Physical activity in people after stroke following discharge from inpatient rehabilitation

Shamala Thilarajah

Master of Health Sciences (Neurological Physiotherapy)

Bachelor of Applied Science (Physiotherapy)

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Abstract

Stroke survivors are not meeting recommended levels of physical activity. Physical activity is defined as any physical movement that causes energy expenditure due to skeletal muscle contraction. There is consensus that the key modifiable prognostic factors that contribute to post-stroke physical activity levels need to be identified so that new interventions can be developed to target these factors. This thesis focused on the measurement of different aspects of post-stroke physical activity and the identification of modifiable prognostic factors that contribute to physical activity levels amongst stroke survivors. Chapters 2 and 3 synthesised current literature in this area and highlighted the gaps. Chapters 4 and 5 explained the methods to the cross-sectional and the prospective cohort studies in Chapters 6 and 7 respectively.

Chapter 3 synthesised the evidence on factors associated with post-stroke physical activity. A systematic search was conducted across nine databases. Observational studies that recruited community-dwelling stroke survivors and measured factors associated with physical activity were included. Quality in Prognosis Studies checklist was used to assess risk of bias. 26 studies were included in the review and a meta-analysis was conducted on factors that had been investigated in at least two studies. The modifiable factors were physical function (meta r = 0.68-0.73; p < 0.001), cardiorespiratory fitness (meta r = 0.35; p = <0.001), fatigue (meta r = -0.22; p = 0.01), falls self-efficacy (meta r = -0.33; p < 0.001), balance self-efficacy (meta r = 0.37; p < 0.001), depression (meta r = -0.58-0.48; p < 0.001) and health-related quality of life (meta r = 0.38-0.43; p < 0.001). The impact of side of infarct, neglect and cognition on post-stroke physical activity were inconclusive. The majority of the studies were cross-sectional and recruited chronic stroke survivors. There is little known about physical activity amongst community-dwelling stroke survivors in the sub-acute phase. There is a need for prospective cohort studies to establish modifiable prognostic factors that contribute to post-stroke physical activity levels.

At the commencement of this thesis, commercially available ankle-mounted accelerometers were expensive, and the systems did not allow access to raw data. Thus, the aim of Chapter 5 was to validate a custom-made ankle-mounted accelerometer for
use in the subsequent studies in this thesis. Twenty participants were asked to walk along a corridor at a comfortable pace while wearing the accelerometer on the ankle of their unaffected lower limb as recommended. The customised unit was validated against a hand-held counter. The customised unit systematically undercounted steps taken by a small amount (mean difference = 5.3%) that was consistent with the measurement error reported for the criterion reference StepWatch Activity Monitor, and thus was deemed acceptable for use in the sub-acute stroke population.

Chapter 6 was a cross-sectional descriptive study of the context, volume and intensity of physical activity levels. It was completed in individuals who were three months post inpatient rehabilitation discharge and who were community-dwelling within Singapore. Fifty-five participants (median (IQR) time since stroke = 117 (109-129) days) were asked to wear the customised ankle-worn accelerometer and a Global Positioning System (GPS) unit to measure step count and outdoor activity for four days. They were also required to complete an activity diary during the activity monitoring period. The International Physical Activity Questionnaire Short 7 days and the Activity Card Sort were also completed to assess physical activity intensity, context, and participation. The results demonstrated that stroke survivors in the late sub-acute phase took a median of 4870 steps per day (IQR = 1904-8885). They participated in no vigorous activities and the total MET-min/week, median (IQR) was 708.5 (231-2079). Walking and fitness areas near home were the two most common modes of exercise. Grocery or leisure shopping constituted 24% of the walking activity outdoors while 18% was incidental walking activity associated with the use of public transport (active transport). Green-space exercise comprised only 8% of outdoor physical activity. Overall, the study findings indicated that most stroke survivors in the late sub-acute phase participated in walking-related physical activity. Stroke survivors did not often exercise outdoors thus the walking related activity was during shopping, in active transport, or within the home and near surrounds. Further investigation of the underlying causes of low levels of outdoor exercise should be explored.

Chapter 7 presents an exploratory prospective cohort study investigating the modifiable prognostic factors at discharge from inpatient rehabilitation that contribute to physical activity levels at three months post-discharge in the same cohort. Sixty-six consented to
participate in the study, with 64 completing baseline assessment and 55 completing the follow-up assessment. The candidate factors were measured within one week prior to discharge from inpatient rehabilitation and repeated at three months following discharge. Additionally, physical activity measures were also completed at this timepoint. Linear regression adjusted for age, gender, stroke severity and time since stroke was used for the statistical analyses. If the assumptions for linear regression was violated, then an ordinal regression was undertaken. Physical function measures (i.e., gait speed and balance) were found to be significant modifiable factors contributing to physical activity participation (i.e., Activity Card Sort), walking related physical activity (i.e., step count) and intensity of physical activity (i.e., IPAQ-S7). Higher intrinsic and introjected regulation, measured using the (Behavioural Regulation in Exercise Questionnaire (BREQ-2), contributed to higher physical activity participation, while only intrinsic regulation was associated with higher physical activity participation and intensity of physical activity at three months post discharge. Anxiety demonstrated a non-linear relationship with physical activity participation which requires further investigation in future studies. The results demonstrated that better physical function contributed to future increased physical activity. However, mood and motivation were also significant modifiable prognostic factors and may potentially be targeted in interventions to improve physical activity levels.

This thesis found that the physical activity levels amongst stroke survivors were low. There was a paucity of research exploring the multiple dimensions of post-stroke physical activity. This thesis found new modifiable prognostic factors that may contribute to physical activity levels and should be investigated further for causal effects. The research contained within this thesis has substantially extended the knowledge on post-stroke physical activity and may contribute to the improvement of stroke rehabilitation in the future.
Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education.

Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

Name: Shamala Thilarajah

Signature:

Date: 22/06/2018
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I am very grateful to my supervisors Ross Clark, Dawn Tan and Pua Yong Hao for giving me an opportunity to undertake doctoral studies and pursue research in an area that I am passionate about. A very big thank you to Kelly Bower for ensuring that I kept on track with my writing and read all my earlier drafts patiently. I am also grateful to Gavin Williams and Gerald Koh for being so supportive, kind and inspiring. I feel incredibly lucky that I have had this break in my professional career to learn, think and discover.

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I would like to express my gratitude to my mum, dad, sisters and brother-in-law for their encouragement and support during these PhD years.

I also feel very blessed to have had Tyrik as a research coordinator for a new study I commenced at the end of my candidature. Without him, I would not have been able to finish writing this thesis in time.

Most importantly, I dedicate this thesis to my parents who have always encouraged me to follow my heart and to lead a life that is useful to others.
Table of Contents

Abstract ........................................................................................................................................ ii
Declaration ................................................................................................................................. v
Acknowledgements .................................................................................................................. vi
List of Tables: ........................................................................................................................... xi
List of Figures: ............................................................................................................................ xii
Abbreviations .............................................................................................................................. xiii
Units of Measurement .............................................................................................................. xv
List of original publications ..................................................................................................... xvi
Preface ......................................................................................................................................... xvii

Chapter 1: Introduction .............................................................................................................. 1
  1.1 Background ......................................................................................................................... 1
  1.2 Aims .................................................................................................................................. 2
  1.3 Thesis synopsis .................................................................................................................... 4
  1.4 Significance of thesis .......................................................................................................... 8

Chapter 2: Literature Review .................................................................................................... 9
  2.1 Overview .............................................................................................................................. 9
  2.2 Stroke aetiology, incidence, prevalence, and sequelae ...................................................... 9
      2.2.1 Stroke definition .......................................................................................................... 9
      2.2.2 Aetiology of stroke ..................................................................................................... 10
      2.2.3 Incidence, prevalence and burden of stroke .............................................................. 11
      2.2.4 Sequelae of stroke ...................................................................................................... 11
  2.3 Physical activity definition ................................................................................................. 14
  2.4 Measurement of physical activity ....................................................................................... 14
  2.5 Direct measurement of post-stroke physical activity ........................................................ 15
      2.5.1 Self-report measures of post-stroke physical activity ............................................... 25
      2.5.2 Psychometric properties of physical activity measures .............................................. 26
  2.6 Physical activity following stroke ..................................................................................... 29
      2.6.1 Physical activity levels amongst community-dwelling stroke survivors .................. 29
      2.6.2 Physical activity levels of stroke survivors compared to other populations ............ 32
      2.6.3 Benefits of post-stroke physical activity .................................................................... 33
2.7 Modifiable prognostic factors of post-stroke physical activity.................. 34
  2.7.1 Definitions .......................................................................................... 34
  2.7.2 Modifiable prognostic factors associated with post-stroke physical activity.............................................................. 36
  2.7.3 Determinants of post-stroke physical activity ................................. 36
2.8 Summary........................................................................................................ 37

Chapter 3:  Factors associated with post-stroke physical activity....38

Chapter 4:  Common Methodology ................................................................. 53
  4.1 Overview .................................................................................................... 53
  4.2 Design, setting and participants ............................................................. 53
    4.2.1 Design ............................................................................................... 53
    4.2.2 Setting .............................................................................................. 53
    4.2.3 Participants and recruitment ........................................................... 54
    4.2.4 Sample size calculation .................................................................... 55
    4.2.5 Ethics approval .................................................................................. 56
  4.3 Procedures and outcome variables......................................................... 56
    4.3.1 Procedure ......................................................................................... 56
    4.3.2 Independent variables ...................................................................... 57
    4.3.3 Dependent Variables ........................................................................ 67
  4.4.1 Summary .............................................................................................. 76

Chapter 5:  Criterion validity of an ankle-mounted accelerometer in people after stroke ........................................... 77
  5.1 Introduction............................................................................................... 77
    5.1.1 Background ........................................................................................ 77
    5.1.2 Aims and hypotheses ......................................................................... 79
  5.2 Methodology ............................................................................................ 79
    5.2.1 Participants and recruitment ............................................................ 79
    5.2.2 Sample size calculation ................................................................. 80
    5.2.3 Procedures ........................................................................................ 80
    5.2.4 Data analysis .................................................................................... 80
    5.2.5 Statistical analysis ........................................................................... 82
  5.3 Results....................................................................................................... 84
    5.3.1 Description of participants............................................................. 84
Chapter 6: Descriptors of physical activity at 3 months following discharge from inpatient rehabilitation

6.1 Introduction
6.1.1 Background
6.1.2 Aims and hypotheses
6.2 Methodology
6.2.1 Design
6.2.2 Participants and recruitment
6.2.3 Procedures
6.2.4 Statistical analysis
6.3 Results
6.3.1 Participants
6.3.2 Activity data and compliance
6.3.3 Correlations between the different measures of physical activity
6.3.4 Descriptors of physical activity at three months following discharge from inpatient rehabilitation
6.3.5 Context of physical activity
6.3.6 Frequency and duration of physical activity
6.3.7 Outdoor physical activity
6.4 Discussion
6.4.1 Strengths and limitations
6.4.2 Clinical implications
6.5 Summary and conclusions

Chapter 7: Factors associated with physical activity after stroke at three months following discharge from inpatient rehabilitation

7.1 Introduction
7.1.1 Background
7.1.2 Aims and hypotheses
List of Tables:

Table 2.1: Summary of properties of self-report measures of physical activity ........ 28
Table 4.1: Outline of assessments at each time point ............................................. 58
Table 5.1: Characteristics of participants ............................................................... 84
Table 6.1: Summary of physical activity output definitions .................................... 91
Table 6.2: Characteristics of participants at three months following discharge from inpatient rehabilitation ................................................................. 93
Table 6.3: Reasons for missing activity data .......................................................... 96
Table 6.4: Spearman’s Correlations between activity measures ............................. 96
Table 6.5: Description of physical activity ............................................................. 97
Table 7.1: Characteristics of participants at discharge from inpatient rehabilitation 111
Table 7.2: Pearson’s Correlations between physical function measures at baseline 112
Table 7.3: Pearson’s Correlations between physical function measures at three-month follow-up ................................................................. 112
Table 7.4: Significant factors at baseline contributing to steps/day at follow-up .... 113
Table 7.5: Significant factors at baseline contributing to ACS-HDL scores at follow-up ................................................................. 114
Table 7.6: Significant factors at baseline contributing to IPAQ-S7 scores at follow-up ................................................................. 114
Table 7.7: Significant factors associated with steps/day at follow-up ............... 116
Table 7.8: Significant factors associated with ACS-HDL scores at follow-up .... 117
Table 7.10 Change scores from baseline to follow-up ........................................ 118
List of Figures:

Figure 2.1: Mean steps/day across different populations .................................................... 33

Figure 2.2: Example illustration of gait speed as a correlate of post-stroke physical activity ......................................................................................................................... 35

Figure 2.3: Example illustration of gait speed as a determinant of post-stroke physical activity .......................................................................................................................... 35

Figure 2.4: Example illustration of age as a confounder of gait speed and post-stroke physical activity ......................................................................................................................... 36

Figure 4.1: Design specifications of custom-made GPS unit .............................................. 71

Figure 4.2: The finished system, with 3D printed shell (printed in ABS plastic) ............. 72

Figure 4.3: An example of the GPS unit being worn ............................................................ 73

Figure 4.4: The accelerometer system used in this thesis .................................................. 75

Figure 5.1: Customised software for data analysis .............................................................. 81

Figure 5.2: A comparison of validity assessment methods that incorporates heterogenous (A) and homogenous (B) data .......................................................... 83

Figure 6.1: GPS data analysis software displays geographical data for cleaning ........... 92

Figure 6.2: Common corridor of a typical flat in Singapore ............................................. 95

Figure 6.3: Common void deck below a typical flat in Singapore ..................................... 95

Figure 6.4: Types of High-Demand Leisure activities done by participants ..................... 98

Figure 6.5: An example of a fitness zones in housing areas in Singapore ....................... 98

Figure 6.6: Gardening in flats in Singapore ....................................................................... 99

Figure 7.1: Study flow diagram .......................................................................................... 110

Figure 7.2: Associations of HADS-Anxiety scores with ACS-HDL scores after adjusting for age, sex, stroke severity and time since stroke. Shaded regions represent 95% CI for the regression estimates. The short vertical lines above the x-axes represent the observed HADS-Anxiety values ........................................................... 115

Figure 8.1: Framework of critical time-points of stroke recovery (Adapted from Julie Bernhardt et al., 2017) .......................................................... 127
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS</td>
<td>Activity Card Sort</td>
</tr>
<tr>
<td>ASCOD</td>
<td>Atherosclerosis, Small-vessel disease, Cardiac source, Other cause, Dissection</td>
</tr>
<tr>
<td>BMI</td>
<td>Body mass index</td>
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<tr>
<td>BPAQ</td>
<td>Baecke Physical Activity Questionnaire</td>
</tr>
<tr>
<td>BREQ-2</td>
<td>Behavioural Regulation in Exercise Questionnaire</td>
</tr>
<tr>
<td>CCS</td>
<td>Causative Classification System</td>
</tr>
<tr>
<td>CE</td>
<td>Cardioembolism</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>COPD</td>
<td>Chronic obstructive pulmonary disease</td>
</tr>
<tr>
<td>DALYs</td>
<td>Disability-adjusted life years</td>
</tr>
<tr>
<td>ES</td>
<td>Effect size</td>
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<tr>
<td>FCI</td>
<td>Functional co-morbidities index</td>
</tr>
<tr>
<td>FES-I</td>
<td>Falls Efficacy Scale - International</td>
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<tr>
<td>GPS</td>
<td>Global positioning unit</td>
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<tr>
<td>HADS</td>
<td>Hospital Anxiety and Depression Scale</td>
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<tr>
<td>HAP</td>
<td>Human Activity Profile</td>
</tr>
<tr>
<td>HDL</td>
<td>Higher demand leisure</td>
</tr>
<tr>
<td>ICC</td>
<td>Intra-class coefficient</td>
</tr>
<tr>
<td>ICH</td>
<td>Intracerebral haemorrhage</td>
</tr>
<tr>
<td>IPAQ</td>
<td>International Physical Activity Questionnaire</td>
</tr>
<tr>
<td>IPAQ-S7</td>
<td>International Physical Activity Questionnaire Short 7 days</td>
</tr>
<tr>
<td>IQR</td>
<td>Interquartile range</td>
</tr>
<tr>
<td>IV</td>
<td>Independent variable</td>
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<tr>
<td>LAA</td>
<td>Large artery atherosclerosis</td>
</tr>
<tr>
<td>MDC</td>
<td>Minimum detectable change</td>
</tr>
<tr>
<td>MET</td>
<td>Metabolic Equivalent of Task</td>
</tr>
<tr>
<td>MET-min/week</td>
<td>MET-minutes per week</td>
</tr>
<tr>
<td>MoCA</td>
<td>Montreal Cognitive Assessment</td>
</tr>
<tr>
<td>mRS</td>
<td>Modified Rankin Scale</td>
</tr>
<tr>
<td>NEA</td>
<td>National environment agency</td>
</tr>
<tr>
<td>NIHSS</td>
<td>National Institute of Health Stroke Scale</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<tr>
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<tr>
<td>OCSP</td>
<td>Oxfordshire Community Stroke Project</td>
</tr>
<tr>
<td>PADS</td>
<td>Physical Activity and Disability Scale</td>
</tr>
<tr>
<td>PAQs</td>
<td>Physical activity questionnaires</td>
</tr>
<tr>
<td>PASE</td>
<td>Physical Activity Scale for the Elderly</td>
</tr>
<tr>
<td>PASIPD</td>
<td>Physical Activity Scale for Individuals with Physical Disabilities</td>
</tr>
<tr>
<td>RE</td>
<td>Relative efficiency</td>
</tr>
<tr>
<td>ROC</td>
<td>Receiver operator characteristic</td>
</tr>
<tr>
<td>SAH</td>
<td>Subarachnoid haemorrhage</td>
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<tr>
<td>SAM</td>
<td>StepWatch Activity Monitor</td>
</tr>
<tr>
<td>SAO</td>
<td>Small artery occlusion</td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>SOC</td>
<td>Stroke of other determined cause</td>
</tr>
<tr>
<td>SRM</td>
<td>Standardised response mean</td>
</tr>
<tr>
<td>Steps/day</td>
<td>Steps per day</td>
</tr>
<tr>
<td>SUC</td>
<td>Stroke of undetermined cause</td>
</tr>
<tr>
<td>TAL</td>
<td>Trip Activity Log</td>
</tr>
<tr>
<td>TOAST</td>
<td>Trial of ORG 10172 in Acute Stroke Treatment</td>
</tr>
<tr>
<td>VO₂ peak</td>
<td>Peak oxygen uptake</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organisation</td>
</tr>
<tr>
<td>YPAS</td>
<td>Yale Physical Activity Survey</td>
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<tr>
<td>7-day PAR</td>
<td>7-day Physical Activity Recall</td>
</tr>
</tbody>
</table>
Units of Measurement

- df: Degrees of freedom
- hrs: Hours
- min: Minutes
- m/s: Metres per second
- r: Correlation coefficient
- \( r^2 \): Variance
- s: Seconds
List of original publications

Journal publications arising from this thesis


Conference presentations

- Australian Physiotherapy Association Conference 2017: Accepted for symposium presentation- *Tracking the “What, Where and How Much” of Post-Stroke Physical Activity in High Density Environments using custom wearables and self-report*. Sydney, Australia

Preface

All studies contained within this thesis were conceived and developed primarily by the author (Ms Shamala Thilarajah) with support from the supervisory team (Dr Ross Clark, Dr Kelly Bower, Dr Dawn Tan, Dr Pua Yong Hao, A/Prof Gavin Williams and A/Prof Gerald Koh). Study 1 was also developed with support from co-author, Dr Benjamin Mentiplay.

Ethics application, study coordination and all assessment sessions for Study 2, 3 and 4 were undertaken by the author. A research assistant, Ng Puey Tiong, provided translation services and support with data collection. The author had input into the design of the custom wearables and software used in Study 2, 3 and 4 which was developed by Dr Ross Clark. The data input, statistical analysis and write-up was completed by the author with contributions in all areas from the team of supervisors.

The two publications resulting from this thesis were prepared by the author. The first publication was an invite to Dr Ross Clark and A/Prof Gavin Williams by the Brain Impairment journal to submit a narrative review. The author prepared this publication and co-authors RC and GV critically appraised the manuscript. The paper was then peer-reviewed and revised before acceptance for publication. This paper has been included in the manuscript as part of the literature review in Chapter 2. The other publication, which is a systematic review (Study 1), was critically appraised by the supervisory team and co-author (Dr Benjamin Mentiplay). Permissions have been granted to include these publications within this thesis (Appendix A, Chapter 2 and Study 1). No third party editorial assistance was provided in preparation of this thesis.

The author obtained postgraduate scholarship funding initially through the Australian Catholic University-Australian Post-Graduate Scholarship (AUD $35, 849 per annum) and then converted on transfer to the University of the Sunshine Coast Research Scholarship (AUD $36, 628 per annum).
Chapter 1: Introduction

1.1 Background

Stroke is one of the primary causes of disability worldwide, with one third of individuals left with permanent deficits impacting on their function (Carroll et al., 2014). Research indicates that at six months poststroke, 70% of people had difficulty performing all activities of daily living, 70% had difficulty accessing the community and 72% were not participating in any meaningful activities on a daily basis (Mayo, Wood-Dauphinee, Côté, Durcan, & Carlton, 2002). Neurological impairments and activity limitations resulting from stroke may contribute to a physically inactive lifestyle. Current evidence demonstrates that physical activity can reduce detrimental secondary changes after stroke such as loss of skeletal muscle (Coralie English, McLennan, Thoirs, Coates, & Bernhardt, 2010; Scherbakov & Doehner, 2011), change in muscle structure (Addison, Marcus, Lastayo, & Ryan, 2014; Hafer-Macko, Ryan, Ivey, & Macko, 2008), loss of bone mass (Borschmann, 2011; Borschmann, Pang, Bernhardt, & Iuliano - Burns, 2012) and reduced cardiorespiratory fitness (Billinger, Coughenour, MacKay-Lyons, & Ivey, 2011; Pang, Charlesworth, Lau, & Chung, 2013; Smith, Saunders, & Mead, 2012). Physical activity has also been shown to modify stroke risk factors by improving glucose regulation, lipid metabolism, insulin sensitivity, blood pressure regulation and cellular function (Endres et al., 2003; Frederick M Ivey, Ryan, Hafer-Macko, Goldberg, & Macko, 2007; Kernan et al., 2014).

In order to achieve these physical activity-related health benefits, the American Heart Association / American Stroke Association Guidelines for Management of Stroke recommend that people after stroke should participate in moderate intensity exercise for 20 to 60 minutes per session (or if unable in 10 to 15 minutes exercise bouts), at least three times a week (Billinger et al., 2014). This activity dose is lower than the American Heart Association / American College of Sports Medicine physical activity recommendations for heathy adults which advises 20 minutes of vigorous intensity activity at least three days a week and strength training at least two days a week (Haskell et al., 2007). Both sets of guidelines advocate that for best health results, structured
exercise combined with an increase in participation in daily household, occupation and social roles is needed (Billinger et al., 2014; Kernan et al., 2014).

Research suggests that many stroke survivors are not meeting the recommended levels of physical activity. A recent meta-analysis found that stroke survivors walked only 50% of the recommended steps per day (steps/day) for healthy older adults and they were even less active than people with other chronic illnesses such osteoarthritis (Field, Gebruers, Shanmuga Sundaram, Nicholson, & Mead, 2013). Thus, there is consensus that following stroke, individuals who are likely to be inactive need to be identified early for targeted interventions to increase physical activity (Billinger et al., 2014). Early intervention in the acute and sub-acute phases may help to address factors associated with low activity to prevent long-term negative consequences. It is, therefore, important to understand the factors associated with physical activity after stroke.

There has been a growing body of research examining the factors associated with physical activity after stroke. However, most of this research is cross-sectional and very few studies have examined factors that reflect the multi-dimensional aspects of post-stroke physical activity levels. Differing definitions and measurements of physical activity amongst existing literature also makes comparing study findings difficult. Additionally, little evidence exists to describe what specific types of physical activities people after stroke are participating in during their daily routine.

1.2 Aims

The overall aim of this thesis was to explore the factors at discharge from inpatient rehabilitation that are associated with post-discharge physical activity levels amongst stroke survivors. This thesis comprises three main studies. The first study is a systematic review and meta-analysis that synthesises and appraises the current evidence around factors associated with post-stroke physical activity. The second study investigates the validity of an ankle-mounted accelerometer for measuring step counts post-stroke, that will be used in the studies 3 and 4. The third study provides a comprehensive description of the amount and type of physical activity undertaken by a cohort of stroke survivors at three months post inpatient rehabilitation. The final study investigates the strength of
association between post-discharge physical activity levels and a range of physical and psychosocial factors.

Thus, in summary, this thesis will address the following aims:

Study 1:

- To integrate current literature on factors associated with post-stroke physical activity

Study 2:

- To validate a custom-made, ankle worn accelerometer against a hand-held counter for measuring step counts in people after stroke undergoing rehabilitation

Study 3:

- To ascertain the correlations between Activity Card Sort (ACS) (physical activity participation), International Physical Activity Questionnaire Short 7 days (IPAQ-S7) (physical activity intensity) and steps/day (walking-related physical activity).
- To identify the context, volume and intensity of physical activity undertaken by stroke survivors at three months following discharge from rehabilitation.
- To understand the proportion of stroke survivors who participate in outdoor physical activity at three months following discharge from inpatient rehabilitation.

Study 4:

- To explore the factors at discharge from inpatient rehabilitation (baseline) associated with physical activity as determined by the ACS, IPAQ-S7 and steps/day.
- To explore the factors at three months after discharge from inpatient rehabilitation associated with physical activity as determined by the ACS, IPAQ-S7 and steps/day.
1.3 Thesis synopsis

To achieve the thesis aims, a systematic review with meta-analysis (Study 1), a validation study (Study 2) and a prospective cohort study (Study 3 and 4) were undertaken. Study 2 and Study 3 were based at the inpatient rehabilitation unit at the Singapore General Hospital (Singapore), with data collection taking place from June 2015 to November 2016. The overall structure of the thesis is outlined in Figure 1.1 followed by an outline of the individual chapters.
Chapter 1: Introduction
To present the need to explore the factors associated with post-stroke physical activity levels

Chapter 2: Literature review
To integrate the current literature on post-stroke physical activity and the factors associated with post-stroke physical activity levels

Chapter 3 (Study 1): Systematic review
To consolidate qualitatively and quantitatively the factors associated with physical activity levels after stroke

Chapter 4: Study methodology
To describe the common methods for the subsequent two studies

Chapter 5 (Study 2): Validation
To validate an ankle-mounted accelerometer for assessing step counts in hospitalised stroke patients for use in subsequent studies

Chapter 6 (Study 3): Cross-sectional study
To describe the context, volume and intensity of physical activity amongst stroke survivors

Chapter 7 (Study 4): Prospective cohort study
To investigate the key modifiable factors contributing to post-stroke physical activity levels at three months following discharge from inpatient rehabilitation

Chapter 8: Discussion and conclusion
To synthesise findings, discuss implications, make recommendations on future research and outline thesis conclusions

Figure 1.1: Overall structure of thesis
**Chapter 1** provides an overview of the aims and structure of the thesis. It serves as an introduction to the problem and explains the significance of the thesis.

**Chapter 2** provides a literature review relevant to this thesis and is organised in five sections. Firstly, the consequences of stroke and the importance of physical activity after stroke is discussed. Secondly, an appraisal of the current body of literature on post-stroke physical activity is conducted. Thirdly, the different methods of physical activity measurement are explored. This is followed by a review on the factors associated with post-stroke physical activity levels as identified by cross-sectional studies. This chapter ends with a review of the factors that predict future physical activity levels at discharge from hospital.

**Chapter 3** is the published manuscript for the systematic review and meta-analysis (Study 1). The main objective of the study was to synthesise the literature investigating the factors associated with post-stroke physical activity. A search was conducted from database across nine databases for observational studies that recruited community-dwelling stroke survivors and measured factors associated with physical activity. The Quality in Prognosis Studies checklist was utilised to assess bias amongst the included studies. A meta-analysis was conducted to examine statistical associations where there were at least two studies that reported a correlation value. Results were described qualitatively for studies that could not be pooled. The results of Study 1 informed the selection of the independent variables for Study 3 and 4.

**Chapter 4** describes the common methodology for studies 2-4. Both the studies were prospective cohort studies involving 64 participants with stroke recruited from the inpatient rehabilitation unit at Singapore General Hospital. The participants were recruited at discharge from the unit and a baseline assessment was conducted. A range of physical and psychosocial assessments were conducted at baseline. The participants were then followed up three months following discharge and underwent the same physical function, cognitive, mood and behaviour assessments as those undertaken at baseline. Additionally, at follow-up, physical activity was measured using self-report and objective measures.
Chapter 5 is a validation study of an ankle-mounted custom-made accelerometer in people after stroke undergoing rehabilitation in an inpatient setting (Study 2). This study recruited 20 participants who could walk with no more than minimal assistance with or without a walking aid. The accelerometer was placed on the unaffected ankle and participants were asked to walk along a hospital corridor until 50 strides were counted by the assessor. The accelerometer was validated for use in Study 3 and 4.

Chapter 6 provides an overview on the amount, type and intensity of physical activity undertaken by stroke survivors at three months following discharge from inpatient rehabilitation (Study 3). This chapter provides the results from the four physical activity outcome measures used (i.e., the accelerometer, GPS unit, ACS and IPAQ-S7). This study also presents the correlations between these four measures and discusses the rationale behind the use of different measures to assess varying aspects of physical activity.

Chapter 7 presents the key modifiable factors at discharge from inpatient rehabilitation that contributes to physical activity levels at three months following discharge (Study 4). The ACS, IPAQ-S7 and the accelerometer results were used as the dependent variables.

Chapter 8 integrates the findings from the four studies and explains the contribution of this thesis to the knowledge base around post-stroke physical activity levels. This chapter also discusses the clinical and research implications of the findings and the future directions for research into identifying target factors to improve physical activity levels amongst stroke survivors.
1.4 Significance of thesis

For physical activity interventions to be successful, we need to identify the individual and/or combination of factors that contribute most to the variance in physical activity levels amongst stroke survivors. These factors may then be targeted for assessment and tailored intervention approaches. Importantly we should also consider how we define and assess physical activity so that appropriate outcome measures can be used to measure change. The current knowledge is mainly limited to cross-sectional research and there is a paucity of cohort studies examining modifiable prognostic factors that contribute to post-stroke physical activity levels. Most of these studies have also been conducted in chronic stroke patients with a focus on walking-related physical activity measured in steps/day. This thesis provides new knowledge on physical activity levels amongst stroke survivors living in an urban setting in Singapore and the factors at discharge from inpatient rehabilitation that predict physical activity three months following discharge. This is also the first study to comprehensively investigate multiple aspects of physical activity such as participation, outdoor activity, intensity of activity and steps/day to enable a holistic understanding of post-stroke physical activity.
Chapter 2: Literature Review

2.1 Overview

This chapter will provide a narrative review of the literature pertaining to post-stroke physical activity. This chapter commences with the aetiology, prevalence and sequelae of stroke. This chapter also explains the definition and measurement of physical activity and expands beyond stroke to appraise literature on physical activity in the older population and in people with other neurological conditions. The chapter then critically appraises the literature investigating the modifiable prognostic factors contributing to post-stroke physical activity levels.

2.2 Stroke aetiology, incidence, prevalence, and sequelae

2.2.1 Stroke definition

Stroke is typically characterized as a vascular damage of the central nervous system resulting from a cerebral infarct, intracerebral haemorrhage or subarachnoid haemorrhage (Sacco et al., 2013). Stroke is currently defined by the World Health Organisation (WHO) as ‘a clinical syndrome consisting of rapidly developing clinical signs of focal (or global in case of coma) disturbance of cerebral function lasting more than 24 hours or leading to death with no apparent cause other than a vascular origin.’ (WHO MONICA Project Principal Investigators, 1988). However, over the years, this definition has been expanded to include spinal and retinal infarction and to clarify that intracerebral haemorrhage (ICH) and subarachnoid haemorrhage (SAH) must not be caused by trauma. The updated definitions also include stroke diagnosed clinically as ‘an episode of acute neurological dysfunction presumed to be caused by ischemia or hemorrhage, persisting ≥24 hours or until death, but without sufficient evidence to be classified as one of the above’. Transient ischaemic attacks, subdural hemorrhages and other neurological conditions that cause similar symptoms to stroke are excluded from these definitions.
2.2.2 Aetiology of stroke

Accurate identification of the cause of stroke is important for both effective treatment and prognosis of recovery (H. P. Adams et al., 1993; B. J. Kim & Kim, 2014). The three pathological types of stroke are ischaemic, ICH and SAH with distinctive vascular causative mechanisms (Tsai, Thomas, & Sudlow, 2013). Characterising different stroke phenotypes accurately in research can help in understanding the biological differences in groups that responds to a treatment in trials or those that demonstrated different recovery patterns (Julie Bernhardt et al., 2017).

Ischaemic stroke can be broadly categorised into thrombotic, embolic and lacunar cerebral infarcts. Thrombotic infarcts are caused by atherosclerotic occlusion of large cervical and cerebral arteries where the root occlusion occurs at the arteriosclerotic site. Embolic stroke refers to an infarct that is caused by an obstruction in the cerebral artery that originates from other parts of the arterial system such as the heart. Lacunar infarcts are small, deep infarcts around the small penetrating arteries mainly due to disease of these vessels.

Haemorrhagic stroke includes intracerebral haemorrhages and subarachnoid haemorrhage. Intracerebral haemorrhage occurs spontaneously and largely due to hypertension. Subarachnoid haemorrhages occur usually due to the rupture of aneurysms at the bifurcations of large arteries. The causative mechanism of stroke are large artery atherosclerosis, cardioembolism, small-artery occlusion (lacunae) and other determined or undetermined causes (H. P. Adams et al., 1993). There are several classifications systems of stroke currently used in research. The most widely used classification scales are the Oxfordshire Community Stroke Project (OCSP) and the TOAST (Trial of ORG 10172 in acute stroke treatment). The OCSP is a simple clinical classification tool that is widely used in clinical practice and in observational studies. The scale uses the clinical presentation of the patient alone or in combination with radiological findings. This scale addressed the severity and outcome of the stroke but not the causes (Paci, Nannetti, D’ippolito, & Lombardi, 2011).
2.2.3 Incidence, prevalence and burden of stroke

Every year, 15 million people worldwide suffer a stroke. Of these, one third do not survive and one third are left with permanent disability (Salbach, Brooks, Romano, Woon, & Dolmage, 2014). Stroke is the leading cause of adult disability worldwide (Mendis, 2013). Stroke burden, measured in disability-adjusted life years (DALYs), is estimated to increase from approximately 38 million in 1990 to 61 million in 2020 (Salbach et al., 2014). In both Australia and Singapore, stroke is one of the leading causes of death and disability (Australian Institute of Health and Welfare, 2016; Valery L Feigin et al., 2014). In Australia, there were 475,000 stroke survivors living in the community in 2017 and the crude incidence of new stroke is 226 cases per 100,000 population (Hachisuka, Umezu, & Ogata, 1997). Similarly, in Singapore, the prevalence of stroke is estimated at 3.65% for adults > 50 years of age (Valery L Feigin et al., 2014). The last published data in 2014 found the crude incidence to be 212.8 per 100,000 population (Sions, Tyrell, Knarr, Jancosko, & Binder-Macleod, 2012). With a rapidly ageing population in both countries, the burden of stroke is expected to increase exponentially, posing challenges to the healthcare system and society.

2.2.4 Sequelae of stroke

The impairments following a stroke can be classified as either primary or secondary. Primary impairments include loss of strength, sensation, dexterity, change in cognition, spasticity, behavioural and mood changes. These directly affect the person’s ability to sit, stand, walk and carry out their activities of daily living. Even at six months after stroke, 70% of individuals had difficulty performing activities of daily living, 70% had difficulty accessing the community and 72% were not participating in any meaningful activities on a daily basis (Mayo et al., 2002). These limitations contribute to a sedentary lifestyle causing secondary impairments such as deconditioning. Deconditioning can further impact on the stroke survivors’ physical function and lead to increased risk of falls and recurrent stroke (Billinger et al., 2014). Deconditioning causes change in muscle mass and structure, muscle metabolism, bone loss and decreased cardiorespiratory fitness. These changes will be detailed in the following sections.
Changes in muscle mass, structure and metabolism

There are significant changes in the structure and size of skeletal muscle after stroke (Hafer-Macko et al., 2008). With ageing, there is a trend towards increased size of slow-twitch (Type II) myosin heavy chain isoforms and decreased size of fast-twitch (Type I) fibres. Fast-twitch fibres have the capacity for higher force generation while slow-twitch fibres are rich in mitochondria which enables them to be high in oxidative metabolism and fatigue resistant (Hafer-Macko et al., 2008). Similar to age-related muscle atrophy, after stroke there is a progressive decrease in muscle fiber size bilaterally, with greater decreases on the affected side (Scelsi, Lotta, Lommi, Poggi, & Marchetti, 1984). These reductions in muscle fibre size leads to a decrease in muscle cross-sectional area (Hachisuka et al., 1997; Toffola, Sparpaglione, Pistorio, & Buonocore, 2001). Thus, stroke survivors have difficulties with muscle force production and contraction speed which translates to activity limitations such as difficulty with standing up or managing stairs (Bohannon, 2007; Cheng, Chen, Wang, & Hong, 2004; C. M. Kim & Eng, 2003). Physical inactivity also results in reduced muscle mass and physical function to a similar degree to the functional decline that occurs with ageing (Hafer-Macko et al., 2008).

Muscle metabolism

Age-related changes and hemiparesis are two factors related to stroke that causes the accumulation and storage of adipose tissues in ectopic locations such as skeletal muscle, liver and abdominal cavity (Addison et al., 2014). Intramuscular fat (i.e., adipose tissue) can cause metabolic, muscular and mobility dysfunction, as it secretes bio-active peptides (e.g. interleukin-6, TNF-α) and pro-inflammatory cytokines which result in glucose intolerance and a decrease in muscle strength, quality and activation. These changes have resulted in reduced physical performance and gait speed amongst stroke survivors (De Deyne, Hafer - Macko, Ivey, Ryan, & Macko, 2004).

