at hospital discharge (Barnsley et al., 2012). Thus, high pre-stroke activity may result in a faster recovery of community ambulation.

Executive function has an impact on complex cognitive processes that may be required when ambulating within the community (Adamit et al., 2014). Ambulating within physical environments and managing additional tasks while in the community will require sufficient cognitive flexibility to cope with the various challenges while maintaining independent walking (Liu-Ambrose et al., 2007). Older adults with impairments of executive function tend to walk at slower gait speeds (Doi et al., 2014). Consequently, it is possible that stroke survivors with impairments of executive function may adopt slower gait speeds to manage additional cognitive demands and maintain safe walking patterns when in the community. In adopting slower gait speeds, the time spent in high intensity community ambulation is potentially reduced. This may be particularly noticed as the community is accessed more after three months post hospital discharge (Desrosiers et al., 2008). This would benefit from further investigation in individuals with stroke.

In the current study, volume of community ambulation after one month, including total number of steps or time spent walking, was not predicted by any factor collected at discharge. This could be because most of the sample were able and independent walkers at discharge (e.g. gait speed >0.8m/s and gait endurance > 300m) (Lord et al., 2004; Perry et al., 1995). Thus, post-stroke factors did not influence recovery of community ambulation after discharge. Also, high variability in community ambulation outcomes are observed in survivors of stroke who meet the minimal functional requirements for community ambulation (e.g. gait speed > 0.8m/s, gait endurance > 300m) (Robinson et al., 2011b; Lord et al., 2004). Suggesting that there may be a range of factors not assessed in this study that could have influenced community ambulation outcomes after one month (e.g. carer status, employment, return to driving, volume and type of therapy). Also, this finding could be reflective of the individual nature of the process of reintegrating into the community. Even stroke survivors discharged from acute stroke units with no functional limitations report participation restrictions at six months following hospital discharge (Desrosiers et al., 2008). Further, timeframes for and process of recovery of community based activities and participation is different between stroke survivors and may only commence later after hospital discharge (Walsh et al., 2014; Ahuja et al., 2013; Desrosiers et al., 2008; Desrosiers et al., 2005). However, a number of stroke survivors report participation and community ambulation restrictions even in the chronic phase of recovery (Walsh et al., 2014; Robinson et al., 2011b; Plante et al., 2010a; Lord et al., 2004) and thus further investigation of factors affecting community ambulation are required.

In the current study, the majority of the sample had no impairments in fatigue or mood and reported high self-efficacy, health outcomes and recovery from stroke. Thus, both the high scores and lack of spread of scores may have contributed to a lack of association with community ambulation. One issue to consider is that these measures were taken just prior to discharge from hospital. In this controlled environment, stroke survivors often receive assistance with usual and instrumental activities of daily living. Thus, it may be important to monitor these factors after discharge, as the effect of these factors on community ambulation may change once stroke survivors attempt to return to pre-stroke roles and duties.

Another reason for why factors at hospital discharge may not predict community ambulation at three and six months could be the adaptations that stroke survivors make to account for post-stroke changes. Subacute stroke survivors have previously reported avoiding shopping centres early after discharge from hospital as this was 'too long' or 'too fatiguing' for them (Lerner-Frankiel et al., 1986). Further, they reported avoiding longer shopping trips and spreading it over two or three trips instead of one long trip (Lerner-Frankiel et al., 1986). Individuals with chronic stroke report that perceptions around walking, anxiety and depression and environment impact choices around community ambulation (Barclay et al., 2014; Barnsley et al., 2012). It is possible that choices around community ambulation and the impact of factors that are measured at discharge will change after stroke survivors attempt these tasks. Thus, it would be beneficial to review potential factors at follow-up appointments, and also interview stroke survivors to glean an idea of how choices are made around community ambulation and what factors impact decisions.

It appears that the goal of community ambulation is complex and individual, and affected by a range of factors across a range of ICF domains. Clinically, gait endurance should be a goal for rehabilitation of stroke survivors, as this contributes to initial recovery of community ambulation at one month after discharge, as well as intensity of community ambulation even at six months after returning home. However, a range of factors not included in this study could also contribute to community ambulation after stroke. Also, it would be beneficial for assessment of community-based goals and restrictions for stroke survivors at three and six months after hospital discharge, with consideration of age-related changes, success in returning to pre-stroke ambulation and attitudes and perspectives of community ambulation (e.g. importance of community ambulation), as factors at hospital discharge do not indicate outcomes at these time points.

It is important to consider the limitations of this study. Due to corruption of GPS data and poor uptake of community ambulation measurement methods (e.g. GPS devices) by some stroke survivors, the sample size used in this study was small (22-30 participants), however significant relationships were still found. Also, gait speed was not included in the final regression models, though in most instances gait endurance was more strongly related to measures of community ambulation, and thus this was chosen for final regression analyses. Including gait speed and gait endurance may have presented slightly different results. It should be noted that the findings of this study can be generalised to individuals with stroke who at discharge were independent walkers returning to home, who report little fatigue, little impairments of mood, and high ambulation self-efficacy. In future, it would be beneficial to investigate participants representative of the lower range of functional abilities and with a range of impairments at discharge.

7.5. Conclusions

Discharge gait endurance can predict most measures of community ambulation at one month following hospital-discharge. After this time point, prediction of volume of community ambulation is not possible by discharge factors alone. Age and pre-stroke activity predict frequency of community ambulation after one month. Similarly, executive function and pre-stroke activity contribute to prediction of intensity of community ambulation after one month. It would be useful to investigate other factors affecting community ambulation relative to each time point in stroke survivors.

Chapter 8

Discussions and conclusion

Free-living ambulation activity and community ambulation are low in individuals with chronic stroke. This leaves many stroke survivors feeling dissatisfied with their ambulation outcomes, at risk of further health decline and reporting a poor quality of life. However, the process of ambulation recovery across the subacute phase of stroke is not well understood. Investigating the recovery of ambulation across the subacute phase is vital to enabling researchers and clinicians to begin to address the issue of low free-living ambulation early after stroke. Understanding the process of recovery and the factors affecting outcomes will allow for increased awareness of potential factors that may contribute to poor outcomes and will help to guide the provision of appropriately timed interventions. Thus, the recovery of ambulation activity and community ambulation across the subacute phase of stroke was investigated in this thesis. Valid and reliable devices were used to measure outcomes at one, three and six months after hospital discharge. Further, factors at discharge from hospital were assessed for their ability to predict outcomes later after returning home. This was done across five studies.

This chapter presents a summary of the findings of the studies and discusses the outcomes in more detail. It also presents clinical implications, strengths and limitations of the thesis and suggestions for clinical practices and research. Finally, the thesis ends with conclusions.

8.1. Summary of findings

This thesis explored free-living ambulation recovery across the subacute phase of stroke – including both ambulation activity and community ambulation. Individuals with chronic stroke have long demonstrated poor ambulation outcomes, yet the recovery of ambulation across the subacute phase has not been investigated. Further, few studies have presented objective and accurate measurement of free-living ambulation in individuals with subacute stroke. Thus this thesis first examined accurate, device-based tools for ambulation measurement after stroke. Using these tools, the studies in this thesis objectively captured ambulation activity and community ambulation across the first six months after stroke survivors returned home. Further, factors at discharge from hospital were identified that predicted ambulation outcomes at one, three and six months after stroke survivors returned home.

8.1.1. Study 1: Measuring community ambulation after stroke

The first step to accurate exploration of free-living ambulation recovery was to determine an accurate and reliable tool for measurement. As limited device-based measurement tools for community ambulation were available, the first study aimed to determine the concurrent validity and retest reliability of accelerometers and global positioning systems (GPS) to measure community ambulation after stroke. Based on earlier research, two accelerometers were chosen: the ActivPAL^{TM} and Sensewear Pro$_2$ Armband, and one GPS device, the Garmin forerunner 405CX. The devices were assessed for their ability to collect measures of step counts, time spent walking, energy expenditure, distance (GPS only) and location (GPS only) during both walking tasks that impose demands similar to those encountered when walking in the community as well as free-living community ambulation over four days.

The ActivPAL^{TM} was accurate for the measurement of step counts, time spent walking and METS during all walking tasks, except at gait speeds below 0.42m/s, where it still demonstrated good validity and reliability. The Sensewear recorded with high absolute error during most test conditions and missed 23% of all recordings. The Garmin GPS was accurate and reliable for all measures except distance. While all devices recorded with high absolute error during free-living community ambulation measurement, this was most likely due to the use of a self-report diary as the comparator. This study also highlighted the potential for activity diaries to provide additional information regarding context, purpose and difficulties associated with community ambulation that device based measures may not capture. Further it revealed the importance of user-friendly devices during free-living ambulation measurement. The touch-sensitive GPS device used in this study also had small buttons that were difficult for a number of stroke survivors to use. Thus, another Garmin GPS watch (Garmin forerunner 910XT) that used the same algorithms, but had a larger display screen and buttons that were easy to manipulate was used for later studies in this thesis.

From the first study of this thesis, it was determined that by using the ActivPAL™ to measure characteristics of ambulation, and the GPS to capture location of walking, measures of ambulation taken within the community could be isolated from total daily ambulation. Thus, these two devices were used in subsequent studies to measure daily ambulation activity (ActivPAL™ alone) and community ambulation (using the ActivPAL™ and Garmin GPS) along with activity diaries.

8.1.2. Study 2: Exploring ambulation activity recovery after stroke

The second study of this thesis explored the ambulation activity recovery after stroke with two aims. The first aim of this study was to characterise ambulation activity after stroke at one, three and six months following discharge from hospital. The second aim was to investigate how ambulation activity changed across the first six months following discharge from hospital after stroke. The ActivPAL™, identified as accurate in Study one, was used to measure ambulation activity over four days, at one, three and six months after stroke survivors left hospital. To characterise ambulation activity, measures of ambulation previously defined (Lord et al., 2011) and applied to studies of activity after stroke (Roos et al., 2012; Manns & Baldwin, 2009) were used. These measures included *volume* (daily step counts and time spent walking, sitting/lying, standing and upright), *frequency* (total number of ambulation bouts as well as number of bouts and total time spent in short, medium and long duration ambulation bouts) and *intensity* (number of bouts and total time per day spent in low, moderate and high intensity ambulation bouts) of ambulation.

Results from this study indicated that daily ambulation activity across the first six months following hospital discharge post-stroke was low. Daily step counts were below that required for health benefits at all time points (Tudor-locke et al., 2008). Most bouts of ambulation were short in duration (< 40 steps) and low in intensity (<30 steps per minute). A positive finding was that most walking was completed at moderate intensity (30-80 steps per minute), despite a high frequency of low intensity ambulation bouts. However, low engagement in long duration and high intensity ambulation bouts at all time points, as well as a high proportion of days with no recorded bouts of long duration or high intensity was concerning.

