School of Allied Health

Measuring lateropulsion following stroke in the clinical setting: exploring the measurement, nature and recovery of lateropulsion using Wii technologies and clinical measures

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.
This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Human Ethics
The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research studies received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number #174/2013, #15/2015 and #55/2016 (Appendix 1).

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Abstract

Lateropulsion following stroke is characterised by individuals pushing toward their weaker side and strongly resisting movement of the altered posture back to vertical. Up to a quarter of individuals following stroke undergoing rehabilitation may present with lateropulsion. Lateropulsion commonly affects an individual's ability to sit and stand. This adversely affects independence in activities of daily life, with individuals with severe lateropulsion often slower to make functional gains and requiring longer hospital stays. The longer-term outcomes of individuals with lateropulsion have received little investigation to date. The use of reliable and valid measures of lateropulsion and postural control in this population, including instrumented measures, may provide an important insight into the postural control deficits these individuals experience. This may in turn guide interventions targeting this challenging impairment.

This thesis explored the measurement of lateropulsion following stroke in clinical research, extending our knowledge about the nature and recovery of this postural control disorder. The thesis focused on three areas: (1) the measurement properties of clinical lateropulsion and sitting balance measures; (2) utilising Wii Balance Board(s) as an instrumented measure of postural control in sitting and standing in stroke survivors with lateropulsion compared to healthy controls; and (3) the longer-term outcomes of stroke survivors with lateropulsion.

The thesis consists of six studies investigating these areas. The first study was a systematic review examining the psychometric properties of clinical sitting balance scales for individuals post stroke. The review could not identify any sitting balance measures with adequate measurement properties to recommend for use clinically. The thesis also included an examination of the internal validity of the Burke Lateropulsion Scale using Rasch analysis. Good psychometric properties of the Burke Lateropulsion Scale were demonstrated. Thirdly, the feasibility of utilising a Wii Balance Board to collect centre of pressure measures in sitting and standing with individuals with lateropulsion was investigated. The utilisation of the Wii Balance Board for this purpose was observed to be feasible, although findings indicated the need for a reduced suite of tasks and enhanced task specificity. Based on results of the feasibility study, a larger observational study was undertaken with stroke survivors with lateropulsion and healthy controls with three different components – a sitting component, a standing component and a longitudinal study component. The key findings

from the sitting and standing studies were that stroke survivors with lateropulsion utilise varied and different postural control strategies to maintain balance in sitting, whilst marked and varied patterns of asymmetry were demonstrated in standing. These findings support the use of different treatment interventions depending on how an individual with lateropulsion presents. Finally, for the longitudinal component, longer-term outcomes of stroke survivors with lateropulsion were reported. In this study, individuals with lateropulsion were found to make meaningful functional gains at six months post stroke, including some individuals with more severe lateropulsion.

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List of Abbreviations

4PPS	Four-Point Pusher Score
BLS	Burke Lateropulsion Scale
COP	Centre of pressure
COSMIN	COnsensus-based Standards for selection of health status Measurement INstruments
FAC	Functional Ambulation Classification
FIM	Functional Independence Measure
PASS	Postural Assessment Scale for Stroke patients
SCP	Scale of Contraversive Pushing
WBA	Weight-bearing asymmetry
WBB	Wii Balance Board

Chapter 1. Introduction

Thesis Overview

Lateropulsion is a unique postural control disorder where an individual's perception of postural verticality is distorted. Lateropulsion commonly affects an individual's ability to sit and stand. Little knowledge exists regarding the postural control strategies used by individuals with lateropulsion to maintain balance in sitting and standing. Longer-term mobility and functional outcomes of individuals with lateropulsion are also relatively unknown. The overall goal of this thesis was to explore the measurement of lateropulsion and postural control following stroke in individuals with lateropulsion using clinical and instrumented measures, thus extending our knowledge about the nature and recovery of this postural control disorder. The studies included in this thesis aimed to address the following research questions:

i. What are the psychometric properties of current clinical assessment scales used to measure sitting balance after stroke? (Chapter 3)
ii. Does the Burke Lateropulsion Scale (BLS) demonstrate internal validity using Rasch analysis? (Chapter 5)
iii. What is the association between baseline lateropulsion scores, and functional outcomes achieved six months post stroke? (Chapter 9)
iv. Is it feasible to use the Wii Balance Board (WBB) as an instrumented measure of sitting and standing balance in stroke survivors with lateropulsion early after stroke? (Chapter 6)
v. What differences exist when comparing instrumented measures of postural control in sitting and standing in stroke survivors with lateropulsion relative to healthy controls? (Chapters 7 and 8)
vi. What is the relationship between instrumented measures of postural control in sitting and standing and clinical measures of lateropulsion and postural function in individuals with lateropulsion? (Chapters 7 and 8)
vii. Are measures of centre of pressure (COP) in sitting and weight-bearing asymmetry (WBA) in standing reliable between test occasions in individuals with lateropulsion? (Chapters 7 and 8)

viii. What mobility and functional outcomes can be achieved by stroke survivors with lateropulsion at six months post stroke? (Chapter 9)

ix. What is the pattern of recovery for lateropulsion and standing symmetry in the subacute phase of stroke? (Chapter 9)

Thus, the first study (Chapter 3) was a systematic review undertaken to examine the psychometric properties of clinical sitting balance scales inclusive of dynamic sitting balance tasks with individuals post stroke. This study was undertaken initially to inform the sitting balance tasks performed with the instrumented measures in the feasibility study. The second study (Chapter 5) investigated the internal validity of the BLS using Rasch analysis. The third study (Chapter 6) determined the feasibility of using a WBB as an instrumented measure of balance in sitting and standing in individuals with lateropulsion with the results used to inform the protocol of the larger longitudinal study subsequently completed. The fourth and fifth studies formed part of the larger observational study and further explored the use of instrumented measures of postural control in sitting and standing respectively in individuals with lateropulsion and healthy controls, including how these measures related to clinical measures of lateropulsion and postural control (Chapter 7 and 8). The final study of this thesis presents the longitudinal component of the larger observational study and investigated the six-month outcomes of individuals with lateropulsion including the association between baseline lateropulsion scores and the six-month outcomes, as well as individual recovery patterns for lateropulsion and postural function in these individuals (Chapter 9).

The following paragraphs outline a more detailed overview of the chapters included in this thesis.

Chapter 2: Literature Review

This chapter initially defined stroke, outlined the common signs of stroke, and then discussed the typical activity limitations which stroke survivors may present with, both initially, and following rehabilitation. The chapter then focused on lateropulsion, defining this term and outlining the key clinical features of this unique postural control disorder. The clinical and instrumented measures available to assess lateropulsion were critically reviewed, and the potential mechanisms underlying lateropulsion, the prevalence of lateropulsion and common lesion locations were outlined. Previous research relating to recovery of lateropulsion, its relationship to balance and gait and the functional recovery and outcomes observed in this patient population were discussed. This chapter also defined the terms of balance and postural control and provided a broad overview regarding the measurement of balance following stroke. Finally, previous studies investigating the use of force platforms and WBB(s) to acquire COP and WBA variables as measures of postural control with individuals following stroke were reviewed.

Chapter 3: Comprehensive clinical sitting balance measures for individuals following stroke: a systematic review on the methodological quality

This chapter is a systematic review of the evidence available until December 2015 on the psychometric properties of clinical sitting balance scales performed with individuals following stroke. The review only included sitting balance measures if they contained at least one dynamic sitting balance task. The review could not identify any clinical sitting balance measures with adequate psychometric properties to recommend as a desired scale to use with individuals following stroke. The review advised that further studies of higher quality evaluating measurement properties of sitting balance measures for individuals following stroke be undertaken before specific scales can be recommended for use.
This chapter is presented in its accepted manuscript format. Additional research evidence until September 2020 which was published following the completion of the original systematic review was also identified and critically appraised using the same format. Evaluation of the additionally identified studies did not identify any clinical sitting balance measures with adequate psychometric properties that could be recommended as the measure of choice for assessing sitting balance following stroke. However, the Function in Sitting Test was flagged as a potential outcome measure with encouraging psychometric properties which warranted further investigation with higher quality studies.

Chapter 4: Methods

This chapter outlines the methodology for the feasibility study (Chapter 6) and the main longitudinal study (with three different components; Chapters 7, 8 and 9) contained within this thesis. The feasibility study investigates the feasibility of using WBB-derived COP variables as measures of sitting and standing balance in stroke survivors with lateropulsion (Chapter 6). The main longitudinal study explores the use of this technology further with a larger sample and the addition of a healthy control group. The main longitudinal study aims to quantify the postural control dysfunction observed in individuals with lateropulsion in sitting (Chapter 7) and standing (Chapter 8), as well as describing the longer-term outcomes of stroke survivors with lateropulsion (Chapter 9).

The chapter includes details regarding the study design, participant inclusion criteria and recruitment, and outcome measures and testing procedures for both the feasibility and main longitudinal studies.

Chapter 5: Rasch analysis of the Burke Lateropulsion Scale (BLS)

This study evaluated the internal validity of the BLS using data from 132 participants. The findings identified good psychometric properties of the BLS using Rasch analysis, supporting the internal validity of the scale. This study provided further support to previous literature recommending the use of the BLS as the preferred clinical scale for measuring lateropulsion following stroke.

This chapter is presented in its original manuscript format.

Chapter 6: Measuring lateropulsion following stroke: a feasibility study using Wii Balance Board technology

This chapter presents a pilot study undertaken with ten individuals with lateropulsion to investigate the feasibility of using COP variables acquired from a WBB in sitting and standing as measures of postural control. The results of the study demonstrated it is feasible to use the WBB for this purpose, with 100% participant retention. Mediolateral amplitude for the static sitting and standing balance tasks was identified as a potential variable of interest for future studies. However, issues were identified with the testing procedures for some individuals, with testing stopped prematurely 20% of the time due to tiredness or discomfort. The pilot study indicated that a larger observational study would be useful to further explore postural control in individuals with lateropulsion using this technology, but with some changes to the pilot study's procedures such as a reduction in the number of tasks included, and inclusion of a healthy control group to aid with interpretation of the results.

This chapter is presented in its published format.

Chapter 7: Postural control strategies in sitting are highly variable in people with lateropulsion post stroke

This chapter presents the sitting component of the main observational study undertaken with 46 participants with lateropulsion and 35 healthy controls investigating the use of WBB-derived COP variables as measures of postural control dysfunction in sitting, in addition to clinical measures of lateropulsion and postural control. The findings demonstrate that compared to healthy controls, people with lateropulsion displayed mediolateral and anteroposterior instability in sitting. However, inconsistency was present in terms of the postural control performance of the participants with lateropulsion, with some participants with lateropulsion demonstrating marked mediolateral instability, and other participants performing the tasks with COP variable scores comparable to those obtained from the healthy controls. Variability in performance between consecutive day testing was apparent for all seated tasks, suggesting that the utility of COP variables in sitting as single-occasion outcome measures early post stroke may be limited.

This chapter is presented in manuscript format.

Chapter 8: Standing weight-bearing asymmetry in adults with lateropulsion following stroke

This chapter reports the standing component of the main observational study involving the healthy control participants and 33 of the 46 participants with lateropulsion who undertook the sitting component of the main study (reported in Chapter 7). The results found that the majority of stroke survivors with lateropulsion stood with marked WBA, predominantly towards the non-paretic leg when standing unsupported. However, when standing with arm support, almost half of the participants with lateropulsion biased their paretic leg more. Whilst the weight-bearing patterns adopted were not associated with lateropulsion severity, a moderate association with postural abilities was demonstrated when standing with arm support. Finally, high test-retest reliability was found for the WBA variables for the stand with arm support task.

This chapter is presented in its original manuscript format.

Chapter 9: Six-month outcomes and patterns of recovery for people with lateropulsion following stroke

This chapter reports the longitudinal component of the main observational study which investigated the six-month outcomes of 41 participants with lateropulsion, along with mapping individual recovery patterns overtime for lateropulsion and WBA in stroke survivors with lateropulsion. The findings showed that individuals with mild lateropulsion achieved high levels of functional ability, with more than three quarters of participants with mild lateropulsion achieving independent mobility at six months post stroke. For the participants with moderate to severe lateropulsion, lower levels of functional ability were reached, with 30% achieving independent walking. Furthermore, the findings demonstrated that the severity of lateropulsion of participants decreased steadily over the eight week assessment time period during rehabilitation. In terms of the WBA recovery patterns, for the standing with arm support task, the WBA pattern participants adopted generally evolved over time towards increasing symmetry, no matter the direction of the asymmetry initially. For the standing without arm support task, the WBA patterns observed over time were more variable.

This chapter is presented in manuscript format.

Chapter 10: Discussion and Conclusion

The final chapter summarises the outcomes of the different studies presented in this thesis (Chapters 3, 5-9). The clinical implications of the various studies are discussed, along with the strengths and limitations of the completed studies. Finally, some recommendations for future research within this area are presented.

Chapter 2. Literature Review

Chapter Outline

This chapter critically examines key literature relating to lateropulsion and balance and postural control following stroke, given these areas form the focus of this thesis. The following topics are covered within this chapter:

2.1 Stroke: Including a definition of stroke, common signs of stroke and discussion regarding common limitations experienced by stroke survivors, both in the short and longer term.

2.2 Lateropulsion: This section defines lateropulsion and outlines the key clinical features of this unique postural control disorder. The assessment of lateropulsion is discussed, both in terms of the clinical and instrumented measures available. The potential mechanisms underlying lateropulsion, the prevalence of lateropulsion, and common lesion locations are described. Finally, literature relating to the resolution of lateropulsion and the functional recovery and outcomes of this patient population are examined.

2.3 Balance and postural control: This section of the chapter describes the terms of balance and postural control. Measurement of balance following stroke is broadly discussed. Previous studies utilising force platforms and WBBs to acquire COP and WBA variables as measures of postural control with individuals following stroke are also reviewed.

2.1 Stroke

A stroke is caused when the supply of blood to the brain is disrupted, typically due to a blood vessel being obstructed by a clot (ischaemic stroke) or bursting (haemorrhagic stroke) (World Health Organisation, 2017). When blood supply to the brain is disturbed, the delivery of oxygen and nutrients is subsequently interrupted, resulting in damage to brain cells. Some common signs of stroke include weakness or numbness of the face, arm and/or leg; difficulty speaking or comprehending speech; trouble swallowing; dizziness, balance difficulties or impaired coordination; confusion; severe headache of sudden onset; fainting or unconsciousness (World Health Organisation, 2017). The effects of stroke differ for every individual, depending upon which area/s of the brain are affected and the extent of the damage. Stroke is a major worldwide health problem with over 13 million people suffering a stroke each year (GBD 2016 Stroke Collaborators, 2016). It is the second major cause of death and the third major cause of disability globally (Feigin et al., 2017). Whilst the incidence of stroke is declining in developed countries, the overall number of strokes continues to rise due to aging populations world-wide (Feigin et al., 2017).