Furthermore, direct effects of the brain injury cause systemic metabolic changes via the tumour necrosis factor – α (TNF-α) that may result in an inflammatory pathway. This may also contribute to muscle atrophy and altered muscle metabolism after stroke (Hafer-Macko et al., 2008). TNF-α directly affects insulin signaling in the muscles
together with interleukin 6. Both are pro-inflammatory cytokines. This further contributes to the state of insulin resistance in the stroke survivor’s body (Hafer-Macko, Yu, Ryan, Ivey, & Macko, 2005).

**Bone loss**

Accelerated bone loss post-stroke is one of the most common secondary complications (Borschmann et al., 2012). The normal rate of loss in bone mineral density amongst older adults aged 60 and above is 1% per year (Jones, Nguyen, Sambrook, Kelly, & Eisman, 1994). However, up to 24% of bone mineral density can be lost in the affected proximal humerus and up to 12% in proximal femur in the first-year post-stroke (Jørgensen et al., 2010). The rate of bone mineral density loss is higher during the first six months post-stroke and is associated with duration of immobility, reduced cardiorespiratory fitness, reduced weight bearing on affected limb, reduced muscle mass and severity of impairment (Borschmann et al., 2012). The risk of fracture is 1.5 to four times higher amongst stroke survivors than in age-matched controls (Dennis, Lo, McDowall, & West, 2002; Ramnemark, Nilsson, Borssén, & Gustafson, 2000). Fractures post-stroke are especially debilitating as it impacts on physical function and mortality (Ramnemark et al., 2000).

**Cardiorespiratory fitness**

Decreased cardiorespiratory fitness after stroke may be the result of a combination of premorbid function, age-related changes, direct effects of stroke and post-stroke physical inactivity (Billinger et al., 2011). Stroke survivors may already have co-morbid conditions (e.g. hypertension, apolipoprotein ration, cardiac conditions) prior to the stroke, that could predispose them to an inactive lifestyle (Valery L. Feigin, Lawes, Bennett, Barker-Collo, & Parag, 2009; O'Donnell et al., 2016). A study describing stroke survivors admitted with a recurrent stroke found that 75% of the cohort had hypertension, 56% had hyperlipidemia, 37% had ischemic heart disease, 29% had atrial fibrillation, and 24% had diabetes mellitus (Leoo, Lindgren, Petersson, & Von Arbin, 2008). There may also be physiological changes that occur with ageing (Milanović et al., 2013). The skeletal muscle changes described earlier contribute to a reduction in gait speed, insulin resistance and fatigue-prone muscles. The consequences of this increases
energy expenditure, decreases peak oxygen consumption and reduces cardiorespiratory fitness (Grundy, 2016).

### 2.3 Physical activity definition

Physical activity is defined as any physical movement that causes energy expenditure due to skeletal muscle contraction (Caspersen, Powell, & Christenson, 1985). This includes energy expenditure during household activities, occupational activities, leisure activities and exercise. Physical activity and exercise are not the same; exercise is a subset of physical activity (Caspersen et al., 1985). Exercise refers specifically to activities that are “structured, planned, repetitive and done for the purpose of improving fitness” (e.g. sports) (Caspersen et al., 1985, p. 127). This thesis will utilise the above definition.

The American College of Sports Medicine/American Heart Association guidelines for healthy adults acknowledge that moderate to vigorous activities that are part of daily living, such as brisk walking to work, gardening and carpentry, can also be counted towards meeting physical activity recommendations if performed in bouts of 10 minutes or more (Haskell et al., 2007). These guidelines further clarify that the recommended dose of aerobic exercise is in addition to the routine light intensity activities of daily living (e.g. personal-care, grocery shopping). Additionally, given the higher energy expenditure of standing tasks and walking in people after stroke, it is possible that these lifestyle activities may be of sufficient intensity for health benefits (Houdijk et al., 2010). Thus, terms which refer to domestic, leisure and social activities (Robison et al., 2009), such as ‘participation’, ‘valued-activities’, ‘community ambulation’, and ‘community integration’, are being used in the physical activity literature in the stroke population (Nicholson et al., 2013).

### 2.4 Measurement of physical activity

Energy expenditure is the basic measurement of physical activity. However, to comprehensively understand post-stroke physical activity, information is also needed on the activity dose (i.e. frequency, duration and intensity), as well as the type and patterns of activity (Norton, Norton, & Sadgrove, 2010). Ideally, activity dose and physical
activity energy expenditure should be measured over a suitable period that is representative of habitual activity levels (B. Ainsworth, Cahalin, Buman, & Ross, 2015). The tools that are currently available to measure physical activity can be categorised into direct methods (e.g. wearable sensors), or indirect methods (e.g. self-report questionnaires). These methods and devices differ in accuracy, simplicity of use and type of output data (B. Ainsworth et al., 2015). This section will include a published narrative review on wearable sensors, a review of the self-report measures of physical activity used in stroke and finally the psychometric properties of direct and self-reported measures.

2.5 Direct measurement of post-stroke physical activity

**Manuscript 1:** Wearable sensors and Mobile Health (mHealth) technologies to assess and promote physical activity in stroke: a narrative review

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Wearable sensors and Mobile Health (mHealth) technologies to assess and promote physical activity in stroke: a narrative review

Shamala Thilarajah,1,2 Ross A Clark1 and Gavin Williams3,4,5
1 School of Exercise Science, Australian Catholic University, Australia
2 Department of Physiotherapy, Singapore General Hospital, Singapore
3 Epworth HealthCare, Richmond, Australia
4 The University of Melbourne, Melbourne, Australia
5 La Trobe University, Melbourne, Australia

Stroke is a leading cause of disability worldwide, with approximately one third of people left with permanent deficits impacting on their function. This may contribute to a physically inactive lifestyle and further associated health issues. Current research suggests that people after stroke are not meeting the recommended levels of physical activity, and are less active than people with other chronic illnesses. Thus, it is important to understand how to support people after stroke to uptake and maintain physical activity. Wearable sensors and mobile health (mHealth) technologies are a potential platform to measure and promote physical activity. Some of these technologies may incorporate behaviour change techniques such as real-time feedback. Although wearable activity trackers and smartphone technology are widely available, the feasibility and applicability of these technologies for people after stroke is unclear. This article reviews the devices available for assessment of physical activity in stroke and discusses the potential for advances in technology to promote physical activity in this population.

Keywords: Wearable sensors, smartphone technology, mHealth, physical activity, measurement, stroke

Introduction

Stroke is a leading cause of disability worldwide and one third of people who suffer from a stroke are left with permanent deficits impacting on their function (Carroll et al., 2014). Physical impairments and activity limitations resulting from stroke may contribute to an inactive lifestyle. Current research suggests that people after stroke are not meeting the recommended levels of physical activity (English, Manns, Tucak, & Bernhardt, 2014). A recent meta-analysis found that people after stroke walked only 50% of the recommended number of steps per day for healthy older adults, and they were significantly less active than people with other chronic illnesses (Field, Gebruers, Shanmuga Sundaram, Nicholson, & Mead, 2013).

Physical activity can reduce detrimental secondary changes after stroke such as loss of skeletal muscle (English, McLennan, Thoirs, Coates, & Bernhardt, 2010; Scherbakov & Doehner, 2011), change in muscle structure (Addison, Marcus, Las-tayo, & Ryan, 2014; Hafer-Macko, Ryan, Ivey, & Macko, 2008), loss of bone mass (Borschmann, 2011; Borschmann, Pang, Bernhardt, & Iulian-Burns, 2012) and reduced cardiorespiratory fitness (Billinger, Coughenour, MacKay-Lyons, & Ivey, 2011; Pang, Charlesworth, Lau, & Chung, 2013; Smith, Saunders, & Mead, 2012). Physical activity has also been shown to modify stroke risk factors by improving glucose regulation, lipid metabolism, insulin sensitivity, blood pressure regulation and cellular function (Endres et al., 2003; Ivey, Ryan, Hafer-Macko, Goldberg, & Macko, 2007).

Address for Correspondence: Shamala Thilarajah, School of Exercise Science, Australian Catholic University, Melbourne, Victoria 3065 E-mail: shamala.thilarajah@acu.edu.au.
In order to achieve these health benefits, international stroke guidelines recommend that people after stroke should participate in moderate intensity exercise for 20 to 60 minutes per session (or three 10 to 15 minutes exercise bouts throughout the day), at least three times a week (Billinger et al., 2014). This activity dose is lower than current physical activity recommendations for healthy adults, which recommend 20 minutes of vigorous-intensity activity at least three days a week and strength training at least two days a week (Haskell et al., 2007). Both sets of guidelines advocate that for best health results, structured exercise combined with an increase in participation in daily household, occupation and social roles is needed (Billinger et al., 2014; Haskell et al., 2007). The mismatch between physical activity guidelines and reported low activity levels of people after stroke highlights an urgent healthcare need to implement targeted interventions to promote physical activity. It is, therefore, important to understand how to support people after stroke to uptake and maintain physical activity behaviours.

Wearable sensors and Mobile Health (mHealth) technology are a potential low-cost and readily accessible platform for assessing and promoting physical activity. Wearable sensors can be defined as body worn sensors, such as accelerometers, sensors that are embedded in clothes or worn as accessories (Bonato, 2009). mHealth refers to all health-related interventions that are available to measure physical activity and also feasibility and design of the current devices reviewed from them is often poor (Bort-Roig, Gilson, Puig-Ribera, Contreras, & Trost, 2014; Morris, MacGillivray, & Mcfarlane, 2014). This narrative review provides an overview of the validity, feasibility and design of the current devices available to measure physical activity and also discusses the potential for advances in technology to promote physical activity in people after stroke.

Wearable Sensors

Pedometers

Pedometers are small, lightweight devices that count steps taken during walking and other locomotion activities. These devices are generally inexpensive and easy to use. Pedometers typically contain a spring-suspended, electric lever arm or a magnetic reed proximity switch that moves up and down with the vertical displacement of the hip (Schneider, Crouter, Lukajic, & Bassett, 2003). More expensive devices contain a horizontal beam and a piezoelectric crystal similar to accelerometers (Schneider et al., 2003). Pedometers are most commonly worn at the waist or hip.

Research in healthy populations have found the Yamax Digi-Walker to be one of the most affordable and accurate pedometers (Bassett Jr et al., 1996; Schneider et al., 2003). However, this does not translate well to the stroke population, with only modest validity when compared with observed step counts (ICC = 0.58) (Elsworth et al., 2009). Pedometer accuracy has been found to decrease at slower walking speeds (<0.9 m/s) and with asymmetrical gait patterns (Berlin, Storti, & Brach, 2006; Fulk et al., 2014; Motl, McAuley, Snook, & Scott, 2005). This inaccuracy could be due to the mechanism of the pedometer or the analysis algorithms not being sensitive enough, to detect the smaller hip displacement that occurs at slower walking speeds, leading to the pedometer underestimating step counts (Melanson et al., 2004). One study did find that an ankle-worn pedometer was more accurate in evaluating step counts at slow speeds than pedometers worn at the waist or hip, however, pedometers still significantly undercount steps when compared to accelerometers (Karabulut, Crouter, & Bassett Jr, 2005).

Accelerometers

Accelerometers are body worn sensors that utilise piezoelectric sensors to detect acceleration of movements. Uniaxial, biaxial and triaxial accelerometers evaluate movement in one, two or three planes respectively, and can provide total step count, activity counts, step rate and postural transition data (Chen & Bassett, 2005). There are several brands of accelerometers that have been used in research to measure physical activity, and the accelerometers also differ by site of wear such as wrist, arm, hip and ankle (Murphy, 2009).

Arm and Wrist Mounted. In recent years there has been a dramatic increase in the number of wrist-mounted activity trackers designed for the general population. Activity trackers are aesthetically pleasing, unobtrusive and often provide either real-time results or have user friendly mobile application interfaces. These wrist-worn trackers contain triaxial accelerometers, and in some models, other sensors such as altimeters or heart rate monitors.
They are able to record step activity, calories burnt and activity patterns. However, the proprietary algorithms are intended for use in healthy adults and may not be sensitive enough to detect movement at low walking speeds. The Fitbit Ultra® (a small device that can be worn on a wrist belt) and the Nike+ Fuelband® (wristband) were validated against observed step counts in patients after stroke or traumatic brain injury (Fulk et al., 2014). Fitbit Ultra® demonstrated moderate agreement with observed step counts (ICC = 0.73) but the Nike+ Fuelband® was found to be inaccurate (ICC = 0.20) for use in this population (Fulk et al., 2014). As is often the case with commercially available products, the hip worn Fitbit Ultra® is no longer available and has been replaced by activity wristbands. The validity of the latest versions of wrist worn activity trackers are not known in the stroke population, but it is possible that their sensitivity to slow or asymmetrical walking may be limited by the proprietary algorithms that determine step counts programmed for healthy adults.

**Hip Mounted.** The hip or waist is usually the preferred site for accelerometers to measure energy expenditure. Hip mounted accelerometers, such as the Caltrac and TriTrac RT3, have been validated in the healthy population with strong correlation to energy expenditure as measured by doubly labelled water (gold standard measure of physical activity) (Pambianco, Wing, & Robertson, 1990; Rothney, Schaefer, Neumann, Choi, & Chen, 2008). However, both the Caltrac and TriTrac RT3 were found to demonstrate poor to moderate test-retest reliability (r = 0.44 and ICC = 0.68 respectively) in people after stroke (Haebumer, Shaughnessy, Forrester, Coleman, & Macko, 2004; Hale, Pal, & Becker, 2008). Generally, hip mounted accelerometers, similar to hip mounted pedometers, do not account for the gait asymmetries in people after stroke and thus it may not be the most accurate site for activity measurement.

**Ankle Mounted.** A recent systematic review evaluating measurement devices found the StepWatch Activity Monitor (SAM) to be the most accurate when compared to other accelerometers in detecting total step counts when validated against video-recordings of a timed walk test (ICC = 0.97) (Fulk et al., 2014). The SAM is an ankle-worn device with accelerometer thresholds which can be adjusted to suit different walking patterns (Mudge, Stott, & Walt, 2007). Measurement information is stored in the internal memory of the device, and can be downloaded at a later time to a computer (Chen & Bassett, 2005). However, the SAM has remained primarily a research tool and this could be due to the cost of the unit and the expertise required to operate, download and analyse the data. In addition, the SAM is relatively large in size when compared to other hip mounted accelerometers. Thus, when attached to the ankle, the SAM could be potentially cumbersome and intrusive compared to waist mounted systems which can be easily hidden under clothing.

**Multi-site Mounted.** Information on postural transitions are useful as it captures time spent in lying, sitting and standing which provides information on the person’s activity patterns. The Intelligent Device for Energy Expenditure and Activity (IDEEA) is one technology that is able to detect postural changes by using five thumb-nail sized sensors attached to the upper sternum, bilateral mid-thighs and feet. The recording device is attached at the waist. The IDEEAA was reported to be 98.7% accurate in detection of different postures in the healthy population compared to timed observation of postural changes (Zhang, Werner, Sun, Pi-Sunyer, & Boozer, 2003). In stroke, one study reported the device to be 99% accurate in measurement of time spent in walking-related activity by utilising a more sensitive algorithm, provided by the manufacturer, to detect slow walking speed (>0.4m/s) (M. A Alzahrani, Dean, Ada, Dorsch, & Canning, 2011). No ICCs were reported in this study. While this multi-sensor and site system may be accurate, its clinical utility for long-term activity monitoring is very restricted as patient compliance is likely to be poor.

Although accelerometers have gained popularity in physical activity research, they have several limitations. A major limitation is the discrepancy in outcome measures and algorithms used between devices. Apart from number of steps per day, many studies have used ‘activity counts’ (M. A. Alzahrani, Dean, & Ada, 2009; M. A Alzahrani et al., 2011) as an outcome measure from accelerometers. An activity count is a combined, unit-less measure of amount and intensity of activity over a specified time period (Ainsworth, Cahalin, Buman, & Ross, 2015). Activity counts are determined by proprietary algorithms. This means that different brands of accelerometers may output different activity counts for the same acceleration signal (Vähä-Ypyä, Vasankari, Husu, Suni, & Sievänen, 2015). Thus, comparing results across studies which have utilised different accelerometer models is difficult (Bonomi, Goris, Yin, & Westerterp, 2009). The majority of commercially available systems do not allow for export and third-party analysis of the raw accelerometer traces. Given that the inherent technology is similar between devices, and that the proprietary algorithms themselves and not the technology are likely to be the cause of their
poor validity, the inability to export the accelerometer data is a potentially insurmountable hurdle for their use in people living with stroke.

Another limitation of accelerometers is that they typically do not detect non-walking related activities such as gardening, swimming or cycling, and thus researchers are unable to gain a complete profile of physical activity behaviours (Butte, Ekelund, & Westerterp, 2012). New technologies have been developed which combine measures of acceleration with physiological parameters such as heart rate and body temperature to calculate a measure of energy expenditure in everyday living. Measurement of energy expenditure, which is the basic unit of physical activity, might be a better indication than steps per day in evaluating if people, after stroke, were meeting the recommended guidelines for physical activity. The SenseWear® Armband (SWA) is a multi-sensor device that is worn on an armband around the upper limb. The device can measure movement (through a biaxial accelerometer) in number of steps per day and energy expenditure through physiological parameters such as heat flux, skin temperature and galvanic skin response (Moore et al., 2012). Proprietary algorithms process the raw data into energy expenditure level; however the contribution of each of the physiological measures to the prediction equation for calculation of energy expenditure is unclear (Chen & Bassett, 2005). In healthy older adults, the SWA version 5.1 and 6.1 have demonstrated a strong correlation (r = 0.901 and r = 0.893 respectively) against doubly labelled water (Mackey et al., 2011). In contrast, validation studies of the SWA in people after stroke have shown that the device (worn on the unaffected upper limb) is not valid for step counts (ICC = 0.352) and has poor to fair correlations for energy expenditure during treadmill walking (ICC > 0.409) (Kuys, Clark, & Morris, 2014; Manns & Haennel, 2012; Vanroy et al., 2013). Although multi-sensor devices are potentially useful, more research is required to determine their suitability for people with stroke.

Portable global positioning systems

Global positioning systems (GPS) technology uses space-based satellite systems to calculate time and location data. It is currently used in various fields such as sports and environmental epidemiology (Rodríguez, Brown, & Troped, 2005) and is common in the communication devices used in everyday life. However, the use of GPS is still novel in physical activity research, particularly in clinical populations (Clark, Weragoda, Paterson, Telianidis, & Williams, 2014). Global positioning systems are able to provide information on the frequency and duration of outdoor physical activity and have been validated against direct observation in people after stroke, with excellent agreement at 94% for number of outdoor trips (McCluskey, Ada, Dean, & Vargas, 2012). Through synchronisation with Google Earth, or for more advanced analysis Geographical Information Systems, the data can also be used to explore relationships between outdoor physical activity and the neighbourhood attributes. Self-report diaries and physical activity questionnaires can be used to complement the data obtained from GPS. Combining accelerometer and GPS data will allow measurement of activity patterns and location of physical activity (Rodríguez et al., 2005). However, GPS is not without its limitations. These include its inability to be used accurately indoors, typically poor signal in built-up environments and on cloudy days, and the power consumed inhibiting long-term monitoring without regular recharging. Further research is required to determine the best design that has adequate battery life to last for the monitoring period.

mHealth Technologies

Smartphone and Mobile Applications

The smartphone is an example of a combined triaxial accelerometer and GPS system that is widely used. Smartphones are mobile phones built on a mobile operating system that allow easy access to the internet and have advance connectivity features such as mobile applications (apps) that expands their function (ACMA, 2013). Some examples of smartphones are Apple iPhones, Android phones, Windows mobile phones and Blackberry. It is now estimated that 96% of the population worldwide has a mobile phone subscription with mobile phone penetration of 121% in developed countries and 90% in developing countries (“The World in 2014: ICT Facts and Figures,” 2014). In 2013, approximately 56% of all phones worldwide are smartphones and the average user would have spent 80% of their time on the smartphone using apps (“Infographic: 2013 mobile growth statistics,” 2013).

Fitness apps have gained popularity amongst the general population (Bort-Roig et al., 2014). Apps vary in function and may contain features such as social support, demonstration and instructions on how to perform the activity and feedback to promote physical activity behaviours (Yang et al., 2015). Intervention trials in weight loss research have utilised apps that combine external (data transferred by wireless connection via Bluetooth) and in-built measurement technologies. Externally measurement technologies utilise self-report
on activity context, non-walking related activities that are not detected by accelerometers and other health-related behaviours (Bort-Roig et al., 2014). By combining information on self-report and objective in-built technologies, the person is able to obtain a complete report of their physical activity levels, diet and sleep.

However, a recent systematic review found that the majority of intervention trials in promoting physical activity after stroke utilised questionnaires to assess physical activity. The type of interventions explored in these trials were categorised into face to face tailored counselling, telephone counselling, supervised exercise programmes and unsupervised home exercise programmes (Morris et al., 2014). Though both assessment and behaviour change techniques can be incorporated into apps to promote physical activity, this is yet to be explored in people after stroke. Furthermore, before these technologies can be used in stroke intervention trials, the accuracy of objective measurement of physical activity via in-built accelerometers in smartphones needs to be examined. In addition, there are battery-life limitations to smartphones which inhibit their use as a daily activity monitor. Continuously logging sensor data from GPS and accelerometers to memory cards causes a major drain on the battery life of smartphones. These sensors need to be constantly operating in the background without interrupting the usual function of a phone (Morillo, Gonzalez-Abril, Ramirez, & de la Concepcion, 2015). If GPS and accelerometer logging is added to its normal use most phones are highly unlikely to last the required amount of time each day. However, as technology becomes increasingly energy efficient these issues may be overcome.

Smartwatch

Smartwatch is a novel wearable mHealth technology that has recently entered the mainstream commercial market. Apart from functioning as a wristwatch, the technology is also characterised by its ability to connect to the internet (Rawassizadeh et al., 2014). Thus, it is premature at present to expand on the applicability and usability of smartwatch technology in stroke or other neurological populations.

User-centred design for long-term sustained engagement

The ‘digital divide’

Although mHealth is a promising avenue for assessing and delivering physical activity interventions, much consideration into design needs to be given before it can be accessible or suitable in the stroke population. People after stroke could be of varying age groups and have different degrees of physical or cognitive impairments. Despite a rapidly growing mobile technology market, in Australia only 33% of people who are 55 years and above own a smartphone compared to 74% in the younger age groups. However, an industry survey estimates that this ‘digital divide’ between the generations is rapidly narrowing and is predicted to equalise by 2020 (Deloitte, 2014). The age-related differences in technology use could be due to changes in income level with aging, perceived need or importance of technology, and/or physical or cognitive impairments (Rogers & Fisk, 2010). Some smartphones have assistive features such as voice control (e.g. Siri on Apple iPhone) and dictation features for people with physical impairments, however these are not uniform amongst the different brand of smartphones. There has been no study to date investigating the use of smartphones and their limitations in the stroke population.

Patients’ perspective on usability

Apart from the technical considerations of enhancing the feasibility of smartphone use to assess and promote physical activity, further exploration is required in establishing design features and support for use in the stroke population with physical and cognitive impairments. There is a paucity of research investigating the needs, wants and limitations in utilising wearable technologies for long term use in the stroke population. Guidance for design could be gleaned from studies
in the general and elderly populations. A recent randomised controlled trial (SMART MOVE) investigated the effectiveness of a physical activity app (Accupedo-pro Pedometer) in increasing activity amongst adults in the primary care population and found that there was a significant increase in steps/day in the intervention group (Glynn et al., 2014). A follow-up qualitative study exploring patient perspectives of this cohort found that patients reported usability barriers such as requiring help to download and setup the app, resetting the app in the morning, the need to carry the phone around and increased battery consumption resulting in charging phone more frequently (Casey et al., 2014). However, the ability of the app to run automatically in the background, a large and simple display, and having the app icon on the home screen, were highlighted as features that promoted usability (Casey et al., 2014).

Similarly, qualitative research in ‘gerontechnology’ application of mHealth to older people has resulted in identification of three key aspects for design which are: 1) identifying usability issues with current technologies, 2) evaluating suitability of training and instruction materials, and 3) understanding the unmet needs of the elderly not provided for by current technology (Rogers & Fisk, 2010). Recommendations for wearable devices design in the older adults include attention to aesthetics, need for the device to be lightweight, comfortable, waterproof, easy to operate, inexpensive and have a long battery life (Murphy, 2009). It should also accurately assess physical activity and provide immediate feedback (Fini, Holland, Keating, Simek, & Bernhardt, 2014). Ideally, raw data from the devices should be able to be transmitted wirelessly or downloaded with ease onto a user-friendly platform. These recommendations could also be applicable for a stroke population.

Existing literature on user perspective of technology use in people after stroke is mainly around assistive devices, virtual reality and robotics for rehabilitation. However, these technologies are different in nature and purpose to wearable and smartphone technologies. Thus, there needs to be research specific to usability problems of wearable sensors and smartphones to aid in the in development of these technologies for people after stroke.

Clinicians’ perspective on supporting technology in stroke

The translation of new technologies from research to clinical settings, and repurposing of existing technologies for clinical use could be influenced by both the therapists’ and patients’ perspective. Current research reports that some of the barriers cited by physiotherapists for using technology in clinical practice were lack of time, insufficient knowledge with use of and interpreting information provided by technological measures, and a lack of technical support and processes to facilitate use of technology (Liu et al., 2014; Pak et al., 2015). Integrating the data from the wearable sensors and smartphone to existing electronic patient records could also enable the results to be more accessible in the clinic for therapists (Veerbeek, Voshaar, & Pot, 2012). One study found that despite the initial difficulties that new technologies could present to clinicians, if the clinician believed that using the new technology will improve patient outcomes then they are more likely to use the technology in clinical practice (Liu et al., 2014). Thus, time and cost needs to be factored in to train both clinicians and patients to ensure uptake and sustainability of a new technology. Future research on new technologies to assess and promote physical activity should routinely report therapists’ and participants’ feedback which will improve our understanding of the feasibility of the devices for clinical use.

Summary

Direct measurements of physical activity, such as accelerometers, have increased in popularity amongst the general population in the form of wearable activity trackers. There is also a growth in literature validating different types of wearable sensors in stroke research. However, the use of wearable sensors and smartphone technology for assessment and promotion of physical activity in people after stroke is still in its infancy. These devices have yet to be translated to everyday clinical use due to the cost and technical expertise required in interpreting and analysing the data. Furthermore, there is a need for the use of a combination of technologies to measure different aspects of physical activity so that an accurate and complete profile of the person’s activity can be generated. Wearable sensors and smartphone technology hold great promise, but need to be validated for measuring activity in people after stroke and other neurological conditions. Incorporation of behaviour change techniques, such as goal-setting, physical activity tracking, visualisation of progress and motivation, into customised apps could complement tailored counselling sessions for physical activity interventions.

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Conflict Of Interest
None

References


Pak, P., Jawed, H., Tiron, C., Lamb, B., Cott, C., Brunton, K., ... Inness, E. L. (2015). Incorporating research technology into the clinical assessment of balance and mobility: perspectives of


2.5.1 Self-report measures of post-stroke physical activity

Prior to the popular use of devices to measure physical activity in health research, physical activity questionnaires (PAQs) were the primary outcome measure. These are typically readily available, inexpensive, easy to administer in the clinic and not laborious for individuals to complete (Prince et al., 2008). To enable evaluation and comparison of physical activity using either questionnaires, observations or diaries, the Compendium of Physical Activities was developed (B. E. Ainsworth et al., 1993). This compendium allows activities to be expressed as an intensity unit in Metabolic Equivalent of Task (MET) depending on the rate of energy expenditure. One MET, which is the metabolic cost of resting quietly, is defined as 3.5 mL.kg\(^{-1}\).min\(^{-1}\) (B. E. Ainsworth et al., 2011). Physical activity can then be categorised as light (1.6–2.9 METs), moderate (4–5.9 METs) or vigorous (≥6 METs) (Blair, Cheng, & Scott Holder, 2001; Pate, O'Neill, & Lobelo, 2008). The American Heart Association guidelines state that for healthy adults to meet current physical activity recommendations, a mixture of moderate to vigorous activities accumulating to 450–750 METS.min.wk\(^{-1}\) is advised (Haskell et al., 2007).

A recent systematic review found that PAQs demonstrated poor validity in measuring physical activity amongst healthy adults (Helmerhorst, Brage, Warren, Besson, & Ekelund, 2012). However, the majority of validity studies have used accelerometers or pedometers as the criterion measure. These may be a poor reference for PAQs, as step-related activities are likely to be only a small component of daily physical activity. For example, previous research observed that people after stroke retained the highest percentage of activities in social and low-demand physical activities such as cooking (Hartman-Maeir, Soroker, Ring, Avni, & Katz, 2007). Activities in these domains would not be detected by accelerometers or pedometers, but could be reported on PAQs (Resnick et al., 2008). Furthermore, validating PAQs against accelerometers or pedometers which themselves have modest validity is also an issue. There is a lack of validation studies of PAQs that have used the StepWatch Activity Monitor (SAM), which is one of the few tools with acceptable validity for quantifying steps in stroke, as a criterion reference (Natalie A. Fini, Holland, Keating, Simek, & Bernhardt, 2015).
Even then, the SAM itself has only been validated in a laboratory or in short bursts of outdoor activity and has not been thoroughly tested in real world environments.

Although PAQs may suffer from potential recall and social desirability biases (Prince et al., 2008; Shephard, 2003), some strategies have been recommended to reduce systematic errors. These include ensuring that the questionnaire is culturally relevant, has a short recall period, focuses on structured activities that are easy to remember and includes standardised prompts (B. E. Ainsworth et al., 2012). Scoring and data analysis should also be carried out as per the protocol of the PAQ used (B. E. Ainsworth et al., 2012). Given their simplicity of implementation and ability to detect different forms of physical activity, PAQs may provide a convenient method of measuring physical activity in the absence of a device that is able to evaluate both walking and non-walking related physical activity.

2.5.2 Psychometric properties of physical activity measures

A recent systematic review found that there were 29 different types of devices that have been used for direct measurement of physical activity amongst stroke survivors (Natalie A. Fini et al., 2015). However, only 11 of these devices were validated in the stroke population and the criterion measures used for validation of these devices in stroke were varied. They included doubly labelled water, metabolic cart, three-dimensional gait analysis and footswitches, hand-held counter or video. For the devices that output step count, the SAM was found to possess the highest validity and test-retest reliability in the stroke population in both settings. The total step count measured by the SAM was found to be strongly correlated to footswitch-measured total step count for both the nonparetic limb ($r = 0.999$) and the paretic limb ($r = 0.963$) (Mudge, Stott, & Walt, 2007). The SAM also demonstrated high test-retest reliability with an intraclass correlation coefficient (ICC) of 0.96 to 0.99 (George D. Fulk et al., 2014; Haeuber, Shaughnessy, Forrester, Coleman, & Macko, 2004; Mudge & Stott, 2008). The Sensewear Pro 3, which is an arm-mounted device that estimates energy expenditure, demonstrated moderate validity in the stroke population for energy expenditure against the metabolic cart, but low validity for steps when measured against the SAM (ICC < 0.35) (Patricia J. Manns & Haennel, 2012).
At present, there is no published systematic review of self-report physical activity measurement in stroke and their psychometric properties. The majority of the self-report measures used to assess physical activity amongst stroke survivors have not been validated in the stroke population. The physical activity self-report measures used thus far in the stroke population include the Activity Card Sort (ACS) (Wolf & Koster, 2013), Baecke Physical Activity Questionnaire (BPAQ) (Baert, Feys, Daly, Troosters, & Vanlandewijck, 2012), Human Activity Profile (HAP) (L. F. Teixeira-Salmela, R. Devaraj, & S. J. Olney, 2007), International Physical Activity Questionnaire (IPAQ) (Aidar et al., 2011), Physical Activity and Disability Scale (PADS) (Rimmer, Wang, & Donald, 2008), Physical Activity Scale for the Elderly (PASE) (Vahlberg, Cederholm, Lindmark, Zetterberg, & Hellström, 2013), Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) (Baert et al., 2012; Rand, Eng, Tang, Hung, & Jeng, 2010), 7-day Physical Activity Recall (7-day PAR), Trip Activity Log (TAL) (Robinson, Matsuda, Ciol, & Shumway-Cook, 2013; Robinson, Shumway-Cook, Ciol, & Kartin, 2011; Robinson, Shumway-Cook, Matsuda, & Ciol, 2011), survey with Likert scale (Shaughnessy, Resnick, & Macko, 2006) and Yale Physical Activity Survey (YPAS) (Resnick et al., 2008). The properties of these questionnaires are summarised in Table 2.1.
Table 2.1: Summary of properties of self-report measures of physical activity

<table>
<thead>
<tr>
<th>Measure</th>
<th>Units</th>
<th>Valid (Y/N)</th>
<th>Recall period</th>
<th>Parameters</th>
<th>Items (n)</th>
<th>Time (mins)</th>
<th>Validity</th>
</tr>
</thead>
</table>
| ACS                | Retained activity score (1-100) | Y           | Pre-morbid vs current | P          | 85-88 cards | 20-30        | Stroke:  
|                    |                |             |                     |            |           |             | Li-Sat 9 (r = 0.57)** (Hartman-Maeir et al., 2007)  
|                    |                |             |                     |            |           |             | RNL (β = 0.14; R² = 0.09)** (Edwards, Hahn, Baum, & Dromerick, 2006)  
|                    |                |             |                     |            |           |             | ComQoL (r = 0.86)** (Chan, Chung, & Packer, 2006) |
| BPAQ               | Likert scale (1-5) | N           | Current             | F          | 16        | 10-15       | Healthy adults:  
|                    |                |             |                     |            |           |             | Activity dairy (r = 0.44-0.56)(Pols et al., 1995) |
| HAP                | METs           | Y           | Pre-morbid vs current | E          | 94        | 10          | Stroke:  
|                    |                |             |                     |            |           |             | Observed & self-report (r = 0.95)**  
|                    |                |             |                     |            |           |             | Observed & proxy (r = 0.80)**  
|                    |                |             |                     |            |           |             | (Luci Fuscaldi Teixeira-Salmela, Revathy Devaraj, & Sandra Jean Olney, 2007) |
| IPAQ               | MET-min/week   | N           | Past 7 days         | F,D,E,S    | 4         | 5           | Older adults:  
|                    |                |             |                     |            |           |             | Accelerometer-steps/day (r = 0.49-0.56)** (Tomioka, Iwamoto, Sacki, & Okamoto, 2011) |
| PADS               | Semi-structured interview | N           | Past 7 days         | F,D,T      | 13        | 20          | Stroke and other chronic conditions:  
|                    |                |             |                     |            |           |             | VO₂ peak (r = 0.23)* (Rimmer, Riley, & Rubin, 2001) |
| PASE               | 0-400 activity score | N           | Past 7 days         | F,D        | 12        | 5-15        | Older adults:  
|                    |                |             |                     |            |           |             | Accelerometer counts (r = 0.64)* (R. Washburn & Ficker, 1999)  
|                    |                |             |                     |            |           |             | VO₂ peak (r = 0.20)* (R. A. Washburn, McAuley, Katula, Mihalko, & Boileau, 1999) |
| PASIPD             | MET hr/day     | N           | Past 7 days         | F,D        | 13        | 5-15        | Stroke and other conditions with physical disabilities:  
|                    |                |             |                     |            |           |             | Accelerometer kilocounts/week (r = 0.30)* (van der Ploeg et al., 2007) |
| 7-day PAR          | Semi-structured interview | N           | Past 7 days         | F,D        | 11        | 20-30       | Healthy adults:  
|                    |                |             |                     |            |           |             | Accelerometer MET/min/day (r = 0.33)* (Jacobs, Ainsworth, Hartman, & Leon, 1993) |
| TAL                | Context        | Y           | Current             | T,F,L      | NA        | Variabele   | Stroke:  
|                    |                |             |                     |            |           |             | Observed no. of outings = 89%  
|                    |                |             |                     |            |           |             | Observed purpose of outings = 82% (McCluskey, Ada, Dean, & Vargas, 2012) |
| YPAS               | kcal/week      | N           | Typical week        | F,D        | 5         | 20          | Older adults:  
|                    |                |             | Last month          |            |           |             | Accelerometer counts (r = 0.31)* (Dipietro, Caspersen, Osfeld, & Nadel, 1993) |

*significant at p < 0.05; **significant at p < 0.01; Correlation coefficient (r) strength was defined such that <0.25 indicated small or no relationship, 0.25 to <0.50 a fair relationship, 0.50 to <0.75 a moderate to good relationship and ≥0.75 an excellent relationship (Portney & Watkins, 2009). Parameters definition: F, Frequency; D, Duration; E, Energy expenditure; S, Sedentary time; L, Location; P, Participation; T, Type

Abbreviations: ACS, Activity Card Sort; BPAQ, Baeecke Physical Activity Questionnaire; ComQoL, Comprehensive Quality of Life scale; FIM, Functional Independence Measure; HAP, Human Activity Profile; IADLq, Instrumental Activities of Daily Living Questionnaire; IPAQ, International Physical Activity Questionnaire; Kcal, kilocalories; Li-Sat 9, Life Satisfaction questionnaire; MET, Metabolic Equivalent; NA, Not Applicable; PADS, Physical Activity and Disability Survey; PASE, Physical Activity Scale for the Elderly; 7-day PAR, 7-day Physical Activity Recall; TAL, Trip Activity Log; YPAS, Yale Physical Activity Scale; RNL, Reintegration to Normal Living Scale; VO₂ peak, peak oxygen uptake.
The summary illustrates that the ACS is the only measure that evaluates participation and the IPAQ, though not validated in stroke, is also the only questionnaire used thus far that evaluates frequency, duration and sitting behaviour. The criterion validity is low for the IPAQ (P. H. Lee, Macfarlane, Lam, & Stewart, 2011) but the questionnaire was measured against accelerometers, which only measure walking related activity or energy expenditure. Furthermore, the TAL offers additional information on the context and location of activity which is often over-looked but is important to understand physical activity behaviour. Thus, a combination of measures is necessary to understand the multi-dimensional contributing factors to post-stroke physical activity levels.