When investigating changes in activity over time, it was evident that after adjustment for age and discharge gait speed, daily volume of ambulation activity increased from one month to both three and six months after discharge from hospital. Most of this recovery was spread across an increase in medium duration ambulation bouts from one month to six months, and moderate intensity ambulation from one month to both three and six month follow-up. Stroke survivors also trended towards increasing time spent in short ambulation bouts between one month and three and six months; suggesting that daily ambulation activity may also increase through short bouts of walking. Unfortunately, there was no change in long duration bouts, or high intensity ambulation bouts from one month. Low engagement in long duration and high intensity ambulation has also been observed in individuals with chronic stroke (Roos et al., 2012). Thus, low engagement in long and high intensity ambulation bouts potentially begins early after hospital discharge following stroke, with no apparent change over time.

8.1.3. Study 3: Factors affecting ambulation activity recovery after stroke

Low levels of ambulation activity observed in Study 2, as well as no change in engagement in beneficial activity behaviours such as, long duration or high intensity ambulation bouts, highlights that stroke survivors are at an increased risk of cardio-metabolic disorders early after stroke (Gordon et al., 2004). Thus, the aim of Study 3 was to determine what factors at discharge were related to and predicted accelerometer-based measures ambulation activity (volume, frequency and intensity) over the first six months following hospital discharge in stroke.

To do this, factors collected at hospital discharge were assessed for the ability to predict volume (daily step counts), frequency (time spent in long ambulation bouts) and intensity (time spent in high intensity ambulation bouts) of ambulation activity at one, three and six months after. Factors collected at hospital discharge included: age, fatigue (Fatigue severity scale), mood (Happiness and depression scale), executive function (Trail-making test), gait speed (Timed 10m-walk test), gait endurance (Six-minute walk test), perceived stroke recovery (Stroke impact scale), pre-stroke activity (Physical activity scale for the elderly), ambulation self- efficacy (Ambulatory self-confidence questionnaire) and perceived health outcome and status (EQ-5D). These factors were chosen as all had been previously identified as potential contributors to outcomes in ambulation in individuals after stroke, and those at risk of mobility decline.

Results of this study highlighted that different factors at discharge predict outcomes in ambulation activity at one, three and six months following hospital discharge. Gait endurance was identified as the single factor predicting all outcomes of ambulation activity at one month, and intensity of ambulation at three and six months after discharge from hospital. Beyond one month after discharge, gait endurance alone did not predict outcomes in ambulation activity. After this time point, pre-stroke activity, age and executive function also contributed to volume, frequency and intensity of ambulation activity. This is an important finding, as thus far, measures of walking capacity alone are generally used to predict activity outcomes after stroke (Fulk et al., 2010). Measures of fatigue, mood, perceived stroke recovery, ambulation self-efficacy and perceived health outcome and status (EQ-5D) did not predict outcomes in ambulation activity at any time point post hospital discharge, but this was a cohort of relatively high functioning stroke survivors who did not report any impairments or limitations in these factors at discharge.

8.1.4. Study 4: Exploring community ambulation recovery after stroke

The fourth study of this thesis explored ambulation that occurs within the community – community ambulation. This study aimed to characterise community ambulation across one, three and six months after stroke survivors were discharged from hospital and also determine if community ambulation changed over these three time points. To capture community ambulation, a combination of the ActivPAL^{TM} accelerometer, a Garmin GPS device and the activity diary were used over four days. These devices were assessed for validity and reliability for community ambulation measurement in Study one of this thesis. Measures of ambulation were based on previous studies of stroke survivors (Roos et al., 2012; Manns & Baldwin, 2009) and also used to characterise ambulation activity in Study 2.

As this study was the first to objectively measure community ambulation after stroke, characteristics of community ambulation could not be compared with previous guidelines or recommendations for positive outcomes. Stroke survivors regularly accessed their communities at all time points, taking on average one trip per day out of the home. They spent an average of 2-3 hours and took 1700 to 2298 steps per day out into the community. Most time each day was spent in long duration and moderate intensity ambulation bouts, except at three months, where most time was spent in medium duration bouts. Comparing the findings of this study with that of ambulation activity recovery in Study 2, it is evident that most long duration and high intensity ambulation after stroke occurs within the community.

The study provided evidence to suggest that the recovery of community ambulation was different to ambulation activity across the first six months following hospital discharge. Recovery of community ambulation does not change until six months after hospital discharge, despite daily ambulation activity increasing across this time period. The changes in characteristics of ambulation for activity and participation are also different over the first six months after discharge. Changes in community ambulation after discharge in this cohort were only observed through an increase in long duration ambulation bouts at six months, while daily ambulation activity increases via medium and moderate intensity ambulation bouts. Thus recovery timeframes and characteristics of ambulation that change may be different between community ambulation and ambulation activity across the first six months after hospital discharge post-stroke.

8.1.5. Study 5: Factors affecting community ambulation after stroke

The final study of this thesis aimed to determine what factors at discharge predicted community ambulation outcomes at one, three and six months following hospital discharge. Community ambulation outcomes were measured in subacute stroke survivors at one, three and six months after hospital discharge. Measures of community ambulation collected by the ActivPAL^{TM} and Garmin GPS watch over four days included: volume (total time spent out in the community, total number of steps taken out in the community), frequency (frequency of trips out in the community, total time spent in long ambulation bouts) and intensity (total time spent in high intensity ambulation bouts). Discharge factors investigated included those previously identified as potential contributors to ambulation outcomes in stroke survivors and older adults at risk of mobility decline, such as: age, fatigue (Fatigue severity scale), mood (Happiness and depression scale), executive function (Trail-making test), gait speed (Timed 10m-walk test), gait endurance (Six-minute walk test), perceived stroke recovery (Stroke impact scale), pre-stroke activity (Physical activity scale for the elderly), ambulation self- efficacy (Ambulatory self-confidence questionnaire) and perceived health outcome and status (EQ-5D).

The study highlighted that a range of factors at discharge predicted community ambulation outcomes after hospital discharge. Discharge gait endurance best predicted community ambulation at one month after hospital-discharge. Gait endurance at discharge also contributed to prediction of intensity of community ambulation at all time points. However, beyond one month, other factors contributed to prediction of community ambulation outcomes. At three and six months, executive function and pre-stroke activity also contributed to intensity outcomes. Further, frequency of trips and total time spent in long bouts of ambulation at three and six months were predicted by age and pre-stoke activity. Surprisingly, volume of community ambulation at three and six months could not be predicted by any factor at discharge. Discharge scores of mood, fatigue, ambulation self-efficacy, perceived health outcomes and stroke recovery did not contribute to the prediction of community ambulation across the first six months following hospital discharge. However, this was again likely due to the current sample not recording any impairments or limitation in these factors at discharge.

8.2. Clinical implications and future directions

This thesis presents findings that have clinical implications for the management of ambulation after stroke. Recovery of ambulation activity and community ambulation is different after stroke; and should be considered separately by therapists. Time frames and characteristics that change over time vary between the two aspects of free-living ambulation. Also, predicting free-living ambulation outcomes at hospital discharge may be possible, though different factors at discharge impact free-living ambulation outcomes at one, three and six months after returning home. Factors that impact outcomes after three months may be separate from post-stroke changes (such as age, pre-stroke activity). Thus, consideration of factors other than clinical measures of walking capacity to predict outcomes may be required, especially later after stroke (Robinson et al. 2011b; Fulk et al., 2010; Mudge et al., 2009; Lord et al., 2004). This thesis also highlights issues around current time frames for follow-up of stroke survivors, and considerations for measurement of ambulation recovery after stroke. These will be discussed in further detail below.

8.2.1. Measuring ambulation recovery: What is the best way?

This thesis highlights the need to measure free-living ambulation recovery after hospital discharge. Currently, free-living ambulation is not routinely measured during rehabilitation of stroke survivors. Rather, recovery is assumed based on performance in clinical measures during rehabilitation. However, as confirmed in this thesis, discharge clinical measures do not predict all of ambulation activity and community ambulation across the first six months after returning home. Thus, it may be important to consider free-living ambulation measurement as a separate outcome measure after stroke and a measure that stroke survivors could consider monitoring themselves once at home. This is especially important if increasing free-living ambulation is a goal after stroke. However, prior to future research and clinical applications of device-based measures of free-living ambulation, there is a need for consideration of tools and measures to ensure accurate and feasible measurement of outcomes.

Measuring free-living ambulation after stroke – considerations for measurement tools

This thesis demonstrates that it is possible to measure free-living ambulation across a four day period after stroke using an accelerometer and GPS device, though the GPS device still requires some consideration prior to future use. In the current thesis, the majority of participants across all studies had none or little concern with wearing the devices for the whole measurement period. No adverse events occurred with the donning and doffing of devices, and only one participant refused to wear both the accelerometer and GPS device during the study period. Some participants preferred the accelerometer over the GPS, as once applied by the investigators, participants did not need to monitor or manage the device except for its removal – thus the accelerometer only put a small burden on participants. Issues with using the GPS device such as the need for participants to remember to take the device with them during community trips, manage small buttons to start and stop recording and the need for regular charging resulted in increased burden with this device. As a result of these issues, a number of GPS trip recordings during follow up measurement in studies four and five of this thesis were missed due to participants forgetting to take the device with them during community trips, not knowing how to manipulate the device (despite information and contact numbers being provided for assistance with troubleshooting) and a few participants not engaging in use of the device. These will need consideration during future research and clinical applications of portable GPS devices. The use of an activity diary is recommended in addition to devices as it not only provided additional information regarding the context of community trips, but it also assisted with verifying information regarding start and stop time, purpose and location of community trips and data analysis.

There are important considerations to be made prior to use of devices for free-living ambulation measurement within the clinical and research settings. When considering tools for measurement, the ActivPAL^{TM} is an easy to use device, and puts only a small burden on participants. It does not display updates of measures like other commercially available accelerometers (e.g. Fitbit), though this is ideal for a research setting, when the aim is to measure participants' usual behaviours, unaffected by feedback. If the aim is to encourage free-living ambulation, then an accelerometer that displays real-time summaries of ambulation data would be useful. The Sensewear Pro_2 Armband assessed in Study one of this thesis may not be feasible for free-living ambulation measurement after stroke, as it is not accurate when worn on the hemiplegic arm and does not provide accurate measures of step counts regardless of testing methods (Manns and Haennel, 2012). It too requires participants to turn the device on, unlike the ActivPAL^{TM}, which records continuously once set up by investigators or therapists. However, the Sensewear Pro_2 Armband does demonstrate some validity with measures of energy expenditure when worn on the unaffected arm (Manns and Haennel, 2012; Moore et al., 2012). Thus this device may be useful for future clinic-based measurement of activity after stroke (where assistance with using devices are readily available), but not free-living ambulation recovery. Though the GPS device was used in this thesis, measurement of community ambulation requires a simpler tool, or one that can be applied to participants and left to record continuously. Ideally, one single device that collects real-time accelerometer data with location data would be ideal for community ambulation measurement. Also, GPS technology still requires investigation to confirm accuracy in all environments when measuring distance. In future, smartphone applications may be a feasible tool for community ambulation measurement after stroke (Albert et al., 2012) and a device that stroke survivors are likely to be familiar with. This would require further investigation.