Initially following stroke, approximately 60% of stroke survivors demonstrate impaired walking ability (Jorgensen et al., 1995; Langhorne et al., 2017). Likewise, basic self-care task performance is impacted for many individuals (Lawrence et al., 2001). Depending on local service practices, stroke survivors may be discharged directly home from the acute hospital (21% to 57% (Ilett et al., 2010; Tinl et al., 2014; Walters et al., 2020)), to nursing home facilities (1% to 18% (Ilett et al., 2010; Tinl et al., 2014; Walters et al., 2020)), or for many stroke survivors, to inpatient rehabilitation services (39% to 60% (Ilett et al., 2010; Tinl et al., 2014; Walters et al., 2020)) with the aim of improving their functional abilities (Berges et al., 2012; Foley et al., 2012; Madden et al., 2006). Outpatient rehabilitation services may also be utilised either in place of or following inpatient rehabilitation services to further maximise an individual's independence and participation (Walters et al., 2020). However, even following rehabilitation, many stroke survivors will have ongoing mobility (Jorgensen et al., 1995) and functional (Berges et al., 2012; Foley et al., 2012) limitations, as well as other issues including depression, poor quality of life and low rates of return to work in stroke survivors 65 years or younger (Walters et al., 2020). Recovery following stroke may be influenced by many factors, such as socio-demographic factors including age (Sennfalt et al., 2019) and race (Berges et al., 2012), as well as clinical factors including the location and size of the initial stroke lesion (Langhorne et al., 2011; Sumer et al., 2003) and comorbidities (Sennfalt et al., 2019). The number, type and severity of deficits a stroke survivor presents with has been shown to affect the functional outcomes obtained (Nijboer et al., 2013; Patel et al., 2000). In addition to those deficits which may be commonly associated with stroke, such as motor, sensory or visual deficits, the presence of lateropulsion, a distinctive postural control disorder affecting the perception of postural verticality, has been shown to adversely influence the functional outcomes achieved by stroke survivors (Danells et al., 2004; Krewer, Luther, et al., 2013).

2.2 Lateropulsion

2.2.1 Definition and clinical features of lateropulsion

Pusher behaviour, contraversive pushing, contraversive lateropulsion and lateropulsion are all terms commonly used in the literature to describe a unique disorder of postural control which may occur following stroke, where individuals display a distorted perception of postural verticality (Bergmann et al., 2016; Karnath et al., 2000a; Pérennou et al., 2002; Pérennou et al., 2008).Throughout this thesis, the term lateropulsion has been used. This disorder is characterised by a tilted body alignment towards the paretic side in sitting and / or standing; the use of the non-paretic arm and leg to actively push towards the paretic side; and active resistance to passive correction of the altered alignment back to and beyond upright (Davies, 1985; Karnath & Broetz, 2003). The existence of a continuum of pusher behaviour severity, which manifests as trying to align body position in space with an altered perception of verticality, has been suggested in the literature (Clark et al., 2012; Pérennou et al., 2002; Pérennou et al., 2008).

At its most severe, lateropulsion may affect body orientation in supine (D'Aquila et al., 2004), with individuals strongly resisting assistance to roll in bed, particularly towards their non-paretic side (D'Aquila et al., 2004). Individuals with severe lateropulsion may also be unable to sit independently, even with supportive seating. This can impact on an individual's ability to engage in basic activities of daily life such as bathing, dressing and toileting. For individuals with mild lateropulsion, transfer and walking ability are often affected, as individuals with lateropulsion often block weight shift onto their non-paretic leg. This in turn affects their ability to move their paretic leg, as well as reducing their overall stability when performing these tasks. Despite often falling to the paretic side when performing activities in sitting or standing, an individual with lateropulsion may report a fear of falling towards their non-paretic rather than their paretic side (Baccini et al., 2006). As recovery from lateropulsion occurs, the characteristics of lateropulsion are present in less positions (i.e. the characteristics may no longer be present in sitting and standing, only during more dynamic tasks such as walking) and the resistance to passive correction of the altered alignment reduces (Clark et al., 2012; Danells et al., 2004).

2.2.2 Assessment of lateropulsion (clinical measures)

Five clinical scales assessing lateropulsion have been evaluated in the literature. These include the Scale of Contraversive Pushing (SCP) (Karnath et al., 2000b), the Modified Scale of Contraversive Pushing (Lagerqvist & Skargren, 2006), the Swedish Scale for Contraversive Pushing (Hallin et al., 2008), the Burke Lateropulsion Scale (BLS) (D'Aquila et al., 2004) and the Four-Point Pusher Score (4PPS) (Chow et al., 2019). Two of these scales, the Modified Scale of Contraversive Pushing and the Swedish Scale for Contraversive Pushing, are scales which have been developed through adaptation of the SCP. In the most recently completed systematic review evaluating clinical lateropulsion measures, the BLS was recommended as the preferred tool to measure lateropulsion (Koter et al., 2017). This recommendation was not only made because the BLS has the strongest psychometric properties of the currently available scales, but also because it can detect small changes in lateropulsion status in individuals with mild or resolving lateropulsion (Bergmann et al., 2014). The 4PPS was not included in this systematic review as its psychometric properties had not been published in a peer reviewed journal prior to when the review was conducted. However, given the responsiveness of the 4PPS may be limited (Chow et al., 2019), the BLS still appears to be the scale of choice for the measurement of lateropulsion following stroke. Information regarding each scale, including the psychometric properties which have been evaluated, is outlined below and summarised in Table 2.1.

Scale of Contraversive Pushing

The SCP assesses lateropulsion in both sitting and standing according to the characteristics originally described by Davies (Davies, 1985). These characteristics include spontaneous body posture, extension and abduction of the non-paretic limbs, and resistance to passive correction of the tilted alignment (Karnath et al., 2000b). Scoring for the SCP ranges from zero to six, with higher scores indicating more severe lateropulsion.

Criterion validity for the SCP has been assessed by utilising clinical diagnosis by an expert as the 'reference standard' criteria. Agreement between the clinical diagnosis and the SCP using the original criterion of a minimum score of one for each of the three variables in the SCP was low (Baccini et al., 2006). High agreement, however, was found with the use of a modified criterion (of a score greater than zero for each SCP variable) (Baccini et al., 2006). The use of this modified criterion has been supported in subsequent studies (Baccini et al., 2008; Bergmann et al., 2014). However, inconsistent classification of the presence of lateropulsion has been found when the SCP was compared with the BLS even when using this modified criterion (22.5% of cases) (Bergmann et al., 2014). In each case, lateropulsion was identified by the BLS, but not by the SCP. The ability of the SCP to detect change in lateropulsion in mild or resolving cases may therefore be limited (Bergmann et al., 2014).

Table 2.1. Summary of psychometric properties of clinical lateropulsion scales

Outcome measure	Author and Year	Internal consistency (analysis; results)	Reliability (results)	Validity (results)	Responsiveness (results)	COSMIN quality score per measurement property evaluated
Single item measures as part of functional or motor scale						
Scale of Contraversive Pushing	Baccini et al., 2006	High internal consistency (Cronbach α = 0.92)	Excellent inter-rater relisability (ICC = 0.97)	Criterion: High agreement with modified criterion of >0 cut-off for each component (Cohen κ = 0.93)		Poor, Poor, Poor
	Baccini et al., 2008			Moderate concurrent validity with mobility, function and balance measures (r = -0.60 to -0.67)		Excellent
	Bergmann et al., 2014			Inconsistent classification compared to Burke Lateropulsion Scale (22.5% of cases)		Poor
Modified Scale of Contraversive Pushing	Lagerqvist & Skargren, 2006		Good inter-rater reliability (r = 0.82 to 0.94)	Low to moderate concurrent validity with balance and functional measures (r = -0.42 to -0.52)		Poor. Poor
Swedish Scale for Contraversive Pushing	Hallin et al., 2008		Good inter-rater reliability (ICC = 0.84)			Poor
Burke Lateropulsion Scale	D'Aquila et al., 2004		High inter-rater (ICC = 0.93) and intra-rater (ICC = 0.94) reliability	High concurrent validity with balance and functional measures (r = –0.56 to –0.58)		Good, Good
	Clark et al., 2012				High (Standardized Response Mean = 1.30 to 2.24)	Poor
Four-Point Pusher Score	Chow et al., 2019		Excellent inter-rater and intra-rater reliability (weighted kappa = 0.97)	High concurrent validity with balance and functional measures -0.65 to 0.77); high construct validity with Burke Lateropulsion Scale and Scale of Contraversive Pushing (r = 0.86 to 0.95)		Good, Good

Instead, the SCP may capture information about the more moderate to severe end of the lateropulsion continuum, which has been identified in the literature (Pérennou et al., 2008).

High internal consistency and good to excellent inter-rater reliability has been reported for the sub-scores and total scores of the SCP (Baccini et al., 2006). The COnsensus-based Standards for selection of health status Measurement INstruments (COSMIN) ratings for these measurement properties were poor though, secondary to the small sample sizes utilised (Koter et al., 2017). Moderate construct validity of the SCP has been demonstrated between SCP scores and mobility, function and balance measures (Baccini et al., 2008). Finally, the cross-cultural validity of the SCP has been questioned in a recent systematic review, given the SCP was originally developed in German and no formal description of the translation process into English has been described (Koter et al., 2017).

As mentioned, two scales that are modifications of the original SCP have been proposed in the literature. These include the Modified Scale of Contraversive Pushing (Lagerqvist & Skargren, 2006) and the Swedish Scale for Contraversive Pushing (Hallin et al., 2008). The Modified Scale of Contraversive Pushing assesses the degree of pushing during four tasks: static sitting, static standing, sitting transfer and standing/walking transfer (Lagerqvist & Skargren, 2006). Each item is scored between zero and two, with zero indicating no symptoms and two indicating continuous contraversive pushing. Good inter-rater reliability has been demonstrated in a study with 19 participants, whilst low to moderate concurrent validity with the Berg Balance Scale and the Swedish Physiotherapy Clinical Outcome Measure has been found (Lagerqvist & Skargren, 2006). The methodological quality of both the inter-rater reliability and the criterion validity assessments however were rated as poor according to the COSMIN checklist (Koter et al., 2017). Studies evaluating other psychometric properties of the Modified Scale of Contraversive Pushing are necessary before recommendations regarding the use of the Modified Scale of Contraversive Pushing clinically can be made (Koter et al., 2017).

The Swedish Scale for Contraversive Pushing is comparable to the original SCP, aside from a modified verbal instruction when determining resistance to correction of the tilted posture (Hallin et al., 2008). Good inter-rater reliability for each variable and the total Swedish Scale for Contraversive Pushing score has been demonstrated in a study involving 22 participants (Hallin et al., 2008). However, the small sample size results in a poor methodological quality rating according to the COSMIN guidelines (Koter et al., 2017). Further studies investigating other psychometric properties of the Swedish Scale for Contraversive Pushing including validity and responsiveness are required before use of the Swedish Scale for Contraversive Pushing can be recommended in Swedish-speaking countries (Koter et al., 2017).

Burke Lateropulsion Scale

The BLS assesses for the presence of lateropulsion across five tasks: rolling, sitting, standing, transfers and walking (D'Aquila et al., 2004). The scale measures how much resistance is present when the rater attempts to correct a tilted body alignment and when the resistance occurs. Scoring for the BLS ranges from zero to 17, with a higher score reflecting greater resistance and greater severity of lateropulsion.

The BLS has been shown to possess high inter-rater and intra-rater reliability and concurrent validity, with moderate correlations demonstrated between the BLS and measures of balance and functional ability (D'Aquila et al., 2004). The methodological quality of both the reliability and the criterion validity assessments of the BLS received ratings of good according to the COSMIN guidelines given the sample size of 85 (Koter et al., 2017). High levels of responsiveness have also been reported with individuals with lateropulsion following stroke at four and eight weeks following admission to rehabilitation, including those with more severe lateropulsion (Clark et al., 2012). However, according to COSMIN, the standardised response mean is an unsuitable measure of responsiveness, and therefore responsiveness was rated as poor using the COSMIN checklist (Koter et al., 2017; Mokkink, Terwee, Patrick, et al., 2010).

A score of two or more has commonly been used in the literature as the BLS cut-off score to diagnose the presence of lateropulsion (Babyar et al., 2015, 2017; Babyar et al., 2009; Babyar et al., 2008; Chow et al., 2019). However, a BLS score greater than two has also been utilised (Clark et al., 2012). Previously, greater agreement between the BLS and SCP in terms of classification of lateropulsion has been reported when a cut-off value of greater than two was used (agreement increased from 77.5% to 85.5%) (Bergmann et al., 2014). More recently, Bergmann and colleagues aimed to validate the BLS cut-off score using the Performance-Oriented Mobility Assessment Balance subscale as a measure of balance, given this function is commonly impaired in individuals with lateropulsion (Bergmann et al., 2019). The investigators found a BLS score of more than two was associated with severe balance deficits during standing and postural transitions (Bergmann et al., 2019). Using the SCP and Performance-Oriented Mobility Assessment Balance subscale as reference standards for validating the BLS cut-off score is problematic however, given neither are considered as reference standard measures of lateropulsion. The lack of an established reference standard for the measurement of lateropulsion has previously been highlighted in the literature (Koter, 2019; Koter et al., 2017). As outlined, the BLS has been identified in a recent systematic review as the strongest clinical scale available for measuring lateropulsion (Koter et al., 2017). However, further investigation of other psychometric properties of the BLS is needed before the BLS itself can be considered as the reference standard clinical scale for measuring lateropulsion following stroke.

One psychometric property which has not been evaluated for the BLS is its internal validity, that is how precisely the BLS assesses lateropulsion. Limitations of the BLS also exist, such as its ordinal nature, which is restrictive when using the BLS to evaluate interventions targeting lateropulsion. The reason for this is that whilst a higher score on the BLS signifies more severe lateropulsion than a lower score, the difference between scores may vary. That is, a change score (i.e. of three points) from different points on the scale may not represent the same amount of change. Rasch analysis is a statistical method that is performed to evaluate the internal validity of a scale and may also be used to transform an ordinal-level measure such as the BLS into an interval-level measure. Recently, the use of Rasch analysis has been strongly encouraged to guide the development of accurate outcome measures for use in rehabilitation (Malec, 2020).

Four-Point Pusher Score

The 4PPS is an ordinal scale which classifies the severity of lateropulsion as absent, mild, moderate or severe (Chow et al., 2019). The 4PPS involves assessment of spontaneous posture, the use of the less affected extremities to push towards the affected side, and resistance to weight shift towards the less affected side (Chow et al., 2019). The assessment occurs across different positions or tasks including lying, sitting, standing and walking. The 4PPS is quick to administer due to its hierarchical nature.

The 4PPS has been observed to have excellent inter-rater and intra-rater reliability and concurrent validity, with very strong correlations demonstrated with the BLS and SCP (Chow et al., 2019). Convergent construct validity has also been reported with strong associations shown between the 4PPS and the Berg Balance Scale, the Chedoke-McMaster Stroke Assessment postural control scale and the Functional Independence Measure (FIM) (motor domain) (Chow et al., 2019). Whilst the 4PPS does identify individuals across the lateropulsion continuum from mild to severe, its responsiveness may be limited due to the small range of possible scores (zero to three points) (Chow et al., 2019). However, this is yet to be investigated.

In summary, different clinical scales exist for assessing lateropulsion in stroke survivors. Based on current evidence, the BLS is recommended as the preferred scale for use in the measurement of lateropulsion following stroke. However, further evaluation of the BLS is needed to determine other important psychometric properties of this scale, such as internal validity, which is yet to be evaluated.

2.2.3 Assessment of lateropulsion (instrumented measures)

Perception of body verticality

Perception of body verticality is thought to be achieved through three different sensory modalities. These include perception of the visual vertical (Dieterich & Brandt, 2019; Piscicelli & Pérennou, 2017; Zwergal et al., 2019), the haptic vertical (Čakrt et al., 2016; Schuler et al., 2010), and the postural vertical (Bergmann et al., 2016; Karnath et al., 2000b; Pérennou et al., 2002; Pérennou et al., 2008). Disorders affecting sensory detection, sensory pathways, or the central processing and integration of sensory signals involved in verticality perception may result in altered postural control (Jahn et al., 2019).