2.6 Physical activity following stroke

This section will describe the current literature on physical activity levels amongst stroke survivors and summarise the benefits of post-stroke physical activity

2.6.1 Physical activity levels amongst community-dwelling stroke survivors

To date, three systematic reviews have synthesised activity levels amongst community-dwelling stroke survivors (Coralie English, Manns, Tucak, & Bernhardt, 2014; Field et al., 2013; Natalie A Fini, Holland, Keating, Simek, & Bernhardt, 2017). In the community setting, the main physical activity measures were evaluated directly using devices or via self-report. A wide variety of measures were used and the SAM was the most common. Physical activity levels were measured across different domains of activity; frequency, duration, intensity, participation, and type. Table 2.2 below is adapted from Natalie A Fini et al. (2017) which describes the different outcomes used in post-stroke physical activity research.
<table>
<thead>
<tr>
<th>Activity Domain</th>
<th>Outcome</th>
<th>Device (D)/ Self-report (SR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Steps/day</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Activity counts/day</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Number of transitions/day</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Number of activity bouts/day</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Likert scale: Never, Seldom (1-2d), Sometimes (3-4d), Often (5-7d)</td>
<td>SR (PASIPD)</td>
</tr>
<tr>
<td></td>
<td>Likert scale: Never, Seldom, Sometimes, Often, Very Often</td>
<td>SR (BPAQ)</td>
</tr>
<tr>
<td>Duration</td>
<td>Time spent in lying/sitting (minutes/percentage)</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Time spent on feet (minutes/percentage)</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Length of activity bouts</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Time spent in walking</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Time spent in outdoor walking activity</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Less than 1hr, 1-2 hrs, 2-4 hrs, &gt; 4hrs per day</td>
<td>SR (PASIPD)</td>
</tr>
<tr>
<td>Intensity</td>
<td>Energy expenditure (kcal/day or METS)</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Total activity kilo counts per day</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Daily minutes of light or moderate activity (Heart rate)</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Steps/min</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Step rate</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>METS-min/week</td>
<td>SR</td>
</tr>
<tr>
<td>Participation</td>
<td>Current activity</td>
<td>SR</td>
</tr>
<tr>
<td></td>
<td>Previous activity</td>
<td>SR</td>
</tr>
<tr>
<td></td>
<td>Percentage retained activities</td>
<td>SR</td>
</tr>
<tr>
<td>Type</td>
<td>Sports/high-demand leisure</td>
<td>SR</td>
</tr>
<tr>
<td></td>
<td>Outdoor activity</td>
<td>D</td>
</tr>
</tbody>
</table>

There is a paucity of longitudinal studies investigating the levels of physical activity amongst stroke survivors. Six studies to date (December 2017) have investigated the change in post-stroke physical activity from acute (0-7 days), early to late sub-acute (7 days-6 months) through to chronic (more than 6 months) (Askim, Bernhardt, Churilov, Fredriksen, & Indredavik, 2013; Duncan et al., 2015; Kunkel, Fitton, Burnett, & Ashburn, 2015; Moore et al., 2013; Sánchez et al., 2015; Tieges et al., 2015). The details of the longitudinal studies are described in Table 2.3.
Table 2.3: Characteristics and significant findings of longitudinal studies

<table>
<thead>
<tr>
<th>Article</th>
<th>N</th>
<th>Days since stroke</th>
<th>Assessment timepoints</th>
<th>Outcome measure</th>
<th>Wear site</th>
<th>Output</th>
<th>Significant findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Askim (2013)</td>
<td>28</td>
<td>8.0 (1-13)</td>
<td>T1: &lt;14 days of stroke</td>
<td>PAL2 (Device)</td>
<td>Thigh</td>
<td>- No. of transitions</td>
<td>Baseline to 1-mth post-stroke:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T2: 1 mth</td>
<td></td>
<td></td>
<td>- Time spent in lying, sitting and upright positions</td>
<td>- ↓ 15.9% time spent lying**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T3: 3 mth</td>
<td></td>
<td></td>
<td></td>
<td>- ↑ 72.4% time spent upright**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T4: 6 mth</td>
<td></td>
<td></td>
<td></td>
<td>1 mth to 3 mth post-stroke:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- ↑ 1.4% transitions**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 mth to 6 mth post-stroke:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- ↑ 1.4% transitions**</td>
</tr>
<tr>
<td>Duncan (2015)</td>
<td>84</td>
<td>Not reported</td>
<td>T1: 1 mth</td>
<td>ActivPAL</td>
<td>Thigh</td>
<td>- Time per day sitting/lying</td>
<td>Median (IQR) steps/day:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T2: 6 mth</td>
<td></td>
<td></td>
<td>- Time per day upright</td>
<td>-2841 (1419–5723; n=84) at 1 mth,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T3: 12 mth</td>
<td></td>
<td></td>
<td>- Time per day stepping</td>
<td>-4047 (2056–5822; n=69) at 6 mth</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Steps/day</td>
<td>-4314 (1657–6890; n=58) at 12 mth</td>
</tr>
<tr>
<td>Moore (2013)</td>
<td>25</td>
<td>Not reported</td>
<td>Within 1 week of stroke onset</td>
<td>Sensewear Pro 3</td>
<td>Arm</td>
<td>- Energy expenditure (kcal/day)</td>
<td>Baseline to 3 mth post-stroke:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T1: 1 week</td>
<td></td>
<td></td>
<td>- Daily energy expenditure relative to baseline metabolism (kcal/kg/hour)</td>
<td>- ↑ 14.1% total energy expenditure**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T2: 3 mth</td>
<td></td>
<td></td>
<td>- time spent doing activities &gt; 3/3 METS</td>
<td>- ↑ 85.2% steps/day**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T3: 6 mth</td>
<td>IPAQ</td>
<td></td>
<td>- steps/day</td>
<td>- ↑ 15% average MET**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- self-reported METS-min/week</td>
<td>- ↑ 128% energy expenditure**</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>- ↓ 2.4% sedentary time**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- ↑ 15.5% sedentary breaks**</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>- ↑ 229.3% MET-min/wk**</td>
</tr>
<tr>
<td>Kunkel (2015)</td>
<td>15</td>
<td>15 (range: 2-83)</td>
<td>Hospital 1, 2 and 3 years post-stroke onset</td>
<td>ActivPAL</td>
<td>Thigh</td>
<td>- % time spent sitting/lying</td>
<td>% time spent sitting/lying**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- % time spent standing</td>
<td>↑ standing time**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- % time spent walking</td>
<td>↑ walking time*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>↑ steps/day*</td>
</tr>
<tr>
<td>Sanchez (2015)</td>
<td>23</td>
<td>Not reported</td>
<td>Within 1 week of stroke onset</td>
<td>Vitaport AM</td>
<td>Sternum</td>
<td>- % time spent sitting/lying</td>
<td>Baseline to 3 mth post-stroke:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bilateral</td>
<td>- % time spent standing</td>
<td>- ↑ 9.12% walking time**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>thighs</td>
<td>- % time spent walking</td>
<td>- ↑ 18.79% upright time**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- ↓ 17.3% sedentary time**</td>
</tr>
<tr>
<td>Tieges (2015)</td>
<td>96</td>
<td>Not reported</td>
<td>T1: 1 mth</td>
<td>ActivPAL</td>
<td>Thigh</td>
<td>- Time spent sedentary (hrs)</td>
<td>Nil change over time (median [IQR]):</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T2: 6 mth</td>
<td></td>
<td></td>
<td></td>
<td>- 1 mth: 19.9 hrs (18.4–22.1),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T3: 12 mth</td>
<td></td>
<td></td>
<td></td>
<td>- 6 mth: 19.1 hrs (17.8–20.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- 12 mth: 19.3 hrs (17.3–20.9)</td>
</tr>
</tbody>
</table>

*significant at p < 0.05; **significant at p < 0.01; ↑, increase; ↓, decrease

Abbreviations: IPAQ, International Physical Activity Questionnaire; IQR, Inter Quartile Range; MET, Metabolic Equivalent of Tasks; Mth, month.
The results of the longitudinal studies show that stroke survivors are not active enough in any phase of stroke recovery to gain health benefits (if the recommended thresholds for healthy people are used). The studies also report that the most significant change in activity levels occurs in the first three months after stroke and then plateaus. However, these studies have not accounted for the differences between physical activity in the hospital setting and habitual activity in the community. The environment could have also contributed to the significant difference in activity levels as the stroke survivor could have moved from hospital to a rehabilitation unit to home. Hospital environments and policies, such as availability of weekend therapy, greatly influences physical activity levels amongst stroke survivors (J. Bernhardt, Dewey, Thrift, & Donnan, 2004; Hokstad et al., 2015; Janssen et al., 2014; Kroeders, Bernhardt, & Cumming, 2013; Scrivener, Jones, Schurr, Graham, & Dean, 2015). Thus, habitual physical activity in the early and late sub-acute phase of stroke needs to be assessed separately to physical activity undertaken in a hospital setting. Also, the most significant changes in neurological recovery and physical function also occurs in the first three months after stroke, which could confound the physical activity pattern seen in these studies (Julie Bernhardt et al., 2017).

2.6.2 Physical activity levels of stroke survivors compared to other populations

A recent review found that stroke survivors participated in approximately 50% less activity than their age-matched healthy peers (Natalie A Fini et al., 2017). The pooled findings for steps/day of physical activity for healthy adults is consistent with other research which has found that walking activity in healthy adults ranges from 2000-9000 steps/day (C. Tudor-Locke, Washington, & Hart, 2009). Stroke survivors average 5535 and 4078 steps/day in the sub-acute and chronic phase respectively (Natalie A Fini et al., 2017). Even when compared to other chronic conditions, stroke survivors remained the least active (Ashe, Miller, Eng, & Noreau, 2009). Figure 2.1 is a graphical representation demonstrating the mean steps/day across different populations (Chmelo et al., 2013; Dlugonski et al., 2013; Natalie A Fini et al., 2017; C. Tudor-Locke et al., 2009). It is not meant to be exhaustive, however summarizes the results of a review articles (where available) in different clinical populations.
Figure 2.1: Mean steps/day across different populations

It was difficult to synthesise results from studies that used self-report measures as there was no common outcome measure to compare across studies in different populations. There is consensus that stroke survivors are not active enough to gain health benefits and that they are even less active than people with other chronic conditions.

2.6.3 Benefits of post-stroke physical activity

Current evidence from longitudinal studies demonstrates that physical activity can reduce detrimental secondary changes after stroke such as loss of skeletal muscle (Coralie English et al., 2010; Scherbakov & Doehner, 2011), change in muscle structure (Addison et al., 2014; Hafer-Macko et al., 2008), loss of bone mass (Borschmann, 2011; Borschmann et al., 2012) and reduced cardiorespiratory fitness (Billinger et al., 2011; Pang et al., 2013; Smith et al., 2012).

The lifetime recurrence of stroke is 30%, with 18% mortality (Billinger et al., 2014). At present, there is no direct evidence that physical activity prevents recurrent stroke (David H Saunders, Greig, Young, & Mead, 2009). However, physical activity has been shown to modify known stroke risk factors by improving glucose regulation, lipid
metabolism, insulin sensitivity, blood pressure regulation and cellular function (Endres et al., 2003; Frederick M Ivey et al., 2007; Kernan et al., 2014). Apart from the physiological benefits, research has highlighted the importance of physical activity in adjusting to life after stroke and as a means to achieve physical and social goals (Jacqui H Morris, Oliver, Kroll, Joice, & Williams, 2014).

2.7 Modifiable prognostic factors of post-stroke physical activity

There are many different physical and psychosocial factors associated with post-stroke physical activity levels. However, it can be difficult to infer causal relationships with cross-sectional research. This section will firstly define modifiable prognostic factors, prognostic determinants and other variables such as mediators. Chapter 3 presents a systematic review and meta-analysis (S. Thilarajah et al., 2017) which integrates the literature on the factors associated with post-stroke physical activity. This section will therefore summarise key literature from the review and will additionally appraise other studies (e.g. RCTs and qualitative research) that have examined post-stroke physical activity.

2.7.1 Definitions

A prognostic factor is a candidate factor (or independent variable) that has a significant association to an outcome measure (or dependent variable), such as physical activity. Although cross-sectional studies cannot uncover causal relationships, as the direction of causality is unclear, this type of study can generate hypotheses for testing in cohort, longitudinal or randomised controlled trials (Bauman, Sallis, Dzewaltowski, & Owen, 2002). For example, gait speed is a factor associated with post-stroke physical activity (measured by steps/day) (Coralie English et al., 2014; Field et al., 2013). It is unknown if gait speed and physical activity influence each other causally, as the direction of the relationship is unclear. Therefore, it may be that people who can walk faster have greater confidence and physical capacity which results in them being more active. Conversely, people who are more active may have a resulting faster gait speed due to task specificity training and strengthening of the muscles involved in walking. If the latter was true, then improving gait speed may not necessarily increase physical activity levels. This is illustrated in Figure 2.2 (Greenland, Pearl, & Robins, 1999).
Prognostic determinants are causal factors that cause a systematic change in the behaviour. The evidence of a causal relationship is first determined by the study design with the best evidence from randomised controlled trials, followed by quasi experimental designs, and lastly observational designs such as cohort and longitudinal studies (Bauman et al., 2002). A temporal sequence is important to establish that the independent variable needs to be measured or intervened at the time point before the collection of the outcome measure (Greenland et al., 1999). This is illustrated in Figure 2.3.

The observed relationship can also be affected by other factors defined as confounders, mediators and moderators (Greenland et al., 1999). A confounder is a factor that is associated with both the independent and dependent variable. For example, age is associated with both gait speed and post-stroke physical activity (Coralie English et al., 2014; Field et al., 2013; Studenski et al., 2011). This is illustrated in Figure 2.4.
A mediator variable is one that intervenes and is causally related in sequence to the behaviour, and a moderator produces different estimates of the association at different levels of the variable (Bauman et al., 2002). The exploration of these relationships is out of the scope of this thesis.

### 2.7.2 Modifiable prognostic factors associated with post-stroke physical activity

Factors associated with post-stroke physical activity examined at the cross-sectional level are explored in detail in the published systematic review in Chapter 3. The majority of research was conducted in the chronic stroke population (i.e. more than six months post-stroke), with a negligible number of studies in the sub-acute phase (seven days to six months post-stroke). Age (inversely) and male sex were the non-modifiable factors that were found to be associated with post-stroke physical activity (S. Thilarajah et al., 2018). This is consistent with the relationship observed between age and gender with physical activity amongst healthy adults (Bauman et al., 2012). The modifiable factors were physical function, cardiorespiratory fitness, fatigue, falls self-efficacy, balance self-efficacy, depression and health-related quality of life. The cause and effect of these relationships were unclear, and the possibility of reverse causality needs to be addressed through further investigation in cohort and longitudinal studies.

### 2.7.3 Determinants of post-stroke physical activity

There is a paucity of cohort and longitudinal studies examining causal relationships between physical, psychological, cognitive and social factors in post-stroke physical activity. Only one longitudinal study, thus far, has investigated prognostic factors of physical activity measured at stroke onset and at one, two and three years after
stroke. (Kunkel et al., 2015) They found that left-sided infarct, neglect and poor cognition predicted low post-stroke physical activity. (Kunkel et al., 2015) However, this study did not report the correlations at all time points or for all measures, making interpretation difficult. Thus, causal factors to post-stroke physical activity need to be explored for better understanding and effective intervention to increase physical activity after stroke.

2.8 Summary
Chapter 2 has highlighted that post-stroke physical activity levels are low despite growing evidence of the benefits of physical activity in the population. Most of the research has been cross-sectional and conducted in the chronic stroke population. Thus, causal relationships cannot be established. There is a need for studies of different designs to explore determinants of physical activity levels amongst stroke survivors to allow early intervention.
Chapter 3: Factors associated with post-stroke physical activity

Manuscript 2: Factors associated with post-stroke physical activity: a systematic review and meta-analysis

Factors Associated With Post-Stroke Physical Activity: A Systematic Review and Meta-Analysis

Shamala Thilarajah, MAppSc, Benjamin F. Mentiplay, PhD, Kelly J. Bower, PhD, Dawn Tan, DClinPT, Yong Hao Pua, PhD, Gavin Williams, PhD, Gerald Koh, PhD, Ross A. Clark, PhD

From the School of Health and Exercise Science, The University of the Sunshine Coast, Sunshine Coast, QLD, Australia; Department of Physiotherapy, Singapore General Hospital, Singapore; Epworth HealthCare, Richmond, Melbourne, VIC, Australia; The University of Melbourne, Melbourne, VIC, Australia; and Saw Swee Hock School of Public Health, National University of Singapore, Singapore.

Abstract

Objective: To integrate the literature investigating factors associated with post-stroke physical activity.

Data Sources: A search was conducted from database inception to June 2016 across 9 databases: Cochrane, MEDLINE, ProQuest, Web of Science, PsycINFO, Scopus, Embase, CINAHL, and Allied and Complementary Medicine Database. The reference lists of included articles were screened for secondary literature.

Study Selection: Cohort and cross-sectional studies were included if they recruited community-dwelling stroke survivors and measured factors associated with physical activity.

Data Extraction: Risk of bias was evaluated using the Quality in Prognosis Studies checklist. A meta-analysis was conducted for correlates where there were at least 2 studies that reported a correlation value. Correlation values were used in an effect size measure and converted to a standardized unit with Fisher r to z transformation and conversion back to r method. Results were described qualitatively for studies that could not be pooled.

Data Synthesis: There were 2161 studies screened and 26 studies included. Age (meta r = .17; P < 0.001) and sex (meta r = .01; P = .02) were the nonmodifiable factors that were found to be associated with post-stroke physical activity. The modifiable factors were physical function (meta r = .68; P < 0.001), cardiorespiratory fitness (meta r = .35; P < 0.001), fatigue (meta r = .22; P = .01), falls self-efficacy (meta r = .33; P < 0.001), balance self-efficacy (meta r = .37; P < 0.001), depression (meta r = -.58 to .48; P < 0.001), and health-related quality of life (meta r = .38 to .43; P < 0.001). The effect of side of infarct, neglect, and cognition on post-stroke physical activity was inconclusive.

Conclusions: Age, sex, physical function, depression, fatigue, self-efficacy, and quality of life were factors associated with post-stroke physical activity. The cause and effect of these relations are unclear, and the possibility of reverse causality needs to be addressed.

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Post-stroke physical activity factors

10 This includes energy expenditure involved in exercise and household, occupational, and leisure activities. Several studies have investigated factors that may be related to physical activity levels among stroke survivors. To date, there have been 2 systematic reviews that have explored physical activity after stroke. 11, 12 The results of these studies demonstrated that physical function was a positive correlate, whereas low mood and poorer quality of life were negatively correlated with steps per day and activity counts. 11, 12 However, the studies were diverse in the measurement of independent variables and physical activity outcomes used. A mix of direct and self-reported measures were also used, which made comparison across different studies challenging. Both reviews reported the correlates of physical activity as a secondary aim, and neither provided a detailed appraisal of the research in this area or a quantitative synthesis of the strength of the associations.

A comprehensive synthesis and appraisal of existing literature will allow a better understanding of the factors which could influence post-stroke physical activity levels. Therefore, the aim of this systematic review with meta-analysis was to investigate the factors associated with physical activity among community-dwelling stroke survivors.

Methods

This review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement guidelines, 13 and was registered on PROSPERO (registration no. CRD42015019097). 14

Literature search

A systematic search was conducted from database inception to June 2016 across 9 databases: Cochrane, MEDLINE, ProQuest, Web of Science, PsycINFO, Scopus, Embase, CINAHL, and Allied and Complementary Medicine Database. Reference lists of included articles were screened for secondary literature. Search terms were customized to each database with no language restriction. An example search using MEDLINE is provided in box 1.

Selection criteria

Original quantitative and observational research articles that recruited community-dwelling adults with stroke and explored associations with physical activity levels were included. Studies involving physical activity measurement in hospital, during therapy sessions, or where the setting of measurement of physical activity was ambiguous or inconsistent were excluded. Studies exploring community ambulation post-stroke were included if frequency, duration, or intensity of outdoor activity was measured. Studies where physical ability or function was measured instead, or where physical activity was not the dependent variable, were excluded. Abstracts and gray literature (eg, reports, conference proceedings, doctoral theses, dissertations) were also excluded.

Screening process and data extraction

The first author (S.T.) conducted the searches and completed the initial screening from the titles and abstracts. The full texts of all potential titles were independently reviewed by 2 authors (S.T. and B.F.M.), with a decision made regarding article selection based on the inclusion criteria. The reasons for article exclusion were recorded. Any disagreements between the 2 reviewers regarding the inclusion of an article were settled by a third reviewer (K.J.B.). Data extraction was independently conducted by the 2 reviewers using a customized database. Data such as study design, methods, participant characteristics, type of physical activity measurement, duration of activity monitoring, independent and dependent variables investigated, statistical tests used in analysis, and correlational values were extracted.

Risk of bias assessment

Selected articles were assessed for bias using the Quality in Prognosis Studies checklist. 15 The Quality in Prognosis Studies tool provides a framework to assess quality of reporting and risk of bias in 6 domains: study participation, study attrition, prognostic factor measurement, confounders’ measurement and adjustment, outcome measurement, and statistical analysis. Each domain is scored either as low, moderate, or high risk of bias. The tool was customized so that within each domain the specific issues pertaining to physical activity post-stroke were defined (appendix 1). For example, the confounding domain was irrelevant in studies that examined the combined influence of multiple possible factors on physical activity. However, this domain would be relevant in studies that examine (1 or 2) specific factors. Reporting quality for each domain was scored as yes, no, partly, or unsure using customized definitions. A final score for the risk of bias was allocated based on the overall reporting quality in each domain. If a study scored a high risk of bias in any 1 of the 6 domains, it scored an overall rating of high risk. 15 If a study did not score a high risk in any domain and scored a low risk in at least 4 of the 6 domains (66%), it was given an overall rating of low risk. 15 This percentage rule was also applied to studies that had 1 or 2 domains that were not applicable, based on the number of domains that were scored. Any cases in between these 2 rules were rated as an overall moderate risk of bias. Risk of bias assessment was rated independently by 2 authors (S.T. and B.F.M.), followed by a consensus meeting with a third author (P.Y.H.), which included a discussion of the individual ratings.

Data synthesis and meta-analyses

A meta-analysis was conducted for studies that reported a correlation value and at least 2 studies that examined the same construct. Multiple values were extracted from the same study if the study used a combination of direct and self-report measures of physical activity. Correlation values were used in an effect size (ES) measure and converted to a standardized unit with Fisher r to z transformation and conversion back to r method. 16, 17

List of abbreviations:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>6MWT</td>
<td>6-minute walk test</td>
</tr>
<tr>
<td>BBS</td>
<td>Berg Balance Scale</td>
</tr>
<tr>
<td>CI</td>
<td>confidence interval</td>
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<tr>
<td>ES</td>
<td>effect size</td>
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<tr>
<td>FSS</td>
<td>Fatigue Severity Scale</td>
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<tr>
<td>HRQOL</td>
<td>health-related quality of life</td>
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<tr>
<td>MMSE</td>
<td>Mini-Mental State Examination</td>
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<tr>
<td>MoCA</td>
<td>Montreal Cognitive Assessment</td>
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www.archives-pmr.org
First, the correlational (r) values were converted to (ES(z) = \frac{1}{2} \log\left(\frac{1 + r}{1 − r}\right)). The transformed scores were entered into a fixed-effect model using the generic inverse variance method. The standardized scores enabled both direct and self-reported physical activity outcomes to be combined in the meta-analysis for comparison preventing a systematic loss of information. Heterogeneity was assessed using the chi-square test which analyzed if the observed differences in results were caused by chance. A P value of <.10 determined a statistically significant heterogeneity where the observed differences could be because of sampling or methodologic variations in the studies. This was interpreted together with the I^2 test which was used to quantify inconsistencies among the pooled studies. The I^2 test was calculated using I^2 = \left(\frac{Q − df}{Q}\right) \times 100\%, where Q is the chi-square test and df refers to the degrees of freedom. A high I^2 score indicates high variability in observed results caused by heterogeneity rather than chance. In a meta-analysis with substantial heterogeneity (determined by I^2 > 50% or a statistically significant chi-square value), the included studies were further examined to explore the reasons for heterogeneity. If there was no plausible explanation for the heterogeneity, then a random-effects model, which incorporates the heterogeneity, was performed. Pooled ES was converted back to r using meta r = \left(\frac{[\log(1 + r)/\log(1 − r)]}{\log(1 + r)}\right). Studies with high risk of bias were excluded from the meta-analysis, but a sensitivity analysis was conducted to ensure the choices made during the review process regarding study quality did not affect the statistical analysis. The meta-analysis was conducted using the Cochrane Collaboration RevMan 5.3 software. Correlation coefficient (r) strength was defined such that <.25 indicated small or no relation, .25 to <.50 indicated a fair relation, .50 to <.75 indicated a moderate to good relation, and ≥.75 indicated an excellent relation.

### Results

#### Study selection and characteristics

The search produced a total of 2161 potential studies, of which 56 articles were selected for full-text review. The search results and eligibility screening process, as recommended by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement, is provided in figure 1. Twenty-six studies with a median sample size of 40 (interquartile range, 19–50) were included in the evidence synthesis. Study characteristics are summarized in table 1. Most studies were prospective cross-sectional in design (n = 24), and studies were cohort. The median age of the participants across the studies was 67 (interquartile range, 64–68) years, with 58% male participation. One study did not report sex. Participants ranged from 10 months to 7 years post-stroke. Four studies did not report time since stroke. Five studies reported stroke severity using the National Institutes of Health Stroke Scale, with a median score of 3 (interquartile range, 3–4), indicating mild stroke severity. The National Institutes of Health Stroke Scale scores were obtained at the entry into the study, except for 1 study where it was measured at stroke onset. Five studies described the type of stroke, with 85% being infarcts. There was variability in describing other stroke details, such as the side of lesion or infarct versus hemorrhage. No consistent stroke measure was reported across all studies.

### Direct measurement of physical activity

The StepWatch Activity Monitor was the most frequently used physical activity measurement device. Other devices included the Intelligent Device for Energy Expenditure and Activity, activPAL, Actical, Actigraph GT3X+, Yamax SW-200 pedometer, Kenz Lifecorder pedometer, VKRfitness Twin Step pedometer, and Polar RS400 heart rate monitor. Except for the Kenz Lifecorder pedometer, the other devices used to measure physical activity in the included studies have been validated in the stroke population. The most common physical activity outcome used was steps per day. Other measures reported were time spent on feet (ie, total minutes spent in postural transitions, walking and stair climbing activities) and activity counts (ie, combined, unitless measure of amount and intensity of activity over a specified time period determined by proprietary algorithms). Therefore, comparing results across studies was difficult because different systems output different variables. The test-retest reliability for the StepWatch Activity Monitor was excellent with an intraclass correlation coefficient of .95 to .98, whereas a conventional pedometer demonstrated a lower reliability of r = .64 for step counts. The activPAL demonstrated test-retest excellent reliability with an intraclass correlation coefficient of .87 to .98 for step counts. The Actical was also found to have excellent test-retest reliability with an intraclass correlation coefficient of .95 for both activity counts and energy expenditure. The Intelligent Device for Energy Expenditure and Activity demonstrated an intraclass correlation coefficient of .69 for time on feet and .80 for activity counts.

Five studies stratified physical activity to intensities and aimed to investigate correlates to different activity profiles. However, there was no common definition of activity intensity. Two studies defined moderate to vigorous activity as 16 steps per minute and >60 steps per minute. The cutoff definitions for low intensity varied between 16 steps per minute and <30 steps per minute across 2 studies. This was the same for high intensity at ≥30 steps per minute and >60 steps per minute. A heart rate monitor was used in only 1 of the included studies in this review to measure exercise intensity.
Self-report measures of physical activity

Five studies used self-report measures, \textsuperscript{33,36,39,41,46} whereas 4 combined direct and self-report measures. \textsuperscript{34,35,40,51} Self-report measures included the Activity Card Sort, \textsuperscript{46} Human Activity Profile, \textsuperscript{41} Physical Activity Scale for the Elderly, \textsuperscript{39} Baecke Physical Activity Questionnaire, \textsuperscript{51} Physical Activity Scale for Individuals with Physical Disabilities, \textsuperscript{34,51} Trip Activity Log, \textsuperscript{33,35,36} 7-Day Physical Activity Recall, and Barriers to Being Active Quiz. \textsuperscript{40} One study used a survey instrument asking participants to describe how often they engaged in physical activity which caused sweating or increases in heart or respiratory rate for at least 20 minutes, on a Likert scale. \textsuperscript{45} Therefore, similar to direct measures of physical activity, there were also no common self-reported measures among the included studies.

Risk of bias assessment

The risk of bias assessment is presented in table 2. Most articles scored an overall rating of low to moderate risk. A high risk of bias was awarded to 5 studies, primarily for unclear reporting of inclusion and exclusion criteria, failure to report stroke details, using measures of physical activity that were not validated, unclear reporting of duration of accelerometer wear, failure to report and/or adjust for important confounders in statistical analysis, and selective reporting of results. \textsuperscript{38-40,45,48,52}
<table>
<thead>
<tr>
<th>Reference</th>
<th>Study Design</th>
<th>Setting</th>
<th>Sampling Strategy</th>
<th>PA Outcome Measure</th>
<th>Sample Size</th>
<th>Sex (M/F)</th>
<th>Mean Age ± SD (Range), y</th>
<th>Mean Stroke Severity NIHSS Score ± SD</th>
<th>Side of Paresis</th>
<th>Mean Time Since Stroke ± SD</th>
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<td>Alzaharani (2009)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>IDEEA</td>
<td>42</td>
<td>29/13</td>
<td>70±10</td>
<td>NR</td>
<td>Right: 23</td>
<td>2.8±1.4y</td>
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<td>Alzaharani (2012)</td>
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<td>Community</td>
<td>Convenience</td>
<td>IDEEA</td>
<td>42</td>
<td>29/13</td>
<td>70±10</td>
<td>NR</td>
<td>Right: 23</td>
<td>2.8±1.4y</td>
</tr>
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<td>Hospital</td>
<td>NR</td>
<td>Pedometer, BPAQ, PASIPD</td>
<td>16</td>
<td>12/4</td>
<td>61.9±11.9</td>
<td>4.9±4.4</td>
<td>NR</td>
<td>NR</td>
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<tr>
<td>English (2016)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>Actigraph</td>
<td>50 (46)*</td>
<td>33/17</td>
<td>67.2±11.6</td>
<td>NR</td>
<td>NR</td>
<td>3.89±9.32</td>
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<tr>
<td>English (2016)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>SAM</td>
<td>19</td>
<td>NR</td>
<td>65.7±11.9</td>
<td>NR</td>
<td>NR</td>
<td>42.1±36.1mo</td>
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<td>Manns (2009)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>SAM</td>
<td>10</td>
<td>4/6</td>
<td>54±11</td>
<td>NR</td>
<td>Right: 4</td>
<td>7.5±8.3y</td>
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<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>SAM</td>
<td>10</td>
<td>4/6</td>
<td>54.3±3</td>
<td>NR</td>
<td>Right: 4</td>
<td>7.5±8.3</td>
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<tr>
<td>Michael (2005)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>SAM</td>
<td>50</td>
<td>28/22</td>
<td>65 (45—84)</td>
<td>3.57 (0—16)</td>
<td>NR</td>
<td>10.3mo (6—166mo)</td>
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<td>Michael (2007)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>SAM</td>
<td>50</td>
<td>28/22</td>
<td>65 (45—84)</td>
<td>3.57 (0—16)</td>
<td>NR</td>
<td>10.3mo (6—166mo)</td>
</tr>
<tr>
<td>Mudge (2009)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>SAM</td>
<td>50 (49)*</td>
<td>29/20</td>
<td>67.4±12.5 (38—89)</td>
<td>NR</td>
<td>Right: 18</td>
<td>66±61mo (6—219mo)</td>
</tr>
<tr>
<td>Paul (2016)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>activPAL</td>
<td>22 (21)*</td>
<td>10/12</td>
<td>55.9±9.9</td>
<td>NR</td>
<td>NR</td>
<td>4.2±4.0y</td>
</tr>
<tr>
<td>Rand (2009)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>Actical</td>
<td>40</td>
<td>13/27</td>
<td>66.5±9.6 (49—82)</td>
<td>NR</td>
<td>Right: 20</td>
<td>2.9±2.4 (1—12)</td>
</tr>
<tr>
<td>Rand (2010)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>Actical PASIPD</td>
<td>40</td>
<td>13/27</td>
<td>66.5±9.6 (49—82)</td>
<td>NR</td>
<td>Right: 20</td>
<td>2.9±2.4 (1—12)</td>
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<tr>
<td>Robinson (2011)</td>
<td>Cross-sectional</td>
<td>Community</td>
<td>Convenience</td>
<td>Pedometer TAL</td>
<td>50 (46)*</td>
<td>27/23</td>
<td>65±8.4 (50—79)</td>
<td>NR</td>
<td>Right: 23</td>
<td>85.0±89.9mo (6—358mo)</td>
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(continued on next page)
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<tr>
<th>Reference</th>
<th>Study Design</th>
<th>Setting</th>
<th>Sampling Strategy</th>
<th>PA Outcome Measure</th>
<th>Sample Size</th>
<th>Sex (M/F)</th>
<th>Mean Age ± SD (Range), y</th>
<th>Mean Stroke Severity NIHSS Score ± SD</th>
<th>Side of Paresis</th>
<th>Mean Time Since Stroke ± SD</th>
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</thead>
<tbody>
<tr>
<td>Salbach (2014)</td>
<td>Cross-sectional Community Convenience</td>
<td>activPAL</td>
<td>16 (15)*</td>
<td>14/2</td>
<td>71.1±9.7 (57–93)</td>
<td>3.1±2.4 (0–10)</td>
<td>Right: 9 Left: 6 Bilateral: 1</td>
<td>Reported as evenly split</td>
<td>NR</td>
<td>2.0±1.1y (0.5–4.2y)</td>
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<tr>
<td>Shaugnessy (2005)</td>
<td>Cross-sectional Hospital Convenience</td>
<td>SAM</td>
<td>21 (19)*</td>
<td>10/11</td>
<td>68±12.8 (48–91)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>60.2±48.1mo</td>
</tr>
<tr>
<td>Shaugnessy (2006)</td>
<td>Cross-sectional Community Convenience</td>
<td>Survey</td>
<td>321 (312)*</td>
<td>127/177</td>
<td>62.9±11.7</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>2.0±2.41y (4mo–8y)</td>
</tr>
<tr>
<td>Teixeira-Salmela (2007)</td>
<td>Cross-sectional Community Convenience</td>
<td>HAP</td>
<td>24</td>
<td>13/11</td>
<td>63.69±11.57 (39–84.5)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>2.0±2.41y (4mo–8y)</td>
</tr>
<tr>
<td>Vahlberg (2013)</td>
<td>Cross-sectional Community Convenience</td>
<td>PASE</td>
<td>195</td>
<td>138/57</td>
<td>74±5.2</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Wolf (2013)</td>
<td>Cohort Hospital NR</td>
<td>ACS</td>
<td>110 (96)*</td>
<td>59/51</td>
<td>Group 1: 64.2±13.4 Group 2: 60.5±12.8 All participants: 62 Group 1: 2.4±1.6 Group 2: 2.2±1.4 All participants: 2.3</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
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<tr>
<td>Zalewski (2011)</td>
<td>Cross-sectional Community Convenience</td>
<td>SAM</td>
<td>17</td>
<td>14/3</td>
<td>71.3±9.5</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td></td>
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</tbody>
</table>

Abbreviations: ACS, activity card sort; BPAQ, Baecke Physical Activity Questionnaire; F, female; HAP, Human Activity Profile; IDEEA, Intelligent Device for Energy Expenditure and Activity; M, male; NIHSS, National Institutes Hospital Stroke Scale; NR, not reported; PA, physical activity; PASE, Physical Activity Scale for the Elderly; PASIPD, Physical Activity Scale for individuals with Physical Disabilities; SAM, StepWatch Activity Monitor; TAL, Trip Activity Log.

* Values in parenthesis indicate the sample size used in the statistical analysis after removal of subjects with missing data.
Data synthesis

Five studies were excluded from the meta-analysis because they were assessed as having high risk of bias.38,40,45,48,52 Twenty-one studies (n = 959) were eventually entered into the final meta-analysis. Forest plots depicting the individual and pooled estimates and confidence intervals (CIs) are illustrated in figure 2. A sensitivity analysis was performed by comparing the results from meta-analyses that included high risk of bias studies with those that excluded high-risk studies. The results were found to be similar. A sensitivity analysis was also conducted by omitting the studies that used self-report measures. There was negligible change in the overall summary estimate, results of heterogeneity tests (I²), or meta r values.

Nonmodifiable factors associated with physical activity

A total of 10 studies assessed the relation between age and physical activity and found negative correlations ranging from \( r = -0.12 \) to \(-0.47.26,29,33,35,36,39,45,49,51 \) Three studies were excluded from the meta-analysis; 1 study was assessed as having high risk of bias45 and 2 others reported only results of regression analysis.33,36 Pooled results from the remaining 7 studies (n = 409) entered into the final meta-analysis demonstrated a small relation between age and physical activity levels (ES \( z = -0.17; 95\% CI, -0.26 \) to \(-0.08; P<.001; meta \( r = -0.17; r^2 = 0.03 \)). Sex was routinely reported, but investigated as a correlate in only 3 studies.45,50,51 One study was removed from the meta-analysis because it was assessed as high risk of bias.45 Consequently, the pooled results from the 2 other studies (n = 58) also demonstrated a small relation between sex and physical activity (ES \( z = -0.21; 95\% CI, -0.37 \) to \(-0.04; P = .02; \) meta \( r = -0.21; r^2 = 0.04 \)).