What is the best measure for free-living ambulation?

An important consideration that has emerged from this thesis is the 'best' measure of free-living ambulation. Measurement of free-living ambulation in the current thesis employed both traditional measures of activity such as daily average step counts, as well as new 'bout' measures (Cavanaugh et al., 2007). Measurement of daily volume of ambulation provides an accurate representation of overall activity after stroke, which can be used to characterise samples and compare with activity guidelines. Bout measures have been deemed more sensitive than average volume measures in identifying changes in activity that occur as people age (Cavanaugh et al., 2007) or develop mobility difficulty (Chastin et al., 2010). Bouts also provide more information regarding the spread of ambulation throughout the day. When considering activity behaviours in people after stroke, it is important to consider both the time spent being *active*, as well as the time spent being *inactive*, or sedentary (Dunstan et al., 2012). Identifying the spread of ambulation across the day (through bouts of ambulation) can provide useful information regarding activity and sedentary patterns and behaviours (Lord et al., 2011). Further, as the 'bout' is a more sensitive measure of change in ambulation, it may be used in future to identify individuals at risk of poor mobility outcomes after stroke. However prior to this measure being used effectively, research investigating long-term outcomes of stroke survivors who engage in different levels of volume, frequency and intensity of ambulation are required to assist in determining criteria for optimal outcomes for measures of ambulation bouts.

When considering the 'best' measure of ambulation recovery within the clinical setting, a measure that can be easily captured and compared to evidence-based daily recommendations is required. From the findings of this thesis and earlier studies of activity in stroke, it is known that daily volume of ambulation is low across all phases of recovery. Measures of volume of ambulation (e.g. daily step counts) are easily obtainable from accelerometers and could be used clinically to set goals during rehabilitation and encourage increased levels of free-living ambulation (Danks et al., 2014). Further measures such as volume of steps, do not require complex analysis methods and mathematical software, as is required for the calculation of ambulation bouts. These measures of volume, also have evidence-based recommendations that can be used to determine if stroke survivors are achieving sufficient free-living ambulation outcomes. For example, a stroke survivor with low daily ambulation (e.g. <5000 steps), could be given an accelerometer and advised to try and increase daily step counts in increments (e.g. by 10%) until 10,000 steps (or a reasonable activity goal) are achieved. This has already demonstrated high potential in survivors of chronic stroke (Danks et al., 2014).

Suggestions for future measurement and use of device-based measures of free-living ambulation

In future, it would be beneficial to look at the ability of commercially available devices to accurately capture measures of free-living ambulation that can be compared with Australian guidelines for activity (eg. How many long, or 10 minute bouts of walking were completed throughout the day, or how many minutes of moderate to high intensity activity took place during the day) (AIHW, 2012). There is sufficient evidence for the requirements in these characteristics of ambulation, and thus validation of commercially available accelerometers to measure these characteristics of ambulation after stroke would be useful to improve free-living ambulation and characteristics of ambulation after stroke survivors return home (Danks et al., 2014). For a group that demonstrates low overall activity, short ambulation bouts, and low to moderate intensity activity, an external device that informs stroke survivors of how much activity is sufficient may help in improving stroke survivors' beneficial activity behaviours. This was demonstrated recently by Danks et al., (2014) in individuals with chronic stroke, who wore an accelerometer and were provided with advice on how to increase bout duration and intensity (Danks et al., 2014). Though, in this activity program, MATLAB software for bout calculation was required and activity summaries were provided at the end of the measurement period (Danks et al., 2014). A commercial tool or smartphone application that can be easily used by stroke survivors and provide real-time feedback to encourage increased activity at that time would be more efficient in reminding stroke survivors if more activity is required to meet daily requirements for health benefits. Consideration of the use of devices for this purpose would be useful for improving, overall activity behaviours after stroke.

Also in future, it would be beneficial to look at the spread of bouts of activity and inactivity, through the measurement of both sedentary and activity behaviours. Though sedentary behaviours were not directly measured in this thesis, time spent 'inactive', or not ambulating or upright, was similar to earlier studies measuring sedentary time after stroke (Alzahrani et al., 2011; Janssen et al., 2010; Rand et al., 2010; Sakamoto et al., 2008). The stroke survivors investigated in this thesis spent up to 20 hours in sitting and lying positions across the first six months of returning home, with no change over time. The detrimental effects of prolonged sitting on health outcomes are well documented, with prolonged sitting an independent risk factor for cardiovascular disease in adult populations (English et al., 2014; Dunstan et al., 2012). However interrupting sedentary time with activity is also known to have potential health benefits. As demonstrated in this thesis, a large proportion of the day is spent in sitting and lying positions after stroke. Thus, this is a significant part of the day during which activity behaviours can be changed to improve health outcomes (e.g. by reducing prolonged sedentary time and increasing activity bouts). Thus, investigating the use of measures of activity (e.g. ambulation volume, frequency and intensity) and inactivity (e.g. sedentary time) in both research and clinical settings after stroke would be beneficial.

Similar to other measures of participation, it may be important to simultaneously capture measures such as satisfaction and importance of outcomes when measuring community ambulation (Dijkers, 2010). As the goal of successful participation after stroke affects so many domains of an individual's life, it may be difficult to characterise it by device-based measures alone. Further, goals and outcomes are highly individual. With respect to community ambulation after stroke, due to the range of pre-stroke engagement in community life, it may be difficult to identify a 'normal outcome' after stroke with respect to age, gender or stroke severity – as is the case with other clinical measures. This thesis demonstrated that self-report tools could be used in conjunction with device-based measures of community ambulation. Using self-report tools which measure satisfaction, importance or areas of limitation with outcomes may assist in determining if community ambulation is completely recovered or not. These self-report tools should also be used in future research with and clinical applications of device-based measures of community ambulation.

8.2.2. Ambulation recovery after stroke – looking at both activity and participation

Ambulation activity and community ambulation should be considered separate during stroke rehabilitation. Theoretically both encompass two aspects of free-living ambulation recovery (WHO, 2001). Ambulation activity refers to activity that results from all free-living walking related tasks. Community ambulation however, refers to free-living ambulation that occurs only outside the home and yard (Lord et al., 2004) and is generally associated with fulfilling a role or purpose within a life situation (WHO, 2001). The results of this thesis identify that recovery of ambulation activity and community ambulation occurs differently. While total daily ambulation activity increases over the first six months after hospital discharge, total community ambulation does not. In addition, the characteristics of ambulation that change over time are different between daily ambulation activity and community ambulation. Factors that predict outcomes in ambulation activity and community ambulation share some similarities early after stroke, but differences are apparent later on. Finally, prediction of community ambulation may be more complex than daily ambulation activity outcomes, with some outcomes difficult to predict beyond three months after hospital discharge.

Characteristics of free-living ambulation after stroke

Looking at characteristics of free-living ambulation in this cohort, daily ambulation activity across the subacute phase of stroke was low at all time points. Most ambulation bouts were short in duration and moderate in intensity across the first six months following hospital discharge.

Though there are no comparators for normal device-based measures of community ambulation, frequency of community trips in this cohort were similar to a sample of individuals with chronic stroke, who demonstrated significantly fewer community trips than their age matched healthy controls (Robinson et al., 2011b). This suggests that frequency of community trips across the subacute phase of stroke may also be reduced. This is despite good functional outcomes at hospital discharge in the study cohort (mean gait speed: 1.0 m/s; 6MWT distance: 327.4 metres – indicating that stroke survivors were on average independent walkers) (Perry et al., 1995).

The results of this thesis highlighted that up to 30 to 40% of total daily walking time and 37 to 47% of daily steps taken by stroke survivors were in the community (see figure 8.1). Further, most of total daily long duration (68-81%) and high intensity (76-81%) ambulation bouts took place within the community (see figure 8.2). Conversely, most short (85%) and low intensity (85%) ambulation bouts were taken inside the home. This is not surprising due to the functional requirements within community and household environments. Community locations generally require individuals to walk for longer distances and at faster gait speeds than household environments (Salbach et al., 2014; Mudge et al., 2013). Thus, most often, ambulation bouts within these environments may be longer in duration and higher in intensity than household environments. In light of this, targeting successful community ambulation during rehabilitation of stroke survivors may assist in increasing beneficial activity behaviours such as long duration and high intensity ambulation bouts.

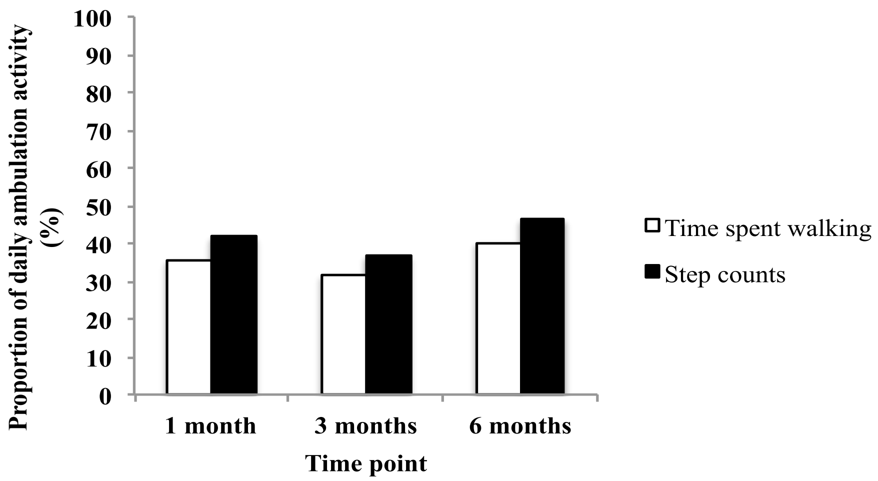

Figure 8.1: Proportion of daily ambulation activity (time spent walking and step count) taken in the community at one, three and six months after hospital discharge.

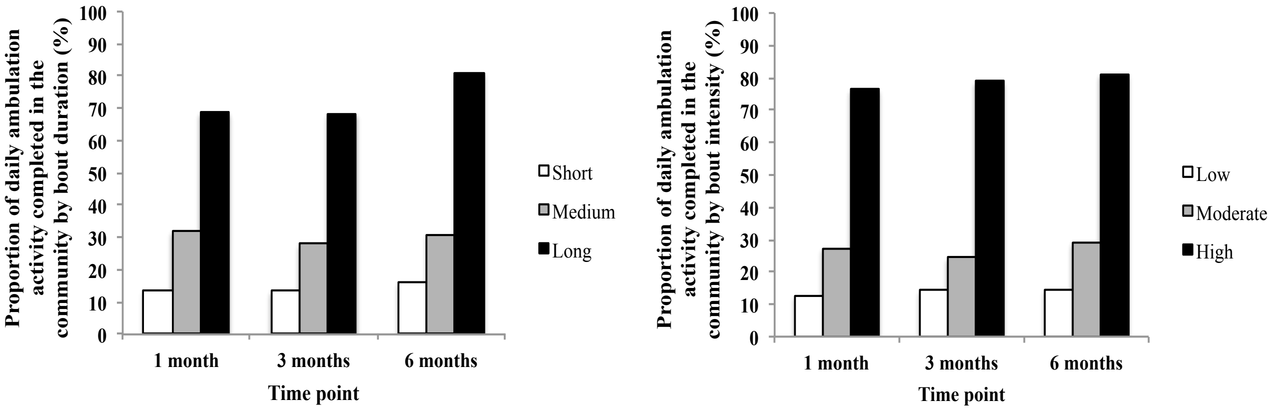

Figure 8.2: Proportion of daily ambulation activity taken in the community by bout duration and bout intensity at one, three and six months after hospital discharge.