The perception of visual vertical is dependent on visuo-vestibular information. The subjective visual vertical is commonly measured using the visual vertical perception test which involves adjusting a luminous line to vertical in darkness. Given the task is performed in absolute darkness the visual contribution to verticality perception is not assessed using this test (Piscicelli & Pérennou, 2017). Instead the visual vertical perception test predominantly assesses the contribution of the vestibular graviceptors, namely the vertical semi-circular canals and the otolith organs, to the perception of verticality in the roll and pitch planes (Pérennou et al., 2014; Piscicelli & Pérennou, 2017).

Haptic perception is reliant on tactile information acquired from the mechanoreceptors of the skin, muscles, tendons and joints through manual exploration of an object (Schuler et al., 2010). The subjective haptic vertical is assessed in darkness with the subject asked to place a rotating bar to vertical using their tactile sense (Pérennou et al., 2014). Following stroke, the assessment of haptic vertical is of particular interest when considering if all three different sensory modalities are tilted, indicating bias in the representation of vertical (Pérennou et al., 2014).

The perception of postural vertical is thought to be reliant on graviceptive-somaesthetic information and reflects how an individual perceives upright body orientation in relation to gravity (Bergmann et al., 2016; Pérennou et al., 2008). The subjective postural vertical is measured in sitting or standing with subjects seated in a motor-driven chair or drum-like framework or standing in a suspension apparatus (Bergmann et al., 2016; Karnath et al., 2000b; Pérennou et al., 2008). With vision occluded, subjects are asked to indicate when they perceive an upright alignment is achieved whilst being rotated in the frontal or sagittal planes (Bergmann et al., 2016; Karnath et al., 2000b; Pérennou et al., 2008). The perception of postural verticality in individuals with lateropulsion has been a key focus of research, with the aim of providing some insight into the underlying mechanism causing lateropulsion to occur (Bergmann et al., 2016; Karnath et al., 2000b; Pérennou et al., 2002; Pérennou et al., 2008).

Perception of postural verticality

Karnath and colleagues initially investigated the mechanism behind lateropulsion by measuring the subjective visual vertical and subjective postural vertical in five individuals with severe lateropulsion and controls (Karnath et al., 2000b). Subjective postural vertical was measured with subjects seated in a motor-driven chair which rotated in the frontal plane. With eyes occluded, the subjects were asked to indicate when vertical alignment was reached. Individuals with lateropulsion were found to have a subjective postural vertical which was tilted 18 degrees to the ipsilesional side, whilst their ability to identify the subjective visual vertical was unimpaired (Karnath et al., 2000b). Thus, whilst their processing of visual and vestibular information appeared intact, their perception of upright body posture in relation to gravity appeared altered.

Pérennou et al originally explored whether lateropulsion affected head and trunk orientation by asking individuals to remain vertical whilst sitting on a laterally unstable, rocking platform (Pérennou et al., 2002). Compared to individuals without lateropulsion and healthy controls, the three individuals with lateropulsion displayed a marked tilt of the pelvis towards the contralesional side, particularly when vision was occluded, whilst a vertical head alignment was maintained (Pérennou et al., 2002). From this preliminary data, the authors reached a similar hypothesis to Karnath et al, that is, that contraversive pushing was not the result of disrupted processing of vestibular information (which mainly informs head position), but the result of disruption to the processing of graviceptive-somesthetic information, which informs trunk orientation (Karnath et al., 2000b). These studies found the postural tilt to be in the opposite direction to each other. However, given the different paradigms investigated in each study comparison of the results is difficult (Paci et al., 2009).

Subsequently, Pérennou and colleagues examined the perception of verticality using three different sensory modalities in 86 individuals following stroke (Pérennou et al., 2008). For the purposes of the study, individuals were grouped as either ‘upright’, ‘listed’ (where individuals displayed severe body tilt in sitting and/or standing) or as ‘pushing’ (where all three variables of the SCP were present). Subjective visual vertical, subjective haptic vertical and subjective postural vertical were assessed. The subjective postural vertical was measured with subjects requested to indicate the point of feeling upright whilst being slowly rotated rightwards-leftwards, sitting restrained in a drum-like framework in a darkened room (Pérennou et al., 2008). The included ‘upright’ subjects demonstrated normal postural vertical, those ‘listed’ individuals displayed moderate contralesional postural vertical tilts and the six ‘pushing’ individuals showed the largest contralesional postural vertical tilts. Lateropulsion severity was found to correlate with the magnitude of the postural vertical bias (Pérennou et al., 2008). The authors propose that ‘pushing’ is a postural behaviour with the aim of trying to align body posture in space with an altered reference of verticality (Pérennou et al., 2008). Again, these results are in conflict to those found by Karnath and colleagues (Karnath et al., 2000b), in regard to the direction of the altered subjective postural vertical. Whilst the paradigms used in both studies were similar, lack of restraint of the head and legs in the study performed by Karnath and colleagues may account for these differences, given movements of the head and legs during testing may have provided biased cues that influenced the perception of postural verticality (Pérennou et al., 2008).

Most recently, Bergmann and colleagues (2016) have investigated the subjective postural vertical in standing with individuals with varying degrees of lateropulsion severity. Eight stroke survivors with lateropulsion, ten age-matched stroke survivors without lateropulsion and ten age-matched healthy controls participated in the study (Bergmann et al., 2016). Participants stood on a platform in a suspension apparatus and were asked to indicate when they perceived being upright while being rotated back in the direction of earth vertical, both in the sagittal and frontal planes. The stroke survivors with lateropulsion demonstrated an ipsilesional subjective postural vertical tilt with greater error than those without lateropulsion or the healthy controls, which was found to be less in those with more mild lateropulsion (Bergmann et al., 2016). These findings, in terms of the ipsilesional subjective postural vertical tilts observed in the stroke survivors with lateropulsion, are similar to those reported in sitting by Karnath et al (2000b), but contrary to those presented by Pérennou and colleagues (Pérennou et al., 2002; Pérennou et al., 2008). Thus, whilst all of these studies support the notion that individuals with lateropulsion have an altered internal reference of postural verticality, the direction of bias remains debated (Mansfield et al., 2019). Subsequently, two potential underlying mechanisms are proposed in the literature to explain the lateropulsion phenomenon.

Potential mechanisms causing lateropulsion

The first potential mechanism proposed in the literature to underlie lateropulsion relates to the research which found individuals with lateropulsion to demonstrate an ipsilesional bias of the subjective postural vertical in sitting (Karnath et al., 2000b) and standing (Bergmann et al., 2016), along with a mismatch between the orientation of visual vertical and postural verticality (Karnath et al., 2000b). Based on these studies it has been postulated that in an attempt to resolve the conflict between these two reference systems, individuals with lateropulsion actively compensate by pushing their longitudinal body axis towards the contralesional side (Karnath et al., 2000b).

The second proposed mechanism relates to the contrary findings of Pérennou and colleagues (2008) which demonstrated a transmodal tilt of the visual and postural vertical to the contralesional side in stroke survivors with lateropulsion. This model proposes that lateropulsion may be a postural behaviour that arises from the misperception of body verticality in relation to earth vertical, with the aim of aligning body posture in space with the perceived (albeit disturbed) postural vertical (Pérennou et al., 2008).

Both of these proposed mechanisms underlying lateropulsion are based on the presence of a disturbed internal reference for postural verticality when lateropulsion is present. However, given the direction of bias remains debated, the connection between impaired postural verticality perception and the behaviour (ie. the adopted natural postural orientation) remains unclear at present (Mansfield et al., 2019). Despite this, it is important to highlight that given the research supports lateropulsion as being a sensory disorder of impaired graviception, treatment may be best directed towards addressing this impairment, rather than focusing on remediating the pushing behaviour (Mansfield et al., 2019). For example, interventions may involve somatosensory stimulation (including of earth vertical with an upright body orientation) to address the underlying sensory integration and perceptual disturbance, rather than focusing on feedback training such as the use of visual cues to vertical to target the aberrant pushing behaviour (Bergmann et al., 2018; Krewer, Rieß, et al., 2013).

Assessment of postural control

Along with the use of rocking platforms and rotating frames to investigate the underlying mechanism of lateropulsion, three studies have used force platforms to quantify the postural dysfunction observed in sitting and standing in individuals following stroke, including some who had lateropulsion. In a sample of 37 individuals following stroke including seven individuals with lateropulsion, Lafosse and colleagues measured centre of gravity while participants sat on a force plate (Lafosse et al., 2007). In this study centre of gravity was shown to shift towards the affected side when lateropulsion was present, while the weight remained on the affected side as the assessor tried to move the participant's weight over towards their non-paretic side. This was observed to be accompanied by lateral flexion of the non-paretic side of the neck and trunk, with elongation of the affected side (Lafosse et al., 2007). Limitations of the study include the fact that less than 20% of the included participants had lateropulsion, and whilst the lateral centre of gravity shift task provided interesting information in terms of weight shift, its reliability has not been reported.

Mansfield and colleagues investigated postural dysfunction in standing with 147 chronic stroke survivors by determining the prevalence of stance asymmetry, its association with postural control and its relationship with other impairments including a prior history of lateropulsion (Mansfield et al., 2013). Weight-bearing asymmetry was assessed by participants standing on two force plates for 30 seconds duration. A prior history of lateropulsion was determined by reviewing each subject's SCP score on admission to inpatient rehabilitation. The researchers found 40% of participants were weight-bearing symmetrically, 12% biasing their paretic lower limb, and 48% loading more through their non-paretic leg (Mansfield et al., 2013). No significant differences between groups were identified when a prior history of lateropulsion was taken into account (Mansfield et al., 2013). These results need to be interpreted carefully, given the presence of lateropulsion at the time of the study assessment was unknown, the chronicity of the included subjects, as well as the low number of individuals with a prior history of lateropulsion within the sample (13 subjects in total).

Barra and colleagues also investigated the relationship between WBA in standing and postural abilities measured using clinical scales in 22 subjects post stroke (Barra et al., 2009). Weight-bearing asymmetry was measured with subjects standing on two force platforms for 32 seconds duration. Postural abilities and lateropulsion were assessed using the Postural Assessment Scale for Stroke (PASS) and SCP respectively. A moderate correlation was found between increased WBA and lower postural abilities ($r=-0.51$, $p=0.035$), whilst a fair correlation was found between SCP scores and WBA ($r=0.36$, $p=0.01$), indicating the greater the SCP score, the greater the weight-bearing through the non-paretic leg (Barra et al., 2009). Of the 22 subjects, all bar one (with an SCP score of 1) took greater weight through their non-paretic leg (Barra et al., 2009). These results were contrary to what was anticipated. Instead, it was expected that the individuals with lateropulsion would place greater load through their paretic leg, given these individuals typically fall towards this side (Pérennou et al., 2008). The researchers hypothesised that loading the non-paretic leg may be a compensatory strategy which individuals with lateropulsion develop in order to avoid falling (Barra et al., 2009). Limitations of the study include the small number of participants with lateropulsion (11 of 22) included and use of parametric tests for statistical analysis with ordinal scales. Despite the limitations of the three studies using force platforms outlined above, these results provide some interesting preliminary findings which clearly warrant further investigation.

Traditionally, the use of instrumented measures such as the rotating frames and force platforms has occurred within a laboratory setting, given these measures cannot easily be accessed within the clinical setting. Over the last decade, other technologies, such as the WBB, have been operated with customised software to capture data similar to that acquired from a force platform (Clark et al., 2010; Clark et al., 2018). The benefit of the WBB over laboratory-based measures is it can easily be utilised within the clinical environment (see Section 2.3.4). This is particularly useful for patient populations with high acuity or severe disability, such as stroke survivors with lateropulsion. Research utilising technology such as the WBB(s) within the clinical setting with stroke survivors with lateropulsion is likely to extend our understanding of the postural dysfunction observed in this patient population.

2.2.4 Prevalence of lateropulsion

The prevalence of lateropulsion in acute stroke survivors has been found to vary from 9.4% - 63% (Abe et al., 2012; Danells et al., 2004; Pedersen et al., 1996). This large range reflects both differences in the scales or criteria used to identify the presence of lateropulsion, as well as the selection procedures utilised within the studies (Paci et al., 2009).

Pedersen and colleagues first reported the prevalence of lateropulsion in acute stroke survivors to be 10.4% in a sample of 327 acute stroke survivors (Pedersen et al., 1996). This sample of acute stroke survivors excluded individuals who did not have lower limb weakness on admission or were not assessed by a physiotherapist due to death or a full rapid recovery. Importantly, the presence of lateropulsion was determined by use of a clinical definition, rather than a validated assessment scale, and therefore the results should be interpreted cautiously.

Danells and colleagues subsequently reported the prevalence of lateropulsion to be as high as 63% in a sample of 65 individuals with moderate to severe stroke (Danells et al., 2004). However, similar to Pedersen et al, the criteria utilised were questionable, given a SCP total score of greater than zero was used to identify patients with lateropulsion, which has subsequently been shown to have low specificity and is not recommended as the SCP cut-off criteria (Baccini et al., 2008). Most recently, Abe and colleagues investigated the prevalence of lateropulsion in 1660 individuals with acute stroke undergoing inpatient rehabilitation, using the SCP with the modified criterion of a score greater than zero for each SCP variable to identify lateropulsion. Lateropulsion was observed in 9.4% of individuals included in this study (Abe et al., 2012).

The prevalence of lateropulsion has been reported to be much higher in other studies conducted in rehabilitation settings, between 17% to 53% (Baccini et al., 2008; Chow et al., 2019; Clark et al., 2012; Krewer, Luther, et al., 2013). This is not surprising given individuals with lateropulsion often have more severe strokes and are more likely to require ongoing rehabilitation in subacute facilities compared to those without lateropulsion (Babyar et al., 2008; Pedersen et al., 1996). The prevalence of lateropulsion in different rehabilitation settings has varied partly due to the outcome measure utilised (Baccini et al., 2008; Chow et al., 2019; Clark et al., 2012; Krewer, Luther, et al., 2013) and may also be related to differing selection criteria for rehabilitation between units (Ilett et al., 2010). Using the SCP, the prevalence of lateropulsion in a rehabilitation sample of stroke survivors has been reported as 18.1% and 17% respectively (Baccini et al., 2008; Krewer, Luther, et al., 2013). When the BLS was used to identify the presence of lateropulsion, the prevalence of lateropulsion was reported as 26.9% in stroke survivors admitted across two rehabilitation sites (Clark et al., 2012). Chow and colleagues recently reported the prevalence of lateropulsion in a stroke rehabilitation setting to be higher than this, using three different measures of lateropulsion. The prevalence of lateropulsion was found to be 52.9%, 51.8% and 42.4% using the 4PPS, BLS and SCP respectively (Chow et al., 2019). As previously discussed, the use of BLS or the 4PPS to diagnose lateropulsion is likely to identify individuals from the milder end of the lateropulsion continuum which may be missed when the SCP is used, given that the SCP does not evaluate lateropulsion during walking.

2.2.5 Prevalence of lateropulsion and side of lesion

A number of studies have also reported the prevalence of lateropulsion in relation to the side of lesion. Whilst some studies have found the prevalence to be similar with both left and right hemispheric stroke lesions (Baccini et al., 2008; Pedersen et al., 1996); most studies have reported a higher prevalence of lateropulsion with right hemispheric damage following acute stroke (Abe et al., 2012; Dai et al., 2021; Danells et al., 2004; Krewer, Luther, et al., 2013; Lafosse et al., 2005; Premoselli et al., 2001). This may be anticipated given the right hemisphere is thought to play a dominant role in controlling body orientation in relation to gravity (Pérennou et al., 2008).