Only 1 longitudinal study included the side of infarct and presence of neglect reported at time of stroke in an exploratory analysis,48 with a left-sided infarct having a moderate and inverse relation to time spent on feet at 1 and 2 years post-stroke (\( r = -0.63, P = .01; r = -0.58, P = .02, \) respectively) and visual neglect moderately associated with physical activity (\( r = -0.67, P<.01 \) 2 years post-stroke. However, these results should be interpreted with caution because this study was assessed as having high risk of bias. Years since stroke was investigated in 4 studies. Three studies (n = 88) were pooled because 2 studies shared the same cohort. The meta-analysis results found no statistically significant association to physical activity.42,45,49,50

Potentially modifiable factors associated with physical activity

The 6-minute walk test (6MWT), Berg Balance Scale (BBS), comfortable gait speed, and Timed Up and Down Stairs were the functional mobility measures that have been investigated thus far in the post-stroke physical activity literature. The 6MWT was investigated as a correlate to objectively measured physical
activity\textsuperscript{26,29,32,37,49} and self-reported physical activity.\textsuperscript{34} The results from the meta-analysis (n=205) demonstrated a statistically significant and moderate to good correlation to physical activity (ES [\(z\)] = .70; 95% CI, .58–.82; \(P<.001\); meta \(r = .60\); \(r^2 = .37\)). The 6MWT explains 37% of the variation in post-stroke physical activity. The BBS was used in 4 studies\textsuperscript{26,28,34,50} and was found to possess a moderate to good correlation to physical activity (ES [\(z\)] = .54; 95% CI, .40–.67; \(P<.001\); meta \(r = .49\); \(r^2 = .24\)) in the meta-analysis (n=151). Ten studies investigated comfortable gait speed,\textsuperscript{26,28,29,31,36,40,42,49,51} with 1 study excluded from the meta-analysis because it was rated at high risk of bias,\textsuperscript{40} and 2 studies did not report correlation values.\textsuperscript{36,41} The meta-analysis (n=243) demonstrated a moderate to good correlation between comfortable gait speed and steps per day (ES [\(z\)] = .65; 95% CI, .54–.76; \(P<.001\); meta \(r = .57\); \(r^2 = .33\)). Cardiorespiratory fitness, as measured by peak oxygen consumption, was included in 5 studies as an independent variable.\textsuperscript{24,25,28,51,52} One study was excluded from the meta-analysis because it was rated at high risk of bias.\textsuperscript{52} Pooled results (n=155) revealed a significant correlation but only a fair relation to physical activity (ES [\(z\)] = .36; 95% CI, .13–.45; \(P<.001\); meta \(r = .35\); \(r^2 = .12\)). A random-effects model did not alter the substantial heterogeneity present (\(I^2 = 82\%\), \(P = .05\)) in the analysis, and there were no clear differences in the sample or methods used among the pooled studies. Similarly, only a fair association was found between peak oxygen consumption and low (<16 steps per minute) (r = .261, \(P<.050\)) and high (≥30 steps per minute) (r = .333, \(P<.01\)) intensity physical activity.\textsuperscript{26} The Timed Up and Down Stairs was found to have an excellent correlation to physical activity (ES [\(z\)] = 0.92; 95% CI, 0.70–1.14; \(P<.001\); meta \(r = .73\); \(r^2 = .53\)), but this outcome was only measured in 1 study.\textsuperscript{49}

A variety of outcome measures and subsections of scales evaluating impairments, functional mobility, activity limitations, and disability were used across studies. Chedoke-McMaster Stroke Assessment Impairment Inventory (ES [\(z\)] = .39; 95% CI, .17–.61; \(P<.001\); meta \(r = .37\); \(r^2 = .14\)) and Rivermead Motor Assessment Scale gross function subscale (ES [\(z\)] = .65; 95% CI, .38–.92; \(P<.001\); meta \(r = .57\); \(r^2 = .33\)) were found to have a fair and moderate relation with physical activity, respectively. For the studies that could not be pooled, the Fugl-Meyer Assessment (Lower Extremity) (r = .06, \(P = .80\))\textsuperscript{50} was found not to have a statistically significant relation to physical activity, whereas the Rivermead Mobility Index (r = .51, \(P<.01\),\textsuperscript{29} Rivermead Motor Assessment (r = .41, \(P<.01\)),\textsuperscript{29} Short Physical Performance Battery (β = −0.5, \(P<.001\)),\textsuperscript{30} and FIM (r = .52, \(P = .02\))\textsuperscript{18} were found to have moderate to good associations with physical activity.

The Fatigue Severity Scale (FSS) was investigated as a correlate in 4 studies.\textsuperscript{25,31,35,45} Three studies (n=146) were included in the meta-analysis, and 1 study was excluded because of high risk of bias.\textsuperscript{45} Pooled results found a statistically significant but small relation between FSS and post-stroke physical activity (ES [\(z\)] = −.22; 95% CI, −.18 to .14; \(P = .01\); meta \(r = −.22\); \(r^2 = .05\)).\textsuperscript{35} Cognition as an independent variable was investigated in 4 studies.\textsuperscript{39,41,42,50} The Short Portable Mental Status Questionnaire was found to have a small or no relation with the Physical Activity Scale for the Elderly (standardized β = −.20, \(P<.01\)).\textsuperscript{39} Pooled results demonstrated that the Mini-Mental State Examination (MMSE) was found to be statistically not correlated with physical activity. The correlation value for the association between the Montreal Cognitive Assessment (MoCA) and self-reported

Fig 2 Forest plot of individual studies and meta-analysis. Abbreviation: \(VO_2\) peak, peak oxygen consumption.
physical activity was not reported, but the authors stated that it was a significant predictor in the regression model.41

Depression was measured in 5 studies with varying assessment tools.35,39,48,50,51 The Beck Depression Inventory-II had a moderate to good association with physical activity levels (ES $z=-.66$; 95% CI, −.94 to −.39; $P<.001$; meta $r=-.58$; $r^2=.33$).31 The Short Depression-Happiness Scale also demonstrated a moderate to good correlation with physical activity (ES $z=52$; 95% CI, −.74 to −.47; $P<.001$; meta $r=-.48$; $r^2=.23$).50 The Center for Epidemiologic Studies Depression Scale (ES $z=-.4$; 95% CI, −.61 to −.19; $P<.01$; meta $r=-.38$, $r^2=.14$)52 and Geriatric Depression Scale ($\beta=-.28$, $P<.001$)39 had a fair relation with physical activity levels and self-reported physical activity, respectively. Finally, the Hospital Anxiety and Depression Scale was found to be not statistically associated with time spent upright, but the correlational value was not reported by the authors in this study.48

Five studies explored the relation between physical activity behavior and self-efficacy.35,39,43,45,50 The General Perceived Self-Efficacy Scale was statistically not correlated with time on feet or activity counts.40 However, the Balance Self-Efficacy Scale (ES $z=.39$; 95% CI, .18–.06; $P<.001$; meta $r=.37$; $r^2=.14$) and the Falls Self-Efficacy Scale (ES $z=-.43$; 95% CI, −.54 to −.31; $P<.001$; meta $r=-.38$; $r^2=.16$) demonstrated a statistically significant and fair association to physical activity levels after stroke.35,50 The Activities-Specific Balance Confidence Scale was also found to be fairly correlated with steps per day (standardized $\beta=.46$, $P<.001$), and this correlate also acted as a mediator in the relation between physical outcome measures (eg, gait speed, 6MWT) and walking-related physical activity (standardized $\beta=.20$, $P<.005$).43 The Short Self-Efficacy for Exercise Scale, which is a self-efficacy questionnaire specific to physical activity behavior, was also found to be fairly correlated with self-reported physical activity as reported on a Likert scale ($r=.41$, $P<.001$).45

Of the 4 studies that investigated the Stroke Impact Scale as a correlate to physical activity,26,42,46,51 3 studies (n=81) were pooled and found to be statistically associated with physical activity (ES $z=.52$; 95% CI, .34–.71; $P<.001$; meta $r=-.48$; $r^2=.23$).26,42,51 One study did not report bivariate correlations and therefore could not be included in the meta-analysis.46 The Stroke Impact Scale was also found to be statistically associated with high demand leisure activities as measured by the Activity Card Sort (odds ratio, 1.027; $P=.05$).46 The findings were similar for studies using health-related quality of life (HRQOL) questionnaires such as the Short Form-36 ($r=.42$, $P<.01$)54 and EuroQol-5D ($\beta=-.43$, $P<.001$).39

Discussion

This is the first systematic review with meta-analysis conducted to synthesize the factors associated with post-stroke physical activity. The factors that were found to have statistically significant correlations to post-stroke physical activity were age, sex, physical function, fatigue, falls self-efficacy, balance self-efficacy, depression, and HRQOL. Years since stroke was not statistically associated with post-stroke physical activity, The effect of side of infarct, neglect, and cognition were inconclusive.

The factors associated with post-stroke physical activity can be categorized into nonmodifiable and potentially modifiable factors which may be amenable to interventions to improve physical activity levels. Among the nonmodifiable factors, post-stroke physical activity was found to be associated with age and sex, whereas years since stroke onset did not influence post-stroke physical activity. Similarly, studies in nonstroke cohorts have found significant associations between age and physical activity.57,58 Male sex has also been found to be correlated with physical activity among healthy adults, but research in people with multiple sclerosis and other physical disabilities has not found an association.59-61

The domains of the potentially modifiable factors can be classified into physical function, fatigue, cognition, depression, self-efficacy, and HRQOL. Among the potentially modifiable factors, measures of physical function (6MWT distance, comfortable gait speed, BBS, and cardiorespiratory fitness) demonstrated a consistent positive association with physical activity. This finding is supported by recent research in the stroke population that supports 6MWT distance, comfortable gait speed, and balance as independent predictors of community ambulation.62,63 Gait speed and balance were also identified as factors associated with higher levels of physical activity in healthy older adults, older adults with osteoporosis, and adults with neuromuscular conditions and osteoarthritis.58,64,65 Functional mobility scales (eg, Rivermead Motor Assessment gross function subscale, Rivermead Motor Assessment, Rivermead Mobility Index, Chedoke McMaster-Impairment assessment, Short Physical Performance Battery, FIM) were also found to be associated with physical activity. This is logical because the physical activity measures are biased toward measuring mobility. Taken together, this provides support for an association between physical function and physical activity. However, physical function only explains less than half of the variance in post-stroke physical activity levels, indicating that this behavior is complex and multifactorial.

The association between the FSS and post-stroke physical activity is consistent with a longitudinal study on post-stroke fatigue that found a significant association between fatigue and steps per day.66 Fatigue has also been found to be correlated with physical activity among people with other neurologic conditions (eg, multiple sclerosis).67,68 A relation between cognition and post-stroke physical activity could not be identified from the results of this review because the pooled results for the MMSE was not significant, but the Short Portable Mental Status Questionnaire and MoCA were found to be significant factors in individual studies. Future studies could use the MoCA as a tool to assess cognition because it has been shown to have high sensitivity and specificity in stroke, whereas the MMSE has a demonstrated ceiling effect which can dilute an association.69

HRQOL was consistently found to be a factor associated with post-stroke physical activity. Depression and self-efficacy were the only 2 psychological constructs that have been investigated in the studies included in this review. Depression, falls, and balance self-efficacy were consistently significant correlates with post-stroke physical activity. Questionnaires specific to assessing self-efficacy for post-stroke physical activity (eg, Short Self-Efficacy for Exercise Scale) require further exploration.70 Other psychological factors found to significantly influence physical activity participation after stroke in qualitative studies (eg, motivation to exercise) have not yet been quantitatively investigated. Motivation to exercise and anxiety were found to be significant predictors of physical activity in the brain injury population and should be explored in stroke.71

In summary, the results of this review indicate that older stroke survivors may be at a higher risk of physical inactivity. Interventions to increase post-stroke physical activity could
evaluate the effect of targeting physical function, depression, self-efficacy, and quality of life on increasing physical activity levels. The effect of cognition and stroke factors needs to be further investigated. This review also demonstrates that the correlates investigated thus far have been focused on physical and some psychological factors. Physical activity research in older adults and people with physical disabilities has investigated factors across domains such as interpersonal factors (eg, physical function, psychological factors), intrapersonal factors (eg, social support), environmental characteristics (eg, access to parks), and national policies (eg, physical activity advocacy).70,72 Future studies should explore factors across other domains for a wider understanding of post-stroke physical activity.

Furthermore, the cause and effect of the factors identified in this review with post-stroke physical activity are also unclear, and the possibility of reverse causality has not been addressed. For instance, depression can be a cause or a consequence of lower physical activity levels. Unadjusted correlational analyses may not expose the complex relations between physical function and psychosocial factors which contribute to post-stroke physical activity behavior. This presents a major gap in the literature, and these factors require further investigation in cohort studies and randomized controlled trials using appropriately validated instruments.

The main clinical implication derived from this review is that physical function only accounted for half of the variance in post-stroke physical activity levels. To optimize physical activity levels among stroke survivors, physical function needs to be maximized but psychological factors (eg, depression, self-efficacy) should also be addressed. A comprehensive model of assessment looking at physical, cognitive, and psychosocial factors could potentially increase the likelihood of stroke survivors being more active in the community.

**Study limitations**

This review has several limitations. Only observational study designs were included; therefore, factors investigated in interventional trials may have been missed. Most studies included in this review (n = 24; 92%) conducted cross-sectional analyses, which have limited capacity to establish causal relations while also carrying the risk of reverse causality bias. Only 7 of the included studies investigated factors associated with physical activity as their primary aim.24,26,29,34,46,49,50 As such, the other studies may not have been appropriately designed or sufficiently powered to investigate associations. However, their results could still be extracted and used in the meta-analysis and therefore were included in the review to provide a broader and more comprehensive perspective of the research in this area. Direct and self-report measures were combined in the meta-analysis to avoid a systematic loss of information because there was a lack of data to allow separate analysis for direct and self-report. However, correlations between both the measures range from low to moderate which must be considered when interpreting the results of this study. The meta-analysis could also be subject to publication bias because the number of included studies was small.

The included studies had several limitations. Although steps per day was the most common outcome measure, it only accounts for walking-related activity, which may not be a stroke survivor’s primary source of physical activity. Furthermore, some studies used pedometers that undercount steps in people with gait impairments73 or devices and parameters (eg, activity counts, questionnaires) that are not validated in the stroke population.72 Floor and ceiling effects of some outcome measures (eg, BBS25) may also have diluted the correlation strength. Only 1 of the 4 studies that investigated BBS as a correlate did not have any participants who achieved the minimum or maximum scores.74 It was also not possible to compare results among studies investigating activity intensity because of the absence of a common definition of intensity classification or validated activity intensity measure. However, this is an important construct to measure because it informs whether stroke survivors are meeting the physical activity recommendations to reap health benefits. Because both accelerometers and self-report measures have limitations, devices directly measuring energy expenditure may provide a more accurate profile of physical activity pattern and intensity.

**Conclusions**

This systematic review and meta-analysis found several modifiable and nonmodifiable factors associated with post-stroke physical activity. Older stroke survivors may be at a higher risk of being physically inactive. However, targeting potentially modifiable factors (eg, physical function, depression, self-efficacy, quality of life) may increase physical activity levels among stroke survivors. Sex, years since stroke onset, and fatigue were not shown to effect on physical activity levels after stroke. The association of cognition and stroke factors to post-stroke physical activity was inconclusive. Overall, there were inconsistencies in the study design, validity of measurement tools, terminology pertaining to physical activity, and time points of measurement across studies. The correlates identified in this review should be investigated further in future research to establish causality and targeted in interventions to increase physical activity among stroke survivors.

**Suppliers**

a. RevMan 5.3; The Nordic Cochrane Centre.

b. Stepwatch Activity Monitor; Modus Health IIc, Washington, DC.

c. Intelligent Device for Energy Expenditure and Activity; MiniSun, Ca.

d. ActivPAL; PAL Technologies Ltd, Scotland, UK.

e. Actical; PHILIPS, OR.

f. Actigraph GT3X++; Actigraph, FL.

g. Yamax SW-200; Yamax, Japan.

h. Kenz Life Corder; Suzuken, Japan.

i. VKRFitness Twin Step; VKR, CA.

j. Polar RS-400; Polar Electro, Lake Success, NY.

**Keywords**

Exercise; Physical fitness; Rehabilitation; Stroke

**Corresponding author**

Shamala Thilarajah, MAppSc, Department of Physiotherapy, Singapore General Hospital, Outram Rd, Singapore 169608. E-mail address: shamala.thilarajah@sgh.com.sg.
<table>
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<tr>
<th>Domains</th>
<th>Prompting Items for Consideration</th>
<th>Additional Customized Prompts</th>
<th>Ratings</th>
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<tr>
<td>Study participation</td>
<td>1. Adequate participation in the study by eligible persons</td>
<td>1. Justification of sample size</td>
<td>High bias: The relation between the PF and outcome is very likely to be different for participants and eligible nonparticipants</td>
</tr>
<tr>
<td></td>
<td>2. Description of the source population or population of interest</td>
<td>2. Description of stroke details of participants (time since stroke, stroke severity, type of stroke, side of lesion)</td>
<td>Moderate bias: The relation between the PF and outcome may be different for participants and eligible nonparticipants</td>
</tr>
<tr>
<td></td>
<td>3. Description of the baseline study sample</td>
<td></td>
<td>Low bias: The relation between the PF and outcome is unlikely to be different for participants and eligible nonparticipants</td>
</tr>
<tr>
<td></td>
<td>4. Adequate description of the sampling frame and recruitment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Adequate description of the period and place of recruitment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Adequate description of inclusion and exclusion criteria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study attrition</td>
<td>1. Adequate response rate for study participants</td>
<td>1. Statistical used to check for differences between dropouts vs completers</td>
<td>High bias: The relation between the PF and outcome is very likely to be different for completing and noncompleting participants</td>
</tr>
<tr>
<td></td>
<td>2. Description of attempts to collect information on participants who dropped out</td>
<td>2. Description of dropouts vs completers (eg, age, sex, stroke severity, physical function)</td>
<td>Moderate bias: The relation between the PF and outcome may be different for completing and noncompleting participants</td>
</tr>
<tr>
<td></td>
<td>3. Reasons for loss to follow-up are provided</td>
<td>3. For cross-sectional studies, record attrition as not applicable</td>
<td>Low bias: The relation between the PF and outcome is unlikely to be different for completing and noncompleting participants</td>
</tr>
<tr>
<td></td>
<td>4. Adequate description of participants lost to follow-up</td>
<td></td>
<td></td>
</tr>
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<td>5. There are no important differences between participants who completed the study and those who did not</td>
<td></td>
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<tr>
<td>Prognostic factor</td>
<td>1. A clear definition or description of the PF is provided</td>
<td>1. All PF measured are used in analysis</td>
<td>High bias: The measurement of the PF is very likely to be different for different levels of the outcome of interest</td>
</tr>
<tr>
<td>measurement</td>
<td>2. Method of PF measurement is adequately valid and reliable</td>
<td>2. Percentage of missing data reported</td>
<td>Moderate bias: The measurement of the PF may be different for different levels of the outcome of interest</td>
</tr>
<tr>
<td></td>
<td>3. Continuous variables are reported or appropriate cut points are used</td>
<td></td>
<td>Low bias: The measurement of the PF is unlikely to be different for different levels of the outcome of interest</td>
</tr>
<tr>
<td></td>
<td>4. The method and setting of measurement of PF is the same for all study participants</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Adequate proportion of the study sample has complete data for the PF</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Appropriate methods of imputation are used for missing PF data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcome measurement</td>
<td>1. A clear definition of the outcome is provided</td>
<td>1. The physical activity measurement tool is validated in the stroke population</td>
<td>High bias: The measurement of the outcome is very likely to be different related to the baseline level of the PF</td>
</tr>
<tr>
<td></td>
<td>2. Method of outcome measurement used is adequately valid and reliable</td>
<td>2. Clear reporting of duration of wear of physical activity monitor</td>
<td>Moderate bias: The measurement of the outcome may be different related to the baseline level of the PF</td>
</tr>
<tr>
<td></td>
<td>3. Method and setting of outcome measurement is the same for all study participants</td>
<td>3. Clear reporting if physical activity was assessed under free-living conditions for all participants</td>
<td>Low bias: The measurement of the outcome is unlikely to be different related to the baseline level of the PF</td>
</tr>
</tbody>
</table>

(continued on next page)
<table>
<thead>
<tr>
<th>Domains</th>
<th>Prompting Items for Consideration</th>
<th>Additional Customized Prompts</th>
<th>Ratings</th>
</tr>
</thead>
</table>
| Study confounding       | 1. All important confounders are measured  
2. Clear definitions of the important confounders measured are provided  
3. Measurement of all important confounders is adequately valid and reliable  
4. The method and setting of confounding measurement are the same for all study participants  
5. Appropriate methods are used if imputation is used for missing confounder data  
6. Important potential confounders are accounted for in the study design  
7. Important potential confounders are accounted for in the analysis | 1. Important confounders such as age, sex, stroke severity, time since stroke, type and site of stroke, setting in which physical activity was measured (institution vs free-living), and ongoing rehabilitation are reported and adjusted in analysis  
2. For studies exploring associations of various factors associated with PA, record this section as not applicable | High bias: The observed effect of the PF on the outcome is very likely to be distorted by another factor related to PF and outcome  
Moderate bias: The observed effect of the PF on outcome may be distorted by another factor related to PF and outcome  
Low bias: The observed effect of the PF on outcome is unlikely to be distorted by another factor related to PF and outcome |
| Statistical analysis and reporting | 1. Sufficient presentation of data to assess the adequacy of the analytic strategy  
2. Strategy for model building is appropriate and is based on a conceptual framework or model  
3. The selected statistical model is adequate for the design of the study  
4. There is no selective reporting of results | 1. Full correlational matrix presented or at least all associations reported  
2. For studies investigating association of a specific factor, regression analysis was conducted | High bias: The reported results are very likely to be spurious or biased related to analysis or reporting  
Moderate bias: The reported results may be spurious or biased related to analysis or reporting  
Low bias: The reported results are unlikely to be spurious or biased related to analysis or reporting |

Abbreviation: PF, prognostic factor.
Adapted with permission from Hayden et al.15
References


Chapter 4: Common Methodology

4.1 Overview

This chapter describes the common extended methodology for the prospective cohort studies described in Chapters 6 and 7 and includes details of the custom-made accelerometer used in Chapter 5.

4.2 Design, setting and participants

4.2.1 Design

A prospective cohort study was carried out in an inpatient rehabilitation setting. Stroke survivors were recruited at discharge from inpatient rehabilitation and followed up at three months following discharge.

4.2.2 Setting

The recruitment of participants was conducted at the inpatient rehabilitation unit at Singapore General Hospital (SGH). The unit has two sites; a 52-bed satellite site located at the Bright Vision Hospital and 20-bed inpatient site located on the acute hospital premises. The unit admits patients with a wide range of conditions including stroke. The decision regarding the site at which patients are admitted for rehabilitation is dependent upon their medical stability and level of eligibility for government subsidies.

The patients were selected for admission to inpatient rehabilitation at the unit if they had been assessed as neurologically and medically stable, had impairments or disabilities which impacted activities of daily living and potential to participate and benefit from a comprehensive goal-directed inpatient stroke rehabilitation programme. The medical consultants from the Department of Rehabilitation Medicine select these patients during conjoint neurology or neurosurgical consultation rounds or on formal referrals from these departments. They subsequently coordinated the transfer of appropriate candidates from acute departments to the rehabilitation unit. All patients received approximately two to three hours of physical and occupational therapy per weekday with referral to
medical, social worker, speech therapist, psychologist, or other disciplines as necessary. The average length of stay in the rehabilitation unit is approximately three weeks and most of the patients are discharged home with follow-up outpatient rehabilitation.

### 4.2.3 Participants and recruitment

Sixty-six participants were consecutively recruited from the inpatient rehabilitation unit of SGH. A consecutive sampling method was used to minimise selection bias and to increase generalisability to the target population (Krause, Lutz, & Boehnke, 2011). All patients admitted to the unit with a diagnosis of stroke, were screened by the thesis author (ST) using a standardised screening form (Appendix D). This was completed from June 2015 to November 2016. The author (ST) then confirmed eligibility by reviewing the individuals’ electronic medical records and discussing the case with the treating multidisciplinary team. Potential participants were then approached, and details of the study were explained by ST. Individuals who agreed to participate in the study were required to read and sign a Participant Information and Consent Form (Appendix E). Mandarin or Malay interpreters were used as needed for obtaining informed consent and undertaking the assessment sessions.

Participants were included based on the following criteria:

- Aged 21 years and over
- Haemorrhagic or ischaemic stroke
- Able to walk greater than 10m with not more than minimal assistance with or without a gait aid. This was to ensure that patients who were recruited could participate in the assessment sessions which evaluated walking and balance.

Participants were excluded based on the following criteria:

- Medically unstable or other medical condition that would confound physical function testing. The treating physician’s medical clearance was required.
• Severe dysphasia or dyspraxia, as participants may not be able to participate in the questionnaires and self-report tests in the study. This was based on the speech therapy assessment of the patient’s communication.

• Cognitive impairment severe enough to prevent the patient from giving informed consent and completing questionnaires. This was based on the speech therapy assessment of the patient’s cognition. A screening tool such as the Mini-Mental State Examination (MMSE) was not utilised due to limitations with the ethic board’s approval which did not allow screening patients prior to informed consent.

• Likely to be living in a nursing home (as determined by the rehabilitation team) at three months after discharge, as the physical activity assessment in an institution may not be representative of community-based physical activity levels.

4.2.4 Sample size calculation

Based on the prognostic factors identified in previous cross-sectional studies, we hypothesised that the sample size needed to be adequate to accommodate up to five variables in the multiple regression model. The five variables include co-variates such as age, gender, stroke severity and time since stroke onset. While it is unknown which independent variables are likely to be required in the regression equation, we chose to power the study to be able to include five independent variables in accordance with the guideline of at least 10 events per regression coefficient (Green, 1991; Maxwell, 2000). Therefore, after accounting for 20% attrition rate, a sample size of n = 60 was calculated as adequate. Clinical expertise and literature review were utilised to select co-variates and independent variables for inclusion in the regression models.
4.2.5 Ethics approval

This study was approved by the SingHealth Research Ethics Committee (CIRB reference: 2015/2010) (Appendix F). The results were reported in accordance with the reporting guidelines for observational studies (STROBE- Strengthening the Reporting of Observational Studies in Epidemiology) from the Equator Network (www.equator-network.org) (von Elm et al., 2014).

4.3 Procedures and outcome variables

4.3.1 Procedure

Recruited participants attended two assessment sessions based at the rehabilitation facility. The first assessment was conducted within seven days prior to discharge from inpatient rehabilitation. The second assessment took place three months (+/- two weeks) following discharge. The rapid recovery in impairments and function typically occurs in the early sub-acute phase (seven days to three months), and the rate of recovery tends to slow in the late sub-acute phase (three to six months post-stroke) (Julie Bernhardt et al., 2017). Also, at three months after discharge, the stroke survivor would have settled into life at home, allowing for a more representative assessment of their community-based physical activity levels. Each assessment session took approximately 1.5 to 2 hours and was conducted by an experienced physiotherapist (author ST). Participants’ demographic, hospitalisation details, type of stroke, NIH Stroke Scale (H. Adams et al., 1999) (Appendix G), modified Rankin Scale score (mRS) (Rankin, 1957; Van Swieten, Koudstaal, Visser, Schouten, & Van Gijn, 1988) (Appendix I), six metre walk test, step test, dorsiflexor strength, Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) (Appendix J), Hospital Anxiety and Depression Scale (HADS) (Bjelland, Dahl, Haug, & Neckelmann, 2002) (Appendix K), Short Falls Efficacy Scale-International (FES-I) (Kempen et al., 2008) (Appendix L) and Behavioural Regulation in Exercise-2 (BREQ-2) (David Markland & Tobin, 2004) (Appendix M) were collected at both time-points. At the three-month follow-up, the primary outcome measures of physical activity were collected. Participants completed the International Physical Activity Questionnaire Short 7 days (IPAQ-S7) (Craig et al., 2003) (Appendix N), Activity Card Sort (ACS) (Doney & Packer, 2008) (Appendix O), wore an ankle-mounted
accelerometer and a global positioning system (GPS) unit in their pocket or bag for four days.

4.3.2 Independent variables

The outcome measures were selected to encompass a range of physical, cognitive, and psychosocial factors potentially relevant to post-stroke physical activity. Psychometric properties and clinical feasibility were considered in the selection of the outcome measures (Table 4.1).
Table 4.1: Outline of assessments at each time point

<table>
<thead>
<tr>
<th>Personal factors</th>
<th>Baseline</th>
<th>Follow up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant demographics</td>
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<td>x</td>
</tr>
<tr>
<td>Hospitalisation and rehabilitation details</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>Stroke details</td>
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<td>x</td>
</tr>
<tr>
<td>Stroke side, type and location</td>
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<td>x</td>
</tr>
<tr>
<td>Stroke severity</td>
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<td>x</td>
</tr>
<tr>
<td>NIH Stroke Scale (Appendix G)</td>
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<td>x</td>
</tr>
<tr>
<td>Inattention testing (star cancellation and line bisection tests) (Appendix H)</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Stroke disability</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Modified Rankin Scale (Appendix I)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Physical function tests</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Six Metre Walk Test</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Step Test</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Strength assessment (ankle dorsiflexion)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cognitive assessment</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Montreal Cognitive Assessment (Appendix J)</td>
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<td>✓</td>
</tr>
<tr>
<td>Psychological assessments</td>
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<td>✓</td>
</tr>
<tr>
<td>Hospital Anxiety and Depression Scale (Appendix K)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Short Falls efficacy scale (Appendix L)</td>
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<td>✓</td>
</tr>
<tr>
<td>Behavioural Regulation in Exercise-2 (Appendix M)</td>
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<td>✓</td>
</tr>
<tr>
<td>Physical activity assessments</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>*Activity Card Sort (Appendix N)</td>
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<td>✓</td>
</tr>
<tr>
<td>*International Physical Activity Questionnaire (IPAQ-S7) (Appendix O)</td>
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<td>✓</td>
</tr>
<tr>
<td>*Accelerometer</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>*Global positioning system (GPS)</td>
<td>x</td>
<td>✓</td>
</tr>
</tbody>
</table>

* primary outcome measure

Where possible, outcome measures were selected if they have been found to be reliable and valid in the stroke population. Where this was not the case, the measurement properties in the elderly or other neurological conditions were considered. The properties examined were those that are important for clinical utility (i.e. validity, reliability, and responsiveness).

- Reliability was assessed by the ability of the instrument to measure what it proposes to measure with consistency and reproducibility (Hobart, Lamping, & Thompson, 1996; Stokes, 2011b). One of the statistical measures of reliability is an ICC that determines the levels of correspondence as well as agreement among ratings.
(Portney & Watkins, 2009). The ICC is obtained through an analysis of variance and ranges from 0 to 1 with 1 indicating perfect agreement. An ICC of above 0.75 may be regarded as good reliability (Portney & Watkins, 2009).

- Validity is assessed by the ability of the instrument to measure what it proposes to measure (Hobart et al., 1996; Stokes, 2011c). This can be further categorised into face/content, criterion, construct and predictive validity. The correlation coefficient is a measure of the strength of the relationship between the new outcome measure and the criterion or gold standard that it is being validated against. The correlation coefficient (r) ranges from 0 to 1, where 0 to 0.25 may be interpreted to indicate little or no relationship, 0.25 to 0.50 a fair relationship, 0.50 to 0.75 a moderate to good relationship and r values above 0.75 an excellent relationship (Portney & Watkins, 2009). However, correlation coefficient values themselves are not necessarily a good indicator of validity, as they can be influenced by heterogeneity of data and do not account for important factors such as the percentage error of measurement (Bates, Zhang, Dufek, & Chen, 1996). This is described in more detail in Chapter 5. Also, many studies assessing validity or physical activity questionnaires have often used accelerometers as gold standard. Accelerometers assess walking related physical activity only whereas physical activity questionnaire encompasses all types of physical activity. Thus, the validation method and clinical feasibility were also considered in the selection of outcome measures in this study.

- Responsiveness is the ability of the measure to detect clinically significant changes (Hobart et al., 1996; Stokes, 2011a). Measurement of the responsiveness may include the standardised response mean (SRM), effect size, relative efficiency (RE) or receiver operator characteristic curve (ROC) (Stokes, 2011a). The SRM is the mean change in the scores over the two time-points divided by the SD of the changes. Effect size (ES) is calculated by dividing change in scores by pooled SD (Cohen, 1988). Cohen’s thresholds (>0.8 large; 0.5 to 0.8 moderate, and <0.5 small) may be used for the interpretation of the SRM and ES values (Stokes, 2011a). Where available, the other measures to clinically evaluate responsiveness, the
Minimal Detectable Change (MDC) Score and Minimal Clinically Important Difference (MCID) were considered in the selection.

Information from medical records and routine clinical assessments

1. Demographics and socioeconomic factors

Participants’ age, gender, height, weight, pre-stroke physical activity levels, previous mobility, and living circumstances (including requirement of a caregiver) were extracted from the electronic medical records or via interview at the baseline assessment.

2. National Institutes of Health Stroke Scale (NIHSS) (Appendix G)

Justification and measurement properties:
The NIHSS is a valid and reliable measure of stroke severity (H. Adams et al., 1999; Brott et al., 1989; Lyden et al., 1994). The scale quantifies the severity of the symptoms resulting from cerebral infarcts and the extent of neurological deficits across different domains. The Stroke Recovery and Rehabilitation Roundtable recommendations state that NIHSS scores should be collected at entry into a study and where possible NIHSS scores should be reported at stroke onset (± 3 days) (Kwakkel et al., 2017). The NIHSS was included in this study to be used as co-variate to adjust for stroke severity in the statistical analysis.

Procedure and outcome variables:
The NIHSS is a 15-point scale assessing levels of consciousness, language, neglect, visual-field loss, gaze, strength, ataxia, dysarthria, and sensory loss. A trained nurse or health professional rates the patent’s ability to answer questions and perform activities. The NIHSS is routinely scored on the patients who are admitted to the acute stroke unit with an ischemic stroke. Each item is scored from 0 to 3-5 with 0 as normal. Thus, the worst score obtained following admission into the unit was recorded for this thesis. For participants who had not been assessed on the NIHSS on admission (e.g. due to transfer from a non-stroke unit or other hospital), retrospective scoring of the NIHSS score was
completed by extracting relevant information from the emergency department admission notes using a validated algorithm (Williams, Yilmaz, & Lopez-Yunez, 2000). The NIHSS scores was used to classify stroke severity: 1 to 4 as mild impairment, 5 to 14 as mild to moderate impairment, 15 to 24 as severe impairment and 25-42 as very severe impairment (H. Adams et al., 1999).

Physical function

1. Six-metre walk test (6MWT)

**Justification and measurement properties:**

Self-selected gait speed is an established indicator of physical function in the elderly and amongst stroke survivors. It is also a correlate of post-stroke physical activity (C. English et al., 2016; Field et al., 2013; S. Thilarajah et al., 2017). There is extensive research on the psychometric properties of gait speed amongst stroke survivors in all settings. Research in the stroke population supports self-selected gait speed as a prognostic factor of community ambulation (Bijleveld-Uitman, van de Port, & Kwakkel, 2013; K. B. Lee et al., 2015). Gait speed was also identified as a factor associated with higher levels of physical activity in healthy older adults, older adults with osteoporosis, adults with neuromuscular conditions and osteoarthritis (Dohrn, Hagströmer, Hellénius, & Ståhle, 2016; Newitt, Barnett, & Crowe, 2016; Stubbs, Hurley, & Smith, 2015). This thesis examined gait speed in both the inpatient rehabilitation setting, where patients may require assistance to walk or use walking aids, as well as in the community. Gait speed has demonstrated good test-retest reliability (ICC = 0.97) in stroke survivors who require physical assistance to walk, those who can walk without physical assistance (ICC = 0.80) and those who require a walking aid (ICC = 0.91) (George D. Fulk et al., 2014). The minimal detectable change (MDC) for these three groups of stroke survivors are 0.07m/s, 0.36m/s and 0.18m/s respectively (George D Fulk & Echternach, 2008). The 6MWT has also shown significant correlations with cadence (Spearman’s rho = 0.92; p = 0.01) and 10m walk test (Spearman’s rho = 0.99; p = 0.01) (Lam, Lau, Chan, & Sykes, 2010). The measurement method in this study was a hand-held stopwatch, which is feasible in any setting.
Procedure and outcome variables:

The 6MWT was measured over a 10m walkway at a comfortable speed. The middle six metres was timed and used for the analysis. If participants required assistance or a gait aid this was provided and recorded. This test was performed twice. The average of the two trials was used for the analysis. The outcome variable was self-selected gait speed in m/s.

2. Step test

Justification and measurement properties:

The step test is a measure of dynamic standing balance while in single-leg stance in stroke survivors (Hill, Bernhardt, McGann, Maltese, & Berkovits, 1996). The test requires sufficient strength of the lower limb in stance in order to steady the body while the other leg is stepping (Hill et al., 1996). The test has demonstrated validity in stroke, in that step test scores highly correlate with lower-limb muscle strength (r = 0.73-0.80), walking speed (r = 0.70), lower-limb motor coordination (as measured by Lower Extremity Motor Coordination Test) (r = 0.90), and balance (as measured by BBS) (r = 0.66) (Hong, Goh, Chua, & Ng, 2012). It possesses excellent test-retest reliability (ICC > 0.88) in a sample of stroke survivors undergoing inpatient rehabilitation (Hill et al., 1996). The SRMs of the step test in a sub-acute stroke population for the unaffected and affected lower limbs were 0.92 and 0.95 respectively (Julie Bernhardt, Ellis, Denisenko, & Hill, 1998). This indicates that the step test possesses excellent responsiveness.

Procedure and outcome variables:

Participants were asked to place one foot onto a 7.5cm step and then back down to the floor repeatedly as fast as possible for 15s without physical support or compromising safety. The participants completed the test first with the affected foot tapping and then with the unaffected foot. Participants were not allowed to use an assistive device during testing. If the participant was unable to perform the test without support, then the number of steps was recorded as zero. If the participant lost balance during the test, the test was stopped, and the complete number of steps recorded (Mercer, Freburger,
Chang, & Purser, 2009). The number of steps completed in 15s for each leg was used for the analysis.

**Psychological measures**

1. Behavioural Regulation of Exercise Questionnaire-2

*Justification and measurement properties:*

There is consistent evidence that motivation is a correlate for physical activity in the general population (Trost, Owen, Bauman, Sallis, & Brown, 2002). Motivation to exercise was also found to be a significant prognostic factor that contributes to physical activity in the brain injury population (Hamilton, Williams, Bryant, Clark, & Spelman, 2015). Amongst stroke survivors, motivation has been identified as a factor associated with physical activity in qualitative research but has not yet been quantitatively investigated (J. Morris, Oliver, Kroll, & MacGillivray, 2012).