Timeframes and recovery of free-living ambulation

Recovery timeframes and characteristics that change over time are different between ambulation activity and community ambulation after stroke. Ambulation activity improved only through an increase in ambulation bouts of less than 300 steps at a time, and of moderate intensity (30-80 steps/minute) walking. There was no increase in long duration and high intensity ambulation activity across the first six months after hospital discharge. Conversely, total community ambulation did not change across the first six months after returning home, except for time spent in long ambulation bouts at six months. However, there were also no improvements in high intensity community ambulation over time. The lack of change in overall daily high intensity ambulation is concerning for a group already at a high risk of cardio-metabolic disorders. Further, though long duration bouts of walking within the community increased at six months, overall community ambulation did not change. This suggests that ambulation for participation does not improve across this phase, despite an anticipated increase as stroke survivors return to pre-stroke roles and responsibilities.

Differences in timeframes for recovery suggest that usual recovery of free-living ambulation for activity and participation are different. While ambulation activity recovery begins early after stroke survivors return home (e.g. one month), community ambulation does not recover until much later (six months). Participation goals including community ambulation are more complex than usual activities of daily living (Walsh et al., 2014; Woodman et al., 2014; Dijkers, 2010). Despite scoring high in clinical measures of function and balance, stroke survivors do not consistently demonstrate successful community ambulation and reintegration outcomes (Walsh et al., 2014; van der Port et al., 2008). Even in the findings of this thesis, recovery of total community ambulation did not occur until much later, despite most stroke survivors achieving minimal gait speed and endurance requirements for independent community ambulation at hospital discharge (Lord et al., 2004; Perry et al., 1995). These findings suggest that recovery of community ambulation is not spontaneous like ambulation activity recovery even if minimal functional requirements are met. Further, though it is believed that community ambulation limitations are the result of an inability to manage community environments and tasks, (Salbach et al., 2014; Barclay et al., 2014; Brown et al., 2010; Mudge et al., 2013), this thesis demonstrates recovery of community ambulation is not dependant upon post-stroke activity limitations alone. The process of recovering community ambulation and re-integration is poorly understood. In future, further qualitative investigation to glean how stroke survivors make choices around re-engaging in community ambulation would assist in understanding the process of community ambulation recovery after stroke (Walsh et al., 2014).

The effect of current practices on free-living ambulation recovery

Differences observed in ambulation activity and community ambulation recovery may be the result of current rehabilitation practices after stroke. Daily ambulation activity improved, while community ambulation did not, suggesting that most improvement in ambulation activity occurs through increased activity within the home. During their hospital admission, stroke survivors engage in ambulation within indoor, controlled clinical environments – similar to household ambulation. Thus, potential barriers and strategies to overcome these are identified and discussed with patients. Additionally, a main priority of inpatient rehabilitation may be safe indoor mobility (Ahuja et al., 2013; Barnsley 2012) rather than community based participation outcomes. Often at discharge from rehabilitation, stroke survivors who deem walking a fundamental part of life, are able to walk in the home, but many are not confident with walking outside the home (Barnsley et al., 2012).

Community ambulation receives minimal attention during post-stroke rehabilitation (Ahuja et al., 2013; Barnsley et al., 2012). In fact, community based participation outcomes are potentially considered more important during community-based rehabilitation (Hayward et al., 2014). After discharge, engagement in community activities is dependent upon a number of other factors such as confidence with exploring community environments, emotional dispositions, the availability of meaningful destinations, expectations of recovery and social supports (Walsh et al., 2014;

Barnsley et al., 2012). The absence of formalised therapy or support at this stage to encourage return to pre-stroke participation and assist with problem solving around barriers, may be a reason as to why recovery of community walking is limited across the first six months after hospital discharge, and restrictions are observed even late after stroke (Walsh et al., 2014). Consequently, it is imperative that community ambulation is addressed during inpatient rehabilitation. This will allow for increased confidence with exploring community environments and tasks (Walsh et al., 2014) and reduce the incidence of sentinel events, which can lead to avoidance of community-based activities (Ahuja et al., 2013; Barnsley et al., 2012; Nalder et al., 2012a; Nalder et al., 2012b) and poor community re-integration. Another option is the implementation of community-based rehabilitation or community follow-up for all stroke survivors following hospital discharge. However, as observed in this study cohort, this is not always provided and the process is not standardised, frequently occurring at the discretion of rehabilitation consultants (Hayward et al., 2014).

8.2.3. When is the 'end-point' of ambulation recovery after stroke?

It is believed that greatest functional recovery occurs over the first six months after stroke (Jang, 2010; Mayo et al., 2002; Jorgensen et al., 1995b). Further, at six months, it has been proposed that improvements in function (Jang, 2010; Kwakkel et al., 2004; Jorgensen et al., 1995b) and free-living activity (Moore et al., 2013; Askim et al., 2013) and participation (Desrosiers et al., 2008) may plateau. Self-reported activity and participation outcomes in individuals with chronic stroke indicate that improvements are still possible after six months post-stroke (Viosca et al., 2005). Currently, post-discharge therapy plans are made based on scores of clinic-based measures at discharge (Hayward et al., 2014). Further, though it is recommended for regular review of stroke survivors at three, six and twelve months after hospital discharge (NSF, 2010), most stroke survivors examined in this thesis were discharged from community rehabilitative services by three months, though medical follow-up end-points varied between participants. The results of this thesis indicate that while stroke survivors continue to increase free-living ambulation activity across the first six months after hospital discharge, they only demonstrate change in usual community ambulation at six months after discharge. Further, factors at discharge are not able to predict all ambulation outcomes after returning home, especially after three months.

This questions the true 'end-point' of rehabilitation after stroke. Stroke survivors assessed in this thesis were often discharged from community-based rehabilitative services at three months after hospital discharge. Yet, it was observed that recovery was possible at three and six months after hospital discharge – though improvement in beneficial activity behaviours and overall community ambulation did not take place. Also, all factors at discharge were not able to predict ambulation outcomes after hospital-discharge, especially at three and six months. Changes in ambulation activity and community ambulation at six months measured in this thesis suggests that review of free-living activity and participation goals at three and six months are required. At these time points, outcomes in free-living ambulation, especially resulting from participation, are likely to be affected by factors different to those measured at discharge from hospital. Thus, assessment at these time points may be required to ensure optimal recovery of activity and participation.

8.2.4. Factors that impact ambulation recovery – considerations for future management of stroke

The results of this thesis indicate that free-living ambulation (ambulation activity and community ambulation) can be predicted by factors at discharge. Gait endurance predicts some aspects of ambulation recovery across the first six months following hospital discharge. In particular, gait endurance at discharge is a significant predictor of intensity of free-living ambulation outcomes both for activity and participation after stroke even at six months after returning home. However, after one month, ambulation recovery may be dependent on factors that are independent of stroke-related impairments and limitations. Further, predicting recovery of community ambulation may not be as simple as predicting overall ambulation activity across the first six months after hospital discharge. Regardless, decreased ambulation activity and community ambulation will most likely be observed in stroke survivors who demonstrate poor gait endurance, are older, less active prior to stroke and display executive function impairments at hospital discharge. These factors also do not predict all variance in free-living ambulation outcomes, and there is a need to consider the effect of other factors across the subacute phase of stroke recovery.

Gait endurance needs to be a priority during stroke rehabilitation

The importance of assessing and training gait endurance during rehabilitation of stroke survivors is highlighted in this thesis. The six-minute walk test was originally designed as a measure of exercise tolerance for people with chronic airway obstruction (Butland et al., 1982). After stroke, it provides a measure of functional gait endurance that accounts for balance impairments, functional limitations and cardiovascular changes that are observed in this group (Manns & Baldwin, 2009;

Eng and Tang, 2007; Pohl et al., 2002; Pohl et al., 2001). As demonstrated in the results of this thesis, gait endurance has a significant relationship with free-living ambulation outcomes even late after stroke survivors return home. Individuals with chronic stroke living in the community, often report gait endurance as a significant barrier to recovering community ambulation outcomes (Barclay et al., 2014; Combs et al., 2014). Despite its relationship to post-discharge activity and participation outcomes, and importance reported by stroke survivors, gait endurance is not routinely measured after stroke (Langhorne et al., 2009). However, it is evident that gait endurance measured over six-minutes would be a useful outcome measure to incorporate into usual rehabilitation assessment of stroke survivors. Further, post-stroke rehabilitation should also target increasing walking endurance, as this may translate to improved free-living ambulation outcomes even at six months after hospital discharge, especially free-living ambulation intensity.

Gait speed versus gait endurance – which is more important?

Though gait endurance was the strongest predictor of free-living ambulation in this thesis, it is also important to consider the effect of gait speed on free-living ambulation outcomes. Both gait speed and gait endurance are important factors for free-living ambulation activity and participation outcomes after stroke (Bijleveld-Uitman et al., 2013; Salbach et al., 2014b; Andrews et al., 2010; Mudge and Stott, 2009; van de Port et al., 2008; Perry et al., 1995). Previously, gait speed has been used to distinguish individuals who will achieve independence with community ambulation outcomes (Lord et al., 2004; Perry et al., 1995; Lerner-Frankiel, 1986). In the studies of this thesis, gait speed was also related to a number of measures of free-living ambulation. However, gait speed and gait endurance also shared a strong relationship ($r > 0.8$). Thus, to meet assumptions of collinearity for regression analysis, only one measure of walking capacity was used. In the case of this study cohort, gait endurance was chosen as it demonstrated a stronger relationship with more measures of outcome of free-living ambulation at all three follow-up time points.

However, this does not conclusively indicate that gait endurance is a more superior outcome measure to gait speed. Gait speed also continues to demonstrate a strong relationship with free-living ambulation outcomes after stroke (Bijleveld-Ultiman et al., 2013; van der Port et al., 2008; Lord et al., 2004). It is possible, that in groups of different functional abilities, the priority of training gait speed and gait endurance may be different. In higher functioning groups, who achieve the minimum gait speed of 0.8m/s for independent ambulation (like the current thesis cohort), improving gait endurance may be more of a priority than gait speed alone. Previous studies have found that survivors who walk at gait speeds below 0.8m/s are consistently limited in free-living ambulation (Robinson et al., 2011b; Lord et al., 2004), while individuals who walk faster than 0.8m/s demonstrate a high variation in outcomes. Further, above this gait speed, the ability of gait endurance to predict outcomes in free-living ambulation is not confounded by other factors such as balance, fear of falling, or time post-stroke stroke, while conversely, gait speed can be affected by these covariates (Bijleveld-Ultiman et al., 2013). This thesis demonstrates that both gait speed and gait endurance were related to measures of ambulation activity and community ambulation. However, in most cases, gait endurance was more strongly related than gait speed. Thus, it is possible that in high functioning stroke survivors gait endurance may have a more significant impact on free-living ambulation outcomes, than gait speed. This may be different in individuals with more severe stroke, for whom independence with gait, and sufficient gait speed may be a higher priority.