2.2.6 Lesion location and lateropulsion

Various sites of stroke have been found to be more commonly affected in individuals with contraversive lateropulsion than those without lateropulsion (Pedersen et al., 1996; Premoselli et al., 2001). These sites include the frontal cortex (Premoselli et al., 2001), temporal cortex (Premoselli et al., 2001), basal ganglia (Premoselli et al., 2001), internal capsule (posterior portion) (Pedersen et al., 1996) and thalamus (Premoselli et al., 2001). Previously, the posterolateral thalamus (Karnath, 2005; Karnath et al., 2000a; Pérennou et al., 2008) and the superior parietal cortex (Johannsen et al., 2006; Pérennou et al., 2008) have been identified as structures which are likely to be critical in the perception of body verticality and have also been associated with contraversive lateropulsion in individuals following acute stroke. More recently, the inferior parietal lobe has been recognised as a key structure associated with the presence of lateropulsion post stroke (Babyar et al., 2019).

2.2.7 Functional recovery and outcomes

Pedersen and colleagues first investigated functional recovery from lateropulsion and found that despite having more severe strokes (as measured by lower neurological status and functional scores on admission), individuals with lateropulsion may achieve a similar functional level to those without lateropulsion, but at a slower speed of recovery (3.6 weeks) (Pedersen et al., 1996). Other studies have also found length of stay in rehabilitation to be 30 days (Clark et al., 2012) and 32 days (Danells et al., 2004) longer for those individuals with lateropulsion compared to non-lateropulsion groups. Whilst Babyar et al found mean length of stay in the Stroke Unit of a Rehabilitation Hospital to be similar in 36 matched pairs of stroke survivors with and without lateropulsion, those individuals with lateropulsion were more likely to be discharged to subacute facilities for ongoing rehabilitation (Babyar et al., 2008). This finding may represent a difference in how the local hospital system operates and therefore limits the conclusions that can be drawn regarding length of stay in this instance. A recently published systematic review undertaken by Nolan and colleagues which investigated this topic, supports the findings discussed, concluding that individuals with lateropulsion can make significant functional gains during rehabilitation, but require a longer period of time than those stroke survivors without lateropulsion to do so (Nolan et al., 2021).

Whilst the need for a longer length of stay in rehabilitation for individuals with lateropulsion has consistently been described in the literature, differences have been reported in terms of functional recovery for individuals with lateropulsion. In some studies, stroke survivors with lateropulsion have demonstrated slower functional improvement compared to those without lateropulsion (Babyar et al., 2008; Pedersen et al., 1996). In other studies, functional recovery has been reported to occur at a similar rate in individuals with and without lateropulsion; however the functional outcomes differed between groups since the individuals with lateropulsion had lower functional levels at baseline (Danells et al., 2004). More recently, Krewer and colleagues found that stroke survivors with lateropulsion were only half as efficient and effective in their motor and functional outcomes recovery compared with individuals without lateropulsion (Krewer, Luther, et al., 2013).

Variations in discharge destination rates following rehabilitation for individuals with and without lateropulsion have also been reported. Clark and colleagues observed that fewer individuals with lateropulsion were discharged home in their sample compared to those without lateropulsion (35/43 (81.4%) for the lateropulsion group and 40/43 (93%) for the non-lateropulsion group) (Clark et al., 2012). Krewer et al found that those stroke survivors with lateropulsion were more likely to be transferred to nursing homes (35%) than a subgroup of individuals without lateropulsion (21%) (Krewer, Luther, et al., 2013). Differences in discharge destination rates between studies are unsurprising. Discharge destination following stroke relies on many different factors aside from the presence of lateropulsion, such as carer availability at home. Variations in practice in the selection for rehabilitation after stroke may also influence discharge destination rates given acceptance of lower level patients who may need prolonged admissions, such as those with severe lateropulsion, may differ between units (Ilett et al., 2010).

The longer-term outcomes of individuals with lateropulsion have received little investigation to date. Karnath and colleagues reported outcomes for 12 individuals with lateropulsion who were assessed initially following their stroke (median (range) of 6 (2-31) days following admission) and reassessed six months later (193 (174-214) days post stroke) (Karnath et al., 2002). In this study, pusher symptoms (as measured by the SCP) completely resolved in seven participants, whilst five patients showed residual characteristics of lateropulsion on one or two of the SCP subsections (Karnath et al., 2002). Karnath and colleagues also reported that eight of the 12 participants could transfer between bed and chair without assistance at the six-month follow-up assessment. Further studies reporting longer-term functional and walking outcomes of individuals with lateropulsion following stroke are needed given the limited research in this area.

2.2.8 Lateropulsion and balance and gait disorders

Previously balance and gait disorders following stroke have been attributed to deficits such as weakness and spasticity (Nonnekes et al., 2018). A recent study undertaken by Dai and colleagues challenged this belief, by identifying lateropulsion as the main factor contributing to balance and gait impairment at 30 days following stroke and on discharge from rehabilitation, in a sample of 220 individuals following stroke with and without lateropulsion (Dai et al., 2021). In this observational study involving individuals following hemispheric stroke, lateropulsion was assessed (using the SCP), along with a number of other common impairments including spatial neglect, aphasia, motor weakness, spasticity and hypoesthesia. Balance impairment and gait ability were also measured, using the PASS and modified Fugl-Meyer Gait Assessment respectively. Through use of a generalised linear model, lateropulsion, motor weakness and hypoesthesia were found to independently influence balance ability, while only lateropulsion and motor weakness were found to negatively affect gait scores. However, for both balance and gait disorders, lateropulsion was identified as the strongest determinant, particularly so for right hemisphere stroke (Dai et al., 2021). Following right hemispheric damage, lateropulsion severity was found to explain 90% of the balance impairment observed at 30 days following stroke ($p<0.001$) and 92% at discharge ($p<0.001$). In regard to gait ability, severity of lateropulsion accounted for 66% and 68% of the gait impairment present at 30 days and discharge respectively for those following right hemispheric stroke ($p<0.001$) (Dai et al., 2021). The authors acknowledge the use of the SCP to measure lateropulsion as a potential limitation of the study. Despite this, this study provides evidence to support the routine assessment of lateropulsion in stroke survivors, given the major contribution lateropulsion made to balance and gait impairment in the subacute phase following stroke, particularly for those with right hemispheric damage.

2.2.9 Factors influencing level of recovery from lateropulsion

Lateropulsion has been shown to resolve during inpatient rehabilitation admissions for between 46-50% of individuals who were identified as having lateropulsion initially (Babyar et al., 2015, 2017; Clark et al., 2012). Factors which influence the rate of recovery from lateropulsion have been explored in a number of recent studies. Abe and colleagues demonstrated that patients with lateropulsion and right cerebral hemisphere damage recovered significantly slower in terms of resolution of lateropulsion, than those individuals with left cerebral hemisphere damage (Abe et al., 2012). This finding of side of lesion differences in recovery time from lateropulsion was also found when the number of stroke-related deficits present was considered (Babyar et al., 2015). Babyar and colleagues completed a retrospective analysis of 169 patients with lateropulsion following hemispheric stroke to determine if the number of deficits present affected rate of recovery from lateropulsion (Babyar et al., 2015). Time to recovery from lateropulsion was found to differ based on the number of deficits, but just for individuals with right sided brain damage. Individuals following stroke with motor deficits only recovered from lateropulsion during their inpatient rehabilitation stay (average length of stay of 27 days), while those with three major deficits (i.e. motor, proprioceptive and hemianopic or visual-spatial deficits) had a slower recovery. This may be expected given these stroke survivors have fewer intact systems available to assist in the relearning of postural control and balance (Babyar et al., 2015). Importantly though, even those individuals with three major deficits made significant improvements in regard to lateropulsion, motor control and functional ability during their rehabilitation stay (Babyar et al., 2015).

Different factors which influence lateropulsion recovery have been identified based on lesion side (Babyar et al., 2017). Using logistic regression with data from 134 stroke survivors with lateropulsion and with motor and functional deficits, Babyar and colleagues found for those with right sided lesions, older age, poor limb proprioception and cognitive issues on admission differentiated those with persistent lateropulsion at discharge (78.3% model accuracy) (Babyar et al., 2017). For individuals with left sided damage, older age and worse admission motor status appeared to influence recovery from lateropulsion (73.8% model accuracy) (Babyar et al., 2017). Visuospatial neglect, gender and general lesion location were not found to influence recovery from lateropulsion regardless of side of lesion (Babyar et al., 2017). Older age has previously been associated with delayed recovery of lateropulsion (Danells et al., 2004).

Studies investigating recovery from lateropulsion have not only reported the presence of lateropulsion at point of discharge from inpatient rehabilitation (Babyar et al., 2015, 2017), but also recovery from lateropulsion over time (Clark et al., 2012; Danells et al., 2004). Clark et al have demonstrated good patterns of recovery in terms of a reduction in lateropulsion severity measured fortnightly using the BLS over an eight and/or four-week period in a group of 43 stroke survivors with lateropulsion undertaking inpatient rehabilitation (Clark et al., 2012). Improved postural function was also demonstrated in this cohort (as measured by the PASS). Whilst the depiction of group progress over time is informative, examination of individual patterns of recovery for lateropulsion and postural control in this patient population may potentially provide greater insight into the lateropulsion phenomena. Previously, Danells and colleagues depicted individual recovery patterns for 20 subjects with lateropulsion using SCP scores to track lateropulsion severity at multiple time points over a three-month period (Danells et al., 2004). The individual recovery patterns showed a steady reduction in lateropulsion scores over this time period for the majority of participants (Danells et al., 2004). However, given the inability of the SCP to demonstrate change at the milder end of the lateropulsion continuum (Bergmann et al., 2014), further examination of individual patterns of recovery for lateropulsion using the BLS, as well as other variables, such as postural function, would be beneficial to provide further insight into this unique postural control disorder. These patterns of recovery are also likely to be of clinical interest to therapists working with stroke survivors with lateropulsion.

2.3. Balance and postural control

2.3.1 Definition of postural control and balance

Postural control involves “controlling the body’s position in space for the dual purposes of stability and orientation” (Shumway-Cook & Woollacott, 2017). The creation of postural stability, or balance, requires an individual to coordinate movement strategies in order to stabilise their centre of mass, both to maintain a posture without voluntary movement (static balance), and during self-initiated and externally generated perturbations (dynamic balance) (Horak, 2006; Ivanenko & Gurfinkel, 2018). Balance in both sitting and standing results from the complex interaction of many different systems including the visual, vestibular, somatosensory, musculoskeletal and cognitive systems (Chiba et al., 2016; Horak, 2006; Ivanenko & Gurfinkel, 2018; Jahn et al., 2019).

2.3.2 Measures of balance and postural control following stroke

Clinical measures

Individuals following stroke commonly present with balance impairments both in sitting and/or standing (Kamphuis et al., 2013; Tessem et al., 2007; Tyson et al., 2006; van Nes et al., 2008; Vincent-Onabajo et al., 2018). A number of different balance scales exist to identify and monitor balance impairment with stroke survivors within the clinical setting. Given the multidimensional nature of balance, a comprehensive assessment of balance should include both static and dynamic tasks (Bernhardt et al., 1998), as well as evaluation of different sensory systems (visual, vestibular, somatosensory) (Jahn et al., 2019). Furthermore, the inclusion of dynamic tasks in standing assessing both the ability to stabilise with upper limb displacements (i.e. reaching tasks) and dynamic single limb stance tasks (i.e. stepping tasks) have previously been recommended, given the different postural control requirements these tasks demand (Bernhardt et al., 1998). Examples of different tests which evaluate these discrete components of balance include the Modified Clinical Test of Sensory Interaction in Balance (Cohen et al., 1993) as a timed static balance test involving evaluation of the different sensory systems, the Functional Reach Test (Duncan et al., 1990) as a reaching test and the Step Test (Hill et al., 1996) as an example of a stepping test. Different tests evaluating specific components of balance may be combined together to provide a more comprehensive assessment. In addition to discrete balance tests, a number of ordinal balance scales exist that incorporate a suite of static and dynamic balance tasks in sitting and/or standing (Tyson & Connell, 2009). Examples of these ordinal scales include the Berg Balance Scale (Berg et al., 1992), the PASS (Benaim et al., 1999), the Brunel Balance Test (Tyson & DeSouza, 2004a), and the balance section of the Fugl-Meyer Assessment (Fugl-Meyer et al., 1975).

Many standing balance measures (both discrete balance tests and ordinal balance scales) have been well validated for use clinically with stroke survivors (Blum & Korner-Bitensky, 2008; Tyson & Connell, 2009; Tyson & DeSouza, 2002). Conversely, sitting balance measures have received less attention to date. Whilst many stroke survivors are able to sit independently within the days following their stroke (Smith & Baer, 1999), this is not the case for all individuals. For some cases, such as those with total anterior circulation infarcts (Smith & Baer, 1999), or for individuals with postural control disorders such as severe lateropulsion, sitting balance difficulties may extend for weeks or months (Smith & Baer, 1999). For these individuals it is important that reliable and valid sitting balance measures are identified for use to monitor progress over time and guide therapeutic interventions (Thornton & Sveistrup, 2010).

Instrumented measures

As outlined, balance scales are commonly performed within the clinical setting to assess balance impairment in individuals following stroke. However, these scales do not provide in-depth information regarding the underlying postural control strategies that an individual may be utilising to maintain balance. Force platforms provide a means by which underlying postural control strategies can be assessed (Haas & Burden, 2000). Force platforms allow data relating to COP movement and WBA to be captured (Clark et al., 2018; Genthon et al., 2007). Centre of pressure is described as the location of the vertical ground reaction force from a force plate and is regarded as the neuromuscular response to a shift of the centre of mass in order to maintain stability (Genthon et al., 2007; Winter, 2009). Both COP and WBA variables have been used extensively in research across many clinical groups (including stroke survivors) to provide valuable information regarding postural control. To date, this has occurred to a lesser extent in the subgroup of stroke survivors with lateropulsion.

2.3.3 Previous force platform studies measuring balance in individuals following stroke

It has previously been outlined that only a few studies (one in sitting (Lafosse et al., 2007); two in standing (Barra et al., 2009; Mansfield et al., 2013)) have used force platforms to quantify the postural dysfunction observed in individuals with lateropulsion, as a subset of the included cohorts of stroke survivors. Many studies have, however, investigated the use of force platforms to acquire measures of COP and/or WBA more broadly with stroke survivors. In sitting, COP variables have been obtained from force platforms with stroke survivors (lateropulsion status unknown) for both static and dynamic tasks (Genthon et al., 2007; Näf et al., 2020; Tessem et al., 2007; van Nes et al., 2008). Moderate test-retest reliability has been reported for COP sway velocity in static sitting (Näf et al., 2020), whilst postural instability has been demonstrated in individuals early following stroke when sitting on both stable

(Genthon et al., 2007) and unstable surfaces (van Nes et al., 2008). The direction of greater instability differed between these two studies from an anteroposterior (Genthon et al., 2007) and mediolateral direction (van Nes et al., 2008). This difference may be attributed to the use of foot support, where no foot support resulted in greater anteroposterior instability (Genthon et al., 2007), whilst mediolateral instability was higher when foot support was provided (van Nes et al., 2008). For dynamic sitting tasks, greater variability in COP patterns during the seated reaching tasks has been found for individuals following stroke compared to healthy controls (Tessem et al., 2007). In this study, stroke survivors also demonstrated greater displacement laterally when reaching forwards and reduced displacement laterally when reaching sideways to the unaffected side compared with the control subjects (Tessem et al., 2007). Importantly, the inclusion criteria for each of these studies required participants to be able to sit unsupported for greater than 30 seconds (Genthon et al., 2007; Näf et al., 2020; Tessem et al., 2007; van Nes et al., 2008). Thus, it is unlikely that individuals with severe lateropulsion would have met this inclusion criterion. Furthermore, given lateropulsion is a unique disorder of postural control, individuals with lateropulsion may display different balance impairments compared to those without lateropulsion following stroke as was demonstrated by the preliminary findings of Lafosse and colleagues (Lafosse et al., 2007) discussed earlier (see section 2.2.3 Assessment of lateropulsion (instrumented measures)).