The BREQ-2 classifies exercise motivation across a continuum, based on the self-determination theory (D. Markland & Ingledew, 1997). Self-determination theory divides motivation into two components. Controlled motivation is derived from external sources, such as family or therapists, while autonomous motivation is internalised and is associated with adherence to exercise (Thøgersen-Ntoumani & Ntoumanis, 2006). The BREQ-2 includes five subscales assessing amotivation (e.g. “I don’t see why I should have to exercise;” n = 4), external regulation (e.g. “I feel under pressure from my family/friends to exercise;” n = 4), introjected regulation (e.g. “I feel guilty when I don’t exercise;” n = 3), identified regulation (e.g. “It’s important to me to exercise regularly;” n = 4), intrinsic regulation (e.g. “I enjoy my exercise sessions” n = 4). Each item is rated on a 5-point scale ranging from 0 = “not true for me” to 4 = “very true for me.” The classification of the BREQ-2 scale differs in the degree of internalisation of exercise behaviours. Amotivation refers to a lack of controlled or autonomous motivation. Extrinsic, introjected, and identified regulation represents the continuum of controlled motivation while intrinsic regulation refers to autonomous (self-determined) motivation (Deci & Ryan, 1985). The questionnaire is designed to assess change across the continuum of motivation and it is suitable to assess changes in exercise motivation over
a period, allowing us to understand exercise adoption behaviour (Ryan & Deci, 2000). Psychosocial interventions should be targeted at moving stoke survivors in rehabilitation along the continuum from extrinsic motivation to intrinsic motivation by using strategies that provides autonomy and positive performance feedback (Deci & Ryan, 2008).

The BREQ-2 has demonstrated good validity (D. Markland & Ingledew, 1997; Wilson, Sabiston, Mack, & Blanchard, 2012) and reliability amongst healthy adults. The Cronbach’s alpha reliability coefficient ranged from 0.73 to 0.86 (David Markland & Tobin, 2004). The BREQ-2 has also been validated in Mandarin (Chung & Dong Liu, 2012).

**Procedure and outcome variables:**

The questionnaire was administered in either English or Mandarin. The Mandarin version was verified for use in the local population by back translating from English to Mandarin and translation back to English by a translator who had prior knowledge of the content. For participants who spoke another language apart from English or Mandarin a translator was used for interpretation. The author (ST) would verbally read out the questions to participants who could not read or preferred not to complete the questionnaire independently. The administration of the questionnaire took place in a quiet area within the physiotherapy gym. The item aggregation method of scoring which is the analysis of scores by the individual categories was adopted for this analysis (Wilson et al., 2012).

2. Short Falls Efficacy Scale - International

**Justification and measurement properties:**

Falls self-efficacy is one of the two psychological constructs that have been investigated in quantitative research in the post-stroke physical activity literature (Matar A. Alzahrani, Dean, Ada, Dorsch, & Canning, 2012; Robinson, Shumway-Cook, Ciol, et al., 2011). Falls self-efficacy was a consistently significant correlate to post-stroke physical activity in chronic stroke survivors (S. Thilarajah et al., 2017). Falls self-
efficacy is a psychological characteristic based on Bandura’s self-efficacy concept (Jackson, Mercer, & Singer, 2018). Falls self-efficacy could influence function to an extent that is beyond that of a physical impairment alone (Tinetti, De Leon, Doucette, & Baker, 1994). Self-efficacy is a concept in the Social Cognitive Theory and is defined as the amount of confidence people have in their ability to perform specific acts successfully (Bandura, 1997). Falls self-efficacy and fear of falling are related, but not identical concepts. The Falls Efficacy Scale (short) is a 7-item questionnaire asking how concerned a stroke survivor is about falling when carrying out activities of daily living (Kempen et al., 2008). This domain is specific, thus falls self-efficacy measures only perceived ability to prevent falls and cannot be generalized to other concepts. Fear of falling has been shown to be associated with physical activity in recent qualitative research (J. Morris et al., 2012; Nicholson et al., 2013). The short FES-I has demonstrated excellent concurrent validity (r=0.97) with the original 16-item version (Kempen et al., 2008; Yardley et al., 2005). The original questionnaire has been validated against the Activities Specific Balance Confidence Scale and the Geriatric Fear of Falling Measurement in the elderly and in stroke (Andersson, Kamwendo, & Appelros, 2008; Yardley et al., 2005).

**Procedure and outcome variables:**

Participants were asked to rate, on a 4-point Likert scale, their concerns about falling when performing seven activities, regardless of whether they perform it. The questionnaire was administered in either English or Mandarin format. The mandarin version was verified for use in the local population as per the BREQ-2. For participants who spoke another language apart from English or Mandarin a translator was used for interpretation. The author (ST) would verbally read out the questions to participants who could not read or preferred not to complete the questionnaire independently. The scores are added up to calculate a total score from a minimum of 7 to a maximum of 28 points (Kempen et al., 2008). A higher score indicates a greater concern of falling.

3. Hospital Anxiety and Depression Scale:
**Justification and measurement properties:**

Multiple cross-sectional studies have found depression to be a significant prognostic factor associated with post-stroke physical activity (Matar A. Alzahrani et al., 2012; Baert et al., 2012; Kunkel et al., 2015; Robinson, Shumway-Cook, Ciol, et al., 2011; Vahlberg et al., 2013). Anxiety was also found to be a prognostic factor of physical activity in the brain injury population (Hamilton et al., 2015) The 14-item HADS has been validated in the general population (Bjelland et al., 2002; Johnson et al., 1995) Amongst sub-acute stroke survivors, the internal consistency of this scale was good, with a Cronbach’s alpha of 0.85 for the depression subscale (Aben, Verhey, Lousberg, Lodder, & Honig). The anxiety subscale demonstrated an area under the curve of 0.78, depression subscale 0.81 and the total HADS a score of 0.83 (Aben et al.). This indicates that the questionnaire has an excellent ability to discriminate between those who are anxious or depressed and those who are not.

**Procedure and outcome variables:**

The HADS is part of the clinical screening for depression and anxiety after stroke at the rehabilitation facility and is typically completed within one week of admission to the unit. For this study, the HADS was administered again at discharge from the unit and at follow-up. The anxiety and depression scores were analysed separately.

**Cognition**

1. Montreal Cognitive Assessment (MoCA)

**Justification and measurement properties:**

The MoCA is screening assessment to identify people with mild cognitive impairments (Nasreddine et al., 2005). It assesses attention, executive function, memory, language, visual-constructional skills, conceptual thinking, calculations, and orientation with the total score computed out of 30. The assessment has been validated in the sub-acute stroke population demonstrating good correlation with the Mini-Mental State Examination (MMSE) \(r=0.79\) and the cognitive sub-section of the Functional Independence Measure (FIM) \(r=0.67\) (Toglia, Fitzgerald, O'Dell, Mastrogiavanni, &
Lin, 2011). The assessment also possesses good internal reliability (Cronbach’s alpha = 0.78) (Toglia et al.).

**Procedure and outcome variables:**

The test was administered in written form in either English, Mandarin or Malay. A translator was used to administer the assessment for participants who spoke languages apart from English. A score of 26 or above is considered normal (Rossetti, Lacritz, Cullum, & Weiner, 2011). For individuals with 12 years or fewer of formal education, one point is added to the score as a correction. For participants who could not complete the test due to their dominant writing hand being affected or poor eyesight, the test was scored on a total of 25 and converted back to 30 (e.g. 21/25 converts back to 30 by performing the following equation: \((21 \times 30) ÷ 25\); total converted score = 25.2 or 25/30) (Nasreddine).

**4.3.3 Dependent Variables**

A combination of direct and self-reported measures of physical activity were selected to ensure that both the context and volume of activity was captured. The dependent variables were measured at three months following discharge from inpatient rehabilitation.

1. International Physical Activity Questionnaire-Short Last 7 days (IPAQ-S7)

**Justification and measurement properties:**

The IPAQ-S7 (Appendix N) was used to evaluate the intensity of physical activity undertaken by the participants (Craig et al., 2003). The questionnaire explores self-reported sedentary behaviour and physical activity over the previous seven days. The IPAQ-S7 demonstrated a fair agreement (median \(r = 0.29\)) with accelerometer measures in a systematic review, that pooled the results from 23 studies of health individuals aged 15 to 65 years (P. H. Lee et al., 2011). The IPAQ-S7 has demonstrated good test-retest reliability amongst healthy adults (Spearman’s rho = 0.80) (Craig et al., 2003). Amongst adults aged 65 to 89 years, the test-retest reliability ranged from \(r = 0.50\) to 0.65, which
is moderate (Tomioka et al., 2011). The IPAQ-S7 is a useful and easy tool to measure physical activity as it contains only four questions and takes 5 minutes to administer. Furthermore, it has been validated in English and Mandarin for use in Singapore (Macfarlane, Lee, Ho, Chan, & Chan, 2007).

**Procedure and outcome variables:**

The IPAQ-S7 was administered through an interview. The participants were asked to report the days and time they spent in the last seven days in four categories: vigorous activity (heavy lifting, aerobics, fast bicycling), moderate activity (light lifting, moderate bicycling), walking, and sitting (watching TV, reading). The total physical activity was calculated as the sum of the vigorous, moderate and walking categories in MET-minutes/week scores. Questions on sitting are related to sedentariness (pattern of activity) and are scored separately (Craig et al., 2003).

2. Activity Card Sort (ACS)

**Justification and measurement properties:**

The ACS (Appendix O) may be used in clinical setting as a means of evaluating the type of activities people after stroke are participating in and as a tool for goal setting (Doney & Packer, 2008). The ACS was developed in the United States and a version for Singapore has also been developed and validated (Eriksson et al., 2011). The ACS differs from questionnaires as it uses 89 labelled photographs of older people doing various activities. The four categories of activities include instrumental activities (20), low-physical-demand leisure activities (35), high-physical-demand leisure activities (17) and social activities (17). The ACS has demonstrated excellent test-retest reliability (ICC = 0.90) amongst community-dwelling older adults (Eriksson et al., 2011; Everard, Lach, Fisher, & Baum, 2000). It has also demonstrated high internal consistency for instrumental activities of daily living and social-cultural activities (Cronbach alpha = 0.82 and 0.80 respectively (Katz, Karpin, Lak, Furman, & Hartman-Maeir, 2003).

However, the internal consistency was lower for low and high physical leisure activities (Cronbach alpha=0.66 and 0.61 respectively) (Katz et al., 2003). The construct validity of the ACS was demonstrated through studies comparing the classification of activities
by healthy adults, older adults and people with various neurological disabilities including stroke (Katz et al., 2003; Sachs & Josman, 2003). This was done by conducting factor analysis for the ACS of the different populations which helped to identify the differences between the different groups (Sachs & Josman, 2003). The labelled photographs are also beneficial as visual prompts for recall as well as for people with language deficits.

Procedure and outcome variables:

The ACS requires the participant to place the photographs into categories of “Previously not Done”, “Continue to Do”, “Do Less” and “Given up”. Activities placed under continued to do score one point, do less score 0.5 point and 0 if given up. Thus, a score for current activity levels can be computed for each category. Previously done activity levels are calculated by allocating one point to all activities not under the “Previously not Done” category. The percentage of activities the person has returned to since a stroke can be calculated by dividing current activities by previously done activities. Only the current activities score was used for statistical analysis, as the percentage change score would limit comparison amongst participants with differing pre-stroke activity levels.

3. Global Positioning Systems (GPS) Unit

Justification and measurement properties:

At present, GPS is a novel technology for evaluating time spent and distance walked outdoors in stroke. The GPS can provide information on the frequency and duration of outdoor physical activity. Through synchronisation with Google Earth, the data can also be used to explore relationships between outdoor physical activity and the neighbourhood attributes (Clark, Weragoda, Paterson, Telianidis, & Williams, 2014; Granger, Denehy, McDonald, Irving, & Clark, 2014). This type of information cannot be obtained from accelerometers. Self-report diaries and physical activity questionnaires can be used to complement the data obtained from GPS. The GPS unit uses space-based satellite systems, to provide time and location data while outdoors. Though the use of GPS is prevalent in communication devices used in everyday life, it is still a novel
device in physical activity research. A custom-made GPS unit was designed by the author’s supervisor (RC), as a highly sensitive system was required for a dense urban city such as Singapore (Figures 4.1 - 4.4).

A prior study has validated the use of GPS in people after stroke against direct observation of the person’s activities and self-reported diary (McCluskey et al., 2012). The agreement between GPS and observation was found to be 94%, whereas diary and observation agreement was 89% (McCluskey et al., 2012). To date, there has been one published study protocol for a randomised controlled trial in stroke that has utilised GPS as an outcome measure of number of outdoor trips (McCluskey et al., 2013) and another pilot study that used GPS to investigate outdoor activity amongst people after traumatic brain injuries (Hamilton et al., 2015). A custom GPS unit was required for this study due to high density urban environment in Singapore. The previously used GPS unit did not have adequate sampling rate or an appropriate antenna to pick up signals in urban environments which could lead to missed signals and large ‘blind spots’.

**Procedure and outcome variables:**

All participants were provided with a GPS unit at the 3-month follow-up. The author (ST) demonstrated and explained use of the GPS unit at this session. The period of activity monitoring included weekdays and weekends. The participant was required to carry the GPS unit in their pocket or bag during their waking hours for four consecutive days. Participants were advised not to change their usual routine. A daily activity diary (Appendix O) was issued to participants to complete. They were encouraged to complete this throughout the day or on completion of the activity. The activity diary was an adjunct to the GPS to account for possible missing data due to technology failure and to add context to the physical activities undertaken by the cohort. To improve compliance of wearing the GPS, the participants were given a user guide (Appendix P) with illustrations on how to manage the device at home. The GPS unit output time spent outdoors in green space exercise (exercise that is performed in man-made green spaces such as parks or natural environments), active transport (incidental walking activity associated with the use of public transport), leisure (incidental walking associated with shopping) and sedentary activities.
Figure 4.1: Design specifications of custom-made GPS unit.

A) 3D print model created using Tinkercad; B) Circuit diagram visualized using Fritzing. After trialing multiple GPS chips we chose an Adafruit Ultimate GPS breakout board with Mediatek Labs MT3339 GPS module. This device has very high sensitivity (-165dBm), multi-GNSS with up to 66 acquisition channels and an onboard ceramic patch antenna mounted on a ground plane to improve accuracy and reduce noise. The lithium polymer battery with integrated protection circuit allowed for between 3-4 days of power supply to the GPS chip, dependent on satellite visibility (less visibility requires more power usage to attempt to find satellites). Data were sampled at 1Hz and stored on a 16GB microSD card using the Openlog.
Figure 4.2: The finished system, with 3D printed shell (printed in ABS plastic).

The extended lip seen at the top of the device was to allow the GPS antenna to be angled towards the sky if worn vertically in the pocket. This figure also shows the device connected to a standard micro-USB charger. Charging was not performed by the subject and was only done by the assessor prior to supplying the unit.
Subjects were instructed to put the GPS unit in their pocket or carry bag, preferably with the antenna pointed skywards.

4. Accelerometer unit

**Justification and measurement properties:**

In the context of physical activity assessment, accelerometers are body worn sensors that utilise piezoelectric sensors to detect acceleration of movements. Uniaxial, biaxial and triaxial accelerometers evaluate movement in one, two or three planes respectively, and can provide total step count, activity counts, step rate and postural transition data (Kong Y. Chen & Bassett, 2005). There are several brands of accelerometers that have been used in research to measure physical activity, and the accelerometers also differ by site of wear such as wrist, arm, hip and ankle (Murphy, 2009). However, only ankle-mounted accelerometers are accurate in measuring physical activity amongst stroke survivors with gait deficits (Treacy et al., 2017). This will be discussed further in the
following chapter. The only commercially available ankle-mounted system that has been shown to be accurate in stroke is the SAM (Natalie A. Fini et al., 2015) but the system is expensive and does not provide access to raw data. Access to raw data allows the inspection of the accelerometer axis traces for errors in the data collection. Therefore, an ankle-mounted system, using high precision components that provided us with raw data, was built by the author’s supervisor (RC).

**Procedure and outcome variables:**

The participants were issued an ankle mounted accelerometer to be worn for the four continuous days that the GPS unit was worn. We chose to use the Tinycircuits microcontroller platform as it allowed for a precise, robust, and small system to be created that could log data for the required time. The processor in this system is an ATmega328p, the accelerometer a Bosch BMA250 triaxial accelerometer with 10-bit resolution set to a measurement range of ±4g, data were collected and stored at 25Hz on an 8Gb microSD card, and it was powered by a 120mA lithium polymer battery with built in overcharge protection. The description of the methods of data analysis are provided, along with evidence of validation in a sub-acute stroke population, in Chapter 5. The unit output was steps/day.
Figure 4.4: The accelerometer system used in this thesis.

A) Shows the 3D print model, which encompassed the lithium polymer battery (in the extended narrow section of the unit) and the stack of 3 Tincircuits boards. The section separate to the main body of the unit was a lid that was fastened using plastic glue. This image shows a front and rear facing view, with the green round sections on the rear facing view showing the clips that were used to connect the device to the ankle worn strap; B) The stack of three Tincircuits boards – bottom = processor, middle = accelerometer, top = SD card. Between subjects the devise was removed and charged using an addition circuit board (not shown); C) A front facing view of the 3D printed shell (using ABS plastic) and the components about to be inserted; D) the finished device, with the accelerometer logger attached to the ankle worn strap. Various straps were explored during the design phase of the accelerometer. The Nike™ shin guard was selected as best choice as the monitor could be easily applied with one hand to suit a hemiplegic stroke survivor.
4.4.1 Summary

In summary, this chapter described the common methodology for the validation study (Chapter 5), the cross-sectional (Chapter 6) and the prospective cohort study (Chapter 7). The study recruitment setting, inclusion and exclusion criteria and outcome measures assessed were described in detail here. Methods that are specific to each chapter will then be illustrated further in the individual chapters.
Chapter 5: Criterion validity of an ankle-mounted accelerometer in people after stroke

5.1 Introduction

5.1.1 Background

Accelerometry is an established method of measurement of physical activity in people after stroke (Natalie A. Fini et al., 2015; Natalie A Fini et al., 2017). A range of activity monitors have previously been employed to measure physical activity following stroke. Activity monitors are an objective method of directly measuring physical activity and have become increasingly popular in the assessment of post-stroke physical activity (S. Thilarajah, Clark RA, Williams G, 2016). Activity monitors typically utilise accelerometers which are body worn sensors that detect acceleration of movements. Uniaxial, biaxial and triaxial accelerometers evaluate movement in one, two or three planes respectively, and can provide total step count, activity counts, step rate and postural position data (Kong Y. Chen & Bassett, 2005). There are several brands of accelerometers that have been used in research to measure physical activity, and the accelerometers also differ by site of wear such as wrist, arm, hip and ankle (Murphy, 2009).

The most commonly used activity monitor in post-stroke physical activity research is the StepWatch Activity Monitor (SAM) e.g. (French, Moore, Pohlig, & Reisman, 2016; G. D. Fulk, Reynolds, Mondal, & Deutsch, 2010; P. J. Manns, Tomczak, Jelani, Cress, & Haennel, 2009). Other devices include the Intelligent Device for Energy Expenditure and Activity (IDEEA) (M. A. Alzahrani, Dean, & Ada, 2009; Matar A. Alzahrani et al., 2012), ActivPAL (Kunkel et al., 2015; Paul et al., 2016; Salbach et al., 2014), Actical (Rand, Eng, Tang, Jeng, & Hung, 2009; Rand et al., 2010), Actigraph GT3X+, Yamax SW-200 pedometer (Baert et al., 2012; C. English et al., 2016), Kenz Life Corder pedometer (Katoh et al., 2002), VKRFitness Twin Step pedometer (Robinson, Shumway-Cook, Ciol, et al., 2011), and Polar RS-400 heart rate monitor (Baert et al., 2012). The most common physical activity outcome used was steps/day e.g. (Baert et al., 2012; French et al., 2016; G. D. Fulk et al., 2010). The devices that were validated
in a clinical setting were validated for steps/day against hand-held counter or video. Whilst the studies that validated the devices in the laboratory setting utilised three-dimensional gait analysis or footswitches. The SAM has demonstrated the highest level of agreement (98% on unaffected side and 87% on affected side) over different environments and walking speeds (Treacy et al., 2017).

While these devices have mostly demonstrated acceptable validity for measuring steps/day in stroke survivors, there are a range of limitations for measuring physical activity. At the time of the start of this thesis, raw data was not accessible for many of these devices (e.g. SAM). These devices contain proprietary algorithms which differ amongst different devices and change the data output and thus it is desirable for researchers to be able to access the raw accelerometer data (Kong Y Chen, Janz, Zhu, & Brychta, 2012). Some can be cumbersome or intrusive to wear continuously. Wearability issues may affect compliance of the subject to donning of the device, and affect the data obtained to ascertain accurate activity patterns in this population (Murphy, 2009). There is a paucity of research investigating the design features of body worn accelerometers to improve compliance in adhering to monitoring protocols. The literature in the use of technology in the elderly suggest that the device needs to be lightweight and comfortable to improve compliance of wear (Murphy, 2009).

Limitations also exist in the statistical procedures used to establish criterion validity. One of the most commonly used validity coefficients in studies examining criterion is the ICC (Shrout & Fleiss, 1979). These are products of correlating the scores obtained on the new instrument with a gold standard or with existing measurements of similar domains. The validity coefficients can range from +1 to -1 (Shrout & Fleiss, 1979). The statistical analysis of ICC does not account for the sources of errors that can occur in the measurement. One source of error when validating activity monitors can arise from the instrumentation and/or data extraction procedures (Bates et al., 1996). Another source of error could arise from the natural variability amongst the individuals being measured and this again will influence the ICC score. In the absence of measurement errors, the ICC scores could change according to variabilities in the sample and this value may not be a true representation of the relationship between the gold standard and the device being validated (K. M. Lee et al., 2012). The use of mean absolute error or percentage
agreement may offer a more accurate understanding of the criterion validity of an activity monitor.

A low-cost accelerometer that is valid in the measurement of steps/day amongst stroke survivors, lightweight and able to be easily donned and removed by a stroke survivor with use of only one hand was required for the main study of this thesis. Thus, this chapter investigated the validity of a low-cost, custom made accelerometer in people after stroke who have gait impairments.

5.1.2 Aims and hypotheses

The primary aim of this study was:

- To validate a custom-made, ankle worn accelerometer against a hand-held counter in people after stroke undergoing rehabilitation

The primary hypothesis for this study is:

- The custom-made accelerometer would demonstrate a percentage agreement of over 90% (Treacy et al., 2017)

5.2 Methodology

5.2.1 Participants and recruitment

Twenty participants were consecutively recruited from Bright Vision Hospital, which is a satellite inpatient rehabilitation unit of the Singapore General Hospital. Singapore General Hospital is a tertiary hospital and one of the centres for acute stroke management and multidisciplinary rehabilitation for individuals residing in Singapore. This study was approved by the SingHealth Research Ethics Committee (CIRB reference: 2015/2010) (Appendix F).

Inclusion criteria were: a diagnosis of stroke; able to walk 10 metres with at least minimal assistance with or without walking aids; and sufficient cognition to provide informed consent. Exclusion criteria were: the presence of skin conditions or lower limb
swelling that contraindicated individuals from wearing an ankle-mounted accelerometer.

5.2.2 Sample size calculation

The sample size in previous validation studies of commercially available activity monitors have ranged from 16-35 (George D. Fulk et al., 2014; Richard F Macko et al., 2002; Treacy et al., 2017). A convenience sample of 20 participants with varying level of mobility was considered adequate to ascertain the mean absolute error of the custom-made accelerometer compared to a hand-held counter. A percentage agreement of over 90% was reasoned as appropriate based on previous studies (George D. Fulk et al., 2014; R. F. Macko et al., 2002; Treacy et al., 2017).

5.2.3 Procedures

The accelerometer was switched on and attached to the ankle of the participant’s unaffected lower limb (as previously shown in Figure 4.9). The participant was asked to walk along a level corridor at their preferred speed and using a walking aid if required for safety. Assistance was provided by the assessor if needed. The assessor counted every stride taken with the unaffected lower limb using a hand-held counter. The participant was asked to stop after 100 steps and the number of any additional steps taken after the assessor instructions to stop was recorded.

5.2.4 Data analysis

The raw data was exported via data files into customised software (Figure 5.1). The customised software derives the step count by:

1. High pass filtering the data for each axis at 3.125Hz using a Coiflet-5 wavelet filter to remove postural effects on the accelerometer data.

2. Using an automated algorithm to identify peaks in data that were separated by no less than six and no more than 50 samples. This equates to step frequencies of between 4 and 0.5Hz. These values were chosen based on visual observation of
the data, and the spatiotemporal characteristics of gait reported previously (Nakamura, Handa, Watanabe, & Morohashi, 1988).

**Figure 5.1:** Customised software for data analysis.

A) The entire trial, with distinct regions for 1: donning the accelerometer, 2: the walking trial, 3: removing and switching off.

B) A close-up section of the accelerometer trace showing the raw data (white trace) and the identified steps (red dots). Note that only one axis of data is shown to aid visual interpretation.
5.2.5 Statistical analysis

Statistical analyses were conducted in IBM SPSS statistics version 22 (SPSS Inc., Chicago). Statistical significance was set at $p \leq 0.05$. The percentage error of the custom-made accelerometer compared to the hand-held counter was calculated as: 

\[(1 - \text{accelerometer count/hand-held counter count}) \times 100.\]

This method of data collection and analysis (fixed step count, assessing error between devices) was chosen over the more common correlation-based analysis (for example a fixed walk distance or time, then correlating the calculated vs. real steps) as we deemed it to provide a much greater indicator of validity. The former approach shows the true measurement error of the device and does not rely on data heterogeneity, whereas the latter is heavily influenced by this factor. This is described in detail in Figure 5.2.
Figure 5.2: A comparison of validity assessment methods that incorporates heterogenous (A) and homogenous (B) data.

Both tables consist of a simulation of 11 participants data for a validation assessment that consisted of a different number of steps (column 2), the real number of steps multiplied by a randomly generated error term (column 3), and the calculation of the actual percentage error (column 4) and the actual number of missed steps (column 5). Table A represents a device with extremely high error rates, with the error term being a random number generated between 0 and 1. This reflects a device that for each step could have anywhere between a perfect (1) or no (0) chance of detecting a step. For example, if the error term was 0.2 it would be expected that the device would only detect 1 in every 5 steps. Table B represents a device with very low error rates, with the error term being a randomly generated number between 0.95 and 1.05. This reflects a device that for each step could have anywhere between a 95% (0.95) or 105% (1.05) chance of detecting a step, with the potential for slightly overestimating step count. Note that the correlation exceeds R=0.90 for Table A despite the very high fluctuations in error (mean = 54%, max = 96%) for each simulated recording. For example, Subject 8 performed 4 times as many steps compared to Subject 6 yet the device reported fewer steps performed. Despite the strong correlation, this device would not be valid. In contrast, while the correlation in Table B is poor (R=-0.05) due to the homogeneity of the data, the percentage error values are very low (mean = 0%, max = 7%) indicating that this would be a valid device.
5.3 Results

5.3.1 Description of participants

The characteristics of the participants are described in Table 5.1. Twenty participants with a median age of 57.5 years were enrolled in the study. There were 11 men and 9 women. The median NIHSS score indicates that the participants were of mild to moderate impairment. Seven participants suffered a right sided lesion, 10 had a left sided lesion and 3 participants had bilateral lesions. At the time of assessment, half the sample (n=10) were independent in their mobility while the other half required contact assistance. Three participants used a walking stick, one participant used a quad stick and one participant used a walking frame. The median gait speed across this cohort was 0.86 m/s.

Table 5.1: Characteristics of participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>$n = 20$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years), median (IQR)</td>
<td>57.5 (49-67)</td>
</tr>
<tr>
<td>Gender, $n$ males (%)</td>
<td>11 (55)</td>
</tr>
<tr>
<td>Severity of stroke, NIHSS (0-21), median (IQR)</td>
<td>6.5 (4-9)</td>
</tr>
<tr>
<td>Side of lesion, $n$ (%)</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>7 (35)</td>
</tr>
<tr>
<td>Left</td>
<td>10 (50)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>3 (15)</td>
</tr>
<tr>
<td>Type of stroke $n$ (%)</td>
<td></td>
</tr>
<tr>
<td>Infarct</td>
<td>16 (80)</td>
</tr>
<tr>
<td>Haemorrhage</td>
<td>4 (20)</td>
</tr>
<tr>
<td>Post-stroke mobility at time of assessment $n$ (%)</td>
<td></td>
</tr>
<tr>
<td>Independent with or without aids</td>
<td>10 (50)</td>
</tr>
<tr>
<td>Gait speed (m/s), median (IQR)</td>
<td>0.86 (0.44-1.00)</td>
</tr>
</tbody>
</table>
5.3.2 Agreement between accelerometer and hand-held counter

The accelerometer only counted 3 out of the 100 steps taken for one participant who used a quad stick for mobility. This participant was removed from the analysis due to possible equipment malfunction. The custom-made accelerometer generally undercounted the steps as compared to the hand held-counter with a mean percentage error of -5.4%. The absolute error was 7 out of 100 steps taken. The percentage agreement, calculated as (custom accelerometer step count/observed step count) X 100, was 94.6% (± 8.3%). The percentage of cases that were within 10% of agreement was 94.7%. No correlation was found between gait speed and mean percentage error or the difference in the number of steps counted by the two devices.

5.4 Discussion

The custom ankle-worn accelerometer demonstrated similar error margins as commercially available accelerometers, when compared to steps counted using a hand-held counter, in a sample of stroke survivors undergoing inpatient rehabilitation. The challenge in this clinical group has been the accuracy of commercially available accelerometers in people with slow and asymmetrical gait speeds. The SAM and the Fitbit One worn on the unaffected ankle demonstrated a percentage agreement of 98% (±12%) and 84% (±13%) respectively (Treacy et al., 2017). The custom accelerometer was approximately 3% less accurate than the SAM and this could be a result of the custom accelerometer being tested over a shorter distance which could have resulted in errors detecting the first and last step. However, the custom accelerometer was at least 10% more accurate than the Fitbit One. The approximate cost of the custom accelerometer was AUD$100 per unit which is a small fraction of the cost of commercially available accelerometer systems.

5.4.1 Strengths and limitations

The main strength of this paper is it is possible to obtain accuracy of measurement with a low-cost custom accelerometer worn on the ankle. A custom accelerometer has also allowed the access to raw data so that data can be visualised if there are doubts about the accuracy of the steps count recorded. Additionally, this allows for modifications to
detection algorithms, if required, to increase the accuracy of measurement. However, a limitation of this validation study is that it was carried out in a clinical environment without variation to the walking surface. Also, the distance was short which could have affected the accuracy. There could have also been possible errors in the observation of step counts using the hand-held counter which may have impacted the validity results. The accelerometer was initially designed to be coupled with a high-power GPS unit to understand where stroke survivors were most active. However, technology at time of this design conceptualisation (2014) did not support this in a wearable format. With the fast evolution of activity monitors and inertial monitoring units in the commercial sphere, this is now possible.

### 5.5 Summary and conclusions

This study has demonstrated that it is possible that similarly constructed low-cost ankle-worn accelerometers can accurately measure step count amongst stroke survivors undergoing rehabilitation in hospital. The custom accelerometer was used in subsequent studies in this thesis as a physical activity measurement tool.
Chapter 6:  Descriptors of physical activity at 3 months following discharge from inpatient rehabilitation

6.1 Introduction

6.1.1 Background

Physical activity levels amongst stroke survivors are low [e.g. (Askim et al., 2013; C. English et al., 2016; Kunkel et al., 2015)]. The pooled data from several studies found that stroke survivors participated in approximately 50% less activity than their age-matched healthy peers (Natalie A Fini et al., 2017). On average, stroke survivors took 5535 and 4078 steps/day in the sub-acute and chronic phase respectively. Even when compared to other chronic conditions, such as people with multiple sclerosis or chronic obstructive pulmonary disease, stroke survivors remained the least active (Chmelo et al., 2013; Dlugonski et al., 2013; Donaire-Gonzalez et al., 2013; Natalie A Fini et al., 2017; C. Tudor-Locke et al., 2009). There is consensus that stroke survivors are not active enough to gain health benefits such as prevention or optimal control of chronic diseases (Billinger et al., 2014).

Physical activity represents a group of complex and multidimensional behaviours. Research in stroke has mainly explored the quantitative dimensions of physical activity, which describes the amount of physical activity that is undertaken by the individual over a period of time (Kelly, Fitzsimons, & Baker, 2016). This may be expressed in terms of frequency, duration and intensity and accumulates to the volume of physical activity undertaken. There is almost no information on the other aspects of post-stroke physical activity such as context and domain (Gabriel, Morrow, & Woolsey, 2012). The context of physical activity describes where, who, when, why and in what conditions physical activity occurs. It can be a specific description such as dance class or walking in the park with family in the evening. The more common categories of context are time, location, purpose (e.g. work, leisure, active transport), incidental or planned (Guell, Shefer, Griffin, & Ogilvie, 2016). Domain of physical activity is interchangeably used with context and refers to categories which describe the purpose
of the activity (e.g. work, leisure) (Sallis et al., 2006). There is emerging evidence that older adults are more likely to be involved in physical activity near the home and perceived as sociable rather than being focused on the health benefits (Boulton, Horne, & Todd, 2018). Initial research into exercise preferences of stroke survivors found that this group had a higher preference for physical activity in a structured and supervised setting (Banks, Bernhardt, Churilov, & Cumming, 2011). Knowledge of context of post-stroke physical activity is important for enhancing intervention strategies to increase physical activity levels.

The measurement of post-stroke physical activity has remained a challenge as there is no one device that is able to measure all aspects (Natalie A. Fini et al., 2015). Direct measures can provide accurate information on walking-related activities or outdoor activity, but non-compliance and device malfunction can lead to missing data (Esliger, Copeland, Barnes, & Tremblay, 2005). Self-report measures are easy to administer, low cost and some are able to provide information on the context of physical activity (B. Ainsworth et al., 2015). However, self-report is subject to recall and social desirability biases leading to over or under reporting (B. E. Ainsworth et al., 2012). To establish the context and volume of physical activity, a combination of measures is necessary. Therefore, this study aims to understand the context of physical activity currently undertaken by stroke survivors by utilising different types of physical activity outcome measures. This is the first study to date that will describe the context of post-stroke physical activity using custom wearables and self-report in high density environments.

6.1.2 Aims and hypotheses

The primary aims of this study were:

- To ascertain the correlations between ACS, IPAQ-S7 and a custom-made accelerometer.
- To identify the context, volume and intensity of physical activity undertaken by stroke survivors at three months following discharge from rehabilitation.
The primary hypotheses for this study were:

- The physical activity measures would demonstrate at least a moderate agreement with each other ($r \geq 0.5$).
- Stroke survivors will participate only in light intensity physical activity at three months following discharge from inpatient rehabilitation.
- The primary mode of physical activity will be walking.

6.2 Methodology

6.2.1 Design

A cross-sectional analysis (as part of a prospective cohort study) was conducted to examine physical activity amongst stroke survivors living in the community at three months following discharge from inpatient rehabilitation.

6.2.2 Participants and recruitment

As outlined in Chapter 4, stroke survivors were included if they had a confirmed diagnosis of an infarct or hemorrhagic stroke and able to walk at least 10 metres with no more than minimal assistance with or without gait aid. They were excluded if they did not have sufficient cognition to provide informed consent or had communication deficits that could affect their participation in the study procedures. Ethical approval was obtained at the institution where the research took place. Informed consent was obtained from all participants.

6.2.3 Procedures

Stroke survivors who could walk were recruited from an inpatient rehabilitation unit prior to discharge. As outlined in Chapter 4, the participants’ demographic, hospitalisation details, type and severity of stroke, modified Rankin Scale score (mRS) and self-selected gait speed were measured to inform the baseline characteristics of the participants. Self-reported physical activity outcome measures were collected using the International Physical Activity Questionnaire Short 7 days (IPAQ-S7) (Craig et al., 2003) and the Activity Card Sort (ACS) (Doney & Packer, 2008). Participants were also
required to wear an ankle-mounted accelerometer and a global positioning system (GPS) unit in their pocket or bag for four days (as described in Chapter 4). Participants were instructed to carry out their usual routine and to wear the monitors always, except when showering or sleeping. Participants were also given an activity diary (Appendix O) to complete. Participant were asked to record down the time, duration, and reason for their outings over the four days. The units and activity diaries were either returned to the research unit at the end of the monitoring period or collected from their residences.

The outputs from the four physical activity measures that were used for the analysis and their definitions are summarised in Table 6.1.
Table 6.1: Summary of physical activity output definitions

<table>
<thead>
<tr>
<th>Physical activity measures</th>
<th>Output</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer</td>
<td>Steps/day</td>
<td>Walking related physical activity</td>
</tr>
<tr>
<td>GPS and activity diary</td>
<td>Time spent in active transport (mins/day)</td>
<td>Incidental walking activity associated with the use of public transport e.g. walking to bus stop</td>
</tr>
<tr>
<td></td>
<td>Time spent in active leisure (mins/day)</td>
<td>Incidental walking activity associated with leisure activities e.g. shopping</td>
</tr>
<tr>
<td></td>
<td>Time spent in green-space exercise (mins/day)</td>
<td>Exercise that is performed in man-made green spaces e.g. parks or natural environments</td>
</tr>
<tr>
<td></td>
<td>Time spent in sedentary outdoor activities (mins/day)</td>
<td>Time spent not participating in any incidental or planned physical activity (e.g. having lunch at restaurant)</td>
</tr>
<tr>
<td></td>
<td>Total time spent active outdoors (mins/day)</td>
<td>Total time spent in active transport, active leisure and greenspace exercise</td>
</tr>
<tr>
<td>ACS</td>
<td>Number of high demand leisure activities (score 0-14)</td>
<td>High demand leisure activities as per ACS: swimming, bowling, golfing, walking, running/jogging/brisk walking, cycling, games in the park, camping, canoeing/boating/sailing, fishing, gardening, tai chi/qigong, other exercises</td>
</tr>
<tr>
<td>IPAQ-S7</td>
<td>MET-min/week</td>
<td>METs are multiples of the resting metabolic rate, MET-minute = MET score of an activity * minutes performed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Walking MET-min/week = 3.3 * walking minutes * walking days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate MET-min/week = 4.0 * moderate-intensity activity minutes * moderate days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vigorous MET-min/week = 8.0 * vigorous-intensity activity minutes * vigorous-intensity days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total physical activity MET-minutes/week = sum of Walking + Moderate + Vigorous MET-min/week</td>
</tr>
</tbody>
</table>

6.2.4 Statistical analysis

Spearman Rank-Order Correlation Coefficient or Pearson’s Product-Moment Correlation Coefficient were used to determine the correlations between ACS, IPAQ-S7 and GPS. Descriptive statistics was applied to derive the median and interquartile range of the type, volume and time spent in outdoor physical activity at three months following discharge from rehabilitation. Customised software (created by supervisor RC, using the LabVIEW software programme) was used to analyse the data (accelerometer as per Chapter 5, GPS as per Figure 6.1).
Figure 6.1: GPS data analysis software displays geographical data for cleaning.