Other factors affecting free-living ambulation recovery

The findings of this thesis also indicated that gait endurance alone could not predict all ambulation outcomes after hospital discharge. Especially at three and six months, walking endurance alone did not predict free-living ambulation outcomes. The process of recovering free-living activity and participation also involves stroke survivors accepting and adapting to post-stroke changes and disruptions to lifestyle (Woodman et al., 2014; Walsh et al., 2014). Thus, beyond these time points factors relating to post-stroke changes may not limit free-living behaviours, as survivors have already adapted to changes post-stroke. In the current thesis, age, executive function and pre-stroke activity were significant predictors of both ambulation activity and community ambulation outcomes. This is interesting, as stroke survivors who are younger and more active prior to stroke also have better prognosis and functional recovery after stroke (Riccardi et al., 2014; Baert et al., 2012; Veerbeck et al., 2011; Stroud et al., 2009; Krarupp et al., 2007; Wendel-vos et al., 2004). Similarly, younger stroke survivors, with high pre-stroke function and activities, and no cognitive impairments are more likely to be accepted into rehabilitation (Hayward et al., 2014; Hakkennes et al., 2011).

From the results of studies five and seven, stroke survivors who are older, display executive function deficits and demonstrate low levels of activity prior to stroke may need to be monitored during stroke rehabilitation, especially after three months following hospital discharge. Age may affect free-living ambulation outcomes through the effect of associated changes in cognitive function (Marchant et al., 2013), balance (Lee and Park, 2014), function (Hollman et al., 2011), social roles and purpose (Desrosiers et al., 2005b) and co-morbidities (Bammer et al., 2014). Executive function impairments can influence the ability of stroke survivors to re-engage in free-living ambulation after returning home from hospital through its effect on uptake of advice and training programs (Best et al., 2014) and gait (Doi et al., 2014). Thus these stroke survivors may require rehabilitation of executive function impairments; or would benefit from a review of advice, recommendations and strategies to assist with returning to free-living ambulation at three months, as these may not be retained from their time in inpatient rehabilitation (Best et al., 2014). Stroke survivors who were previously inactive, are more likely to have less drive and motivation to recover an active lifestyle after stroke (Rimmer, 2008). Further, they may have more concerns regarding commencing new activity and community based roles and responsibilities (Barnsley et al., 2012). Thus, it may take longer for these stroke survivors to initiate walking activities after returning home. Follow-up and interventions beyond three months of hospital discharge should also consider the role of these factors on outcomes.

One important finding in the current thesis was that both volume of steps and time spent in the community was not predicted by any factor at discharge after three months. This is further to a limited recovery of overall community ambulation over the first six months after hospital discharge. Though a range of factors was assessed, no factor was significantly related at these time points. This could be the result of a low proportion of stroke survivors reporting an impairment or limitation in a number of factors assessed in the research studies of the current thesis. It could also suggest that there are other factors that may impact upon community ambulation outcomes after stroke. For example, community environments are often reported as barriers or facilitators to community ambulation outcomes (Barclay et al., 2014; Robinson et al., 2013; Shumway-Cook et al., 2002). These were not explored in this thesis. Also, the process of community reintegration has been highlighted as a more complex goal that may be affected by the personal processes of accepting change and building individual confidence and meaning to initiate tasks in the community (Woodman et al., 2014; Walsh et al., 2014; Barnsley et al., 2012). Investigation of these factors would be beneficial in the future, as recovery of community ambulation is low across the first six months after stroke. A lack of recovery or successful return to community ambulation across this stage may result in stroke survivors having limited recovery in these domains even later after stroke (Nalder et al., 2012; Woodman et al., 2014). Review of post-stroke free-living ambulation outcomes (especially community ambulation) may be required at three months, as factors at discharge no longer contribute to all outcomes.

Significant predictors were found for all measures of ambulation activity, and most measures of community ambulation across the first six months after hospital discharge. However, not all variance in outcomes were predicted. Thus, it is important to consider the role of other factors at discharge on the recovery of both ambulation activity and community ambulation after stroke. While the studies in this thesis found that factors such as ambulation self-efficacy, fatigue, perceived health status and stroke recovery had a poor relationship with free-living ambulation outcomes after discharge, this could be because the cohort had no deficits in these factors. In individuals with chronic stroke, fatigue, mood, gait speed, balance and self-efficacy have significantly predicted free-living ambulation outcomes (Alzahrani et al., 2012; Fulk et al., 2010; Michael et al., 2005; Lord et al., 2004). Also, at hospital discharge, self-reported outcomes in these factors may be different to those experienced by stroke survivors once they return home – to an environment where help is not readily available and deficits are observed as they attempt to re-integrate back into their pre-stroke lifestyles. Scores in these factors may be different later after discharge as survivors begin to re-integrate. Thus, review of these factors on outcomes respective to each time point is required.

Other factors such as the physical environment (Patla and Shumway-Cook, 1999), strength (Rosa et al., 2014; Robinson et al., 2011b), social support (Barnsley et al., 2012), driving (Barnsley et al., 2012), therapy volume and intensity, priorities (Korner-Bitensky et al., 2008), return to work and social roles (Plante et al., 2010a; Treger et al., 2007) could potentially affect outcomes in free-living ambulation. These were beyond the scope of this thesis, and thus not assessed. Also, return to activity and participation after stroke, may also be largely affected by the personal processes that take place once stroke survivors return home, including accommodation to changes and disruptions in life (Woodman et al., 2014; Barnsley et al., 2012; Nalder et al., 2012). In future, qualitative assessment of how choices are made to recover ambulation and what factors act as barriers and facilitators to optimal outcomes is required.

8.2.5. Suggestions for management

Recovery of free-living ambulation is limited after stroke. Low levels of ambulation activity are observed across the subacute phase. Further, recovery of community ambulation does not occur until six months after hospital, despite stroke survivors meeting functional requirements for optimal outcomes. Even later after stroke, survivors report high dissatisfaction with ambulation outcomes (Robinson et al., 2011a; Lord et al., 2004). They also report goals to increase walking capacity (Combs et al., 2013), and limitations within body structures and function, activity, environment and personal domains of the ICF that impact upon ambulation outcomes (Barclay et al., 2014; Nicholson et al., 2012; Robinson et al., 2011; Lord et al., 2004). Poor free-living ambulation can impact upon general health outcomes and contribute to further burden resulting from stroke. Thus, there is a need to consider current management of stroke to encourage increased activity and assist with community ambulation recovery.

Gait endurance training (including cardiorespiratory training) should be a priority during rehabilitation after stroke. Current inpatient rehabilitation of stroke survivors in Australia rarely push stroke survivor heart rate past 35% of maximal heart rate reserve, even if survivors are able walkers (Kuys et al., 2006). Thus, improvements in cardiorespiratory fitness and exercise tolerance, and resultant improvements in gait endurance are rarely achieved during inpatient rehabilitation. This is especially important after stroke, as many stroke survivors demonstrate poor activity behaviours prior to stroke onset (Ricciardi et al., 2014; Baert et al., 2012), and are likely to return to sedentary behaviours without appropriate intervention (English et al., 2014). Gait endurance is strongly related to beneficial activity behaviours (e.g. long duration and high intensity ambulation), even at six months after hospital discharge (see Chapters 5 and 7). It also demonstrates a strong relationship with activity volume and intensity in people with chronic stroke (Alzahrani et al., 2011; Fulk et al., 2010; Mudge & Stott, 2009). Targeting gait endurance through improving both functional and balance problems, and cardiorespiratory fitness during rehabilitation may be a successful way of encouraging increased beneficial activity behaviours. This in turn will result in improved outcomes in general health, function and quality of life (Billinger et al., 2014; Gordon et al., 2004).

Currently, community ambulation is not always a priority during inpatient rehabilitation after stroke (Hayward et al., 2014). However, while characteristics of community ambulation may change over the first six months of returning home (through increased time spent in long duration ambulation bouts), total daily averages for step count, time spent walking and time spent in the community do not increase over this time. This is despite post-discharge therapy and stroke survivors meeting functional requirements for independent community ambulation (i.e. gait speed > 0.8m/s and gait endurance > 300m) (Andrews et al., 2010; Perry et al., 1995; Lerner-Frankiel et al., 1986). Even in the chronic phase of recovery, stroke survivors report difficulty and dissatisfaction with community ambulation outcomes (Robinson et al., 2011b; Lord et al., 2004), reduced community trips (Robinson et al., 2011a) and limitations in community ambulation (Barclay et al., 2014; Rosa et al., 2014; van der Zee et al., 2013; Robinson et al., 2011b).

Community ambulation goals, expectations and interventions should be addressed early, to avoid negative experiences and mismatched expectations during the early phase of returning home (Ahuja et al., 2013; Sarre et al., 2014; Wood et al., 2010). This could be done from within the inpatient setting, by assisting stroke survivors to successfully transition between goals such as: (1) gaining physical function, (2) establishing independence, (3) adjusting expectations and (4) physical capacity to engage in meaningful roles (Wood et al., 2010). At around six months, community ambulation goals should be revisited and any restrictions addressed through appropriate intervention and problem solving with the assistance of a health professional, as this is when changes may be first observed. Further study of appropriate ways to encourage return to community-based activities after stroke, including community ambulation is required.

This thesis demonstrated that most daily ambulation bouts of long duration and high intensity took place outside the home and yard (see figures 8.1 and 8.2). As high intensity and long bouts of walking are beneficial for health, improving independence and recovery of community ambulation may improve activity behaviours after stroke. Similarly, community-based programs that encourage free-living ambulation activity and participation may increase longer duration and high intensity bouts of ambulation, rather than household therapy alone, due to the distance and speed requirements associated with community environments (Andrews et al., 2010). Thus, recovery of community ambulation should be a priority during rehabilitation after stroke, as it may also increase daily beneficial activity behaviours.

Individuals who are inactive prior to stroke will most likely return to poor ambulation levels after stroke – unless interventions are put in place. Hospital based exercise groups during rehabilitation may also assist in changing these attitudes and perceptions around exercise and what is sufficient activity. In other population groups, like those with heart disease, rehabilitation following surgical intervention (i.e. cardiac rehabilitation) targets lifestyle modifications to improve activity behaviours. For a group who are potentially in hospital for a significant period of time, it would be a useful opportunity to intervene with programs to change perceptions on ‘sufficient activity levels’ for health benefits. Further, during rehabilitation, it is possible to incorporate facilitators of exercise and activity after stroke. Group exercise sessions that are easily accessible within the hospital ward, incorporated as part of a daily routine, with therapist assistance to plan and manage barriers to activity would be useful during inpatient post-stroke rehabilitation. Changing perceptions around free-living ambulation, beneficial activity behaviours and what is sufficient activity following stroke are required early during post-stroke management.