A number of studies have also investigated COP measures and/or WBA in standing in individuals following stroke (lateropulsion status unspecified) (Barra et al., 2009; de Haart et al., 2004; Mansfield et al., 2013; Marigold & Eng, 2006; Martins et al., 2011; Nardone et al., 2009; Pereira et al., 2010). These studies have shown impaired balance control, with increased sway during quiet stance particularly in the frontal plane (de Haart et al., 2004; Marigold & Eng, 2006; Nardone et al., 2009) and WBA between the lower limbs (Barra et al., 2009; de Haart et al., 2004; Mansfield et al., 2013; Marigold & Eng, 2006; Martins et al., 2011; Pereira et al., 2010). Most commonly, individuals following stroke have been shown to load more weight through their non-paretic leg, both in quiet standing (Barra et al., 2009; de Haart et al., 2004; Eng & Chu, 2002; Mansfield et al., 2013; Marigold & Eng, 2006; Martins et al., 2011; Pereira et al., 2010) and during the performance of dynamic tasks such as sit to stand (Cheng et al., 1998; Eng & Chu, 2002). Greater loading of the non-paretic leg post stroke is thought to result from the complex interaction of different factors including behavioural neglect (Barra et al., 2009; Genthon et al., 2008), motor weakness (Barra et al., 2009; Genthon et al., 2008), spasticity (de Haart et al., 2004; Genthon et al., 2008) and sensory deficits (Barra et al., 2009; Genthon et al., 2008).

Some studies have also described WBA loading the paretic leg in a smaller proportion of hemiplegic subjects (Hesse et al., 1994; Mansfield et al., 2013; Martins et al., 2011; Pereira et al., 2010). It has been hypothesised that stroke survivors with lateropulsion may exhibit WBA favouring their paretic leg (Mansfield et al., 2013; Pereira et al., 2010). This has not been supported in the two preliminary studies outlined earlier (Barra et al., 2009; Mansfield et al., 2013) (see section 2.2.3 Assessment of lateropulsion (instrumented measures)). Mansfield and colleagues found no difference in the weight-bearing pattern adopted when a history of lateropulsion was taken into account (Mansfield et al., 2013), whilst Barra et al. found unexpectedly, that more severe lateropulsion was associated with greater weight-bearing through the non-paretic leg (Barra et al., 2009). Further studies undertaken with larger samples of individuals with lateropulsion are clearly needed to verify these results.

2.3.4 Wii Balance Board studies

Despite providing useful information regarding the underlying postural control strategies utilised to maintain balance in sitting and standing, force platforms are not easily accessible within the clinical setting. As previously mentioned, the WBB is a transportable, low-cost device, which can be controlled with customised software to acquire data that measure aspects of postural control such as COP movement and WBA (Clark et al., 2010; Clark et al., 2018). The key benefit of the WBB technology over force platforms is the capacity to transport the WBB to the individual within the clinical environment. This is particularly pertinent to individuals following an acute stroke with lateropulsion, given these individuals often have higher acuity needs and are more severely disabled.

The WBB has been shown to be reliable (Bower et al., 2014; Castelli et al., 2015; Chang et al., 2014; Clark et al., 2010; Clark et al., 2018; Scaglioni-Solano & Aragon-Vargas, 2014) and valid, yielding comparable COP and WBA variable data to what is obtained from a laboratory force plate when measuring standing balance (Clark et al., 2010; Clark et al., 2018; Holmes et al., 2012; Scaglioni-Solano & Aragon-Vargas, 2014), both in healthy controls (Chang et al., 2014; Clark et al., 2010; Clark et al., 2018; Scaglioni-Solano & Aragon-Vargas, 2014) and in some neurological patient populations including stroke (Bower et al., 2014; Castelli et al., 2015; Holmes et al., 2012; Llorens et al., 2016). Whilst previous studies involving stroke survivors using the WBB have focused on standing, the WBB has also been utilised to measure postural control in sitting with individuals with severe knee osteoarthritis (Pua et al., 2013).

Bower and colleagues investigated test-retest reliability and construct validity of the WBB in standing with 30 stroke survivors greater than three months post stroke, all of whom could stand unsupported for more than 30 seconds (Bower et al., 2014). Participants were assessed on two occasions standing on the WBB(s) with eyes open and closed, as well as performing sit to stand and a dynamic mediolateral weight shifting task, in conjunction with clinical measures (10 Metre Walk Test, Timed Up and Go, Step Test and Functional Reach Test). Test-retest reliability for all of the WBB-derived measures including COP velocity and WBA were shown to be high. Poor to moderate associations were found between WBB-derived measures and the clinical tests, with the greatest correlations demonstrated between outcome measures related to a specific task, such as the dynamic mediolateral weight shift activity and the Step Test (Bower et al., 2014).

In another study involving individuals following stroke, excellent intra-rater and inter-rater reliability of a number of WBB-derived COP variables including mean COP speed and mean maximum displacement in a mediolateral and anteroposterior direction have been reported with 10 chronic stroke survivors performing a series of balance tasks in standing, including the modified Clinical Test of Sensory Interaction on Balance (Llorens et al., 2016). Concurrent validity was established with moderate to high correlations between the WBB-derived COP variables and COP measures obtained from an alternate posturography system ($r=0.649$–0.911, $p<0.01$) (Llorens et al., 2016). Poor to moderate correlations were found between the WBB-derived COP measures and a number of included clinical balance and gait tests (Berg Balance Scale, Functional Reach Test, Step Test, 30 second Chair-to-Stand Test, Timed Up and Go, the Timed Up and Down Stair Test and the 10 Metre Walk Test), similar to those reported previously (Bower et al., 2014). In addition, the WBB-derived COP variables were found to differentiate individuals with stroke from the healthy controls (Llorens et al., 2016).

To the author's knowledge, no studies have utilised WBB-derived variables to assess postural control specifically in stroke survivors with lateropulsion or in populations with limited ability to sit or stand, i.e. for greater than three seconds without assistance. However, given the WBB has been shown to be reliable and valid and can easily be utilised within the clinical environment, its use with stroke survivors with lateropulsion may provide an important insight into the postural control deficits these individuals experience in sitting and standing. This may in turn guide what treatment approaches may be appropriate for use in addressing this challenging impairment.

This thesis addressed a number of the research gaps identified in the review chapter for people with stroke with lateropulsion. It explored the measurement of lateropulsion following stroke in clinical research, extending our knowledge about the nature and recovery of this distinct postural control disorder. The thesis focused on three main areas: (1) the measurement properties of clinical lateropulsion and sitting balance measures in individuals following stroke; (2) the use of WBB(s) as an instrumented measure of postural control in sitting and standing in stroke survivors with lateropulsion; and (3) the longer-term outcomes and individual recovery patterns over time of individuals following stroke with lateropulsion.

Chapter 3. Comprehensive clinical sitting balance measures for individuals following stroke: a systematic review on the methodological quality

Chapter Outline

Individuals with severe lateropulsion often have difficulty maintaining balance in sitting. However, unlike standing balance measures which have been extensively investigated with stroke survivors, sitting balance measures have not. This chapter presents a systematic review investigating the psychometric properties of published sitting balance measures which include dynamic tasks for use with individuals after stroke.

This chapter is presented in its accepted manuscript format. Details of the publication are: Birnbaum M, Hill K, Kinsella R, Black S, Clark R, Brock K. (2018). Comprehensive clinical sitting balance measures for individuals following stroke: a systematic review on the methodological quality. *Disability and Rehabilitation* 40(6): 616-630, https://doi.org/10.1080/09638288.2016.1261947.

This study has also been presented at the following conferences:
Clinical measurement of sitting balance after stroke: a systematic review. Australian Physiotherapy Association Conference, Gold Coast, 2015.
Clinical measurement of sitting balance after stroke: a systematic review. Stroke 2015 Conference, Melbourne, 2015.

After the accepted manuscript paper, this chapter also includes an update of additional research evidence which has been published subsequent to publication of this systematic review.

3.1 Abstract

Purpose: The aim of this systematic review was to examine the psychometric properties of published clinical sitting measurement scales containing dynamic tasks in individuals following stroke.

Method: Databases, including CINAHL, MEDLINE, EMBASE, Cochrane, PubMed and AMED were searched from inception to December 2015. The search strategy included terms relating to sitting, balance, and postural control. Two reviewers independently selected and extracted data from the identified articles and assessed the methodological quality of the papers using the Consensus-based Standards for selection of health status Measurement Instruments (COSMIN) checklist.

Results: Fourteen clinical sitting measurement scales (39 papers) containing dynamic tasks met the inclusion criteria and various measurement properties were evaluated. The methodological quality of the majority of the included studies was rated as poor to fair using the COSMIN checklist, with common limitations including small sample size and inappropriate use of statistical methods.

Conclusions: This review was unable to identify measures with sufficient psychometric properties to enable recommendation as preferred tools. However, measures were identified that warrant further specific psychometric investigations to fulfil requirements for a high quality measure.

Implications for Rehabilitation:

- Fourteen clinical sitting balance scales containing dynamic tasks are available to measure sitting balance with individuals following stroke.
- No single scale has sufficient psychometric properties to enable recommendation as a preferred tool for measuring sitting balance with stroke survivors.
- Use of a balance scale or dedicated sitting balance measure containing static and dynamic sitting items should be utilised to monitor progress for individuals following stroke with more severe deficits.

3.2 Introduction

Sitting balance is commonly impaired initially after stroke (Morgan, 1994). Whilst the majority of stroke survivors regain the ability to sit unsupported soon after, this is not the case for all individuals (Smith & Baer, 1999). For some clinical presentations, such as total anterior circulation infarcts, impaired sitting balance may persist for weeks and independent sitting balance may not be achieved (Smith & Baer, 1999). Likewise, clinical disorders such as lateropulsion, where an individual's perception of body verticality is impaired (Pérennou et al., 2008), may interfere with the ability to sit independently. An inability to maintain balance in sitting may inhibit recovery of basic self-care activities, including eating, dressing and toileting.

A number of studies have demonstrated that sitting balance ability is an important variable in the prediction of mobility and functional outcomes for individuals following stroke (Morgan, 1994; Nichols et al., 1996; Nitz & Gage, 1995; Tsang & Mak, 2004; Tyson et al., 2007) However, whilst clinical measures of standing balance have been well validated with stroke survivors (Tyson & DeSouza, 2002), sitting balance measures have received less attention to date. Previous reviews have focused on trunk impairment or have included studies conducted with a broad range of neurological conditions (Tyson & Connell, 2009; Verheyden, Nieuwboer, de Winckel, et al., 2007).

Balance is defined as the ability to statically or dynamically control one's body position in space over the base of support (Shumway-Cook & Woollacott, 2017). This may be in response to internal and/or external perturbations. Internal perturbations result from voluntary movements of the body, such as reaching for an object, and are controlled by proactive postural control mechanisms (Winter, 1995). Conversely, external perturbations are applied to an individual through external forces and rely more on reactive postural control mechanisms (Horak et al., 1997). It is imperative that clinical balance assessments contain items that are representative of the type of disturbances that are encountered in everyday life (Winter, 1995). For sitting balance measures, the inclusion of items assessing response to internal perturbations are mandatory, given self-generated perturbations are inherent to the majority of functional tasks performed while sitting.

Static sitting items have commonly been utilised to measure sitting balance following stroke

(Collin & Wade, 1990; Smith & Baer, 1999), and have been shown to be predictive of mobility outcomes in stroke survivors (Morgan, 1994). However, sitting measures which only evaluate static sitting items fail to assess the dynamic requirements of sitting balance required for the completion of many functional activities (Thornton & Sveistrup, 2010). Likewise, scales such as the Fugl-Meyer Balance subscale, which only include static and external perturbation items, also lack tasks that assess the dynamic requirements of sitting balance. Poor convergent validity of the Fugl-Meyer sitting items has previously been reported (Malouin et al., 1994; Poole & Whitney, 1988). For those stroke survivors for whom sitting balance impairments persist, and standing and walking ability is limited, it is imperative that reliable, valid and responsive sitting balance measures containing dynamic tasks are utilised. The use of these measures will allow clinicians to monitor an individual's progress over time, may inform retraining activities, and assist with recommendations regarding an individual's rehabilitation potential (Thornton & Sveistrup, 2010). The aim of this systematic review was to examine the psychometric properties of clinical measurement tools used to assess sitting balance following stroke, that contain dynamic sitting tasks.

3.3 Methods

Search Strategy (inception to 31st December 2015)

Six electronic databases including the Cumulative Index of Nursing and Allied Health Literature (CINAHL), MEDLINE (OVID), EMBASE (OVID), the Cochrane Library, PubMed and the Allied Health and Contemporary Medicine Database (AMED) were searched for peer-reviewed articles, from inception to 31st December 2015. The search strategy utilised is outlined in Appendix 10. In order to identify further relevant articles, the reference lists of all included papers were reviewed and additional database searches were performed using the included outcome measure names as keywords.

Selection Criteria

All clinical measurement scales that contained at least one item assessing sitting balance for adults following stroke were included in the initial screen. However, for a measurement scale and corresponding articles to be included for review, additional criteria needed to be met. Firstly, measurement scales were only included if they contained a dynamic task item assessing response to internal perturbations in sitting. Measures were excluded if they only contained items assessing static unsupported sitting, resistance to movement of the trunk and/or reaction to external perturbations in sitting, without the inclusion of self-generated dynamic sitting items. Scales were also excluded if predictive validity was the only psychometric property evaluated. For articles assessing global measures, separate data specific to the sitting balance component of the scale was required for inclusion. Likewise, for studies with greater than 50% of the sample as adults following stroke to be eligible, separate data was needed for the stroke survivors. Only full text articles published in English were included for review.

Data Extraction and Quality Assessment

Two reviewers independently reviewed all titles and abstracts identified by the literature search. Two reviewers (MB and RK) then independently assessed the full text articles of potentially relevant studies for inclusion. Where there was disagreement and consensus could not be reached, a third reviewer (KB) decided whether a paper was included for review. Two reviewers (MB and SB) conducted data extraction and assessed the methodological quality of the included papers using the COnsensus-based Standards for selection of health status Measurement INstruments (COSMIN) checklist (Mokkink, Terwee, Patrick, et al., 2010). The COSMIN checklist is a standardised instrument containing twelve boxes designed to assess the method quality of studies investigating measurement properties (Mokkink, Terwee, Patrick, et al., 2010). Nine of the boxes, which relate to different measurement properties, contain items assessing aspects of design and statistical analysis for the given property (Terwee et al., 2012). Each item within a box is rated as excellent, good, fair or poor quality according to specific criteria. For each measurement property investigated, a quality score is determined by using the lowest rating item within the particular box (Terwee et al., 2012). For studies which investigate multiple measurement properties, the completion of several COSMIN boxes is required (Terwee et al., 2012). Through this process a separate quality score is determined for each measurement property investigated within a study, rather than an overall quality score for the study itself. The COSMIN checklist has been used to examine measurement properties of assessment tools in a number of systematic reviews (Elbers et al., 2012; van Bloemendaal et al., 2012). The third reviewer (KB) reviewed any discrepancies between the two reviewers in this process.