The analysis software allowed for median filtering of the data to remove random noise that commonly occurs when a person is indoors. Data were updated automatically in Google Maps using the API, which was controlled by the custom software. Zooming capability and the use of cursors, in addition to timestamped data and velocity of movement at each timepoint allowed for the identification and classification of walking, passive transport, leisure, sedentary outdoor and greenspace activities.
6.3 Results

6.3.1 Participants

Fifty-five participants were recruited in the physical activity monitoring at three months following discharge from inpatient rehabilitation. The median age was 59 years (interquartile range [IQR], 49-67), 64% were male and the majority (95%) had suffered their first stroke (Table 6.2). The average Body Mass Index (BMI) of 24.6 was on the upper limits of the normal range. The median time since stroke was 117 days (IQR, 109-129). 76% of the participants suffered an infarct and 9% had received recombinant tissue plasminogen activator therapy. All participants were independent prior to the stroke and 91% had recovered independent mobility with or without aids by three months post-discharge from inpatient rehabilitation. More than half (56%) the participants were continuing to attend outpatient rehabilitation and 13% had returned to work.

Table 6.2: Characteristics of participants at three months following discharge from inpatient rehabilitation

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>n = 55</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years), median (IQR)</td>
<td>59 (49-67)</td>
</tr>
<tr>
<td>Gender, n males (%)</td>
<td>35 (64)</td>
</tr>
<tr>
<td>Body Mass Index, median (IQR)</td>
<td>24.6 (21-27)</td>
</tr>
<tr>
<td>First ever stroke, n (%)</td>
<td>52 (95)</td>
</tr>
<tr>
<td>Time since stroke at follow-up (days), median (IQR)</td>
<td>117 (109-129)</td>
</tr>
<tr>
<td>Side of lesion, n (%)</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>26 (47)</td>
</tr>
<tr>
<td>Left</td>
<td>23 (42)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>6 (11)</td>
</tr>
<tr>
<td>Type of stroke, n (%)</td>
<td></td>
</tr>
<tr>
<td>Infarct</td>
<td>42 (76)</td>
</tr>
<tr>
<td>Haemorrhage</td>
<td>13 (24)</td>
</tr>
<tr>
<td>FCI (0-18), median (IQR)</td>
<td>1 (1-2)</td>
</tr>
<tr>
<td>Pre-stroke mobility, n (%)</td>
<td></td>
</tr>
<tr>
<td>Independent with or without aids</td>
<td>55 (100)</td>
</tr>
<tr>
<td>Post-stroke mobility at time of follow-up, n (%)</td>
<td></td>
</tr>
<tr>
<td>Independent with or without aids</td>
<td>50 (91)</td>
</tr>
<tr>
<td>Undergoing outpatient rehabilitation, n (%)</td>
<td>31 (56)</td>
</tr>
<tr>
<td>Gait speed (m/s), median (IQR)</td>
<td>0.89 (0.51-1.11)</td>
</tr>
</tbody>
</table>
6.3.2 Activity data and compliance

The accelerometer unit was not given to participants who had skin conditions or lower limb swelling as they may experience tightness, redness or itchiness (n = 3). There was incomplete activity data for four participants as they reported that the shell of the unit became came apart (n= 1) or the unit came off the ankle band (n = 3) while it was being worn (Table 6.3). These participants were excluded from the analysis. The Secure Digital (SD) card failed to log activity in four participants. All 55 participants reported wearing the monitors for four days.

The GPS unit was given to all participants. The SD card could not be read or did not log for five participants. The GPS has missing data (when compared to the activity diary) for four participants. The unit did not pick up any signals if the participant undertook exercise along the corridor outside their flat (Figure 6.2) or below their flat in the common corridor (Figure 6.3). Similarly, the unit did not pick up activity undertaken in an indoor swimming pool. One participant took the underground train to work at a casino in the basement of a shopping centre. These data could not be captured by the GPS unit. There was 100% compliance to wearing the GPS unit, however an average of only three days was recorded due to relatively high battery consumption associated with spending a large portion of time indoors. There was full data for the two self-report measures of intensity of physical activity and participation (i.e. IPAQ-S7 and ACS).
Figure 6.2: Common corridor of a typical flat in Singapore
Photo source: Google images

Figure 6.3: Common void deck below a typical flat in Singapore
Photo source: Google images
Table 6.3: Reasons for missing activity data

<table>
<thead>
<tr>
<th>Reasons for missing or excluded data</th>
<th>Accelerometer</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin conditions/swelling, n</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>SD card malfunction, n</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Unit malfunction, n</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

6.3.3 Correlations between the different measures of physical activity

The accelerometer, GPS, ACS and IPAQ-S7 were fairly correlated with each other with correlation strength ranging from r=0.30 to 0.43 (Table 6.4).

Table 6.4: Spearman’s Correlations between activity measures

<table>
<thead>
<tr>
<th></th>
<th>IPAQ-S7 Walk</th>
<th>IPAQ-S7 Total</th>
<th>ACS-HDL</th>
<th>ACS Global</th>
<th>Steps/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>0.33*</td>
<td>0.28</td>
<td>0.36*</td>
<td>0.23</td>
<td>0.41*</td>
</tr>
<tr>
<td>Steps/day</td>
<td>0.31*</td>
<td>0.31*</td>
<td>0.40*</td>
<td>0.43*</td>
<td>0.43*</td>
</tr>
<tr>
<td>ACS-Global</td>
<td>0.32*</td>
<td>0.40*</td>
<td></td>
<td></td>
<td>0.43*</td>
</tr>
<tr>
<td>ACS-HDL</td>
<td>0.43*</td>
<td>0.43*</td>
<td></td>
<td></td>
<td>0.40*</td>
</tr>
<tr>
<td>IPAQ-S7 Total</td>
<td></td>
<td>0.43*</td>
<td>0.40*</td>
<td>0.31*</td>
<td></td>
</tr>
</tbody>
</table>

* significant at p < 0.05

Abbreviations: ACS, Activity Card Sort; GPS, Global Positioning Systems; IPAQ-S7, International Physical Activity Questionnaire Short 7 days.
6.3.4 Descriptors of physical activity at three months following discharge from inpatient rehabilitation

In this sample, stroke survivors took a median (IQR) of 4870 (1904-8885) steps/day, with a wide range of individual daily counts from 58 to 16,643 steps/day. There was a large variability in the IPAQ-S7 and GPS results (Table 6.5). Most participants did not participate in any moderate or vigorous intensity physical activity. On average, the participants engaged most frequently in two out of 14 high demand leisure activities as per the ACS.

Table 6.5: Description of physical activity

<table>
<thead>
<tr>
<th>Physical activity measures</th>
<th>IPAQ-S7 (MET-min/week), median (IQR)</th>
<th>ACS, (number) median (IQR)</th>
<th>Steps/day, median (IQR)</th>
<th>GPS, median (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vigorous</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>0 (0-560)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking</td>
<td>495 (231-1386)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total physical activity</td>
<td>708.5 (231-2079)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting (hours)</td>
<td>4 (3-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDL-current (14)</td>
<td>2 (1-3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDL-current (28)</td>
<td>7.5 (5-10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrumental-current (26)</td>
<td>10.5 (6.5-14)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social-current (17)</td>
<td>5.5 (4-8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total time spent active outdoors (mins/day)</td>
<td>6 (0-47)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average proportion of time spent active outdoors (%)</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: ACS, Activity Card Sort; ACS; GPS, Global Positioning System; HDL, High Demand Leisure; LDL, Low Demand Leisure; IPAQ-S7, International Physical Activity Questionnaire-Short 7 days; IQR, Interquartile Range.

6.3.5 Context of physical activity

Walking was the most frequent form of exercise for participants who were independent and those who required assistance to walk (Figure 6.7). Other exercises were the second most preferred activity. Other exercises as defined by the ACS referred to home-based exercises such as using the fitness zone in housing areas (Figure 6.8) or exercises taught by their physiotherapist at home. The third preferred activity was gardening. In Singapore, this usually involves potted plants along the common corridors of the flats (Figure 6.9).
Abbreviation: ACS-HDL: Activity Card Sort-High Demand Leisure

Figure 6.4: Types of High-Demand Leisure activities done by participants

Figure 6.5: An example of a fitness zones in housing areas in Singapore
Photo source: Google images
6.3.6 Frequency and duration of physical activity

Thirty-two percent of participants reported that they were engaged in moderate intensity activity for at least 10 minutes per day for at least three days of the week. Eighty percent reported that they participated in walking-related activity for at least 10 minutes per day for at least three days of the week. The IPAQ-S7 scores walking separately from moderate intensity activities. More than half of the participants (56%) were continuing to attend outpatient physiotherapy sessions.

6.3.7 Outdoor physical activity

Fifty-one percent of outdoor trips made were for social or medical reasons and involved the use of passive transportation (i.e. car or public transport) with minimal walking-related activity outdoors. Two participants (4.2%) did not have any outings over the monitoring period. Only 8% of the sample engaged in greenspace exercise. 18% of the participants participated in walking during active transport while 24% as part of grocery or leisure shopping.

Figure 6.6: Gardening in flats in Singapore
Photo source: Google images
6.4 Discussion

The results of this study indicated that the different physical activity measures were only fairly correlated (Portney & Watkins, 2009). Thus, our hypothesis that the measures will be moderately correlated was not supported. This could be due to the various outcomes measuring different aspects of a similar construct. As hypothesised, this cohort walked an average of 5382 steps/day and mostly engaged in light intensity physical activities. This finding is consistent with a previous meta-analysis that found that the pooled mean steps/day was 5535 in the sub-acute phase following stroke (Natalie A Fini et al., 2017). Also, those who had returned to work (n = 7) spent 32 mins more in active outdoor physical activity. Walking and near home-based exercises were the most common mode of physical activity by stroke survivors at three months following discharge from inpatient rehabilitation. Walking and exercise near home were the most frequently reported physical activities as measured by the ACS scores. This finding was consistent with the GPS, and activity diary results which also indicated that most of the walking exercise performed by this sample was in or around their dwelling. Active transport and leisure activities such as shopping were the two main reasons for walking-related activity outdoors. Despite the proximity of greenspaces within the high-rise housing estates, very few stroke survivors utilised these for walking exercise.

This study was the first to utilise a mix of direct and self-report measures of physical activity to establish the context and volume of both indoor and outdoor physical activity levels amongst stroke survivors in the sub-acute phase. Those whom recovered to independent mobility walked an average of 6800 steps which was in the lower limits of recommended steps/day for older adults and those with cardiac conditions, approximately 7000-10,000 steps/day and 6500-8500 steps/day, respectively (C. Tudor-Locke et al., 2009). There are very few studies that have explored intensity of post-stroke physical activity. However, a recent study conducted in the United Kingdom using a self-designed questionnaire for stroke survivors found that 75.9% of their participants participated in low intensity physical activity, 46% in moderate-intensity and 9.2% engaged in high-intensity physical activity (Jackson et al., 2018). The difference in results could be due to the design of the questionnaire in this study which did not exclude walking related activities from the scoring. The IPAQ-S7 scores
walking related activity separately from moderate intensity activities. Walking may result in a moderate intensity exercise for stroke survivors but the IPAQ-S7 may not able to capture this information. This limitation was also described in other cohorts (Vassbakk-Brovold et al., 2016). Studies that have utilised accelerometery and cadence of gait as a measure of intensity (increasing cadence reflecting increasing intensity) also found that stroke survivors spent significantly higher proportion of their walking time in light intensity compared to healthy controls (P. J. Manns & Baldwin, 2009; Paul et al., 2016). Thus, our findings are consistent with other studies that demonstrate that stroke survivors are not meeting the post-stroke physical activity recommendations of 20-60 minutes (or in accumulated bouts of 10 minutes) of moderate intensity physical activity at least three days per week (Billinger et al., 2014).

There is accumulating evidence for low physical activity levels amongst stroke survivors but very little is known of the most frequent mode of physical activity. Walking and use of public fitness areas near home were the main mode of physical activity in this cohort which is consistent with that of healthy older adults in Singapore (Krishnasamy, Unsworth, & Howie, 2011). The use of outdoor exercise fitness areas near home or walking along a corridor is also consistent with healthy adults in Singapore preferring to use free public facilities for exercise (Sports Singapore, 2016).

There is also emerging interest in the use of GPS to evaluate physical activity with the understanding that physical activity is not a single act but a multidimensional behaviour. Previous studies using GPS to investigate outdoor physical activity in the traumatic brain injury population found higher levels of outdoor physical activity, with 35% of their participants performing less than 10 minutes compared to 52% in this cohort (Clark et al., 2014). Similarly, 71% of TBI subjects performed at least 30 mins of outdoor activity per day compared to 37.5% in this present cohort (Clark et al., 2014). This could be due to the much younger cohort in the above-mentioned study, with average age of 28 years, or the difference in transport and urban structure between the two different settings when the studies were conducted (Australia and Singapore). Another study that utilised GPS and activity diaries to explore outings amongst stroke survivors in Australia, found that the most common purpose of outings were leisure
activities and few outings were for exercise, which is consistent with our study findings (McCluskey et al., 2012).

6.4.1 Strengths and limitations

This study is the first to provide data on physical activity levels amongst stroke survivors using a mix of self-report and direct measures in Singapore. It is also the first study to provide a comprehensive overview of domain, frequency, duration and intensity as well as GPS data on outdoor physical activity stroke. However, there were several limitations. The sample was relatively small and may not have captured enough variability in the population. There was also loss of data from malfunction of the activity and GPS monitors that further reduced the sample size. An accelerometer combined with a GPS unit with enhanced features to pick up signals indoors (e.g. radio-frequency identification) could have provided further insights into the context and volume of post-stroke physical activity. However, this technology was not available at the time of the study. The self-report measures were administered before the period of activity monitoring by direct measures and thus, the combined activity data are not over the same period. At three months following discharge from inpatient rehabilitation, more than half of the stroke survivors were continuing to attend outpatient rehabilitation which could have influenced the frequency and duration of physical activity measures.

6.4.2 Clinical implications

The main clinical implication derived from this study is that there is no one device, at present, that can comprehensively assess physical activity behaviours amongst stroke survivors. The IPAQ-S7 should be used and interpreted with caution in the stroke population. Walking and near home or home-based exercise was the most frequently reported types of physical activity post-stroke. These findings could be taken into consideration during physical activity counselling sessions with stroke survivors.

6.5 Summary and conclusions

In conclusion, measurement of physical activity is a challenge and there is no one device that provides comprehensive information on the context, volume and intensity of physical activity. At three months following discharge from inpatient rehabilitation, the
volume of physical activity amongst stroke survivors was insufficient to gain health benefits. Walking and near home physical activity were the common mode of physical activity. Time spent in walking related activity outdoors was mostly incidental for leisure or active transport. This new information on context and physical activity levels amongst Singaporean stroke survivors should be combined with knowledge on the modifiable factors at discharge from inpatient rehabilitation which could influence physical activity levels. There needs to be further explorative studies investigating the factors at discharge from rehabilitation that are predictive of physical activity levels. Interventions targeted at the modifiable factors and physical activity programme design introduced in this sub-acute phase of recovery could have implications for long-term adherence to physical activity.
Chapter 7: Factors associated with physical activity after stroke at three months following discharge from inpatient rehabilitation

7.1 Introduction

7.1.1 Background

Physical inactivity after stroke is a growing health concern and focus of research in recent years (Billinger et al., 2014). Stroke is the leading cause of long-term adult disability worldwide and the incidence of stroke is likely to escalate due to the ageing society and an increasing trend of cardiovascular risk factors such as hypertension, hyperlipidemia and diabetes mellitus (World Health Organisation, 2004). Many stroke survivors are living with physical disabilities resulting from post-stroke impairments (Gadidi, Katz-Leurer, Carmeli, & Bornstein, 2011; Hartman-Maeir et al., 2007; Mayo et al., 2002). They may also have co-morbidities such as heart disease which has a negative impact on function. In addition to this, the person may develop post-stroke changes such as elevated energy cost of walking, fatigue and depression which further affects function and may lead to a physically inactive lifestyle (Ayerbe, Ayis, Wolfe, & Rudd, 2013; Billinger et al., 2011; Danielsson, Willén, & Sunnerhagen, 2007; Duncan, Kutlubaev, Dennis, Greig, & Mead, 2012). This then exacerbates the deconditioning and places the person in a perpetuating, deleterious cycle that can negatively impact their health, independence, and quality of life.

Physical activity can help to decrease the risk factors for stroke such as hypertension, hyperlipidemia and diabetes (Hafer-Macko et al., 2008; Hafer-Macko et al., 2005; F. M. Ivey, Macko, Ryan, & Hafer-Macko, 2005). It can also help to improve the secondary consequences of stroke such as deconditioning and falls. Despite the known benefits of physical activity, there is now sufficient evidence to demonstrate that stroke survivors are not physically active enough to gain health benefits (C. English et al., 2016; Field et al., 2013; Natalie A Fini et al., 2017; Gebruers, Vanroy, Truijen, Engelborghs, & De Deyn, 2010). Recent research also demonstrates that stroke survivors are even less
active than people with other long-term neurological or musculoskeletal conditions (Chmelo et al., 2013; Dlugonski et al., 2013; Donaire-Gonzalez et al., 2013; Natalie A Fini et al., 2017; C. Tudor-Locke et al., 2009). Before we can implement successful interventions to increase physical activity amongst people after stroke, we need to understand what modifiable factors are associated with physical activity behaviour in this population. However, there is very little information available on the key modifiable factors that contribute to post-stroke physical activity levels. At the commencement of this thesis, only 10% of the existing research in physical activity after stroke has explored factors that are related to physical activity (Cleveland, Driver, Swank, & Macklin, 2015). Also, most of the research studies in this area are cross-sectional and involve chronic stroke cohorts (C. English et al., 2016; Field et al., 2013; S. Thilarajah et al., 2017). The studies might report, for example, that depression is associated with low post-stroke physical activity levels amongst chronic stroke survivors. However, the direction of this relationship is unclear. Does depression cause low activity levels or do low activity levels cause depression? Understanding the direction of this relationship would enable interventions to target the contributing factors to increase physical activity. A chronological sequence where the factor is measured at a timepoint preceding the measurement of physical activity levels is needed to establish the factors that explain low physical activity levels after stroke (Grobbee & Hoes, 2009).

The findings of cross-sectional studies are useful to generate hypotheses for prospective cohort or longitudinal studies even if they do not explain causality (Bauman et al., 2002). Recent systematic reviews identified self-selected gait speed, Berg Balance Scale (BBS), depression, self-efficacy, and quality of life as potentially modifiable factors in the chronic stroke population (Coralie English et al., 2014; Field et al., 2013; S. Thilarajah et al., 2017). Psychosocial factors have not been studied consistently even in cross-sectional studies. The measurement of the candidate factors has also been varied which makes comparison between studies challenging. Furthermore, these questionnaires do not assess anxiety which has been shown to be prevalent in the stroke population. Self-efficacy related to balance, falls and exercise have been explored but it is unclear which of these different aspects contribute to low physical activity levels.
Other factors identified in qualitative research as barriers to post-stroke physical activity, such as motivation to exercise, have yet to be explored in quantitative studies to understand causal effects.

Generally, there is a paucity of cohort and longitudinal studies investigating post-stroke physical activity, with very few studies exploring factors that contribute to low physical activity levels (Askim et al., 2013; Duncan et al., 2015; Kunkel et al., 2015; Moore et al., 2013; Sánchez et al., 2015; Tieges et al., 2015). To date, only physical function measures, BBS, Barthel Index and Rivermead Motor Index (at stroke onset) have been investigated in the handful of longitudinal studies and found to be significantly associated with time spent upright (measured by a thigh-mounted accelerometer) (Askim et al., 2013; Kunkel et al., 2015). However, these studies have not consistently adjusted for confounders such as age, gender and stroke severity in their statistical analysis which could have biased their results (Rothman, 2008). The studies have also not investigated psychosocial factors, such as mood or motivation, and thus their results are also biased towards physical function when it is becoming apparent that physical function only contributes partially to low post-stroke physical activity levels (C. English et al., 2016).

Furthermore, the majority of research has been in the chronic phase of stroke. Studies that have investigated the change in post-stroke physical activity across the recovery continuum have found that the most significant change in activity levels occurs in the first three months after stroke (Askim et al., 2013; Duncan et al., 2015; Kunkel et al., 2015; Moore et al., 2013; Sánchez et al., 2015; Tieges et al., 2015). This is also the same timeframe where accelerated neurological recovery occurs and when stroke survivors are discharged from rehabilitation to home (Julie Bernhardt et al., 2017). The sub-acute phase may be an important timepoint to provide interventions to increase physical activity levels and to promote long-term adherence to an active lifestyle.

Therefore, there is an overwhelming need for prospective cohort studies that explore factors across physical and psychosocial domains, and utilise appropriate statistical techniques. This will allow the identification of key modifiable factors to improve our understanding of the contributing factors to low post-stroke physical activity levels. The
point of discharge from rehabilitation into the community may be an opportunistic time to identify patients who could benefit from a tailored, early community-based intervention to improve their uptake and long term maintenance of physical activity (J. Morris et al., 2012).

7.1.2 Aims and hypotheses

The primary aim of this study was:

- To prospectively explore the factors at discharge from inpatient rehabilitation (baseline) associated with physical activity at three months post-discharge (prospective), as determined by the Activity Card Sort (ACS), International Physical Activity Questionnaire Short 7 days (IPAQ-S7) and steps/day.

The secondary aims of this study were:

- To explore the factors at three months after discharge from inpatient rehabilitation associated with physical activity (cross-section) as determined by the ACS, IPAQ-S7 and steps/day.
- To determine the change in physical function, mood, cognition, and motivation scores from discharge from inpatient rehabilitation to three months later.

The hypotheses for this study were:

- Self-selected gait speed, balance, depression, and motivation measures at discharge from inpatient rehabilitation, will be significant factors associated with the ACS, IPAQ-S7 and steps/day.
- Self-selected gait speed, balance, depression, and motivation measures at three months after discharge from inpatient rehabilitation, will be significant factors associated with the ACS, IPAQ-S7 and steps/day.
- There will be a significant (p ≤ 0.05) improvement in scores across the physical function measures between baseline and three months later.
7.2 Methodology

7.2.1 Design

A prospective cohort study design was used to examine physical activity at three months following discharge from inpatient rehabilitation. The details of the methodology are described in Chapter 4 of this thesis. In summary, physical function, cognition and mood were assessed within seven days prior to discharge (baseline) and at three months following discharge from inpatient rehabilitation. Participation (ACS) and intensity (IPAQ-S7) of physical activity were assessed at the follow-up. As described in Chapter 4, each participant was also issued an accelerometer (steps/day) on completion of the assessment to wear over four days in the community at this point. Participants were instructed to carry out their usual routine and to wear the activity monitors except when showering or sleeping.

7.2.2 Participants and recruitment

As outlined in Chapter 4, stroke survivors were included if they had a confirmed diagnosis of an infarct or hemorrhagic stroke and were able to walk at least 10 metres with no more than minimal assistance with or without gait aid. They were excluded if they did not have sufficient cognition to provide informed consent or had communication deficits that could affect their participation in the study procedures. Ethical approval was obtained at the institution where the research took place. Informed consent was obtained from all participants.

7.2.3 Procedures

Details are described in Chapter 4: Common methodology.

7.2.4 Statistical analysis

To address the study’s aims of identifying the factors at baseline and three months after discharge that are associated with physical activity, the following statistical procedures were undertaken:

- Linear regression analysis was performed adjusting for age, gender, stroke severity and time since stroke.
• Model residuals were checked to ensure all assumptions were satisfied.
• If model residuals were not normal, the independent variables were log-
  transformed, and model residuals re-checked.
• The appropriateness of all model residuals was assessed using quantile-quantile
  plots.
• If model residuals remain skewed, an ordinal regression was undertaken.
• The odds ratio and the 95% confidence intervals for ordinal regression were
  calculated from the parameter estimates using the formulas below:
  ▪ Odds ratio = $e^{\beta \text{estimate}}$
  ▪ Lower confidence interval = $e^{\text{lower bound}\beta}$
  ▪ Upper confidence interval = $e^{\text{upper bound}\beta}$
  ▪ The odds ratio was also scaled to the IQR using the equation
    below:
    ▪ $\text{OR}_{\text{IQR}}$ (95% CI, lower $\text{OR}_{\text{IQR}}$ to upper $\text{OR}_{\text{IQR}}$).
• Regression coefficients were scaled to the IQR of each continuous variable to
  provide a standardised and clinically meaningful distinction from the convention
  alone-unit change in prognostic factor values (Harrell, 2015):
  ▪ $\text{Beta} \times \text{IQR}$ (95% CI, IQR × lower CI to IQR × upper CI).
• Only the HDL component of the ACS was used in the analysis as the activities
  in this category matched closest to physical activity or exercise.

To determine the change in physical function, mood, cognition, and motivation scores
from discharge from inpatient rehabilitation to three months later:

• A paired samples t-test was used to assess if there was a significant difference
  in outcome measures between the two-time points.
7.3 Results

Following screening of 480 patients, 66 were consented into the study, with 64 participants completing baseline analyses and 55 the follow-up assessment (Figure 7.1).

**Figure 7.1:** Study flow diagram
The characteristics of the participants at discharge from inpatient rehabilitation are described in Table 7.1. At discharge from inpatient rehabilitation, the median time since stroke was 24 days (IQR, 20-36). More than half of the participants suffered a stroke of moderate severity, 76% were a result of infarcts and 9% had received recombinant tissue plasminogen activator therapy. The NIHSS scores obtained at time of admission to the acute stroke unit indicated that this cohort had a mild to moderate level of impairment. At discharge from inpatient rehabilitation, less than half (45%) were able to walk independently. However, at follow-up, the majority (91%) had regained independent mobility.

### Table 7.1: Characteristics of participants at discharge from inpatient rehabilitation

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>n = 55</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years), median (IQR)</td>
<td>59 (49-67)</td>
</tr>
<tr>
<td>Gender, n males (%)</td>
<td>35 (64)</td>
</tr>
<tr>
<td>Body Mass Index, median (IQR)</td>
<td>24.6 (21-27)</td>
</tr>
<tr>
<td>First ever stroke, n (%)</td>
<td>52 (95)</td>
</tr>
<tr>
<td>Time since stroke at baseline assessment (days), median (IQR)</td>
<td>24 (20-36)</td>
</tr>
<tr>
<td>Time since stroke at follow-up (days), median (IQR)</td>
<td>117 (109-129)</td>
</tr>
<tr>
<td>Severity of stroke, NIHSS (0-21), median (IQR)</td>
<td>6 (4-10)</td>
</tr>
<tr>
<td>Side of lesion, n (%)</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>26 (47)</td>
</tr>
<tr>
<td>Left</td>
<td>23 (42)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>6 (11)</td>
</tr>
<tr>
<td>Type of stroke, n (%)</td>
<td></td>
</tr>
<tr>
<td>Infarct</td>
<td>42 (76)</td>
</tr>
<tr>
<td>Haemorrhage</td>
<td>13 (24)</td>
</tr>
<tr>
<td>Inattention, n (%)</td>
<td>6 (11)</td>
</tr>
<tr>
<td>Received tPA, n (%)</td>
<td>5 (9)</td>
</tr>
<tr>
<td>FCI (0-18), median (IQR)</td>
<td>1 (1-2)</td>
</tr>
<tr>
<td>Pre-stroke mobility, n (%)</td>
<td></td>
</tr>
<tr>
<td>Independent with or without aids</td>
<td>55 (100)</td>
</tr>
<tr>
<td>Post-stroke mobility at time of baseline assessment, n (%)</td>
<td>25 (45)</td>
</tr>
<tr>
<td>Independent with or without aids</td>
<td></td>
</tr>
<tr>
<td>Post-stroke mobility at time of follow-up, n (%)</td>
<td></td>
</tr>
<tr>
<td>Independent with or without aids</td>
<td>50 (91)</td>
</tr>
</tbody>
</table>

#### 7.3.1 Correlations between physical function independent variables

The physical function measures of gait speed, step test and dorsiflexor strength of the affected leg demonstrated moderate to excellent strength correlations with each other ($r = 0.55$ to 0.80; Table 7.2). The step test with the affected leg demonstrated an excellent
correlation with gait speed at assessment 1 \((r = 0.80)\) and 2 \((r = 0.84)\). Furthermore, the step test with affected leg and step test with unaffected leg were also very strongly correlated \((r = 0.80)\). Tables 7.3 shows the correlation matrix between the physical function measures at three-month follow-up.

**Table 7.2:** Pearson’s Correlations between physical function measures at baseline

<table>
<thead>
<tr>
<th></th>
<th>Gait speed</th>
<th>Step test with affected leg</th>
<th>Step test with unaffected leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsiflexor affected leg</td>
<td>0.607**</td>
<td>0.546**</td>
<td>0.613**</td>
</tr>
<tr>
<td>Step test with unaffected leg</td>
<td>0.781**</td>
<td>0.796**</td>
<td></td>
</tr>
<tr>
<td>Step test with affected leg</td>
<td>0.801**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Significant at \(p < 0.01\) level (2-tailed)

**Table 7.3:** Pearson’s Correlations between physical function measures at three-month follow-up

<table>
<thead>
<tr>
<th></th>
<th>Gait speed</th>
<th>Step test with affected leg</th>
<th>Step test with unaffected leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsiflexor affected leg</td>
<td>0.617**</td>
<td>0.552**</td>
<td>0.599**</td>
</tr>
<tr>
<td>Step test with unaffected leg</td>
<td>0.791**</td>
<td>0.892**</td>
<td></td>
</tr>
<tr>
<td>Step test with affected leg</td>
<td>0.841**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Significant at \(p < 0.01\) level (2-tailed)
7.3.2 Factors at discharge from inpatient rehabilitation predicting post-stroke physical activity three months after discharge

Tables 7.4 and 7.5 show the results of the adjusted linear regression and Table 7.6 the ordinal regression analyses. An ordinal regression was undertaken to analyse the positively skewed IPAQ-S7 data in a ranked order. Log transformation of the dependent variables did not improve regression model residuals. To facilitate the interpretation and a clinically meaningful comparison between different variables which were quantified on different scales, the effect size for significant independent variables were scaled and expressed to their respective interquartile range (IQR) (Harrell, 2015).

| Table 7.4: Significant factors at baseline contributing to steps/day at follow-up |
|---------------------------------|-----------------|--------|--------|--------|
| **Prognostic factors**          | **Comparison**  | **Difference** | **Sig.** | **95% CI for β** |
| Gait speed (m/s)                | 0.95 vs. 0.33   | 2732   | 0.04   | 127.77  | 5336.12 |
| Step test unaffected leg (n)    | 11 vs. 6        | 1864   | 0.01   | 464.04  | 3264.54 |

All analyses were adjusted for age, sex, time since stroke and stroke severity

*comparison of scores recorded between the 75th and 25th quartiles

*the modelled difference in steps/day for participants who were at the 75th vs. 25th percentile. A higher score reflects more steps per day performed by someone at the 75th percentile.

Abbreviations: β, beta coefficient; CI, confidence interval; Sig., statistical significance value; vs., versus.
Table 7.5: Significant factors at baseline contributing to ACS-HDL scores at follow-up

<table>
<thead>
<tr>
<th>Prognostic factors</th>
<th>Comparison*</th>
<th>Difference^</th>
<th>Sig.</th>
<th>95% CI for β</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Gait speed (m/s)</td>
<td>0.95 vs. 0.33</td>
<td>1.23</td>
<td>0.01</td>
<td>0.37</td>
</tr>
<tr>
<td>Step test unaffected leg (n)</td>
<td>11 vs. 6</td>
<td>0.75</td>
<td>&lt;0.001</td>
<td>0.26</td>
</tr>
<tr>
<td>Dorsiflexor strength affected leg (Nm/kg)</td>
<td>0.18 vs. 0.09</td>
<td>0.08</td>
<td>0.02</td>
<td>1.15</td>
</tr>
<tr>
<td>Introjected regulation (0-12)</td>
<td>8 vs. 0</td>
<td>0.97</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Intrinsic regulation (0-16)</td>
<td>16 vs. 8</td>
<td>0.84</td>
<td>0.03</td>
<td>0.00</td>
</tr>
</tbody>
</table>

All analyses were adjusted for age, sex, time since stroke and stroke severity

*comparison between the 75th and 25th quartiles

^the modelled difference in ACS-HDL scores for participants who were at the 75th vs. 25th percentile. A higher score reflects participation in higher number of high-demand leisure activities performed by someone at the 75th percentile.

Abbreviations: ACS-HDL, Activity Card Sort-High Demand Leisure; β, beta coefficient; CI, confidence interval; Sig., statistical significance value; vs., versus.

Table 7.6: Significant factors at baseline contributing to IPAQ-S7 scores at follow-up

<table>
<thead>
<tr>
<th>Prognostic factors</th>
<th>Comparison*</th>
<th>Odds Ratio^</th>
<th>Sig.</th>
<th>95% CI for Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Gait speed (m/s)</td>
<td>0.95 vs. 0.33</td>
<td>2.61</td>
<td>0.05</td>
<td>1.02</td>
</tr>
<tr>
<td>Step test unaffected leg (n)</td>
<td>11 vs. 6</td>
<td>1.93</td>
<td>0.02</td>
<td>1.10</td>
</tr>
<tr>
<td>Dorsiflexor strength affected leg (Nm/kg)</td>
<td>0.18 vs. 0.09</td>
<td>2.61</td>
<td>0.01</td>
<td>1.30</td>
</tr>
</tbody>
</table>

All analyses were adjusted for age, sex, time since stroke and stroke severity

*comparison between the 75th and 25th quartiles

^the modelled difference in IPAQ-S7 scores for participants who were at the 75th vs. 25th percentile. A higher odds ratio reflects increased likelihood of higher IPAQ-S7 scores achieved by someone at the 75th percentile.

Abbreviations: β, beta coefficient; CI, confidence interval; IPAQ-S7, International Physical Activity Questionnaire Short 7 days; Sig., statistical significance value; vs., versus.

At baseline, gait speed and step test with the unaffected leg were significant prognostic factors for all measures of physical activity at three months. Participants who had a gait speed of 0.95 m/s (75th percentile) walked 2732 steps/day more, participated in 1.23 times more higher demand leisure activities and were 2.61 times more likely to achieve
a higher MET-min/week than those who walked at 0.33 m/s (25th percentile). Similarly, participants who had a step test score of 11 (75th percentile) walked 1864 steps/day more, participated in 0.75 more higher demand leisure activities and were 1.93 times more likely to achieve a higher MET-min/week than those who had a step test score of 6 (25th percentile).

The psychological factors, introjected and intrinsic regulation from the motivation to exercise questionnaire (BREQ-2) were significant prognostic factors that contributed to participation of physical activity, measured using the ACS. Figure 2 indicates a steep rise in ACS-HDL scores with increasing anxiety levels, observed up to an approximate threshold value of 4-5 points, above which there was no appreciable association between HADS-Anxiety and ACS-HDL.

![Graph showing the association between HADS-Anxiety and ACS-HDL scores.](image)

**Abbreviations:** ACS-HDL, Activity Card Sort-High Demand Leisure; HADS, Hospital Anxiety and Depression Scale.

**Figure 7.2:** Associations of HADS-Anxiety scores with ACS-HDL scores after adjusting for age, sex, stroke severity and time since stroke. Shaded regions represent 95% CI for the regression estimates. The short vertical lines above the x-axes represent the observed HADS-Anxiety values.
7.3.3 Factors correlated with post-stroke physical activity three months after discharge from inpatient rehabilitation

At three months post discharge, gait speed and balance remained as modifiable prognostic factors that contribute to post-stroke physical activity levels (Table 7.7 to 7.9). Anxiety was no longer significant at this time point, but depression became a significant factor associated with participation. Introjected motivation was no longer significant but intrinsic regulation remained significant at both time points. Fear of falling and intrinsic regulation were also significant factors at three months but not at discharge from inpatient rehabilitation.

Table 7.7: Significant factors associated with steps/day at follow-up

<table>
<thead>
<tr>
<th>Prognostic factors</th>
<th>Comparison*</th>
<th>Difference^</th>
<th>Sig.</th>
<th>95% CI for β Lower</th>
<th>95% CI for β Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait speed (m/s)</td>
<td>1.11 vs. 0.51</td>
<td>3418</td>
<td>0.01</td>
<td>1044.59</td>
<td>5791.69</td>
</tr>
<tr>
<td>Step test unaffected leg (n)</td>
<td>13 vs. 7</td>
<td>2914</td>
<td>&lt;0.001</td>
<td>1359.08</td>
<td>4469.31</td>
</tr>
<tr>
<td>Dorsiflexor strength</td>
<td>0.23 vs.0.11</td>
<td>2342</td>
<td>0.02</td>
<td>3167.38</td>
<td>36190.49</td>
</tr>
<tr>
<td>affected leg (Nm/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All analyses were adjusted for age, sex, time since stroke and stroke severity

*comparison of scores recorded between the 75th and 25th quartiles

^the modelled difference in steps/day for participants who were at the 75th vs. 25th percentile. A higher score reflects more steps per day performed by someone at the 75th percentile.