It is important to consider appropriately timed, targeted interventions specific to the patient and their goals after stroke (Pollock et al., 2014). Priorities, goals and barriers and facilitators may be different based on impairments, activity limitations and participation restrictions. However, incorporating these into management after stroke may lead to better outcomes. For example, individuals with stroke who are high functioning, may need to focus more on gait endurance than those who are still attempting to achieve independence with gait. Also, with the current pressure on rehabilitation services, tailoring management styles to characteristics of stroke survivors may be a more efficient way of managing post-stroke limitations and restrictions. Identifying and appropriately referring stroke survivors with traits suited for self-management programs (Lennon et al., 2013) may allow health services to focus on those who require more assistance to engage in free-living ambulation. For example, this thesis found stroke survivors who were younger and engaged in more activity prior to stroke were more likely to have increased free-living ambulation after hospital discharge. Individuals who were active prior to stroke may be highly motivated to return to pre-stroke activities and participation, and thus self-management programs, where advice and strategies are given, and follow-up is offered periodically may suffice (Lennon et al., 2013). Conversely, individuals who are older, previously inactive and display executive function deficits may require more frequent follow-up to ensure that recovery of free-living ambulation is optimal. Finally, follow-up of stroke survivors should be appropriately timed. Follow-up of participation goals, such as community ambulation, may need review later after hospital discharge, at around three to six months after stroke survivors return home. At this time, factors at hospital discharge are unable to predict all outcomes, and thus other factors may influence outcomes in individuals with stroke. Thus, while participation goals like community ambulation should be addressed early within the inpatient setting after stroke, review of changes in community ambulation should occur again around three to six months.

The goal of improving free-living ambulation should be targeted through assessment of free-living ambulation outcomes and management of free-living ambulation activity and participation behaviours (rather than clinic-based interventions alone). It is possible to measure outcomes in free-living ambulation after stroke, and thus these tools should be used to assess outcomes clinically. Also, while improvement in clinic-based measures of gait are important, it is also important to consider training ambulation activity and community ambulation within stroke survivors' living environments. A recent study has looked at providing stroke survivors with accelerometers, advice on how to adopt beneficial activity behaviours within household and community environments (e.g. to increase longer ambulation bouts) and assistance with setting patient-specific, targeted goals (e.g. 25% increase in daily steps per week) (Danks et al., 2014). By doing this, the issues (e.g. barriers) directly relating to free-living ambulation can be managed, and goals are specific to improving free-living ambulation.

There is a dire need for increased public health awareness campaigns surrounding activity requirements for health benefits. Post-stroke outcomes are predicted by pre-stroke activity behaviours. Thus, encouraging and establishing healthy behaviours within the healthy population will not only reduce stroke risk, but also increase the ease with which stroke survivors may recover free-living ambulation after hospital discharge.

8.3. Strengths and limitations of the thesis

8.3.1. Strengths

This thesis prospectively investigates the recovery of free-living ambulation across the subacute phase of stroke. The series of studies are the first to use a combination of a validated accelerometer and GPS device to measure free-living ambulation outcomes across the subacute phase of stroke. No other research study has presented isolated measures of community ambulation from total daily ambulation outcomes after stroke. Further, the studies of this thesis prospectively investigated characteristics other than traditional volume measures of ambulation alone. Data has been presented in a manner that shows overall daily averages of volume, frequency and intensity of free-living ambulation, measured over four days. These characteristics of ambulation have been defined based on previous definitions used to characterise ambulation in older adults and individuals with chronic stroke and provide a better representation of how ambulation activity and community ambulation is spread across each day.

The study designs used in the current thesis employ a repeated measures design with a longer follow-up period of six months. Thus far, studies of ambulation activity and community ambulation after stroke has mostly been measured across time points up to three months (Manns & Baldwin, 2009; Shaughnessy et al., 2005; Lord et al., 2004), with only one study measuring daily step counts at six months (Moore et al., 2013). This thesis captures ambulation recovery longitudinally over the first six months after stroke, where survivors may potentially experience the greatest changes. This was significant as this thesis demonstrated that free-living ambulation outcomes could increase or change even at six months, when functional recovery is believed to plateau. This is different to earlier reports of activity and participation recovery after stroke (Moore et al., 2013; Desrosiers et al., 2008).

8.3.2. Limitations

Limitations for each study are reported in their respective chapters and will not be repeated in this section. However, overall limitations of the thesis require consideration. The high proportion of drop outs across all studies resulted in a lower final number of participants for analysis. However, even though this number was small, participants represented a range of characteristics in age, pre-stroke activity and participation level as well as therapy and carer support on discharge. Further, high drop out rates demonstrated the importance of using simple and easy to use devices and research methods to ensure better uptake of measurement methods and attendance at future follow-ups.

Also, the results of this thesis may only be applicable to high functioning stroke survivors living in Brisbane, Australia. Though this was not the intention during recruitment, inclusion and exclusion criteria used in these studies have contributed to sample slightly selective of higher functioning stroke survivors. The results of this thesis may not be applicable to stroke survivors discharged to residential aged care facilities, demonstrating dependence with gait or cognitive impairment or living in other locations (eg. Canada).

The first follow-up time point employed in studies two to four was one month. In other studies of subacute stroke survivors, often an earlier time point is used (one to two weeks prior to or following discharge). This earlier time point may have allowed for measurement of changes that occurred across the very early stages of returning home, when stroke survivors are still accommodating to changes after their stroke.

Though the use of devices for measurement of ambulation recovery is promising, it is important to consider limitations. The GPS device has been a popular tool to measure outdoor walking, and community based activities in individuals with mobility difficulty and stroke. However, though deemed accurate and reliable for location and time spent walking in Study one, the GPS device still relies on stroke survivors to switch the device on and start recording during free-living ambulation measurement. This relies on participant memory. During free-living ambulation measurement, there were times that participants forgot to wear the device, charge the device overnight or switch the device on at the beginning of each community trip, and stop it on their return home. Thus, a large proportion of community trip recordings were missing during the three measurement periods. Conversely, the accelerometer used in the thesis (ActivPAL^{TM}) was attached to the participants' leg at the beginning of the measurement period and did not require any input from participants during the four day measurement period. Thus, accelerometer data was available for most participants. In future studies, issues with GPS battery life should be considered, to enable use of the device for longer periods of measurement. This will enable continuous monitoring of ambulation without a reliance on participants to don devices and start recordings. Thus, the risk of missing data will be reduced. Also, alternative devices that are familiar to patients with a longer battery life, such as smartphones would benefit from consideration for free-living ambulation measurement after stroke.

In studies two to four, intensity of ambulation activity was determined by cadence or steps per minute. This method has been previously used (Manns et al., 2009), but has not been validated as a true measure of intensity after stroke. Thus, the cadence definitions used in this thesis may not truly reflect low, moderate and high intensity ambulation outcomes after stroke. Intensity of activity is more commonly measured in terms of METS (ACSM, 2013). Both accelerometers tested in Study one (ActivPAL^{TM} and Sensewear) provide METS measures. However, validating these devices for accuracy of METS scores was beyond the scope of this thesis. Cadence definitions used in the current thesis would benefit from comparison with accurate measures of METS to ascertain if such definitions are representative of these intensities after stroke.

In studies three and five, only factors at discharge were assessed for their ability to predict outcomes at one, three and six months after hospital discharge. This was chosen to allow for improved awareness of factors that could affect free-living ambulation outcomes later after hospital discharge, to thus assist in improving current goal-setting processes and discharge planning, while accounting for these factors at discharge. These factors would benefit from investigation over time, as factors assessed (e.g. mood, gait endurance and gait speed, ambulation self-efficacy) may change over time. Cross-sectional analysis of how these factors predict outcomes at each time point would be useful.

8.4. Conclusions

This thesis has contributed original, new information regarding the measurement and recovery of ambulation activity and community ambulation after stroke. It demonstrated that measurement of free-living ambulation after stroke is possible with devices such as accelerometers and GPS, but that further investigation of devices with GPS capacity is warranted to ensure accuracy in the measurement of distance, a longer battery life, reduced issues with satellite interruptions and to ensure easy use by people with disability. When the recovery of ambulation after stroke was investigated, this suite of studies found that ambulation activity is low across the first six months after discharge from hospital post-stroke and that the recovery of activity occurs only through an increase in bouts short to medium in duration and moderate in intensity, with no increase in beneficial activity behaviours such as long duration bouts or high intensity walking. Community ambulation does not change until six months after hospital discharge, primarily through an increase in time spent in long ambulation bouts. When the prediction of free-living ambulation was investigated, gait endurance best predicted outcomes at one month. Beyond this time point, other factors such as age, executive function and pre-stroke activity contributed to outcomes in free-living ambulation. Interventions targeting free-living ambulation are required to improve volume of ambulation activity and community ambulation, as well as increase beneficial activity behaviours such as long duration and high intensity ambulation bouts after hospital discharge. The studies included in this thesis have demonstrated that recovery of free-living ambulation across the first six months after stroke survivors return home is low, despite high scores in clinic-based measures of ambulation, and high recovery potential. The thesis also proposes tools and measures for free-living ambulation measurement within both research and clinical settings, and considerations for follow-up time frames and management of free-living ambulation after stroke. Using these suggestions, free-living ambulation outcomes may be improved after stroke.

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Appendices

Appendix one: Institutional ethics approval and patient information and consent forms for Study one (The University of Queensland)

THE UNIVERSITY OF QUEENSLAND

Institutional Approval Form For Experiments On Humans Including Behavioural Research

Chief Investigator:	Ms Niruthikha Mahendran
Project Title:	Reliability And Validity Of Devices Measuring Community Walking Following Stroke
Supervisor:	A/Prof Sandra Brauer
Co-Investigator(s):	Ms Emma Downie, Ms Phoebe Ng, Dr Suzanne Kuys
Department(s):	Division of Physiotherapy, School of Health & Rehabilitation Sciences
Project Number:	2011000446
Granting Agency/Degree:	PhD
Duration:	30th June 2012

Comments:

Name of responsible Committee:-
Medical Research Ethics Committee
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

Name of Ethics Committee representative:-
Professor Bill Vicenzino
Chairperson
Medical Research Ethics Committee

Date: 13.5.2011 Signature: ____________

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

School of Health and Rehabilitation Sciences

Head of Division
Professor Bill VICENZINO, BPhty, Grad Dip Sports Phty, MSc, PhD

The University of Queensland
Brisbane Qld 4072 Australia
Telephone (07) 3365 2275
International +61 7 3365 2275
Facsimile +61 7 3365 1622
Internet www.shrs.uq.edu.au

Participant Information Sheet

TITLE: Reliability and validity of devices measuring community walking following stroke

LAY TITLE: Investigating the accuracy of devices to measure the amount of walking in the community performed by people with stroke.