3.4 Results

The study selection process is outlined in figure 3.1, with 313 studies assessed for eligibility. Thirty-nine studies were identified for inclusion, relating to a total of 14 different measures. Five of the measures were single items included in motor or functional scales; four scales contained sitting tasks as part of balance measures and five solely evaluated sitting balance, including one trunk performance measure, which contained sitting balance items and was therefore included for review. Eleven of the 14 identified measures assessed static sitting along with dynamic sitting ability. Information regarding the individual measures is presented in table 3.1. Characteristics of the included studies are outlined in table 3.2. Measurement properties of studies investigating aspects of reliability for the included outcome measures are presented in table 3.3, while those assessing various aspects of validity and responsiveness are summarised in table 3.4 and table 3.5. The overall quality scores obtained using the COSMIN checklist for each measurement property investigated are outlined in tables 3.3 to 3.5 (itemised results are available on request from the authors).

Overall, the methodological quality of all of the measurement properties evaluated in this systematic review (including aspects of reliability, validity and responsiveness) was predominantly rated as poor (56%) to fair (36%) using the COSMIN checklist (as outlined in tables 3.3 to 3.5). In order to calculate these figures, the number of each COSMIN quality score listed in the three tables were counted and converted to a percentage. The main reasons for these ratings were small sample sizes, the use of only one measurement point when evaluating inter-rater reliability, inappropriate use of statistical methods, and inadequate formation of hypotheses prior to data collection. The agreement level between the two reviewers for the overall COSMIN quality scores for reliability, validity, and responsiveness were 89%, 78% and 14% respectively. The disagreement observed between the two reviewers when evaluating responsiveness related to scoring of the statistical analysis item in the responsiveness box. This discrepancy was resolved in consultation with the third reviewer (KB).

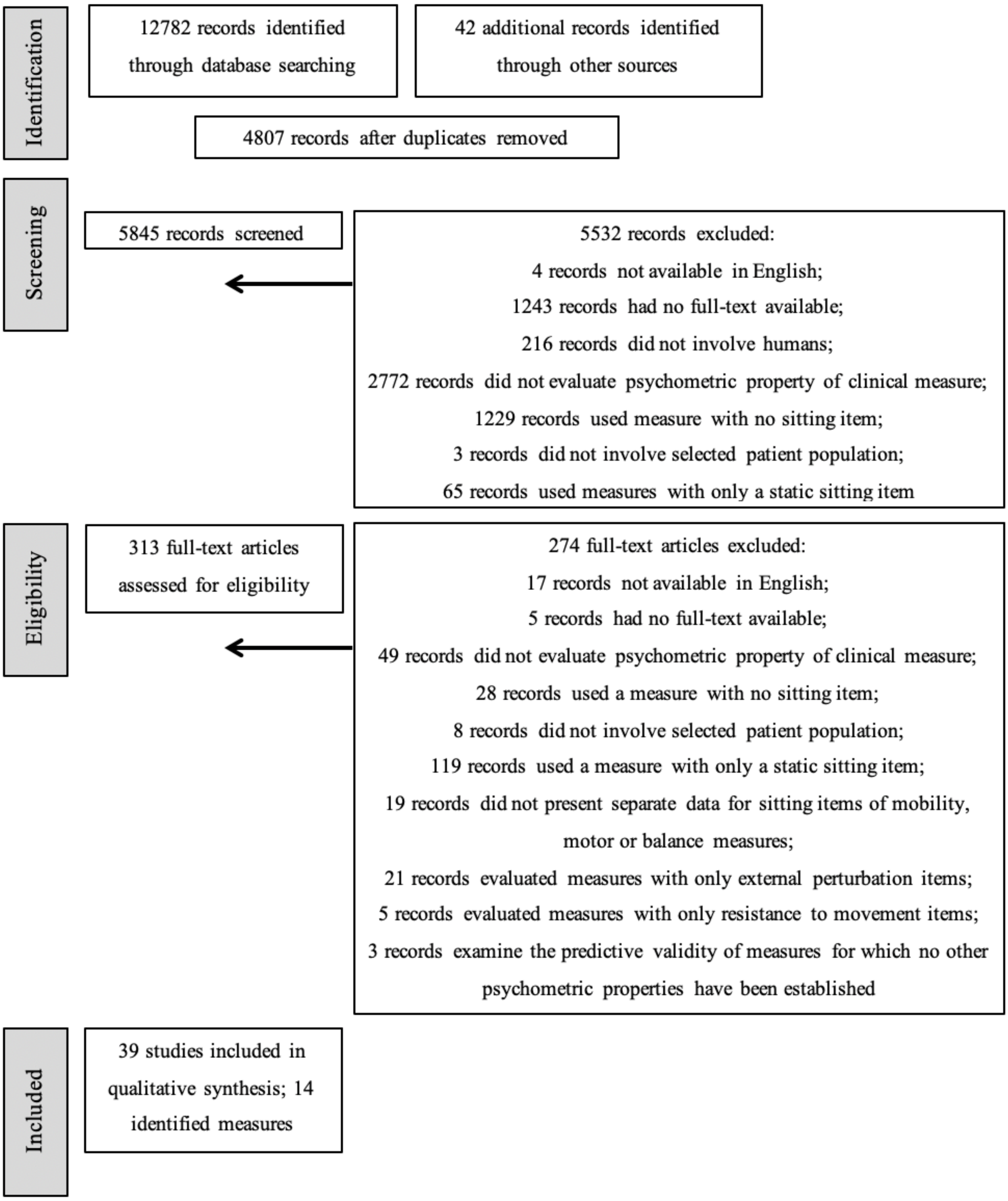

Figure 3.1. Flow diagram outlining study selection process

Single item measures as part of functional or motor scales

Five single item measures of sitting balance from functional or motor scales were identified. Four of these measures, the Clinical Outcome Variables Scale sitting item (Seaby & Torrance, 1989), the dynamic sitting TELER indicator (Mawson, 1995), the Physical Ability Scale sitting item (Jackson et al., 2011) and the Stroke Activity Scale sitting balance item (Horgan et al., 2003), have only had one psychometric property evaluated. For the Motor

Table 3.1. Characteristics of sitting balance measures

Measure (sitting item only)	Description of Measure	Number of items assessing sitting balance / total	Aspects of balance assessed in sitting
Single item measures as part of functional or motor scale			
Clinical Outcome Variables Scale (Seaby & Torrance, 1989)	Performance-based measure of functional mobility	1 / 13	Static sitting, moving within and beyond base of support, ability to tolerate external perturbation
Dynamic sitting TELER indicator (Mawson, 1995)	Measure of functional recovery to track clinically significant change; single item ordinal scales	1 / multiple	Dynamic balance tasks, including moving limb or tilting pelvis and transferring weight side to side in sitting
Motor Assessment Scale (Mawson, 1995)	Assesses functional capabilities of stroke patients	1 / 8	Tasks including sitting with and without support, turning one's head while sitting and reaching forwards and sideways to touch floor
Physical Ability Scale (Jackson et al., 2011)	Evaluates trunk impairment after stroke	1 / 5	Ability to be placed in and maintain sitting position, move within and to/from sitting position
Stroke Activity Scale (Horgan et al., 2003)	Measures motor function at a disability level	1 / 5	Static and dynamic balance tasks
Sitting items as part of balance measure			
Balance Computerized Adaptive Testing (Hsueh et al., 2010)	Computerized adaptive testing system for assessing balance function	7 / 34	Sitting with and without trunk support, reaching for a pen in pocket, lifting one leg off ground, picking pen up from ground
Brunel Balance Assessment (Tyson & DeSouza, 2004a)	Functional tests of balance disability in sitting, standing and stepping; hierarchical ordinal scale	3 / 12	Supported sitting test, sitting arm raise test, sitting forward reach test
Hierarchical Balance Short Forms (Hou et al., 2011)	Set of three Hierarchical Balance Short Forms; sitting form	8 / 24	Sitting with and without trunk support, tasks requiring movement of the upper or lower limbs with or without trunk movement such as picking up a pen from the floor
Postural Control and Balance for Stroke (revised) (Pyöriä et al., 2005)	Measures sitting and standing balance with focus on assessment of balance strategies	5 / 23	Unsupported sitting, touching a marker placed on both sides, reaching forward and picking an object up from floor
Sitting balance measures			
Function in Sitting Test (Gorman et al., 2010)	Performance-based measure of functional balance in sitting	14 / 14	Static and dynamic balance tasks, including ability to respond to various internal and external perturbations

Modified Functional Reach Test (Katz-Leurer et al., 2009)	Assesses limits of stability in sitting	3 / 3	Maximum forwards and sideways lean
Sit-and-Reach Test (Tsang & Mak, 2004)	Assesses limits of stability reaching forwards in sitting	1 / 1	Maximum forwards lean
Sitting Balance Scale of Hemiplegia (Nieuwboer et al., 1995)	Rating scale for static and dynamic sitting balance including quality rating of posture or movement	12 / 12	Sitting unsupported, sitting with legs crossed, leaning sideways to both sides and leaning forwards
Trunk Impairment Scale (Verheyden et al., 2004)	Evaluates trunk impairment by assessing static and dynamic sitting balance and trunk coordination	17 / 17	Static sitting, sitting with movement of legs, selective lateral flexion and rotation of trunk

Table 3.2. Characteristics of included studies

Outcome measure (sitting item only)	Author and Year	Country	Participant n	Type of stroke stroke	Mean time after (% male)	Distribution of sex	Mean age years discipline	Assessor n,
Single item measures as part of functional or motor scale								
Clinical Outcome Variables Scale	(Amusat, 2009)	Canada	51	Infarct, haemorrhage	NR	57%	72.5	NR
TELER indicator	(Mawson, 2002)	UK	29	NR	NR	76%	61	10
Motor Assessment Scale	(Carr et al., 1985)	Australia	5 (inter-rater); 15 (test-retest) (test-retest)	NR	14 weeks (inter-rater); 55 months	20% (inter-rater); 67% (test-retest)	65 (inter-rater); 70 (test-retest)	20 (inter-rater); 1 (test-retest), PT and PT students
	(Loewen & Anderson, 1988)	Canada	7	NR	NR	29%	73.6	14, PT and OT
	(Poole & Whitney, 1988)	US	24 (inter-rater); 30 (validity)	NR	12 months	57%	63.3	2
	(Loewen & Anderson, 1990)	Canada	50	Thrombotic, haemorrhage, embolic	≤3 days after admission to hospital	56%	68	2, PT
	(Malouin et al., 1994)	Canada	32	Thrombo-embolic, haemorrhage	64.5 days	63%	60	3, PT
	(Kjendahl et al., 2005)	Norway	5	NR	Range 8 weeks – 24 years	60%	63.6	18, PT
	(Aamodt et al., 2006)	Norway	137	Infarct, haemorrhage	NR	65%	60	NR
	(English et al., 2006)	Australia	61	NR	NR; within 1/52 of admission to rehabilitation	NR	65.2	1, PT
	(Gustavsen et al., 2006)	Norway	44	Infarct, haemorrhage, SAH, combination	NR, within 1/52 admission to rehabilitation	61%	Median 53	1
	(Brauer et al., 2008)	Australia	566	NR	NR	54%	72.5	NR

	(Conte et al., 2009)	Brazil	6 (inter-rater); 15 (intra-rater)	Infarct, haemorrhage (intra-rater)	37.5 months (inter-rater); 32.7 months	83% (inter-rater); 60% (intra-rater)	55.8 (inter-rater); 56.5 (intra-rater)	23 (inter-rater); 7 (intra-rater), PTs
	(Kuys et al., 2009)	Australia	120	NR	NR, <72 hours post admission to rehabilitation	53%	70	Numerous, treating PT
	(Tucak et al., 2010)	Australia	239 (validity); 5 (reliability)	Ischaemic, haemorrhage	NR, within 1-2 days of admission to rehabilitation	52%	78.1	4, PT
	(Scrivenor et al., 2014)	Australia	190	Infarct, haemorrhage, other	<48 hours from admission to stroke unit	51%	76	NR; treating PT
Physical Ability Scale	(Jackson et al., 2011)	UK	10	Infarct, haemorrhage	82.6 days	80%	70.3	4, PT
Stroke Activity Scale	(Horgan et al., 2003)	Ireland	12	NR	Median 22.5 days	42%	Median 71.5	7, PT
Sitting items as part of balance measure								
Balance Computerized Adaptive Testing	(Hsueh et al., 2010)	Taiwan	764	Infarct, haemorrhage	6.8 months	65%	61.6	5, NR
Brunel Balance Assessment	(Tyson & DeSouza, 2004b)	UK	83 (35 reliability; 48 validity testing)	NR	Median 11 weeks	61%	66.7	2, PT
	(Tyson, 2007)	UK	35	NR	Median 11 weeks	65%	66	2, PT
	(Tyson et al., 2007)	UK	102	Ischaemic, haemorrhage	21 days	53%	70.7	NR
Hierarchical Balance Short Forms	(Hou et al., 2011)	Taiwan	85	Ischaemic	4.2 months	65%	64.2	2, OT
Postural Control and Balance for	(Pyöriä et al., 2005)	Finland	50 (responsiveness); 19 (reliability)	Infarct, haemorrhage	7, 120, 360 days (responsiveness);	62% (responsiveness);	69.6 (responsiveness);	5, PT

Stroke					between 7-60 days (reliability)	53% (reliability)	69.7 (reliability)	
	(Pyöriä et al., 2007)	Finland	40	Ischaemic, haemorrhage	7 and 90 days	30%	72	2, PT
Sitting balance measures								
Function in Sitting Test	(Gorman et al., 2010)	US	31	Ischaemic, embolic	NR: <3 months	68%	61.5	NR
Modified Functional Reach Test	(Katz-Leurer et al., 2009)	Israel	10 (reliability); 35 (validity)	Ischaemic	Range 14 -21 days	50% (reliability); 51% (validity)	63 (reliability); 60 (validity)	NR
Sit-and-Reach Test	(Tsang & Mak, 2004)	Hong Kong	10 (reliability); 26 (validity)	Infarct	7-10 days post stroke (reliability); within 5 days of D/C (validity)	50% (reliability); 62% (validity)	76.2 (reliability); 73.5 (validity)	NR
Sitting Balance Scale of Hemiplegia	(Nieuwboer et al., 1995)	Belgium	27	NR	101 days	44%	62	2; junior and senior PT
Trunk Impairment Scale	(Verheyden et al., 2004)	Belgium	28	Ischaemic, haemorrhage	Median 61 days	50%	Median 63	2, PT
	(Verheyden et al., 2005)	Belgium	40	Ischaemic, haemorrhage	Median 46 days	50%	64	2
	(Verheyden et al., 2006)	Belgium	51	NR	Median 129 days	69%	65	1
	(Verheyden, Nieuwboer, De Wit, et al., 2007)	Belgium, Germany and Switzerland	102	Ischaemic, haemorrhage	Median 20 days	54%	70	5
	(Di Monaco et al., 2010)	Italy	60	Vascular	NR, <3 days post admission to rehabilitation	62%	68	NR
	(Verheyden & Kersten, 2010)	NR	162	NR	Median 19 days	54%	67	NR
	(Gjelsvik et al., 2012)	Norway	201	Ischaemic, haemorrhage,	4.7 days	58%	72	3, PT

			undiagnosed				
(An et al., 2014)	Korea	72	Infarct, haemorrhage	10.4 months	68%	61.8	2, therapists
(Helmy et al., 2014)	Egypt	40	Ischaemic	9.8 months	73%	56.1	NR
(Kim et al., 2015)	South Korea	135	Ischaemic, haemorrhage	NR	61%	62.1	NR

n indicates number; NR, not reported; PT, physical therapist; OT, occupational therapist; SAH, subarachnoid haemorrhage; 1/52, one week; %, percentage.