Abbreviations: β, beta coefficient; CI, confidence interval; Sig., statistical significance value; vs., versus.
Table 7.8: Significant factors associated with ACS-HDL scores at follow-up

<table>
<thead>
<tr>
<th>Prognostic factors</th>
<th>Comparison*</th>
<th>Difference^</th>
<th>Sig.</th>
<th>95% CI for β Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait speed (m/s)</td>
<td>1.11 vs. 0.51</td>
<td>1.32</td>
<td>&lt;0.001</td>
<td>0.62</td>
<td>2.02</td>
</tr>
<tr>
<td>Step test unaffected leg (n)</td>
<td>13 vs. 7</td>
<td>1.10</td>
<td>&lt;0.001</td>
<td>0.63</td>
<td>1.58</td>
</tr>
<tr>
<td>Dorsiflexor strength affected leg (Nm/kg)</td>
<td>0.23 vs.0.11</td>
<td>0.97</td>
<td>&lt;0.001</td>
<td>3.02</td>
<td>13.01</td>
</tr>
<tr>
<td>Intrinsic regulation (0-16)</td>
<td>16 vs. 8</td>
<td>0.91</td>
<td>0.03</td>
<td>0.01</td>
<td>0.09</td>
</tr>
<tr>
<td>HADS-Depression (0-21)</td>
<td>7 vs. 2</td>
<td>-0.72</td>
<td>0.04</td>
<td>-5.76</td>
<td>-0.13</td>
</tr>
</tbody>
</table>

All analyses were adjusted for age, sex, time since stroke and stroke severity

*comparison between the 75th and 25th quartiles

^the modelled difference in ACS-HDL scores for participants who were at the 75th vs. 25th percentile. A higher score reflects participation in higher number of high-demand leisure activities performed by someone at the 75th percentile.

Abbreviations: ACS-HDL, Activity Card Sort-High Demand Leisure; β, beta coefficient; CI, confidence interval; Sig., statistical significance value; vs., versus.

Table 7.9: Significant factors associated with IPAQ-S7 scores at follow-up

<table>
<thead>
<tr>
<th>Prognostic factors</th>
<th>Comparison</th>
<th>Odds Ratio^</th>
<th>Sig.</th>
<th>95% CI for Odds Ratio Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait speed (m/s)</td>
<td>1.11 vs. 0.51</td>
<td>3.97</td>
<td>&lt;0.001</td>
<td>1.69</td>
<td>9.30</td>
</tr>
<tr>
<td>Step test affected leg (n)</td>
<td>12 vs. 6</td>
<td>3.30</td>
<td>&lt;0.001</td>
<td>1.68</td>
<td>6.61</td>
</tr>
<tr>
<td>Step test unaffected leg (n)</td>
<td>13 vs. 7</td>
<td>3.81</td>
<td>&lt;0.001</td>
<td>1.97</td>
<td>7.21</td>
</tr>
<tr>
<td>Short FES-I</td>
<td>13 vs. 7</td>
<td>0.40</td>
<td>&lt;0.001</td>
<td>0.21</td>
<td>0.74</td>
</tr>
<tr>
<td>Intrinsic regulation</td>
<td>16 vs. 8</td>
<td>2.48</td>
<td>0.03</td>
<td>1.08</td>
<td>5.96</td>
</tr>
</tbody>
</table>

All analyses were adjusted for age, sex, time since stroke and stroke severity

*comparison between the 75th and 25th quartiles

^the modelled difference in IPAQ-S7 scores for participants who were at the 75th vs. 25th percentile. A higher odds ratio reflects increased likelihood of higher IPAQ-S7 scores achieved by someone at the 75th percentile.

Abbreviations: β, beta coefficient; CI, confidence interval; IPAQ-S7, International Physical Activity Questionnaire Short 7 days; Sig., statistical significance value; vs., versus.

7.3.4 Change scores between baseline and at three months

There were significant differences in the scores for the physical function measures and Modified Rankin Scale from discharge to three months post discharge. However, there
were no significant differences in cognition, fear of falling, depression, anxiety or motivation between the two-time points (Table 7.10).

Table 7.10 Change scores from baseline to follow-up

<table>
<thead>
<tr>
<th>Prognostic factors</th>
<th>Mean baseline</th>
<th>Mean follow-up</th>
<th>Mean change</th>
<th>SD</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait speed (m/s)</td>
<td>0.64</td>
<td>0.82</td>
<td>-0.17</td>
<td>0.22</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Step test- affected leg (no.of steps)</td>
<td>6.62</td>
<td>8.84</td>
<td>-1.97</td>
<td>3.86</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Step test- unaffected leg (no.of steps)</td>
<td>8.00</td>
<td>10.27</td>
<td>-2.24</td>
<td>3.78</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Dorsiflexor strength affected leg (Nm/kg)</td>
<td>0.14</td>
<td>0.16</td>
<td>-0.03</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>MoCA (0-30)</td>
<td>23.73</td>
<td>24.45</td>
<td>-0.46</td>
<td>3.47</td>
<td>0.34</td>
</tr>
<tr>
<td>Short FES-I (7-28)</td>
<td>13.27</td>
<td>11.47</td>
<td>0.80</td>
<td>7.19</td>
<td>0.41</td>
</tr>
<tr>
<td>HADS-Depression (0-21)</td>
<td>5.03</td>
<td>5.22</td>
<td>-0.18</td>
<td>4.50</td>
<td>0.76</td>
</tr>
<tr>
<td>HADS-Anxiety (0-21)</td>
<td>3.39</td>
<td>4.24</td>
<td>-0.87</td>
<td>5.10</td>
<td>0.21</td>
</tr>
<tr>
<td>BREQ-2-Amotivation (0-16)</td>
<td>1.74</td>
<td>1.71</td>
<td>0.31</td>
<td>4.80</td>
<td>0.64</td>
</tr>
<tr>
<td>BREQ-2-External regulation (0-16)</td>
<td>3.17</td>
<td>3.42</td>
<td>-0.13</td>
<td>4.30</td>
<td>0.82</td>
</tr>
<tr>
<td>BREQ-2-Introjected regulation (0-12)</td>
<td>4.52</td>
<td>4.96</td>
<td>-0.49</td>
<td>4.54</td>
<td>0.26</td>
</tr>
<tr>
<td>BREQ-2-Identified regulation (0-16)</td>
<td>12.29</td>
<td>12.85</td>
<td>-0.56</td>
<td>4.26</td>
<td>0.14</td>
</tr>
<tr>
<td>BREQ-2-Intrinsic regulation (0-16)</td>
<td>11.50</td>
<td>11.16</td>
<td>-0.34</td>
<td>5.36</td>
<td>0.94</td>
</tr>
<tr>
<td>mRS (0-6)</td>
<td>2.95</td>
<td>1.85</td>
<td>1.04</td>
<td>0.94</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Abbreviations: BREQ-2, Behavioural Regulation in Exercise Questionnaire; HADS, Hospital Anxiety and Depression Scale; mRS, Modified Rankin Scale; MoCA, Montreal Cognitive Assessment; SD, standard deviation; Short FES-I, Short Falls Efficacy Scale - International; Sig., statistical significance value.

7.4 Discussion

The main purpose of this prospective cohort study was to identify the factors at discharge from inpatient rehabilitation that contribute to post-stroke physical activity three months later. The physical function measures of self-selected gait speed, balance (step test) and strength of the ankle dorsiflexors were significant prognostic factors that contributed to number of steps/day, IPAQ-S7 and ACS-HDL scores at three months after discharge from inpatient rehabilitation. Apart from physical function, motivation and anxiety were significant prognostic factors of ACS-HDL scores. In addition, this
study found an inverse u-shaped relationship between anxiety and ACS-HDL scores. All other prognostic factors exhibited a linear relationship with dependent variables.

This study has further confirmed physical function factors identified in cross-sectional studies such as self-selected gait speed, balance, and strength as a contributing factor to post-stroke physical activity levels (M. A. Alzahrani et al., 2009; Baert et al., 2012; C. English et al., 2016; G. D. Fulk et al., 2010). Self-selected gait speed has been widely studied amongst older adults and has been shown to be predictive of activity limitations, low physical activity, increased falls, higher risk of hospitalisation and decreased survival (Egerton, Paterson, & Helbostad, 2017; Fritz & Lusardi, 2009; Studenski et al., 2011). Self-selected gait speed has also been identified as a correlate of physical activity amongst healthy older adults, older adults with chronic musculoskeletal conditions and adults with neuromuscular conditions (Dohrn et al., 2016; Newitt et al., 2016; Stubbs et al., 2015). This study was the first to examine the association of balance, as measured by the step test, with post-stroke physical activity levels. The BBS has been the most widely used measure of balance in post-stroke physical activity prognostic factor research. However, the BBS takes approximately 20 mins to complete. The step test which is also a valid and reliable tool as a measure of dynamic balance only requires 5 mins to administer. The results of this study have shown that balance as measured by the step test is also a significant prognostic factor of post-stroke physical activity in the sub-acute phase. The BBS and step test (unaffected) have been shown to be strongly correlated (Hong et al., 2012). Thus, the step test is recommended as an outcome measures to assess the contribution of balance to physical activity levels. Dorsiflexor strength of the affected leg was found to be a significant prognostic factor of ACS-HDL score and MET-min/week, but not steps/day. This could be due to the ACS-HDL involving recreational activities that require a higher level of physical function such as gardening.

This study found that anxiety had a non-linear relationship with participation in post-stroke physical activity. Figure 2 indicates a steep rise in ACS-HDL scores with increasing anxiety levels, observed up to an approximate threshold value of 4-5 points, above which there was no appreciable association between HADS-Anxiety and ACS-HDL.
Previous studies that included anxiety as a candidate factor, have only examined linear relationships and have not investigated further to assess a possible non-linear relationship between the variables. Kunkel et al. (2015) did not find anxiety and depression, measured using the HADS (at stroke onset), to be significant factors associated with time spent upright at one, two or three years post-stroke. Kroeders et al. (2013) also explored anxiety and depression (Irritability, Depression and Anxiety Scale) in people less than a week post-stroke and found that both these factors did not contribute significantly to time spent in standing and walking. An alternative explanation may be that discharge from rehabilitation (early sub-acute) could be a better time to measure mood to predict post-stroke physical activity levels than the acute phase. There is evidence suggesting that anxiety decreases significantly between four and six months after stroke (De Wit et al., 2008). Despite studies reporting that anxiety and depression are both common in the first six months following stroke, the interaction of anxiety with physical recovery, physical activity and depression is understudied (Mitchell et al., 2017). To our knowledge, the nonlinear relationship between anxiety and post-stroke physical activity have not been previously reported and warrants further exploration in future studies. Depression, which has been found to be a significant correlate of physical activity in previous studies in the chronic phase, was not found to be a prognostic factor at discharge from rehabilitation in the current study. This could be due to patients having hope in rehabilitation as they have yet to be discharged home and to be confronted with reality (Kortte, Stevenson, Hosey, Castillo, & Wegener, 2012; Walsh, Galvin, Loughnane, Macey, & Horgan, 2015). Alternatively, this finding could imply that low physical activity levels after stroke might cause depression rather than depression causing low physical activity levels.

Motivation has not previously been investigated as a factor that contributes to post-stroke physical activity levels, even though it has been identified as an enabler to post-stroke physical activity in a qualitative study (Jacqui H Morris, Oliver, et al., 2014). This study found introjected and intrinsic regulation, as measured by BREQ-2, to be a significant prognostic factor of ACS-HDL score but not steps/day at discharge from inpatient rehabilitation. Introjected regulation refers to exercise behaviour performed to avoid shame or anxiety. It is partially internalised but not fully autonomous (self-
Intrinsic regulation refers to an autonomous form of motivation when a person engages in behaviour because it is enjoyable, and an inherent desire to seek out experiences and to become more competent (Ryan & Deci, 2000). The significant contribution of both controlled and autonomous motivation factors to post-discharge physical activity levels, demonstrates that there could be changes in motivation behaviours that a stroke survivor undergoes in rehabilitation. A greater understanding on the shift in type of motivation may lead to strategies that can be utilised to promote self-determined behaviours for physical activity. Similar research in the traumatic brain injury population found the BREQ-2 (total score) to be a significant factor associated with number of steps/day amongst people with sub-acute traumatic brain injuries (Hamilton et al., 2015). However, motivation issues are known to be more pronounced in the traumatic brain injury population as compared to stroke due to direct damage to the frontal cerebral structures (Groswasser, Reider-Groswasser, Soroker, & Machtay, 1987; Levin, Williams, Eisenberg, High, & Guinto, 1992). Therefore, this may not be a reasonable comparison.

The cross-sectional analyses at three months after discharge demonstrated additional or different relationships between the prognostic factors and post-stroke physical activity. Self-selected gait speed and step test scores remained associated to all physical activity outcomes at follow-up. Higher Short FES-I (fear of falling) score was also associated with a lower MET-min/week as measured by the IPAQ-S7. These results are similar to prior cross-sectional research in chronic stroke survivors. The new factors that were found at the cross-sectional analyses were strength of dorsiflexors of the affected limb, depression, sub-score of HADS and motivation (BREQ-2). Strength of knee extensors of the affected limb and anxiety have previously demonstrated no significant associations with physical activity levels in the chronic phase (Matar A. Alzahrani et al., 2012). Whereas, the BREQ-2 has not been investigated in a stroke cohort. This could suggest that the stage of recovery from stroke should be considered when attempting to understand the key modifiable factors contributing to post-stroke physical activity levels so that the appropriate factors are targeted. The physical activity research amongst chronic stroke survivors should also expand to include investigation of factors across different domains apart from physical function.
The change scores between the two time-points demonstrated that significant change between discharge and follow-up occurred in physical function measures such as self-selected gait speed, step test and strength of the dorsiflexor muscles of the affected limb. The changes in self-selected gait speed also reached the minimal clinically important difference (MCID) value of 0.16m/s (Tilson et al., 2010). These results are also consistent with prior research, which demonstrates that the largest gains in post-stroke physical function occur in the subacute stage (Kollen, Van De Port, Lindeman, Twisk, & Kwakkel, 2005; Kwakkel, Kollen, & Twisk, 2006).

The HADS scores demonstrated an upward trend (increased symptoms), but this was not statistically significant. A cut-off score of more than or equal to eight in the sub-sections of anxiety and depression have been used in the diagnosis of these mood disorders in the medically ill population (Bjelland et al., 2002). However, several studies have found that a lower cut-off score of four to six for the anxiety sub-scale and four to eight for the depression sub-scale had improved sensitivity and specificity to detect these mood symptoms amongst stroke survivors (Johnson et al., 1995; O’Rourke, MacHale, Signorini, & Dennis, 1998; Sagen et al., 2009). There is no agreement yet on the threshold for HADS in people with stroke as different studies have utilised different definitions of anxiety. Using a lower cut-off score, the results of this study would indicate that on average the cohort had mild anxiety and depressive symptoms that remained unchanged over time following discharge home.

Cognition, as measured by the MoCA, improved by almost one point from 23.73 to 24.45 in this cohort. Though this change was not significant, the scores and improvement is consistent with another study by Nijsse et al. (2017) that investigated the change in cognition amongst stroke survivors at two to six months after stroke. Using the cut-off score of less than 26 would indicate that the prevalence of cognitive impairment was 58.8% at discharge from inpatient rehabilitation and 50.9% at three months following discharge. A longer period of follow-up is required to identify the temporal pattern of cognitive changes after stroke (Sun, Tan, & Yu, 2014). Patients with significant or diagnosed cognitive impairment were excluded from this study. Thus, the percentage of stroke survivors with cognitive impairments is likely to be higher than that presented here.
The Short FES-I scores showed a trend towards an improved score at follow-up indicating an increased confidence in performing activities without falling. This is consistent with other studies demonstrating a similar pattern (Batchelor, Mackintosh, Said, & Hill, 2012; Hellström, Lindmark, & Fugl-Meyer, 2002; Hellström, Lindmark, Wahlberg, & Fugl-Meyer, 2003; Schmid et al., 2011), though a longer follow-up will be required to establish a clear trajectory and correlation with number of falls. Motivation scores as measured by the BREQ-2 remained unchanged over time. Skatteboe et al. (2016) used the BREQ-2 to examine longitudinal changes in motivation in people with physical disabilities admitted to inpatient rehabilitation. The authors found that controlled motivation remained unchanged over a period of one year, but autonomous motivation declined following discharge from inpatient rehabilitation. Autonomous motivation is associated with adherence to physical activity (Thøgersen-Ntoumani & Ntoumanis, 2006). There has been no research on the longitudinal changes in motivation amongst stroke survivors. There is also no known clinically significant change score for motivation.

7.4.1 Strengths and limitations

The main strength of this study is that it has found new key modifiable factors (step test, motivation, and anxiety) at discharge from inpatient rehabilitation that contribute to physical activity levels at three months after discharge amongst stroke survivors in the sub-acute phase of stroke. This is the first study to explore different aspects of post-stroke physical activity at discharge from inpatient rehabilitation and candidate factors across a range of physical function, cognition, and mood domains. It is also one of the very few cohort studies done in the sub-acute stroke population.

The main limitation of this study is the small sample size. Although small, similar findings have been made in chronic stroke or traumatic brain injury research. The sample may not also be representative, as a large proportion of the patients screened were not eligible due to significant cognitive impairments or requiring more than minimal assistance to walk at discharge. Most of the participants used gait aids and/or required assistance at baseline assessment which may have confounded the association between gait speed and physical activity levels. Therefore, the modifiable prognostic
factors identified in this study should be replicated in a larger sample to understand if the same trends with anxiety, depression and motivation are repeated. Fatigue and balance confidence which are known factors associated with post-stroke physical activity (S. Thilarajah et al., 2018) were not investigated in this study due to sample size limitations and the risk of overfitting the regression model. These factors should be explored in future prospective studies.

### 7.4.2 Clinical implications

The main clinical implication derived from this study is that a range of factors across different domains, and not just physical capacity, impacts on post-stroke physical activity levels. Physical activity levels can be influenced by multiple factors such as physical function and psychosocial factors. The factors that contribute to physical activity levels may also differ depending on the stage of stroke recovery. The findings of this study stress the importance of optimising gait and balance early after stroke but the influence of other factors such as mood and motivation also should be considered.

### 7.5 Summary and conclusions

In summary, gait speed and balance are modifiable prognostic factors that contribute to all aspects of post-stroke physical activity at discharge from inpatient rehabilitation. Controlled and autonomous forms of motivation were both significant prognostic factors of physical activity participation, but only autonomous motivation remained significant at follow-up. Anxiety demonstrated a non-linear association with participation in high demand leisure activities at discharge but was no longer significant at follow-up. Depression was a significant correlate at follow-up only. The results imply that physical function needs to be maximised in rehabilitation to allow stroke survivors to be as active as possible. However, psychological factors such as motivation, anxiety, depression and fear of falling need to be investigated further to establish causality.
Chapter 8: Discussion and conclusions

8.1 Introduction

Investigation of post-stroke physical activity levels is one of the top 10 research priority areas relating to life after stroke (Pollock, St George, Fenton, & Firkins, 2014). Further to this, David H. Saunders, Greig, and Mead (2014) mapped physical activity and exercise as an intervention that could impact on five of the other top research priorities (i.e., cognition, balance and gait, arm function, fatigue and confidence). Although the benefits of physical activity amongst stroke survivors are well-known, research in this area could be better coordinated in terms of measurement, investigation of prognostic factors and interventions targeting specific key modifiable factors that have been identified in cohort or longitudinal studies. The formation of an Australian research consensus group in 2016, ACtivity To Improve Outcome after Stroke (ACTIONS), also indicates the urgency and importance of combining efforts to understand physical activity amongst stroke survivors (Kwakkel et al., 2017).

This thesis has highlighted and addressed two pressing issues in research and clinical knowledge of increasing physical activity levels amongst stroke survivors. The first is the gaps in the measurement of post-stroke physical activity levels, and second is in the identification of the key modifiable factors that contribute to post-stroke physical activity levels. This concluding chapter of the thesis will synthesise the two main themes of the thesis; comprehensive measurement of post-stroke physical activity and identification of key modifiable factors. For each of the two points, a summary of the thesis findings, and the significance of the findings in moving forward future research and clinical practice will be discussed.

8.2 Measurement of post-stroke physical activity

8.2.1 Summary of thesis findings

Chapters 2 and 3 reviewed the vast variations amongst studies measuring and investigating physical activity levels in stroke survivors. It identified the lack of consensus in definitions and terminology, measurement of physical activity and study
methodology. The gaps in the measurement of post-stroke physical activity levels related to the timing, method, and unit of the measurement.

**Timepoint of measurement of physical activity levels**

Most of the studies examining prognostic factors of physical activity amongst community-dwelling stroke survivors were cross-sectional and recruited chronic stroke survivors. The systematic review (Chapter 3) found that younger age, male gender, higher levels of physical function, better cardiorespiratory fitness, lower fatigue levels, higher balance self-efficacy, higher health-related quality of life, lower levels of depression and less fear of falling were associated with higher levels of post-stroke physical activity. The cohort study (Chapter 7) found that in the sub-acute phase, higher levels of physical function remained a significant prognostic factor of physical activity levels. Depression and fear of falling did not emerge as significant factors at discharge from inpatient rehabilitation. However, at the cross-sectional analysis at three months post-discharge from inpatient rehabilitation, depression and fear of falling were significantly associated with physical activity levels. This could indicate a temporal pattern change in key modifiable factors contributing to post-stroke physical activity. The Stroke Recovery and Rehabilitation Taskforce recommended a framework that defines the critical timepoints of stroke recovery based on known stroke recovery trajectories (Julie Bernhardt et al., 2017), that could be used as a guide to standardise candidate factor and physical activity measurement timepoints (Figure 8.1). Alternatively, the finding from Chapter 7, could also indicate that causality needs to be further explored amongst physical activity, depression and fear of falling.
**Method of measurement of physical activity levels**

The increasing popularity of direct measurement of post-stroke physical activity levels using wearable sensors was discussed in Chapter 1. However, current accelerometers used in research offer limited insight into the different aspects of post-stroke physical activity such as physical activity preferences, duration, frequency, and intensity. Chapter 6 utilised a combination of accelerometer, GPS and self-report and found the measures demonstrated a fair correlation to each other. This indicated that the constructs are related but the measures are evaluating different aspects of physical activity.

This sample of stroke survivors walked a mean of 5382 steps/day, which is similar to the findings of a recent systematic review demonstrating an average of 5535 steps/day in the sub-acute stroke phase (n=406) (Natalie A Fini et al., 2017). Number of steps/day in the sub-acute stroke population was higher than that reported in a chronic stroke population (average steps/day ranged from 4078 to 4355.2) (Field et al., 2013; Natalie A Fini et al., 2017), but less than healthy older adults (average steps/day of 5314-14,730 steps/day) (Caterine. Tudor-Locke et al., 2011). The IPAQ-S7 results showed that stroke survivors did not participate in any vigorous physical activity and in very little moderate intensity activity. However, in addition to knowledge of step or walking-related activity or MET-min/week, exercise preferences and barriers to engaging in

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**Figure 8.1:** Framework of critical time-points of stroke recovery (Adapted from (Julie Bernhardt et al., 2017))

1 Haemorrhagic stroke specific. 2 Treatments extend to 24 hours to accommodate options for anterior and posterior circulation, as well as basilar occlusion.
physical activity should also be considered to plan an intervention to increase post-stroke physical activity levels.

The context of physical activity has not yet been explored widely in post-stroke physical activity. Walking and use of public fitness areas near home were the main mode of physical activity in this cohort, which is consistent with the exercise preferences of healthy older adults in Singapore and in other countries (Siegel, Brackbill, & Heath, 1995; Tomioka et al., 2011). The GPS and activity diary results highlighted that there were some environmental features that were unique to the urban lay-out of Singapore that may encourage physical activity, such as the common corridors along the flats, void decks below the flat and outdoor fitness areas. However, less than 10% utilised the park connector networks or neighbourhood parks that are features of the Singapore environment. Most of the physical activity that stroke survivors in this cohort participated in was incidental (i.e., shopping or active transport). There needs to be further exploration of the facilitators and barriers to the use of public park networks amongst stroke survivors.

*Measurement unit of physical activity*

Chapter 2 and 3 highlighted the difficulty of integrating findings from different studies due to the variety of accelerometry and measurement units used. Accelerometers or other body-worn sensors of different brands contain different proprietary algorithms, filtering schemes and inherent noise and error. This means that the data will vary between brands and devices. Units of measurement such as activity counts or count-based cut points for measurement of energy expenditure is also specific to the brand of accelerometer used. New research has validated cut-off points using the Actical® activity count thresholds for measurement of intensity of physical activity amongst chronic stroke survivors (Serra et al., 2017). Again, this threshold will need to be validated in the stroke population, if a different brand accelerometer such as the Actigraph were used. Ideally, access to the raw accelerometer data will allow for a standard comparison across different brands of accelerometers.
8.2.2 Clinical implications

There is currently insufficient information on the different aspects of physical activity undertaken by stroke survivors. Physical activity levels can be influenced by multiple variables and may differ depending on the aspect of physical activity assessed. Exercise preferences, barriers, or facilitators to participating in regular physical activity should be addressed. Stroke survivors could also be taught self-monitoring of intensity of physical activity such as the talk test (Porcari et al., 2018; Reed & Pipe, 2016).

8.2.3 Limitations

There were several limitations to the studies in this thesis. Direct and self-report measures were combined in the meta-analysis (Chapter 3) to avoid a systematic loss of information as there were a lack of data to allow separate analysis for direct and self-report. The meta-analysis could also be subject to publication bias as the number of included studies was small. Chapter 5 validated a custom-made accelerometer, but this was conducted only in the clinical environment across one type of terrain over a short distance. Validation of step counts in the community is challenging but the variations could be obtained by designing the walking route to include different terrains. Also, initially, the accelerometer was meant to be linked to the GPS system, but that prototype did not work in a way that was wearable without high risk of non-adherence. The combination of two measurement systems could have allowed a better understanding of the location of walking-related physical activity. It could have also allowed for comparisons of physical activity levels amongst stroke survivors who preferred to stay home versus those who were active outdoors. The cross-sectional and cohort studies (Chapter 6 and 7) had data missing at random due to equipment malfunction which reduced the sample size. The self-report measures, though easier to administer and to obtain complete data, also had limited use in stroke. The IPAQ-S7 excludes walking from its self-report on moderate intensity physical activity. As walking is the preferred mode of physical activity for stroke survivors, this questionnaire may not have captured walking activity at moderate intensity.
8.2.4 Recommendations for future research

Despite a rapid increase in research in post-stroke physical activity over the recent years, the accurate measurement of multi-dimensions of post-stroke physical activity remains a challenge. There is no one device that can capture this information objectively and seamlessly. Future research in this area should include collaboration with engineers, researchers, clinicians, and stroke survivors to achieve design for compliance and comfort and clinical translation. With rapidly evolving technology in wearables, the possibility of new devices with better capabilities is real. In tandem, a consensus to standardise measurement of physical activity will also improve our understanding of the key modifiable factors contributing to post-stroke physical activity levels (Kwakkel et al., 2017). This may then be used to guide interventions and measure outcomes in a reproducible, comparable and meaningful manner.

8.3 Identification of key-modifiable factors contributing to post-stroke physical activity levels

The systematic review (Chapter 3) and the prospective cohort study in this thesis (Chapter 7) identified the key modifiable factors that contribute to post-stroke physical activity levels in the sub-acute phase. The meta-analysis synthesised the research done thus far, and the cohort study identified new factors that contributed to post-stroke physical activity. Both studies highlighted two main gaps in current research relating to the selection of candidate factors and study design for investigation of the contributing factors to post-stroke physical activity levels.

8.3.1 Summary of thesis findings

Selection of candidate factors

The selection of the candidate factors to be investigated in Chapter 7 included exploration of the literature in stroke and other populations. Factors that were found to be significantly associated with post-stroke physical activity levels in cross-sectional studies were included (e.g. self-selected gait speed) in the cohort study. Some factors that have been identified as significant in other neurological populations, but not yet
investigated in stroke, were also included (e.g. BREQ-2). Other candidate factors were selected for pragmatic reasons; BBS is a known factor that is associated with physical activity, but the Step Test was chosen instead to determine whether a less time-consuming measure of balance, would yield similar results. Similar to the measurement of physical activity levels, the systematic review (Chapter 3) also found that a variety of different outcome measure assessments were used in different studies to measure candidate factors. For example, the HADS, Beck Depression Inventory, Short-Depression-Happiness Scale, Centre for Epidemiology Depression Scale and Geriatric Depression Scale were used in different studies to examine the association of depression to post-stroke physical activity levels. Chapter 7 utilised the HADS to measure anxiety and depression due to its clinical utility as compared to the other depression questionnaires.

The results of Chapter 7 indicated that self-selected gait speed and the step test were significant factors contributing to physical activity levels as measured by steps/day, MET-min/week, and the ACS-HDL scores. This finding remained constant for both the prospective cohort and cross-sectional analysis. Components of the BREQ-2 were also significant factors of ACS-HDL scores at both time-points. Anxiety demonstrated a non-linear association with ACS-HDL scores.

**Standardisation of methods and reporting in prognostic factor research studies in post-stroke physical activity**

Physical activity literature is confusing in the nomenclature used to identify key modifiable factors. Bauman et al. (2002) recommended the use of the term ‘correlates’ to describe the factors found to be statistically associated with physical activity while the term ‘determinant’ to be used only when a causal relationship is established. Whereas, the PROGnosis RESearch Strategy (PROGRESS) Partnership, which is an international collaboration to improve the quality of prognostic research, have proposed a standard nomenclature where ‘prognostic factors’ is used for factors that have been found to be associated with the outcome and ‘prognostic determinant’ for prognostic factors that have proven to have a causal effect of the outcome (Hemingway et al.,
2013). The use of standard nomenclature in physical activity literature will allow clinicians and researchers to accurately interpret the research findings.

Most of studies included in the systematic review (Chapter 3) conducted only Pearson’s or Spearman’s correlation to understand the association between the candidate factor and post-stroke physical activity. It is unclear if the non-modifiable factors such as stroke severity would influence the association. In exploratory prognostic factor research where the aim of the study is to identify the relationship between an independent variable and dependent variable, other factors that might influence this relationship need to be adjusted statistically (Riley et al., 2013). 8.3.2 Clinical implications

The general trend from the findings of the exploratory prognostic factor research studies, directs towards optimising physical function but to also consider motivation and mood when designing interventions to increase physical activity levels amongst stroke survivors. However, clinicians need to be aware that reverse causality has not yet been investigated in this area of research (i.e. low physical activity levels cause gait and balance impairments) and thus continue to interpret these findings appropriately.

8.3.3 Limitations of the studies

The main limitation of this study is the generalisability of the findings to cohorts from other rehabilitation units. Less than half of the patients (38%) who were admitted to the rehabilitation unit (excluding those whose final diagnosis was not stroke) met the eligibility criteria. 29.5% did not meet the mobility criteria and 30.7% were diagnosed with significant cognitive impairments. Of those who were eligible, 38.8% declined to participate. Thus, it is not certain if the participants in this study is a representative sample.

A pragmatic decision was made to measure the candidate variables at discharge from inpatient rehabilitation (relative time point) instead of using a fixed timepoint (e.g. one or three months post stroke). However, being aware of this limitation, time since stroke was included as a co-variante to adjust for the time-associated recovery as recommended previously (Kwakkel et al., 2006).
8.3.4 Recommendation for future research

The modifiable psychosocial prognostic factors identified in the study should be examined in randomised controlled trials to confirm their association with post-stroke physical activity in the sub-acute phase of recovery. Established prognostic factors such as gait speed and balance should be assessed in longitudinal studies and randomised controlled trials for causality. The possibility of reverse causality has not been addressed and should be investigated in longitudinal studies. Standardising the outcome measures used to measure the factors that have already been found to be prognostic factors contributing to post-stroke physical activity levels, would further improve the ease of interpretation and application of research results.

Prognostic factor research studies should state clearly if their aim is identifying modifiable prognostic factors or building a prediction model (Herbert, 2014). For the former aim, potential non-modifiable factors that could be adjusted in a regression analysis are age, gender, stroke severity (NIHSS) and time since stroke onset (if a fixed timepoint was not used). Adjusted regression analysis will aid in uncovering the true relationship between the candidate factor and the outcome. For prognostic model research, adjusting for confounders may not be essential as including the non-modifiable factors may increase the accuracy of prediction of the model (Steyerberg, 2008). At present, the utility of building a prediction model for post-stroke physical activity is unknown.

A recent qualitative study by Jacqui H. Morris, Oliver, Kroll, Joice, and Williams (2017) provided some insights into the environmental and motivational factors that impact on stroke survivors capability to participate in physical activity. These included lack of knowledge of opportunities to exercise, cost, weather and organised activities being conducted at inconvenient times. The paper also reported that embarrassment of physical deficits, lack of confidence in physical activity participation and poor knowledge regarding benefits of post-stroke physical activity were barriers. Research amongst healthy adults has investigated physical environment factors as well as social and cultural factors (Chaudhury, Campo, Michael, & Mahmood, 2016; Wendel - Vos, Droomers, Kremers, Brug, & Van Lenthe, 2007). Physical environment factors that are
associated with higher levels of physical activity include exercise equipment at home, access to facilities, and community level influences such as neighbourhood safety and enjoyable scenery (Bauman et al., 2012). However, little is known about the effect of the environmental factors on physical activity levels amongst stroke survivors or even amongst those with other physical disabilities. People with disabilities have described how aspects of the built environment affect neighbourhood walking, suggesting a positive moderating role of features related to safety and aesthetic qualities, such as benches, lighting and pedestrian crossing timing (Eisenberg, Vanderbom, & Vasudevan, 2017). There is a need to understand if environmental attributes contribute to the variance in post-stroke physical activity. Stroke survivors may be at an added disadvantage compared to people with physical disabilities from other conditions due to the hemiparetic nature of their disability (Simpson, Eng, & Tawashy, 2011).

Large scale randomised controlled trials are necessary to understand causality of prognostic factors as well as effectiveness of interventions targeted to increase physical activity levels. Future trials could consider the inclusion of psychological interventions targeted at mood and motivation instead of tailored counselling alone (Jacqui H Morris, MacGillivray, & Mcfarlane, 2014). Based on the results of this thesis, home and near-home-based exercises were the most common modes of physical activity. Thus, home-based walking or exercise programmes maybe a better alternative to centre-based supervised exercise programmes. To explore causality, future research could utilise a three-group randomised controlled trial design comparing the effectiveness of 1) combined psychological and home-based exercise intervention, 2) psychological intervention alone, and 3) home-based exercise alone.

Further exploration of the findings of this thesis may also be relevant to personalised healthcare interventions. Personalised healthcare is an emerging area of focus and there is much debate about the definition of this mode of healthcare delivery. Generally, personalised healthcare refers to the use of personal health profiles to develop personalised health plans (Cesuroglu, Syurina, Feron, & Krumeich, 2016). An example of this, is the use of a profiling electronic questionnaire, completed while waiting for appointment, that can give the physician information on the patient’s psychological and cognitive status. The physician can then utilise this information to personalise their
delivery of information to the patient (Kondylakis et al., 2014). Perhaps, such a tool customised for physical activity counselling could be explored in the future.

8.4 Conclusions

Overall, this thesis has emphasised the multi-dimensional nature of physical activity, and the importance of standardising measurement and research methods to understand the complex nature of stroke survivors’ behaviour in adopting and sustaining appropriate levels of physical activity. Research into post-stroke physical activity has exponentially increased in the last decade and is continuing to evolve. However, prognostic factor research to identify the modifiable factors is still in the early stages. The studies in this thesis have provided new insights into post-stroke physical activity. The thesis has explored the gaps in the measurement of all aspects of post-stroke physical activity using multiple measurement tools including innovative customised accelerometer and GPS units. It has also provided new information on the context of physical activity and demonstrated that motivation and mood are contributing factors to post-stroke physical activity levels. This thesis has provided the basis for prognostic factor research in post-stroke physical activity, which will improve our understanding of how we can assist stroke survivors to be more active to gain health benefits and to improve quality of life.
References:


Appendices

Appendix A: Permission from Brain Impairment and Archives to reproduce papers
Appendix B: Manuscript one authors’ endorsements
Appendix C: Manuscript two authors’ endorsements
Appendix D: Study screening log
Appendix E: Participant Information and Consent Form
Appendix F: SingHealth Ethics Approval
Appendix G: NIH Stroke Scale (NIHSS)
Appendix H: Inattention testing (Star cancellation and Line Bisection tests)
Appendix I: Modified Rankin Scale (mRS)
Appendix J: Montreal Cognitive Assessment (MoCA)
Appendix K: Hospital Anxiety and Depression Scale (HADS)
Appendix L: Short Falls Efficacy Scale-International (Short FES-I)
Appendix M: Behavioural Regulation in Exercise Questionnaire-2 (BREQ-2)
Appendix N: International Physical Activity Questionnaire Short 7 days (IPAQ-S7)
Appendix O: Activity card sort (ACS)
Appendix P: Activity Diary
Appendix Q: User guide
Appendix A: Permission from journal to reproduce published papers in manuscript

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The University of Queensland, QLD 4072, Australia
Co-Editor, Brain Impairment
Phone: +61 7 3386 9729, Jenny@uq.edu.au;
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Please feel free to contact me if you have any queries.

Kind regards,

Anita Mercy M.
Senior Copyright Coordinator, Global Rights Department [ELSEVIER]
Ambedkar International Tech Park, OMR - SHuru (Pancham, Chennai 600113 - India)
Tel: +91-44-48687171
a.vethakkan@elsevier.com

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150
Manuscript One

Wearable sensors and Mobile Health (mHealth) technologies to assess and promote physical activity in stroke: a narrative review

Shamala Thilarajah¹,²*, Ross A Clark¹, Gavin Williams³,⁴,⁵

Authors’ affiliations:

¹School of Exercise Science, Australian Catholic University, Australia

²Department of Physiotherapy, Singapore General Hospital, Singapore

³Epworth HealthCare, Richmond, Australia

⁴The University of Melbourne, Melbourne, Australia

⁵La Trobe University, Melbourne, Australia

I, Shamala Thilarajah, contributed to the literature review, preparation and revision of this paper entitled, Wearable sensors and Mobile Health (mHealth) technologies to assess and promote physical activity in stroke: a narrative review.