INVESTIGATORS: **Ms Niruthikha Mahendran**
Post- graduate student, Division of Physiotherapy, School of Health and Rehabilitation Sciences, University of Queensland
Associate Professor Sandra Brauer
Division of Physiotherapy, School of Health and Rehabilitation Sciences, University of Queensland
Dr Suzanne Kuys
School of Physiotherapy and Exercise Science, Griffith University
Ms Phoebe Ng
Honours Student, Division of Physiotherapy, University of Queensland
Ms Emma Downie
Honours Student, Division of Physiotherapy, University of Queensland

You are invited to participate in the research titled 'Reliability and validity of devices measuring community walking following stroke'. Your participation in this study is voluntary.

Research aim and participant selection
This study aims to determine the accuracy and reliability of various devices to measure community walking in people with stroke. There are many devices that have been used to measure the amount of walking performed; however, there is a lack of research investigating the use of these devices on the stroke population. The study will help us to determine which device is most appropriate to measure community walking in the stroke population, allowing us to assess the effectiveness of different treatments designed to improve community walking. You are invited to participate in this research because you currently live in the community, have had a stroke at least 6 months prior and are able to walk 10 metres.

Description of research
If you agree to participate in this research you will be asked to wear 3 small, light devices that will be used to measure the amount of walking you perform whenever you leave your house. One device, will be worn around the thigh, one around the arm and one will slip into a pocket on a loose fitting vest. Two of these devices will measure your level of activity. The last device, a Global positioning device (GPS) will provide information on the location of your trip. Information from the three devices will be used by researchers to determine exactly how far from home you travelled and the types of places you visited (for example, the shops,

medical practice). Additionally, you will be asked to complete a diary, detailing the amount of community walking performed. The data from the devices and dairy will be collected over two 4-day periods, with a 7 day break between these 2 testing periods. Data will be collected at the University of Queensland, St Lucia. We do not guarantee that you will receive any direct benefit from participating in this study; however you will be helping us in determining the most appropriate way to measure community walking post stroke and therefore use these devices to determine the effectiveness of different treatments on community ambulation. There are no personal risks associated with any tasks outlined in this description of research.

Confidentiality and Privacy Protection
Your privacy and confidentiality will be maintained at all times during this research. Any information that is obtained in this study will remain confidential and will only be disclosed with your permission, except if required by law. No data collected from the devices will be linked or associated with any of your personal details. If you give us permission by signing the consent form, we plan to publish the results in international scientific journals. Your identity will not be disclosed in any publication. If you experience any problems or have any questions or concerns during the study, you can contact the research staff on the telephone number provided. We will report the findings and conclusions of this study in the Stroke Association Queensland Support Group's newsletter and on your request, we can discuss your personal results with you and provide a summary of the overall results and conclusions at the completion of the study. You can also be directed to any publications arising from this research.

Withdrawal from the research
Your participation in this research is voluntary and if at any time you wish to withdraw from the research you can do so freely and without reason. This will not affect your relations with the University of Queensland.

This study has been cleared by one of the human ethics committees of The University of Queensland in accordance with the National Health and Medical Research Council's guidelines. You are of course, free to discuss your participation in this study with project staff:

Niru Mahendran on 0413 656 226, or E-mail niru_uq@hotmail.com

If you would like to speak to an officer of the University not involved in the study, you may contact the Ethics Officer on 3365 3924.

Thankyou
We would like to thank you for your interest in the research titled 'Reliability and validity of devices measuring community walking following stroke'. You will be given a copy of this form to keep.

Niru Mahendran, Sandra Brauer, Suzanne Kuys, Emma Downie and Phoebe Ng

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

School of Health and Rehabilitation Sciences

Head of Division
Professor Bill VICENZINO, BPhty, Grad Dip Sports Phty, MSc, PhD

The University of Queensland
Brisbane Qld 4072 Australia
Telephone (07) 3365 2275
International +61 7 3365 2275
Facsimile +61 7 3365 1622
Internet www.shrs.uq.edu.au

Consent Form

TITLE: Reliability and **v**alidity of devices measuring community walking following stroke

LAY TITLE: The accuracy of devices used to measure walking in people with stroke.

INVESTIGATORS: **Ms Niruthikha Mahendran**
PhD candidate, Division of Physiotherapy, School of Health and Rehabilitation Sciences, University of Queensland
A/Prof Sandra Brauer
Division of Physiotherapy, School of Health and Rehabilitation Sciences, University of Queensland
Dr Suzanne Kuys
School of Physiotherapy and Exercise Science, Griffith University
Ms Phoebe Ng
Honours Student, Division of Physiotherapy, University of Queensland
Ms Emma Downie
Honours Student, Division of Physiotherapy, University of Queensland

1. I ____________________(PRINT NAME) hereby consent to my involvement in the research titled "Reliability and **v**alidity of devices measuring community walking following stroke".

2. I have read and understood the participant information sheet and have received a copy to keep. All proposed aims of this study have been explained by research staff to my satisfaction. I voluntarily give my consent to participate in this study.

3. The procedure of the study has been explained to me, including the length of time the study will take, the frequency with which the procedure will be performed, and an indication that there is little or no personal risk involved in this study. I understand I will be asked to do the following:
   - Attend one session where I will walk indoors, outdoors and on a treadmill and complete questionnaires
   - Wear 3 devices for one 4 day period during waking hours.
   - Write in a diary detailing where I walked, how far I walked and my reasons for walking every time I leave the vicinity of my house and front/back garden.

4. I understand that my involvement in this study may not benefit me directly.

5. I understand that I am free to withdraw from this study at any time without reason and without affecting my relations with the University of Queensland or Princess Alexandra Hospital.

6. I am informed that all of my personal details will be kept confidential and that if results are published, they will be presented in such a way that my identity will be unidentifiable.

Signed: _________________Name: ____________________Date: _______________
(Participant)
Signed:_________________ Name: ____________________Date: _______________
(Investigator)
Signed: _________________Name: ____________________Date: _______________
(Witness)

Appendix two: Activity diary

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Date_______________P________

Thank you for participating in this study. This study aims to determine how accurate devices are when used to measure walking in people with stroke. To do this, we require you to wear the Sensewear, ActivPAL and GPS watch and to record your outings over 4 consecutive days. Instructions are detailed below:

Day 1 ____

Day 2 ____

Day 3 ____

Day 4 ____

1. When you first get up in the morning, attach the ActivPAL to your thigh and Sensewear on your arm (as per instruction sheet). They need to be removed before sleeping, showering or any activity where it would get wet (ie swimming).
2. Before you leave the house, put on the GPS watch and follow the instruction sheet. Start recording your trip and write down the time you left the house on the activity diary.
3. Once you have returned home, save the GPS data and remove the GPS watch as per instruction sheet. The ActivPAL and Sensewear remains attached. Fill in the rest of the activity diary for each trip.
4. Once you have completed your recordings over the 4-day period, you can remove the devices and place all equipment in the bags provided. When you come in for your next appointment please return all equipment.

Next Appointment: ____

If you run into any problems during this activity, please contact Niru on **0413 656 226**.

DAY 1: ____________________

MORNING (AFTER BREAKFAST) **TIME:**

*How **fatigued** do you feel right now?*

0 10

No fatigue Worst fatigue imaginable

Comments:

____

____

____

How **motivated** are you to be active?

Morning

0 10

No motivation at all Extremely motivated

Comments:

____

____

____

EVENING (BEFORE DINNER) **TIME:**

How **fatigued** do you feel right now?

0 ______________________________ 10

No fatigue Worst fatigue imaginable

Comments:

____

____

____

How **motivated** are you to be active?

0 ______________________________ 10

No motivation at all Extremely motivated

Comments:

____

____

____

____

TRIP INFORMATION (DAY 1)

Trip 1

Time Out	Time In	Where did you go?	Comments

1. Why did you leave your house – to go to (tick)

□ Shops in your local area □ Friends'/ Families homes □ The doctor

□ Shops outside your local area □ Church □ For exercise

□ Walk pets □ Your workplace (paid or unpaid) □ The Chemist

□ Sports facilities (participate /spectator) □Cafés, cinemas etc

Other:____

____

2. How long did this trip last for?

☐ <30mins ☐ 30mins-1 hr ☐ 1-3 hrs ☐ 3-4 hrs ☐ >4 hrs

3. How much walking did you do during this trip?

☐ none ☐ 0 - 15min ☐ 15-30mins ☐ 30-45mins ☐ 1hr ☐ 1hr – 1.5hrs ☐2hrs ☐>2hrs

4. How did you get to your destination? (e.g. drove, walked)

☐ Drove yourself ☐Carer/spouse/friend drove you ☐Walk ☐ Other (e.g. bus)

5. Did you go alone or with someone? Who? (e.g. wife, Carer, family member)

____

7. Did you experience any of the difficulties below when on your trip?

☐Fall ☐Loss of Balance ☐ Anxiety ☐Fatigue ☐ Too difficult to walk ☐ Other ☐No Problems

Trip 2

Time Out	Time In	Where did you go?	Comments

1. **Why did you leave your house – to go to (tick)**

□ Shops in your local area □ Friends'/ Families homes □ The doctor

□ Shops outside your local area □ Church □ For exercise

□ Walk pets □ Your workplace (paid or unpaid) □ The Chemist

□ Sports facilities (participate /spectator) □Cafés, cinemas etc

Other:____

____

2. How long did this trip last for?

☐ <30mins ☐ 30mins-1 hr ☐ 1-3 hrs ☐ 3-4 hrs ☐ >4 hrs

3. How much walking did you do during this trip?

☐ none ☐ 0 - 15min ☐ 15-30mins ☐ 30-45mins ☐ 1hr ☐ 1hr – 1.5hrs ☐2hrs ☐>2hrs

4. How did you get to your destination? (e.g. drove, walked)

☐ Drove yourself ☐Carer/spouse/friend drove you ☐Walk ☐ Other (e.g. bus)

5. Did you go alone or with someone? Who? (e.g. wife, Carer, family member)

____

7. Did you experience any of the difficulties below when on your trip?

☐Fall ☐Loss of Balance ☐ Anxiety ☐Fatigue ☐ Too difficult to walk ☐ Other ☐No Problems

Appendix three: Institutional ethics approval for Studies two to four (The University of Queensland)

THE UNIVERSITY OF QUEENSLAND

Institutional Approval Form For Experiments On Humans Including Behavioural Research

Chief Investigator:	Miss Niruthikha Mahendran
Project Title:	Barriers And Facilitators To Community Ambulation Post-Stroke: A Longitudinal Perspective
Supervisor:	A/Prof Sandra Brauer, Dr Suzanne Kuys
Co-Investigator(s)	A/Prof Sandra Brauer, Dr Suzanne Kuys
Department(s):	Division of Physiotherapy, SHRS; Allied Health Research Collaborative, PCH
Project Number:	2012000060
Granting Agency/Degree:	PhD
Duration:	31st January 2014

Comments:

Expedited review on the basis of approval from the Prince Charles Hospital HREC, dated 18/10/2011.