Table 3.3. Measurement properties and methodological quality of studies on reliability

Outcome measure (sitting item only)	Author and Year (analysis; results)	Internal consistency (results)	Test-retest reliability (results)	Inter-rater reliability (results)	Intra-rater reliability (results)	Measurement error	COSMIN quality score per measurement property evaluated*
Single item measures as part of functional or motor scale							
Motor Assessment Scale	(Carr et al., 1985)			Percentage agreement=99%			Poor
	(Loewen & Anderson, 1988)			Percentage agreement=77.9%, mean kappa= 0.56	Kendall's rank-order correlation coefficient=0.47-1.00		Poor; Poor
	(Poole & Whitney, 1988)			Spearman correlation coefficient=0.99			Poor
	(Kjendahl et al., 2005)			PEA=83.3, ICC=0.72			Poor
	(Conte et al., 2009)			ICC=0.98	ICC=0.80		Poor; Poor
	(Tucak et al., 2010)			PEA=55%			Poor
Physical Ability Scale	(Jackson et al., 2011)			ICC=0.00			Poor
Stroke Activity Scale	(Horgan et al., 2003)			Generalised kappa=0.70 (time 1), 0.47 (time 2)			Poor
Sitting items as part of balance measure							
Balance Computerized Adaptive Testing	(Hsueh et al., 2010)	IRT including chi-square and factor loading; 34 items met model's expectations					Good
Brunel Balance Assessment	(Tyson & DeSouza, 2004b)		Supported sitting kappa=1.0, sitting AR ICC=0.96, sitting FR ICC=0.93	Supported sitting kappa=1.0, sitting AR ICC=0.99, sitting FR ICC=0.99 session)	Supported sitting kappa=1.0, sitting AR ICC=0.96, sitting FR ICC=0.98 (within		Fair; Poor; Fair

	(Tyson, 2007)					% mean: sitting AR 29% error; sitting FR 23% error; test-retest error: sitting AR 33% error; sitting FR 42% error	Fair
Postural Control and Balance for Stroke	(Pyöriä et al., 2005)	Cronbach's alpha=0.77		ICC=0.91	ICC=0.94, weight kappa=0.77		Poor; Poor; Poor
Sitting balance measures							
Function in Sitting Test	(Gorman et al., 2010)	Coefficient alpha=0.98					Poor
Modified Functional Reach Test	(Katz-Leurer et al., 2009)		Within session reliability ICC=0.90-0.95				Poor
Sit-and-Reach Test	(Tsang & Mak, 2004)		Inter-trial ICC=0.98, inter-session ICC=0.79				Poor
Sitting Balance Scale of Hemiplegia	(Nieuwboer et al., 1995)			Kappa=0.2-1.00, weighted kappa slight to high agreement depending on items			Poor
Trunk Impairment Scale	(Verheyden et al., 2004)	Cronbach's alpha; SSB 0.79; DSB 0.86; COO 0.65, total TIS 0.89	SBB ICC=0.91; DSB ICC=0.94; COO ICC=0.87, total TIS ICC=0.96	SBB ICC=0.99; DSB ICC=0.98; COO ICC=0.85, total TIS ICC=0.99		95% test-retest and inter-rater measurement error; test-retest 3.68, inter-rater 1.84	Poor; Poor; Poor; Poor
	(Verheyden & Kersten, 2010)	Chi-square, PSI; DSB and COO fit Rasch model, SSB does not					Fair
	(Gjelsvik et al., 2012)	Cronbach's alpha= 0.85					Good

AR indicates arm raise; COO, Coordination subscale; COSMIN, COnsensus-based Standards for selection of health status Measurement Instruments; DSB, Dynamic sitting balance subscale; FR, forward reach; ICC, intraclass correlation; IRT, Item response theory; Kappa, Kappa coefficient; PEA, Percentage exact agreement; PSI, Person separation index; SSB, Static sitting balance subscale; TIS, Trunk Impairment Scale; %, percentage.

*If more than one measurement property investigated, methodological quality for each measurement property is listed in order of description in the table.

Table 3.4. Methodological quality and measurement properties of studies on aspects of validity

Outcome measure (sitting item only)	Author and Year	Content validity (method; results)	Structural validity (analysis; results)	Cross-cultural validity	COSMIN quality score per measurement property evaluated*
Single item measures as part of functional or motor scale					
Motor Assessment Scale	(Kjendahl et al., 2005)			Translated into NV	Poor
	(Aamodt et al., 2006)		PCM; scalability good		Fair
Sitting items as part of balance measure					
Balance Computerized Adaptive Testing	(Hsueh et al., 2010)		IRT; 7 items did not met model's expectations, resulting in 34 item bank		Good
Hierarchical Balance Short Forms	(Hou et al., 2011)	Developed 3 hierarchical function-related balance levels from 34 item bank; high correlation between sitting short form and full item bank (Pearson r=0.98)	IRT reliability; average for sitting short form 0.94		Excellent; Good
Sitting balance measures					
Function in Sitting Test	(Gorman et al., 2010)	Expert panel survey, factor analysis; high face and content validity	IRT; 3 misfitting items identified, resulting in 14 item test		Fair; Poor
Sitting Balance Scale of Hemiplegia	(Nieuwboer et al., 1995)	Interviewed experienced physiotherapists, observation of stroke patients, pilot testing			Fair
Trunk Impairment Scale/s	(Verheyden et al., 2004)	Literature review, observation of stroke patients, clinical experience of authors and discussion of scale content with stroke rehabilitation specialists			Poor
	(Verheyden & Kersten, 2010)		IRT; DSB and COO found to be unidimensional, fitted the Rasch model; presented TIS 2.0		Fair
	(Gjelsvik et al., 2012)		Factor analysis and IRT; modified	Translated into NV	Excellent; Poor

	TIS-NV fitted a locally dependent unidimensional IRT model well

COO indicates Coordination subscale; DSB, Dynamic sitting balance subscale; IRT, Item response theory; NV, Norwegian version; PCM, Partial credit models; Pearson r, Pearson product-moment correlation coefficient; TIS-NV, Trunk Impairment Scale-Norwegian version.

*If more than one measurement property investigated, methodological quality for each measurement property is listed in order of description in the table.

Table 3.5. Methodological quality and measurement properties of studies on aspects of construct validity and responsiveness

Outcome measure (sitting item only)	Author and Year	Hypotheses testing: *Convergent* (other measure; results*)	*Discriminative* (results*)	*Predictive* (analysis; results*)	Responsiveness (results*)	COSMIN quality score per measurement property evaluated†
Single item measures as part of functional or motor scale						
Clinical Outcome Variable Scale	(Amusat, 2009)				ES=0.46	Poor
TELER indicator	(Mawson, 2002)	MAS SB item; r_s=0.66-0.99				Poor
MAS	(Poole & Whitney, 1988)	Fugl-Meyer SB score; r_s= 0.28				Fair
	(Loewen & Anderson, 1990)			r_s, stepwise regression. SB item at 1 week correlated with D/C motor, functional and walking measures (r=0.81, 0.72, 0.71 respectively); regression equations using scores at 1 month produced highest r^2 values (0.76-0.95) in predicting D/C scores (all contained SB score)		Fair
	(Malouin et al., 1994)	Fugl-Meyer SB score; r_s=-0.10				Fair
	(English et al., 2006)				No floor effect, ceiling effect 57.4% on admission and 91.8% on D/C, 60.7% of patients showed no change, ES=0.61	Poor
	(Gustavsen et al., 2006)	BBS; r_s=0.80 on admission, r_s=0.73 on D/C			Ceiling effect on admission 57%, 32% patients changed score, SRM=-0.2	Fair; Poor
	(Brauer et al., 2008)			r_s, logistic regression; D/C destination. r_s= 0.305 for SB item. Not included in final model		Fair
	(Kuys et al., 2009)			Univariate and multiple regression; D/C walking speed; r=0.19. Not included in final model		Fair

	(Tucak et al., 2010)			Multiple linear and logistic regression; D/C destination, walking function at D/C, length of stay; only total MAS scores included in regression. Association between SB item and D/C destination χ^2=50.22		Fair
	(Scrivenor et al., 2014)				ES=0.72, SRM=0.71, median-based ES=0.50	Poor
Sitting items as part of balance measure						
Brunel Balance Assessment	(Tyson & DeSouza, 2004b)	MAS SB item, BBS, RMI; Sitting arm raise: MAS r_s=0.33, BBS r_s=0.54, RMI r_s=0.53, sitting forward reach: MAS r_s=0.54, BBS r_s=0.54, RMI r_s=0.61				Fair
	(Tyson et al., 2007)			Univariate and multi-variate linear regression; balance disability strongest predictor of function in acute stage (r^2 = 30-85%)		Fair
Hierarchical Balance Short Forms	(Hou et al., 2011)	BBS; r_s=0.80				Fair
Postural Control and Balance for Stroke	(Pyöriä et al., 2005)				Wilcoxon matched-pairs tests=2.91 for 7-120 days, NS for 120-360 days, floor effect 27%, 12%, 9% at 7, 120 and 360 days post stroke respectively, ceiling effect 29%, 44% and 49% respectively	Poor
	(Pyöriä et al., 2007)	BI, four neuropsychological domains; BI r_s=0.69, visual inattention r_s=0.55	Discriminated between healthy subjects and stroke patients	Median and logistic regression; BI and falls at 90 day follow-up; SB subscale NS predictor	Median change during 90 day follow up=1.7	Fair; Poor; Fair; Poor

Sitting balance measures						
Function in Sitting Test	(Gorman et al., 2010)	Static and dynamic SB grades, mRS; Static SB grade r_s=0.93, dynamic SB grade r_s=0.93, mRS r_s=0.73				Poor
MFRT	(Katz-Leurer et al., 2009)	BM, SAS, FIM; forward MFRT T1: BM r_p=0.55, FIM r_s=0.49, T2: BM r_p=0.50, FIM r_s=0.45; paretic side MFRT T1: BM r_p=0.48, SAS r_s=0.50, FIM r_s=0.51, T2: BM r_p=0.48; non-paretic side MFRT T1: BM r_p=0.56, T2: BM r_p=0.52. Other results NS			forward MFRT ES=0.6, paretic side MFRT ES=0.80, non-paretic side MFRT ES=0.57	Fair; Poor
Sit-and-Reach Test	(Tsang & Mak, 2004)			Multiple linear regression; Sit-and-Reach Test significantly accounted for 32.7% of variance of FIM mobility score (p=.002) and 27.5% of variance in timed walk at D/C (p=.006)		Poor
Trunk Impairment	(Verheyden et al., 2004)	TCT; r_s=0.83				Poor
Scale/s	(Verheyden et al., 2005)		Significant differences between stroke patients and healthy individuals			Fair
	(Verheyden et al., 2006)			Univariate and multivariate linear regression; TIS significantly related to balance, gait and functional ability. DSB of TIS is a significant contributor in addition to TCT score for measures of gait and functional ability (R^2=0.55-0.62)		Fair
	(Verheyden, Nieuwboer, De Wit, et al., 2007)			Univariate and correlation analysis, multiple regression; total TIS (partial R^2=0.52) and SSB		Fair

	score (partial R^2=0.50) most important factors when predicting BI 6 months post stroke	
(Di Monaco et al., 2010)	Linear correlation, multiple linear regression; TIS significantly associated with FIM at D/C (p=.010), change in FIM during rehabilitation (p=.003), FIM effectiveness (p=0.024) and D/C destination (p=.04)	Fair
(An et al., 2014)	Multiple linear and logistic regression; DSB of TIS identified as one factor affecting balance subscale of Performance-Oriented Mobility Assessment.	Poor
(Helmy et al., 2014)	r_p, univariate regression; TIS significantly correlated with balance and functional ability measures. DSB of TIS had highest effect on measures	Poor
(Kim et al., 2015)	Multiple linear regression; DBS of TIS was only significant factor when predicting Korean version of Modified BI at 6 months post stroke (R^2=0.653) in those unable to walk on admission	Fair

BM indicates Balance Master result; BI, Barthel Index; BBS, Berg Balance Scale; COSMIN, COnsensus-based Standards for selection of health status Measurement Instruments; D/C, discharge; DSB, Dynamic sitting balance subscale; ES, Effect size; FIM, Functional Independence Measure; MFRT, Modified Functional Reach Test; mRS, Modified Rankin Scale; MAS, Motor Assessment Scale; NS, not significant; RMI, Rivermead Motor Index; r_p, Pearson product-moment correlation coefficient; SB, Sitting balance; SRM, Standardised response mean; SSB, Static sitting balance subscale; r_s, Spearman's rank correlation coefficient; SAS, Stroke Activity Scale; T1, first evaluation; T2, second evaluation; TCT, Trunk Control Test; %, percentage.

*Please note, results as significant unless indicated as not significant (NS).

†If more than one measurement property investigated, methodological quality for each measurement property is listed in order of description in the table.

Assessment Scale Balance sitting item, seven different psychometric properties have been evaluated across 14 articles. However, the quality of all of the measurement properties evaluated for the Motor Assessment Scale Balance sitting item was rated as poor (60%) and fair (40%) quality according to the COSMIN checklist.

Sitting items as part of balance measures

Four measures that contain sitting items as part of balance scales, including the Balance Computerized Adaptive Testing (Hsueh et al., 2010), the Brunel Balance Assessment (Tyson & DeSouza, 2004a), the Hierarchical Balance Short Forms (Hou et al., 2011) and the revised Postural Control and Balance for Stroke measure (Pyöriä et al., 2005) were identified. Whilst some aspects of reliability and validity have been investigated for the sitting components of these scales, the overall quality of all of the measurement properties evaluated for the sitting items of these balance measures was predominantly rated as poor (37%) to fair (42%) using the COSMIN guidelines. The exception to this was two articles that utilised Item Response Theory to investigate the internal consistency and structural validity of the Balance Computerized Adaptive Testing (Hsueh et al., 2010), and the content and structural validity of the subsequently developed Hierarchical Balance Short Forms (Hou et al., 2011).

Sitting balance measures

Five stand-alone sitting balance measures were identified, including the Function in Sitting Test, the Modified Functional Reach Test, the Sit-and-Reach Test, the Sitting Balance Scale of Hemiplegia, and the Trunk Impairment Scale. A varying number of psychometric properties have been evaluated for these measures, from two psychometric properties for the Sit-and-Reach Test and the Sitting Balance Scale of Hemiplegia, to 10 psychometric properties for the Trunk Impairment Scale. However, as with the other identified scales, the methodological quality of all of the measurement properties evaluated for these stand-alone sitting balance measures was rated as poor (59%) to fair (34%), with the exception of one article investigating the internal consistency and structural validity of the Trunk Impairment Scale using Item Response Theory (Gjelsvik et al., 2012).

3.5 Discussion

In this systematic review, 39 studies investigating various measurement properties of 14 sitting balance measures were evaluated. Three different types of measures were identified which contained dynamic sitting items- single items included as part of motor or functional scales, sitting tasks as part of balance measures and stand-alone sitting balance measures. Discussion of the included outcome measures is outlined using these three groupings.

Single item measures as part of functional or motor scales

Five single ordinal items from functional or motor scales assessing dynamic sitting balance were identified in this review. High quality studies supporting the use of these single items as stand-alone scales of sitting balance are lacking. It is important to recognise that these single item measures were developed as part of broader scales and were not designed for use as single item scales. Thus, limitations such as a lack of responsiveness to monitor change over a prolonged period of time for individuals following severe stroke with impaired sitting balance are also likely to exist (Gustavsen et al., 2006). Multi-item or interval measures of sitting balance may therefore be more appropriate for use with these individuals.