I, as a co-author, endorse that this level of contribution by the candidate indicated above is appropriate.
<table>
<thead>
<tr>
<th>Name of co-author</th>
<th>Signature</th>
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<tbody>
<tr>
<td>Dr Ross Clark</td>
<td></td>
<td>12/06/2018</td>
</tr>
<tr>
<td>A/Prof Gavin Williams</td>
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<td>12/06/2018</td>
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</tbody>
</table>
Appendix C: Manuscript two authors’ endorsements

Manuscript Two

Factors associated with post-stroke physical activity: a systematic review and meta-analysis

Shamala Thilarajah,1,2 Benjamin F Mentiplay,1 Kelly J Bower,1 Dawn Tan,2 Pua Yong Hao,2 Gavin Williams,3,4 Gerald Koh,5 Ross A Clark,1

Authors’ affiliations:

1School of Health and Exercise Science, The University of the Sunshine Coast, Queensland, Australia

2Department of Physiotherapy, Singapore General Hospital, Singapore

3Epworth HealthCare, Richmond, Melbourne, Australia

4The University of Melbourne, Melbourne, Australia

5Saw Swee Hock School of Public Health, National University of Singapore, Singapore

I, Shamala Thilarajah, contributed to the literature review, preparation and revision of this paper entitled, Factors associated with post-stroke physical activity: a systematic review and meta-analysis.

I, as a co-author, endorse that this level of contribution by the candidate indicated above is appropriate.
<table>
<thead>
<tr>
<th>Name of co-author</th>
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<tr>
<td>Dr Benjamin Mentiplay</td>
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<td>18/06/2018</td>
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<tr>
<td>Dr Kelly Bower</td>
<td></td>
<td>18/06/2018</td>
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<tr>
<td>Dr Dawn Tan</td>
<td></td>
<td>18/06/2018</td>
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<tr>
<td>Dr Pua Yong Hao</td>
<td></td>
<td>18/06/2018</td>
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<tr>
<td>A/Prof Gavin Williams</td>
<td></td>
<td>12/06/2018</td>
</tr>
<tr>
<td>A/Prof Gerald Koh</td>
<td></td>
<td>18/06/2018</td>
</tr>
<tr>
<td>Dr Ross Clark</td>
<td></td>
<td>12/06/2018</td>
</tr>
</tbody>
</table>
PARTICIPANT INFORMATION SHEET

You are being invited to participate in a research study.

Before you take part in this research study, the study must be explained to you and you must be given the chance to ask questions. Please read carefully the information provided here. If you agree to participate, please sign the informed consent form. You will be given a copy of this document to take home with you.

STUDY INFORMATION

Protocol Title:


Principal Investigator:

Dr Dawn Tan, Principal Physiotherapist, Singapore General Hospital

Contact number: 8125 2985

Research support:

This research is supported by SingHealth and the Australian Catholic University.
PURPOSE OF THE RESEARCH STUDY

You are being invited to participate in a research study that is investigating low-cost motion-tracking and force sensing technologies in assessing balance and movement abilities after stroke. These technologies are the Microsoft Kinect camera, which can track a person’s body movements, and the Wii Balance Board, which can sense the movement in a person’s centre of balance. These will be used in addition to some commonly performed clinical tests of balance. We will be able to see if they are useful for assessing balance and predicting a person’s risk of falling. If the tests are shown to be valuable this could provide benefits for rehabilitation and research in stroke care and a range of other fields. We hope to learn which tests are the best for assessing balance and risk of falling. In addition, we also hope to learn more about the level of physical activity people after stroke take part in after they are discharged home from hospital. We will also be testing the accuracy of the activity monitor in evaluating physical activity in people after stroke. You were selected as a possible subject in this study because you are undergoing rehabilitation after a stroke and you are about to be discharged home. This study will recruit 80 subjects from Singapore General Hospital over a period of 2 years.

STUDY PROCEDURES AND VISIT SCHEDULE

If you agree to take part in this study, you will be asked to go through the same assessment process as all other participants. The first assessment will be performed within a week of being discharged from the inpatient rehabilitation ward. The second assessment will be performed three months later.

At the first assessment, we will take measures of your height and weight, and ask you some questions about your previous living circumstances, falls and medical conditions. The research team will require access to your personal medical record to obtain details about your medical condition. We will also do a quick test of your memory and thinking. Following this, you will be assessed on walking and balance tasks, such as standing from a chair, turning, tapping your foot on a step, balancing on the spot and reaching. We will be using the Wii Balance Board platform and the Kinect camera during some of these tests to obtain extra information about how you are moving. There will also be questionnaires asking about your
level of physical activity, concern about falling and thinking and memory. The testing session will take between 60 to 90 minutes to complete. The tests at three months follow-up will be similar to the first session.

After the three months assessment, you will be sent home with a physical activity unit. The unit consists of a small accelerometer worn around your ankle and a Global Positioning System (GPS) chip that can be carried in your pocket or handbag. The monitor is able to collect information on the amount, duration and location of physical activity. You will be required to wear this for four consecutive days and to complete an activity diary. This information will help us to learn more about how active people are after a stroke. The GPS will ONLY track physical activity outdoors.

Over the 12 months following the first assessment we will ask you to use a falls diary to document any falls you have during this period. If you report any falls, we will give you a phone call about this.

You will also receive a telephone follow-up six months after the date of the stroke. You will be asked questions about how much physical activity you are doing at this point. This phone call should only take five to ten minutes.

Schedule of visits and procedures:

Visit 1: One week before you are discharged from hospital

Final Visit: Three months after your discharge home

Telephone follow-up: Six months after the date of the stroke
Additional Study Procedures

You will be required to:

Complete an activity diary during the four days of activity monitoring

Complete a diary recording any falls over a 12 months period.

(Optional) Wear physical activity monitor for four days after the three months follow-up visit.

YOUR RESPONSIBILITIES IN THIS STUDY

If you agree to participate in this study, you should:

Keep your study appointments. If it is necessary to miss an appointment, please contact the study staff to reschedule as soon as you know you will miss the appointment.

Be prepared to visit the hospital once after discharge and undergo all the procedures that are outlined above. To minimise inconvenience to you, the study assessment will be conducted on the same day as your hospital outpatient appointment where possible.

WITHDRAWAL FROM STUDY

You are free to withdraw your consent and discontinue your participation at any time without prejudice to you or effect on your medical care. If you decide to stop taking part in this study, please notify a member of the research team.

If you withdraw from the study, the study staff will not collect additional personal information from you, although personal information already collected will be retained to ensure that the results of the research project can be measured properly. You should be aware that data collected up to the time you withdraw will form part of the research project results. You will also have to return any study related materials you may have.
The Principal Investigator of this study may stop your participation in the study at any time for one or more of the following reasons:

Failure to follow the instructions of the Principal Investigator and/or study staff.

The Principal Investigator decides that continuing your participation could be harmful.

The study is cancelled.

WHAT IS NOT STANDARD CARE OR EXPERIMENTAL IN THIS STUDY

The use of physical activity monitor is not part of standard care. You will also undergo additional clinical tests using the Wii Balance Board and Kinect camera. We hope that your participation will help us to determine whether use of these technologies is equal or superior to existing rehabilitation assessments in stroke.

Although some of the walking and balance assessments and questionnaires may be part of standard rehabilitation, in this study these assessments are being performed for the purposes of the research.

POSSIBLE RISKS, DISCOMFORTS AND INCONVENIENCES

The assessment procedures are unlikely to have any side effects, however, as with any form of physical activity there are possible risks associated with participation. Possible risks include pain, fatigue or injury. The treatment does not involve any invasive procedures.

Your medical history will be thoroughly screened and the assessment sessions will be performed by an experienced physiotherapist. You will be closely monitored for any adverse effects such as pain, fatigue or other symptoms.
There may be additional risks that the researchers do not expect or do not know about. You will need to tell a member of the research team immediately about any new or unusual symptoms.

**POTENTIAL BENEFITS**

There is no assurance you will benefit from this study. However, you will receive a thorough assessment of your balance and movement which may benefit your ongoing rehabilitation.

Your participation will allow us to determine the usefulness of these types of assessments. It will also give us new information on how active stroke patients are after they are discharged from hospital and return home. This research will help to improve our understanding on how to improve care to assist people with stroke in the future.

**ALTERNATIVES**

If you are interested in the study but have concerns over the physical activity monitoring, you can discuss this further with the study team member. You can choose not to take part in activity monitoring but still participate in the rest of the study. Please let the study team member know if you would like to opt out of the activity monitoring.

Tick to opt-out of activity monitoring

If you choose not to take part in this study, the alternative is to have what is considered standard care for your condition. In our institution this would be the usual clinical walking
and balance tests with the physiotherapist. There will be no monthly follow-up on falls or activity monitoring.

This standard care has the usual benefits of a routine physiotherapy assessment and poses the same possible risks as associated with physical activity which includes pain, fatigue or injury.

**SUBJECT’S RIGHTS**

Your participation in this study is entirely voluntary. Your questions will be answered clearly and to your satisfaction.

In the event of any new information becoming available that may be relevant to your willingness to continue in this study, you or your legal representative will be informed in a timely manner by the Principal Investigator or his/her representative.

By signing and participating in the study, you do not waive any of your legal rights to revoke your consent and withdraw from the study at any time.

**CONFIDENTIALITY OF STUDY AND MEDICAL RECORDS**

Information collected for this study will be kept confidential. Your records, to the extent of the applicable laws and regulations, will not be made publicly available. Only your Investigator(s) will have access to the confidential information being collected.

However, the Regulatory Agencies, Institutional Review Board and Ministry of Health will be granted direct access to your original medical records to check study procedures and data, without making any of your information public.

By signing the Informed Consent Form attached, you or your legal representative are authorizing (i) collection, access to, use and storage of your “Personal Data, and (ii) disclosure to authorised service providers and relevant third parties.

“Personal Data” means data about you which makes you identifiable (i) from such data or (ii) from that data and other information which an organisation has or likely to have access. This includes medical conditions, medications, investigations and treatment history.
Research arising in the future, based on this Personal Data, will be subject to review by the relevant institutional review board.

By participating in this research study, you are confirming that you have read, understood and consent to the SingHealth Data Protection Policy- the full version is available at www.singhealth.com.sg/pdpa. Hard copies are also available on request.

Data collected and entered into the Data Collection Form(s) are the property of Singapore General Hospital. In the event of any publication regarding this study, your identity will remain confidential.

COSTS OF PARTICIPATION

If you take part in this study, the following will be performed at no charge to you:

Two 60 to 90 minutes assessment of your balance and movement

Follow-up on falls for 12 months

If you complete the follow-up visit at three months after discharge, you will be paid $50.00.

RESEARCH RELATED INJURY AND COMPENSATION

The Hospital does not make any provisions to compensate study subjects for research related injury. However, compensation may be considered on a case-by-case basis for unexpected injuries due to non-negligent causes.

By signing this consent form, you will not waive any of your legal rights or release the parties involved in this study from liability for negligence.

WHO TO CONTACT IF YOU HAVE QUESTIONS

If you have questions about this research study or in the case of any injuries during the course of this study, you may contact the Study Team Member:
Ms Shamala Thilarajah

Senior Physiotherapist, Singapore General Hospital

Contact number: 9116 0364

This study has been reviewed by the SingHealth Centralised Institutional Review Board for ethics approval.

If you have questions about your rights as a participant, you can call the SingHealth Centralised Institutional Review Board at 6323 7515 during office hours (8:30 am to 5:30pm).

If you have any complaints about this research study, you may contact the Principal Investigator or the SingHealth Centralised Institutional Review Board.

CONSENT BY RESEARCH SUBJECT

Details of Research Study

Protocol Title:


Principal Investigator:

Dr Dawn Tan

Principal Physiotherapist

Singapore General Hospital

Contact number: 8125 2985
<table>
<thead>
<tr>
<th>Subject’s Particulars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name:</td>
</tr>
<tr>
<td>Address:</td>
</tr>
<tr>
<td>Sex: Female/Male</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Race: Chinese/ Malay/ Indian /Others (please specify)</td>
</tr>
</tbody>
</table>
I, _____________________________________(NRIC/Passport No._______________________)

(Name of patient)

agree to participate in the research study as described and on the terms set out in the Patient Information Sheet.

I have fully discussed and understood the purpose and procedures of this study. I have been given the Participant Information Sheet and the opportunity to ask questions about this study and have received satisfactory answers and information.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reasons and without my medical care being affected.

By participating in this research study, I confirm that I have read, understood and consent to the SingHealth Data Protection Policy. I also consent to the use of my Personal Data for the purposes of engaging in related research arising in the future.

________________________________                                ______________________
Signature/Thumbprint (Right / Left) of participant                                             Date of signing
**To be filled by parent / legal guardian / legal representative, where applicable**

I, ___________________________ hereby give consent for the above participant to participate in

(parent / legal guardian)

the proposed research study. The nature, risks and benefits of the study have been explained clearly to me and I fully understand them.

<table>
<thead>
<tr>
<th>Signature/Thumbprint (Right / Left) of parent /legal guardian</th>
<th>Date of signing</th>
</tr>
</thead>
<tbody>
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<td></td>
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</tbody>
</table>

**Translator Information (if required)**

The study has been explained to the participant/ legal representative in

Language: ___________________________  Name of translator: ___________________________
An impartial witness should be present during the entire informed consent discussion if a subject or the subject’s legal representative is unable to read. After the written informed consent form and any written information to be provided to subjects, is read and explained to the subject or the subject’s legal representative, and after the subject or the subject’s legal representative has orally consented to the subject’s participation in the study and, if capable of doing so, has signed and personally dated the consent form, the witness should sign and personally date the consent form.

<table>
<thead>
<tr>
<th>Witnessed by:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of witness</td>
<td>Designation of witness</td>
</tr>
<tr>
<td>Signature of witness</td>
<td>Date of signing</td>
</tr>
</tbody>
</table>
**Investigator’s Statement**

I, the undersigned, certify to the best of my knowledge that the patient/patient’s legal representative signing this informed consent form had the study fully explained and clearly understands the nature, risks and benefits of his/her / his ward’s / her ward’s participation in the study.

<table>
<thead>
<tr>
<th>_______________________________</th>
<th>_______________________________</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Name of Investigator</td>
<td>Signature</td>
<td>Date</td>
</tr>
</tbody>
</table>
Appendix F: SingHealth Ethics Approval

24 Feb 2015

Dr Pua Yong Hao
Department of Physiotherapy
Singapore General Hospital

Dear Dr Pua

SINGHEALTH CENTRALISED INSTITUTIONAL REVIEW BOARD (CIRB) APPROVAL

Protocol Title: Physical function, activity and falls Risk Evaluation using innovative Sensor Technologies in Clinical and GERiatric populations (PRESTIGE): Stroke

We are pleased to inform you that the SingHealth CIRB F has approved the above research project to be conducted in Singapore General Hospital.

The documents reviewed are:

a) CIRB Application Form dated 12 Feb 2015
b) Study Protocol: Version 1.4
c) Participant Information Sheet and Consent Form: Version 1.4 dated 7 Feb 2015
d) Data Collection Form (PRESTIGE: Stroke-SG)

The SingHealth CIRB operates in accordance with the ICH: Singapore Guideline for Good Clinical Practices, and with the applicable regulatory requirement(s).

The approval period is from 24 Feb 2015 to 19 Jan 2016. The reference number for this study is CIRB Ref: 2015/2010. Please use this reference number for all future correspondence.

The following are to be observed upon SingHealth CIRB Approval:

1. No subject should be admitted to the trial before the Health Sciences Authority issues the Clinical Trial Certificate. (only applicable for drug-related studies).

2. The Principal Investigator should ensure that this study is conducted in compliance with the Singapore Guideline for Good Clinical Practice, the ethical guidelines of which are applicable to all studies to be carried out, and to ensure that the study is carried out in accordance to the guidelines and the submitted protocol. The Principal Investigator should meet with his collaborator(s) regularly to assess the progress of the study, and be familiar and comply with all applicable research policies in the Institution.

3. No deviation from, or changes of, the protocol should be initiated without prior written SingHealth CIRB approval of an appropriate amendment, except when necessary to eliminate immediate hazards to the subjects or when the change(s) involve(s) only logistical or administrative aspects of the trial (e.g. change of monitor(s), telephone number(s)).

SingHealth Academic Healthcare Cluster
Singapore General Hospital - Duke-NUS Medical School
National Cancer Centre Singapore • National Dental Centre Singapore • National Heart Centre Singapore • National Neuroscience Institute
Singapore National Eye Centre • SingHealth Polyclinics • Bright Vision Hospital • SingHealth Health
4. Only the approved Participant Information Sheet and Consent Form should be used. It must be signed by each subject prior to enrolling in the study and initiation of any protocol procedures. Two copies of the Informed Consent Form should be signed and dated. Each subject or the subject’s legally accepted representative should be given a copy of the signed consent form. The remaining copy should be kept by the PI / medical record.

5. The Principal Investigator should report promptly to the SingHealth CIRB of:
   i. Deviations from, or changes to the protocol including those made to eliminate immediate hazards to the trial subjects.
   ii. Changes increasing the risk to subjects and/or affecting significantly the conduct of the trial.
   iii. All serious adverse events (SAEs) and adverse drug reaction (ADRs) that are both serious and unexpected.
   iv. New information that may affect adversely the safety of the subjects or the conduct of the trial.
   v. Completion of the study.

6. Study Status Report should be submitted to the SingHealth CIRB for the following:
   i. Annual review: Status of the study should be reported to the SingHealth CIRB at least annually using the Study Status Report.
   ii. Study renewal: the Study Status Report is to be submitted at least one month prior to the expiry of the approval period. A valid SingHealth CIRB renewal is essential, as any research performed outside of an approved time frame is not legal, and thus not covered by the hospital’s research insurance in case of unexpected adverse reactions.
   iii. Study completion or termination: the Final Report is to be submitted within three months of study completion or termination.

Yours sincerely,

Dr Aloysius Ho Yew Leng
Chairman
SingHealth Centralised Institutional Review Board F

Enc.

cc: Institution Representative, SGH
Head, Department of Physiotherapy, SGH
<table>
<thead>
<tr>
<th>NIH Stroke Scale</th>
<th>Admission Date</th>
<th>Time:</th>
<th>Before</th>
<th>24h</th>
<th>Disch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a Level of Consciousness</td>
<td>0: Alert</td>
<td>1: Not alert but arousable with minimal stimulation</td>
<td>2: Not alert requires repeated stimulation to attend</td>
<td>3: Coma</td>
<td></td>
</tr>
<tr>
<td>1b LOC question: Ask patient the month and their age</td>
<td>6: Answers both correctly</td>
<td>3: Answers one correctly</td>
<td>1: Both incorrect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1c LOC command: Ask patient to open/close eyes and form/release first</td>
<td>6: Obey both correctly</td>
<td>3: Obey one correctly</td>
<td>1: Both incorrect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Best gaze Only horizontal eye movement</td>
<td>6: Normal</td>
<td>1: Partial gaze palsy</td>
<td>3: Forced gaze palsy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Visual field testing</td>
<td>6: No visual field loss</td>
<td>3: Partial hemianopia</td>
<td>1: Complete hemianopia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Facial palsy Ask patient to show teeth or raise eyebrows and close eyes tightly</td>
<td>6: Normal symmetrical movement</td>
<td>3: Motor paralysis (flattened nasolabial fold, symmetry on smiling)</td>
<td>1: Partial paralysis (total or near total paralysis of lower face)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Motor function arm</td>
<td>6: Normal (extends arm 90° or 45° for 10 sec without drift)</td>
<td>3: Some effort against gravity</td>
<td>1: No effort against gravity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Motor function leg</td>
<td>6: Normal (holds leg in 30° position for 5 sec without drift)</td>
<td>3: Some effort against gravity</td>
<td>1: No effort against gravity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Limb ataxia</td>
<td>4: No ataxia</td>
<td>3: Present in one limb</td>
<td>1: Present in two limbs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Sensory Use pinprick to test arms, legs, trunk and face, compare side to side</td>
<td>6: Normal</td>
<td>3: Mild to moderate decrease in sensation</td>
<td>1: Severe to total sensory loss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Best language Ask patient to describe picture, name items</td>
<td>6: No aphasia</td>
<td>3: Mild to moderate aphasia</td>
<td>1: Severe aphasia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Dysarthria Ask patient to read several words</td>
<td>6: Normal articulation</td>
<td>3: Mild to moderate slurring of words</td>
<td>1: Inarticulate or other physical barrier (do not add score)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Extinction and innervation Use visual double stimulation or sensory double stimulation</td>
<td>6: Normal</td>
<td>3: Inattention or extinction to bilateral simultaneous stimulation in one of the sensory modalities</td>
<td>1: Hemineglect, severe or to more than one modality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Distal motor function Ask patient to extend his/her fingers as much as possible</td>
<td>6: Normal</td>
<td>3: At least some extension after 5 sec but not fully extended</td>
<td>1: No voluntary extension after 5 sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score:</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

171
Appendix H: Inattention testing (Star cancellation and Line Bisection tests)
Appendix I: Modified Rankin Scale (mRS)

MODIFIED RANKIN SCALE (mRS)

Score Description

0 No symptoms at all

1 No significant disability despite symptoms; able to carry out all usual duties and activities

2 Slight disability; unable to carry out all previous activities, but able to look after own affairs without assistance

3 Moderate disability; requiring some help, but able to walk without assistance

4 Moderately severe disability; unable to walk without assistance and unable to attend to own bodily needs without assistance

5 Severe disability; bedridden, incontinent and requiring constant nursing care and attention

6 Dead
Appendix J: Montreal Cognitive Assessment (MoCA)
### Appendix K: Hospital Anxiety and Depression Scale (HADS)

<table>
<thead>
<tr>
<th>Item</th>
<th>Yes, definitely</th>
<th>Yes, sometimes</th>
<th>No, not much</th>
<th>No, not at all</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I wake early and then sleep badly for the rest of the night.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2. I get very frightened or have panic feelings for apparently no reason at all.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3. I feel miserable and sad.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4. I feel anxious when I go out of the house on my own.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5. I have lost interest in things.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>6. I get palpitations or sensations of ‘butterflies’ in my stomach or chest.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>7. I have a good appetite.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>8. I feel scared or frightened.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>9. I feel life is not worth living.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>10. I still enjoy the things I used to.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>11. I am restless and can’t keep still.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Statement</td>
<td>Score 1</td>
<td>Score 2</td>
<td>Score 3</td>
<td>Score 4</td>
</tr>
<tr>
<td>---------------------------------------------------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>12. I am more irritable than usual.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>13. I feel as if I have slowed down.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>14. Worrying thoughts constantly go through my mind.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Anxiety: 2,4,6,8,11,12,14

Anxiety score: _________

Depression: 1,3,5,7,9,10,13

Depression score: _________

Grading: 0-7=non-case  8-10=Borderline case  11+=case
Appendix L: Short Falls Efficacy Scale-International (Short FES-I)

Now we would like to ask some questions about how concerned you are about the possibility of falling. Please reply thinking about how you usually do the activity. If you currently don’t do the activity, please answer to show whether you think you would be concerned about falling IF you did the activity. For each of the following activities, please tick the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.

以下每项活动，请想若要是你做这个活动的时候，关注自己会因此跌倒的程度。若是说你现在没有在做这项活动（如有人帮你买菜），请想象你若是现在要你做这项活动，关注跌倒的程度。

<table>
<thead>
<tr>
<th>Activity</th>
<th>Not at all concerned</th>
<th>Somewhat concerned</th>
<th>Fairly concerned</th>
<th>Very concerned</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Getting dressed or undressed</td>
<td>1 †</td>
<td>2 †</td>
<td>3 †</td>
<td>4 †</td>
</tr>
<tr>
<td>2 Taking a bath or shower</td>
<td>1 †</td>
<td>2 †</td>
<td>3 †</td>
<td>4 †</td>
</tr>
<tr>
<td>3 Getting in or out of a chair</td>
<td>1 †</td>
<td>2 †</td>
<td>3 †</td>
<td>4 †</td>
</tr>
<tr>
<td>4 Going up or down stairs</td>
<td>1 †</td>
<td>2 †</td>
<td>3 †</td>
<td>4 †</td>
</tr>
<tr>
<td>5 Reaching for something above your head or on the ground</td>
<td>1 †</td>
<td>2 †</td>
<td>3 †</td>
<td>4 †</td>
</tr>
<tr>
<td>6 Walking up or down a slope</td>
<td>1 †</td>
<td>2 †</td>
<td>3 †</td>
<td>4 †</td>
</tr>
<tr>
<td>7 Going out to a social event (e.g. religious service, family gathering or club meeting)</td>
<td>1 †</td>
<td>2 †</td>
<td>3 †</td>
<td>4 †</td>
</tr>
</tbody>
</table>

**TOTAL SCORE = ________**

ADD ALL 1S  ADD ALL 2S  ADD ALL 3S  ADD ALL 4S
Appendix M: Behavioural Regulation in Exercise Questionnaire-2 (BREQ-2)

The following questions aim to gain an understanding of why you choose to engage, or not engage in physical exercise. Using the scale below, please indicate to what extent each of the items is true for you. **Please note:** There are no right or wrong answers and no trick questions; we simply want to know how you personally feel about exercise. Thank you.

我们对你选择参加或者不参加体育运动的原因感到兴趣，同时也希望多了解你对参加体育运动的感受。借由下面的问题，请在每一个选项中，选出最适合你的描述。本问卷并没有标准答案，因此每个选项并没有对错，也没有陷阱问题存在。我们只是单纯地想了解你对于运动的个人观感。

<table>
<thead>
<tr>
<th></th>
<th>Not True for Me</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sometimes True for Me</td>
</tr>
<tr>
<td>1. I exercise because others say I should</td>
<td>0   1    2    3    4</td>
</tr>
<tr>
<td>我会运动，是因为别人认为我应该运动</td>
<td></td>
</tr>
<tr>
<td>2. I feel guilty when I don’t exercise</td>
<td>0   1    2    3    4</td>
</tr>
<tr>
<td>我不运动时会有罪恶感</td>
<td></td>
</tr>
<tr>
<td>3. I value the benefits of exercise</td>
<td>0   1    2    3    4</td>
</tr>
<tr>
<td>我重视运动带来的益处</td>
<td></td>
</tr>
<tr>
<td>4. I exercise because it is fun</td>
<td>0   1    2    3    4</td>
</tr>
<tr>
<td>我运动是因为运动很有趣</td>
<td></td>
</tr>
<tr>
<td>5. I don’t see why I should have to exercise</td>
<td>0   1    2    3    4</td>
</tr>
<tr>
<td>我不认为我应该要运动</td>
<td></td>
</tr>
<tr>
<td>6. I take part in exercise because my friends / family / partner say I should</td>
<td>0   1    2    3    4</td>
</tr>
<tr>
<td>我去运动，是因为我的朋友 / 家人 / 伴侣说我应该要运动</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Not True for Me</strong>&lt;br&gt;(完全不适合)&lt;br&gt;(完全不适)&lt;br&gt;(完全不适合)&lt;br&gt;(完全不适)</td>
<td><strong>Sometimes True for Me</strong>&lt;br&gt;(有时适合我)&lt;br&gt;(有时适合我)&lt;br&gt;(有时适合我)&lt;br&gt;(有时适合我)</td>
</tr>
<tr>
<td>7.</td>
<td>I feel ashamed when I miss an exercise session&lt;br&gt;当我缺席了一次运动，我会感到羞愧</td>
</tr>
<tr>
<td>8.</td>
<td>It is important to me to exercise regularly&lt;br&gt;对我而言规律运动是很重要的</td>
</tr>
<tr>
<td>9.</td>
<td>I can’t see why I should bother exercising&lt;br&gt;我实在不认为为什么要运动</td>
</tr>
<tr>
<td>10.</td>
<td>I enjoy my exercise sessions&lt;br&gt;· 我非常喜欢我的运动</td>
</tr>
<tr>
<td>11.</td>
<td>I exercise because other will not be pleased with me if I don’t&lt;br&gt;我去运动是因为如果我不运动，别人会感到不高兴</td>
</tr>
<tr>
<td>12.</td>
<td>I don’t see the point in exercising&lt;br&gt;· 我不觉得运动有什么重要性</td>
</tr>
<tr>
<td>13.</td>
<td>I feel like a failure when I haven’t exercised in a while&lt;br&gt;当一段时间没运动，我会觉得自己像个失败者</td>
</tr>
<tr>
<td>14.</td>
<td>I think it’s important to make the effort to exercise regularly&lt;br&gt;我认为努力地维持规律运动是很重要的</td>
</tr>
<tr>
<td>15.</td>
<td>I find exercise a pleasurable activity&lt;br&gt;· 我觉得运动是个充满乐趣的事情</td>
</tr>
<tr>
<td>16.</td>
<td>I feel under pressure from my friends/family to exercise&lt;br&gt;我感受到来自朋友或家人的压力，促使我去运动</td>
</tr>
<tr>
<td>17.</td>
<td>I get restless if I don’t exercise regularly&lt;br&gt;· 我如果不规律运动会感到烦躁不安</td>
</tr>
</tbody>
</table>
18  I get pleasure and satisfaction from participating in exercise  
    我从参与运动中，获得快乐和满足

19  I think exercising is a waste of time  
    我认为运动是浪费时间的行为

Date: ........................    Signature and Stamp of PT: ........................
Appendix N: Short International Physical Activity Questionnaire-7 days (IPAQ-S7)

We are interested to find out the types of activities you engage in, to help guide your physiotherapy management. The questions will ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

我们希望多了解你在日常生活中所进行的种种身体活动，以便能更好地为你拟定治疗方案。这个问题会问你在最近7天花在身体活动的时间，请回答每一个问题，甚至如果你想自己是一个没有活动的人，请想一想你在工作时的活动，像是你在家或园艺的部分，从一个地方到一个地方及在你空闲的时间运动或娱乐。

Think about all the vigorous activities that you did in the last 7 days. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

想一想在最近7天里你做过所有强而有力的活动，强而有力的身体活动是指以费力的身体负荷且让你呼吸较正常更为急促的活动，仅回想你所做过每次至少10分钟的那些身体活动。

1. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   ______ days per week 每周几天

   □ No vigorous physical activities 跳到问题3

2. How much time did you usually spend doing vigorous physical activities on one of those days?

   ______ hours per day 每天几个小时
   ______ minutes per day 每天几分钟

   □ Don’t know/Not sure 不知道/不确定

   Think about all the moderate activities that you did in the last 7 days. Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

   想一想最近7天里你做过所有适度的活动，适度的活动是指以适度的身体负荷并且让你呼吸比正常费力一些的活动。

3. During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.
4. How much time did you usually spend doing moderate physical activities on one of those days?

在参与适度身体活动的那些天，通常你花多少时间做适度的身体活动？

______ hours per day 每天几小时
______ minutes per day 每天几分钟
☐ Don’t know/Not sure 不知道/不确定

Think about the time you spent walking in the last 7 days. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

想一想最近7天你花多少时间在走路，包含工作，在家，从某地到某地，娱乐，游戏或休闲时的走路。

5. During the last 7 days, on how many days did you walk for at least 10 minutes at a time?

最近7天里，你花多少天走每次至少10分钟的路？

______ days per week 每周几天
☐ No walking 跳到问题7

6. How much time did you usually spend walking on one of those days?

在走路的那些天，你通常花多少时间在走路？

______ hours per day 每天几小时
______ minutes per day 每天几分钟
☐ Don’t know/Not sure 不知道/不确定

The last question is about the time you spent sitting on weekdays during the last 7 days. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

最近7天里，你花多少时间做适度的身体活动，像是提轻的物品，正常的速度骑脚踏车或网球双打？不包含走路。

______ days per week 每周几天
☐ No moderate physical activities 跳到问题5

没有适度的身体活动跳到问题5
7. During the last 7 days, how much time did you spend sitting on a week day?

_____ hours per day 每天几小时

_____ minutes per day 每天几分钟

☐ Don't know/Not sure 不知道/不确定
## Appendix O: Activity card sort (ACS)

### Activity Card Sort (Singapore Version)

#### Form B

<table>
<thead>
<tr>
<th>No.</th>
<th>Activity (Instrumental)</th>
<th>Not Done Before Current Illness/Injury</th>
<th>Continued to Do During Illness/Injury</th>
<th>Doing Less since Illness/Injury</th>
<th>Given Up Due to Illness/ Injury</th>
<th>Done Previously</th>
<th>New Activity Since Illness/ Injury</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Shopping in a Store</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>Shopping for Groceries</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>Dishes</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>04</td>
<td>Laundry</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>05</td>
<td>Garden Maintenance</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>06</td>
<td>Taking Out the Trash</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>07</td>
<td>Cooking Meals</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>08</td>
<td>Mending</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09</td>
<td>Preserving Food</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Household Maintenance</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Fixing Things around the House</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Driving</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Pumping Petrol</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Car Maintenance (e.g. Car Wash)</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Taking Care of a Pet</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Paying Bills</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Managing Investments</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Resting</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Hairdressing</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Child Care</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Ironing</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Preparing Hot Beverage</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Taking Money from an ATM Machine</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Using Public Transportation</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Topping up EZ-link Card</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Using Postal Services</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Instrumental Activities**

<table>
<thead>
<tr>
<th>No.</th>
<th>Activity (Low Demand Leisure)</th>
<th>Not Done Before Current Illness/Injury</th>
<th>Continued to Do During Illness/ Injury</th>
<th>Doing Less since Illness/Injury</th>
<th>Given Up Due to Illness/ Injury</th>
<th>Done Previously</th>
<th>New Activity Since Illness/ Injury</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>Spectator Sports</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Window Shopping</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Cooking/ Baking as a Hobby</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Sewing (e.g. Clothes)</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Hand Crafts</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Table Games (e.g. Chess, Checkers, Cards)</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Flower Arranging</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Computer</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
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<td></td>
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<td>Done Previously</td>
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**Total Low Demand Leisure Activities**

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<th>Doing Less since Illness/Injury</th>
<th>Given Up Due to Illness/Injury</th>
<th>Done Previously</th>
<th>New Activity Since Illness/Injury</th>
<th>Score</th>
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<td>Bowling</td>
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<td>Golfing</td>
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<td>Walking</td>
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<td>59</td>
<td>Running/ Jogging/ Brisk-walking</td>
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<td>Playing Racket Games (e.g. Badminton, Table Tennis)</td>
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<td>Games in the Park (e.g. Frisbee, Gateball)</td>
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<td>64</td>
<td>Canoeing/ Boating/ Sailing</td>
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<td>Fishing</td>
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<td>Practising Taochi/ Qigong</td>
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<td>Other Exercises</td>
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**Total High Demand Leisure**

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<th>No.</th>
<th>Activity (Social)</th>
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<th>Continued to Do During Illness/Injury</th>
<th>Doing Less since Illness/Injury</th>
<th>Given Up Due to Illness/Injury</th>
<th>Done Previously</th>
<th>New Activity Since Illness/Injury</th>
<th>Score</th>
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<td>Studying for Personal Advancement</td>
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<td>Parties/ Picnics/ Barbeques</td>
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<td>Visiting Family/ Friends Who are Ill</td>
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<td>Storytelling with Children</td>
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<tr>
<td>Marriage/ Relationship</td>
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<td>Entertaining at Home or Club</td>
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<tr>
<td>Visiting the Cemetery/ Paying Respect to Ancestors</td>
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<td>Joining Competitions</td>
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</table>

Global ACS Scores:
- Current Activity (sum total of Current Activity sectional scores)
- Previous Activity (sum total of Previous Activity sectional scores)
- Percent Retained (divide global Current Activity score by global Previous Activity score)
Appendix P: Activity Diary

What are the reasons for your outings today? Please indicate any activity that you did outside of your home (gardening, walking along the corridor outside your flat, going shopping, attending a medical appointment etc.) 请您把今天在户外进行的活动记录如下（例如整理花草，在屋外的走廊散步，去购物，去看医生等）。

Make a note in the diary if you used a wheelchair for any of your trips. 如果在任何行程中有用到轮椅，请注明在下面。

<table>
<thead>
<tr>
<th>Day 1:</th>
<th>Morning (out of bed till 12pm) 早上（起床到中午十二点之间）</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td>Afternoon (12-5pm) 下午（中午十二点到下午五点之间）</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evening (5pm to bedtime) 傍晚（下午五点到睡觉之间）</td>
</tr>
<tr>
<td>Day 2: 第二天:</td>
<td>Morning (out of bed till 12pm) 早上（起床到中午十二点之间）</td>
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<tr>
<td></td>
<td>Afternoon (12-5pm) 下午（中午十二点到下午五点之间）</td>
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<td></td>
<td>Evening (5pm to bedtime) 傍晚（下午五点到睡觉之间）</td>
</tr>
<tr>
<td>Day 3:</td>
<td>Morning (out of bed till 12pm) 早上（起床到中午十二点之间）</td>
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<tr>
<td>下午 (12-5pm) 下午（中午十二点到下午五点之间）</td>
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<tr>
<td>傍晚 (5pm to bedtime) 傍晚（下午五点到睡觉之间）</td>
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</tr>
<tr>
<td>Day 4:</td>
<td>Morning (out of bed till 12pm) 早上（起床到中午十二点之间）</td>
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<tr>
<td></td>
<td>Afternoon (12-5pm) 下午（中午十二点到下午五点之间）</td>
</tr>
<tr>
<td></td>
<td>Evening (5pm to bedtime) 傍晚（下午五点到睡觉之间）</td>
</tr>
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</table>
Appendix Q: User guide

Dear __________________,

You have been issued an activity monitor that consist of 2 devices:

1. Accelerometer worn around the ankle of your unaffected side.

2. GPS (Global Positioning System) carried in your pocket or in a bag.
**Purpose:**
These devices will provide valuable information on how active people are after stroke. Please do not change your routine and go about your day as per usual.

**Instructions for use:**
- You are required to wear/carry both the devices for 4 days.
- Please put on/carry the devices first thing in the morning when you wake up and take it off/put away when you go to bed.
- Do not wear the devices when you are showering.
- You can leave the GPS in a visible place even if you are not going out.
- You are not required to switch on/off or charge the devices.

**Battery use and safety:**
The devices contain a lithium battery similar to a mobile phone battery.
- Do not let the devices get wet.
- Do not place the devices near a heat source.

If you have any questions/concerns, contact Ms Shamala Thilarajah on 91160364.

Thank you for your support and participation.
PRESTIGE Research Team