Name of responsible Committee:-
Behavioural & Social Sciences Ethical Review Committee
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

Name of Ethics Committee representative:-
Associate Professor John McLean
Chairperson
Behavioural & Social Sciences Ethical Review Committee

Date 25/1/2012 Signature [signature]

Appendix four: Hospital (TPCH) ethical approval and patient information and consent forms for Studies two to four

Ms Niruthikha Mahendran
School of Health and Rehabilitation Sciences
University of Queensland
BRISBANE QLD 4072

Human Research Ethics Committee
The Prince Charles Hospital
Metro North Health Service District
Administration Building, Lower Ground
Rode Road, Chermside QLD 4032
Executive Officer Research & Ethics Ph: (07) 3139 4500
Office Ph: (07) 3139 4691

18 October 2011

Our Ref: PL/JL/ Low Risk Approval

Dear Ms Mahendran,

Re: HREC/11/QPCH/160: Barriers and facilitators to community ambulation post-stroke: A longitudinal perspective. N. Mahendran

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.

I am pleased to advise that the Human Research Ethics Committee has granted approval of this research project. The documents reviewed and approved include:

Document	Version	Date
Low Risk Application (including Site Specific Assessment)		
Protocol	1	September 2011
Participant Information Sheet & Consent Form (Stroke Survivor)	1.1	20 September 2011
Participant Information Sheet & Consent Form (Carers and Therapists)	1.1	20 September 2011

Approval of this project is subject to the same confidentiality and privacy requirements as apply to other research projects and research subjects are not recognisable in publications or oral presentations.

Please complete the Commencement Form before starting your study and return to the office of the Human Research Ethics Committee. http://www.health.qld.gov.au/tpch/documents/form_notification.dot

If you intend to publish the results of your work, it is advisable to ascertain from prospective journal editor/s the actual requirements for publication e.g. some journals may require full ethical review of all studies. When results are published, appropriate acknowledgment of the hospital should be included in the article. Please forward copies of all publications resulting from the study for inclusion in the Internet website list.

On behalf of the Human Research Ethics Committee, I would like to wish you every success with your research endeavour.

Yours truly,

Dr Russell Denman
Chair
HUMAN RESEARCH ETHICS COMMITTEE
METRO NORTH HEALTH SERVICE DISTRICT

Office	Postal	Phone
The Prince Charles Hospital	Administration Building, Lower Ground Rode Road Chermside Q 4032	(07) 3139 4500/3139 4691

The Prince Charles Hospital
Metro North Health Service District

Queensland Government
Queensland Health

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

School of Health and Rehabilitation Sciences

Head of Division
Professor Bill VICENZINO, BPhty, Grad Dip Sports Phty, MSc, PhD

The University of Queensland
Brisbane Qld 4072 Australia
Telephone (07) 3365 2275
International +61 7 3365 2275
Facsimile +61 7 3365 1622
Internet www.shrs.uq.edu.au

Participant Information Sheet

HREC No:	
Project Title:	Barriers and facilitators to community ambulation post-stroke : A longitudinal perspective
Name of Researchers:	Ms Niruthikha Mahendran, Associate Professor Sandra Brauer, Dr Suzanne Kuys

Project Title: Barriers and facilitators to community ambulation post-stroke : A longitudinal perspective

Lay Title: Factors affecting walking out in the community after stroke – an analysis over time.

Name of Researchers:

Ms Niruthikha Mahendran
Post- graduate student, Division of Physiotherapy, School of Health and Rehabilitation Sciences, University of Queensland
Associate Professor Sandra Brauer
Division of Physiotherapy, School of Health and Rehabilitation Sciences, University of Queensland
Dr Suzanne Kuys
Allied Health Research Collaborative, The Prince Charles Hospital and School of Physiotherapy and Exercise Science, Griffith University

You are invited to participate in the research titled 'Barriers and facilitators to community ambulation post-stroke : A longitudinal perspective'. Your participation in this study is voluntary.

Background

Walking out in the community to return to previous social, leisure, employment and exercise-related activities is an important goal for a number of stroke survivors. However, many stroke survivors do not walk as much as required for health benefits or as much as they would like to. The aim of this study is to identify stroke survivor goals for walking in the community, and the factors that challenge and assist them in walking within their community. Moreover, we hope to better understand the changes in walking behaviours, goals for walking and challenges/assistive factors that are associated with walking in the community over time, and with functional recovery, and also the differences between therapists, carers and stroke survivors to see if there are any discrepancies between these groups.

If you agree to partake in this research project, you will be required to attend four assessment sessions of maximum two hour duration. One of these will be just before you are discharged home, and the others will be at one, three and six months after discharge home. All assessments will involve an interview and some questionnaires about your physical activity levels, fatigue, and walking confidence. At the one, three and six month reviews, we will provide you with three light-weight devices that will measure the amount of walking you complete out in the community and the locations you visit. One device will be worn around the thigh, one around the arm and one will slip into a pocket on a loose fitting vest. Two of these devices will measure your level of activity. The last device, a Global positioning device (GPS) will provide information on the location of your trip. Information from the three devices will be used by researchers to determine exactly how far from home you travelled and the types of places you visited (for example, the shops, medical practice). Additionally, you will be asked to complete a diary, detailing the amount of community walking performed. The devices will measure your walking activities for four days, after which we will pick up the devices from you.

Benefits

Each year, more than 60,000 Australians experience a stroke. Many of these individuals experience difficulty with walking. Decreased walking has been shown to be related to a poor health status, further loss of strength and function, increased risk of chronic diseases like diabetes and an overall decreased quality of life. Walking out in the community to return to previous social, leisure, employment and exercise-related activities is an important goal for a number of stroke survivors. It is important to identify those factors that both assist, and challenge stroke survivors to get out and about within their community. By identifying what factors make walking in the community difficult, health professionals and researchers may be able to develop more specific rehabilitation programs to cater for stroke survivors' needs. Moreover, by understanding the changes with time and recovery after stroke, health professionals will have a better understanding of the changes in stroke survivors' goals and expectations, and also the changes in the factors that assist/challenge a stroke survivor walking out in the community over time. With this knowledge, researchers and health professionals will be better equipped with knowledge to develop rehabilitation programs and community services that will allow for greater support of stroke survivors at each phase of their recovery. Thus we can improve functional outcomes and independence in walking out in the community, and ultimately prevent further hospitalisation and improve stroke survivors' overall quality of life.

We cannot guarantee that you will receive any direct benefit from participating in this study; however you will be assisting us in identifying those challenges and assisting factors to walking in the community and general goals of stroke survivors. Thus you will be assisting the development of improved rehabilitation practices.

Risks and Side Effects

We do not foresee there to be any personal risks associated with any tasks outlined in this description of research.

Confidentiality and Privacy

Your privacy and confidentiality will be maintained at all times during this research. Any information that is obtained in this study will remain confidential and will only be disclosed with your permission, except if required by law. No data collected from the devices will be linked or associated with any of your personal details. If you give us permission by signing the consent form, we plan to publish the results in international scientific journals. Your identity will not be disclosed in any publication. If you experience any problems or have any questions or concerns during the study, you can contact the research staff on the telephone number provided. We anticipate reporting the findings and conclusions of this study in the Stroke Association Queensland Support Group's newsletter and on your request, we can discuss your personal results with you and provide a summary of the overall results and conclusions at the completion of the study. You can also be directed to any publications arising from this research.

Withdrawal from the research

Your participation in this research is voluntary and if at any time you wish to withdraw from the research you can do so freely and without reason. This will not affect your relations with the Prince Charles Hospital or University of Queensland.

Further Information

This study has been cleared by The Prince Charles Hospital Human Research Ethics Committee. If you wish to discuss your involvement with someone not connected to the study, please feel free to contact the Executive Officer on 07 3139 4500 who will forward your concerns to the Chair of the Human Research Ethics Committee.

You are of course, free to discuss your participation in this study with project staff:

Niru Mahendran on 0413 656 226, or E-mail niru_uq@hotmail.com

Thank you

We would like to thank you for your interest in the research titled 'Barriers and facilitators to community ambulation post-stroke : A longitudinal perspective' . You will be given a copy of this form to keep.

Niru Mahendran, Sandra Brauer and Suzanne Kuys

Participant Consent Form

Project Title:	Barriers and facilitators to community ambulation post-stroke : A longitudinal perspective
Name of Researchers:	Ms Niruthikha Mahendran, Associate Professor Sandra Brauer, Dr Suzanne Kuys

I, ____agree to participate in the above named project and understand that I:

- € may be interviewed on my perceptions of walking in the community
- € Will need to return to the Prince Charles hospital for a follow-up review at one month, three months and six months after my discharge.
- € Will be required to wear three small, light-weight devices to measure my walking activity at each review for four days.

- I have been informed as to the nature and extent of any risk to my health or well-being.
- I am aware that, although the project is directed to the expansion of medical knowledge generally, it may not result in any direct benefit to me.
- I have been informed that my refusal to consent to participate in the study will not affect in any way the quality of treatment provided to me.
- I have been informed that I may withdraw from the project at my request at any time and that this decision will not affect in any way the quality of treatment.
- I have been advised that the Executive Director, The Prince Charles Hospital, on recommendation from The Prince Charles Hospital Metro North Human Research Ethics Committee has given approval for this project to proceed.
- I am aware that I may request further information about the project as it proceeds.
- I am aware that my GP may be informed that I am taking part in the project.
- I understand that, in respect of any information (which may consist of records outside of this hospital) including audiovisual records obtained during the course of the project; confidentiality will be maintained to the same extent as for my Hospital medical records. In the event of any results of the project being published, I will not be identified in any way.
- I agree that, if necessary, my medical records (in respect of my involvement in this project) may be inspected by a Research Assessor. This assessor may be external to but approved by the Hospital, provided that the Assessor does not identify me or my hospital's medical records in any way to a third party.

Patient's name: .... Signature: .... Date:_ _ / _ _ _ / _ _ _ _
DD / MMM / YYYY

Name of Investigator: ....Signature: .... Date:_ _ / _ _ _ / _ _ _ _
DD / MMM / YYYY

Revocation of Consent Form - Participant

HREC No:	
Project Title:	Barriers and facilitators to community ambulation post-stroke : A longitudinal perspective
Name of Researchers:	Ms Niruthikha Mahendran, Associate Professor Sandra Brauer, Dr Suzanne Kuys

- I hereby wish to WITHDRAW my consent to participate in the research project described above and understand that such withdrawal WILL NOT jeopardise any treatment or my relationship with The Prince Charles Hospital Metro North Health Service District or the University of Queensland.

Participant's name (please print): ....

(Signature)... Date:_ _ / _ _ _ / _ _ _ _
DD / MMM / YYYY

This Revocation of Consent should be forwarded to:

Ms Niruthikha Mahendran
School of Health and Rehabilitation sciences
University of Queensland
St Lucia, 4072