Sitting items as part of balance measures

Four measures that contain dynamic sitting items as part of balance scales were included in this review. Whilst quality studies are currently lacking to support the use of the sitting components of the Brunel Balance Assessment and the Postural Control and Balance for Stroke measure, the Balance Computerized Adaptive Testing and subsequently developed Hierarchical Balance Short Forms were designed using Item Response Theory and have established structural validity (Hou et al., 2011; Hsueh et al., 2010). Both the Balance Computerized Adaptive Testing and the Hierarchical Balance Short Forms allow clinicians to tailor the difficulty of the balance assessment to the stroke survivor. For example, when using the Hierarchical Balance Short Forms, the therapist selects the short form most relevant to an individual’s ability levels. Using global balance measures inclusive of dynamic sitting balance tasks in individuals following stroke may allow clinicians to capture balance ability across the spectrum of disability and monitor progress. However, before use of the Balance Computerized Adaptive Testing and the Hierarchical Balance Short Forms can be recommended clinically, the reliability and responsiveness of these scales needs to be established. For those stroke survivors with more severe deficits, use of a dedicated sitting balance measure may still be warranted if responsiveness of the sitting components of these measures is limited (Thornton & Sveistrup, 2010).

Sitting balance measures

Five stand-alone sitting balance scales were identified. Few psychometric properties have been evaluated for four of these measures, including the Sit-and-Reach Test, the Modified Functional Reach Test, the Function In Sitting Test and the Sitting Balance Scale of Hemiplegia, whilst those studies that have investigated the psychometric properties of these scales are of limited quality. The exception to this is the Trunk Impairment Scale, which is a trunk performance measure inclusive of dynamic sitting balance tasks, for which a number of psychometric properties have been evaluated. Modified versions of the Trunk Impairment Scale have been developed through Item Response Theory analyses (the Trunk Impairment Scale 2.0 and the modified Trunk Impairment Scale-Norwegian Version) (Gjelsvik et al., 2012; Verheyden & Kersten, 2010). Whilst sound psychometric properties exist for this scale, it is important to consider that unlike other sitting balance measures, the Trunk Impairment Scale assesses sitting balance in relation to trunk impairment rather than through the performance of functional sitting activities.

Across the three different types of measures identified, 11 out of the 14 measures assessed static sitting in addition to dynamic sitting ability. The three measures that do not include static sitting items are the Dynamic sitting TELER indicator, the Modified Functional Reach Test and the Sit-and-Reach Test. These measures are designed to assess sitting balance when an individual can sit unsupported. For those individuals who are unable to regain the ability to sit without assistance soon after stroke, one of the 11 measures that contain both static and dynamic sitting tasks should be utilised. This will allow clinicians to capture the achievement of sitting unsupported initially, and then to monitor change in dynamic sitting ability over time.

Methodological limitations of included studies

As part of this systematic review, the methodological quality of each psychometric property evaluated within a study was assessed. Results indicated the methodological quality of the majority of measurement properties assessed was rated as poor to fair using the COSMIN checklist. Only six measurement properties, out of the 72 evaluated across the included studies, scored good or excellent on the COSMIN checklist. These included internal consistency and structural validity of the Balance Computerized Adaptive Testing (Hsueh et al., 2010), content and structural validity of the Hierarchical Balance Short Forms (Hou et al., 2011), and internal consistency and structural validity of the Trunk Impairment Scale

(Gjelsvik et al., 2012). As discussed however, further psychometric properties need to be established for the Balance Computerized Adaptive Testing and the Hierarchical Balance Short Forms prior to their use being recommended clinically. Whilst for the Trunk Impairment Scale, it is important to consider that the focus of this measure is trunk impairment, rather than functional sitting tasks.

For those measurement properties rated as poor to fair using the COSMIN checklist in this systematic review, common limitations include small sample sizes, the use of only one measurement point when evaluating inter-rater reliability, inappropriate use of statistical methods and inadequate formation of hypotheses prior to data collection. Over half of the studies involved small to moderate sample sizes, containing less than 50 participants. A sample size of at least 50 participants, or larger for some analyses such as factor analysis, has been recommended (Terwee et al., 2007; Terwee et al., 2012). Nine of the studies investigating inter-rater reliability used video assessments or had raters observing participants simultaneously. These studies were rated as "poor" according to the COSMIN guidelines, as the studies lacked two separate measurement points. The advantage of using video or simultaneous observation for assessment of inter-rater reliability in performance-based measures is that it separates error attributed to raters from test-retest error attributed to difference in patient performance.

Another common issue identified was the statistical methods utilised, particularly when reliability and responsiveness were evaluated. For reliability, despite the ordinal nature of many of the included measures, percentage agreement or intraclass correlation coefficients were calculated rather than weighted kappa. Effect size and the standardised response mean were commonly used as parameters to evaluate responsiveness. These parameters are considered inappropriate measures of responsiveness according to the COSMIN guidelines (Mokkink, Terwee, Knol, et al., 2010). However, this view has been strongly challenged (Angst, 2011). Where these parameters are used, it is important that clear hypotheses regarding the expected changes are stated (Mokkink, Terwee, Knol, et al., 2010). Inadequate formation of hypotheses prior to data collection was another common limitation identified, not only for responsiveness, but also for studies of convergent, predictive and discriminative validity.

Further studies exploring measurement properties of current sitting balance measures for stroke survivors should aim to address these methodological limitations. For example, larger sample sizes (at a minimum greater than 50 participants, or larger for some analyses) should be utilised when evaluating psychometric properties of the sitting balance measures (Terwee et al., 2007; Terwee et al., 2012). For studies investigating convergent validity, predictive validity, discriminative validity and responsiveness of sitting balance measures, clear hypotheses should be set prior to data collection commencing (Mokkink, Terwee, Knol, et al., 2010). Researchers should also ensure that the statistical analysis methods utilised to evaluate a given measurement property for a sitting balance measure are the most appropriate for the type of data acquired. For example, when investigating the reliability of an ordinal sitting balance scale, weighted kappa should be the chosen method of analysis. The COSMIN checklist can be used as a guide by researchers when designing future studies to evaluate the measurement properties of sitting balance measures, in order to identify the requirements of excellent quality (Mokkink, Terwee, Patrick, et al., 2010).

To the authors' knowledge, this is the first systematic review that specifically investigates the quality of comprehensive sitting balance measures available for use with individuals following stroke. Previous reviews have either investigated balance activity more broadly by including sitting, standing and stepping tasks with adults with various neurological conditions (Verheyden, Nieuwboer, de Winckel, et al., 2007), or have focused on trunk impairment scales rather than assessment of sitting balance through the performance of functional activities in sitting with stroke survivors (Tyson & Connell, 2009). Given the different focuses, it is difficult to draw comparisons between this current review and those previously completed (Tyson & Connell, 2009; Verheyden, Nieuwboer, de Winckel, et al., 2007).

3.6 Conclusion

This is the first systematic review that solely evaluates the quality of comprehensive sitting balance measures inclusive of dynamic tasks for use with stroke survivors. For those individuals with impaired sitting balance following stroke, the use of a dedicated sitting balance measure may be indicated. This review has identified a number of measures with dynamic sitting balance items. However, none of the measures have sufficient psychometric properties established to warrant recommendation as a 'reference standard' for clinical or research use. There is a need for higher quality studies exploring measurement properties of these scales before specific recommendations can be made.

3.7 Comprehensive clinical sitting balance measures for individuals following stroke: Additional research evidence

The systematic review identified 39 articles investigating 14 different clinical sitting balance measures that contain dynamic sitting tasks. No lateropulsion scales were included in the review given these scales do not include dynamic sitting balance items. The review was unable to identify a specific sitting balance measure with adequate psychometric properties to be chosen as the preferred scale for the measurement of sitting balance following stroke. The systematic review examined the evidence available until 31 December 2015. An updated search was conducted from January 2016 until September 2020. For the updated search, only one reviewer (MB) assessed the titles and abstracts, and subsequently the full text articles of those flagged to be included. Data extraction and application of the COSMIN checklist for each evaluated psychometric property in the additionally identified articles was also completed by one reviewer (MB) only.

An additional 12 articles which met the inclusion criteria were identified in the updated search, relating to five clinical sitting balance measures, including one measure, the Sitting Balance Scale, which was not included in the original systematic review. The Sitting Balance Scale contains 11 items which assess diverse aspects of static and dynamic sitting balance. Examples of tasks included in this measure include sitting with eyes closed, sitting on foam, turning to look behind, reaching forwards, reaching laterally, and picking up an object from the floor (Medley & Thompson, 2011).

Details of the additionally identified studies are summarised in Table 3.6. Psychometric properties of the studies evaluating different aspects of reliability of the sitting balance measures are outlined in Table 3.7. Table 3.8 outlines the studies investigating different aspects of validity and responsiveness. The overall quality rating assigned by utilising the COSMIN checklist to evaluate each psychometric property examined are listed in Tables 3.7 and 3.8. As was the case in the original systematic review, using the COSMIN checklist, the majority of properties examined in the additional review (outlined in Tables 3.7 and 3.8)

Table 3.6. Characteristics of additionally identified studies

Outcome measure (sitting item only)	Author and Year	Country	Participant n	Type of stroke	Mean time after stroke	Distribution of sex (% male)	Mean age years	Assessor n, discipline
Single item measures as part of functional or motor scale								
Motor Assessment Scale	(Lima et al., 2019)	Brazil	52 (reliability)	Infarct; Haemorrhage	51 months	64%	57	2 (inter-rater), NR; 1 (test-retest), NR
Sitting items as part of balance measure								
Brunel Balance Assessment	(Aydoğan Arslan et al., 2020)	Turkey	145 (40 inter-rater testing)	Ischaemic, Haemorrhage	NR	47%	65.5	2, PT
Sitting balance measures								
Function in Sitting Test	(Cabanas-Valdés et al., 2017)	Spain	60	Ischaemic, Haemorrhage	Median 37.5 days	68%	68.2	3, PTs and OT
	(Ozdil et al., 2019)	Turkey	30	NR	8.2 months	53%	70.6	NR
	(Alzyoud et al., 2020)	US	43	Ischaemic, Haemorrhage	106 days	58%	71.6	1, NR
Sitting Balance Scale	(Alzyoud et al., 2020)	Details outlined above under Functional in Sitting Test, Alzyoud, 2020 #358}						
Trunk Impairment Scale/s *TIS 2.0*	(Cabanas-Valdés et al., 2016)	Spain	58	Ischaemic, Haemorrhage	NR	62%	70.6	3, NR
TIS-I	(Lombardi et al., 2017)	Italy	41	Ischaemic. Haemorrhage	13.1 days	39%	68.8	2, NR (reliability); NR, PT (validity)
m-TIS	(Lee et al., 2018)	Republic of Korea	55	Ischaemic, Haemorrhage	8.4 months	51%	60.0	s2, research assistants
Original TIS	(Kong & Ratha Krishnan, 2019)	Singapore	577	Infarct, haemorrhage	NR	65%	63.2	NR
Original TIS	(Monticone et al., 2019)	Italy	103 acute (cohort 1), 100 chronic (cohort 2)	Ischaemic, Haemorrhage	Median 22 days (cohort 1) and 12 months (cohort 2)	54% (cohort 1), 58% (cohort 2)	74.5 (cohort 1). 67.2 (cohort 2)	NR; PTs

Turkish version of TIS	(Sag et al., 2019)	Turkey	80	Ischaemic, Haemorrhage	1.9 months	58%	63	NR
TIS 2.0	(Karthikbabu & Verheyden, 2021)	NR	177	Ischaemic. Haemorrhage	Median 12 months	62%	Median 57	3, PT

m-TIS indicates modified TIS-Norwegian version; n, number; NR, not reported; PT, physical therapist; OT, occupational therapist; %, percentage; TIS, Trunk Impairment Scale; TIS-I, Trunk Impairment Scale-Italian

Table 3.7. Measurement properties and methodological quality of additionally identified studies on reliability

Outcome measure (sitting item only)	Author and Year	Internal consistency (analysis; results)	Test-retest reliability (results)	Inter-rater reliability (results)	Intra-rater reliability (results)	Measurement error (results)	COSMIN quality score
Single item measures as part of functional or motor scale							
Motor Assessment Scale	(Lima et al., 2019)			Kappa=0.81	Kappa=0.87		Fair (inter-rater reliability); Fair (intra-rater reliability)
Sitting items as part of balance measure							
Brunel Balance Assessment	(Aydoğan Arslan et al., 2020)				Supported sitting ICC=0.70, sitting AR ICC= 0.89, sitting FR ICC=0.81		Poor (intra-rater reliability)
Sitting balance measures							
Function in Sitting Test	(Cabanas-Valdés et al., 2017)	Cronbach's alpha=0.97		ICC=0.997	ICC=0.999		Poor (internal consistency); Poor (inter-rater reliability); Poor (intra-rater reliability)
Trunk Impairment Scale/s *TIS 2.0*	(Cabanas-Valdés et al., 2016)	Cronbach's alpha; DSB 0.899, COO 0.613, total TIS 0.896		Kappa=0.487-0.965; DSB ICC=0.996 COO ICC0.984 Total TIS=0.996	Kappa>0.80, DSB ICC=0.998, COO ICC=0.990, Total TIS=0.998		Fair (internal consistency); Fair (inter-rater reliability); Fair (intra-rater reliability)
TIS-I	(Lombardi et al., 2017)	Cronbach's alpha; SSB 0.83; DSB 0.79; COO 0.82, total TIS 0.88		Kappa=0.48-1 SBB ICC=0.90; DSB ICC=0.87; COO ICC=0.73, total TIS ICC=0.93	Kappa=0.41-1 SBB ICC=0.89; DSB ICC=0.82; COO ICC=0.77, total TIS ICC=0.91	SEM for Total TIS; inter-rater 0.46, intra-rater 1.64	Poor (internal consistency); Fair (inter-rater reliability); Fair (intra-rater reliability); Fair (measurement error)
Original TIS	(Monticone et al., 2019)	Cronbach's alpha; cohort 1 0.79, cohort 2 0.73		cohort 1 Kappa=0.85-1 cohort 1 ICC=0.99 cohort 2 Kappa=0.9-0.98 cohort 2 ICC=0.99	cohort 1Kappa=0.9-1 cohort 1 ICC=0.99 cohort 2 Kappa=0.9-1 cohort 2 ICC=0.99	SEMs for subscales and total score; cohort 1 <0.7, cohort 2 <0.4	Poor (internal consistency); Fair (inter-rater reliability); Fair (intra-rater reliability); Poor (measurement error)

Turkish version of TIS	(Sag et al., 2019)	Cronbach's alpha; SSB 0.78; DSB 0.91; COO 0.85, total TIS 0.93	total TIS ICC=0.96	SBB ICC=1.00; DSB ICC=0.99; COO ICC=0.97, total TIS ICC=0.99	SBB ICC=0.99; DS ICC=0.98; COO ICC=0.98, total TIS ICC=0.99		Poor (internal consistency); Poor (test-retest reliability); Poor (inter-rater reliability); Poor (intra-rater reliability)

AR indicates arm raise; COO, Coordination subscale; COSMIN, Consensus-based Standards for selection of health status Measurement Instruments; DSB, Dynamic sitting balance subscale; FR, forward reach; ICC, intraclass correlation; Kappa, Kappa coefficient; SEM, standard error measurement; SSB, Static sitting balance subscale; TIS, Trunk Impairment Scale.

Table 3.8. Methodological quality and measurement properties of additionally identified studies on aspects of validity and responsiveness

Outcome measure (sitting item only)	Author and Year results*)	Hypotheses testing *Convergent* (other measure; (results*)	*Discriminative* (analysis; results*)	*Predictive*	Cross-cultural validity	Responsiveness (results*)	COSMIN quality score
Single item measures as part of functional or motor scale							
Motor Assessment Scale	(Lima et al., 2019)				Translated into Brazilian Portuguese		Fair (cross-cultural)
Sitting items as part of balance measure							
Brunel Balance Assessment	(Aydoğan Arslan et al., 2020)				Translated into Turkish		Poor (cross-cultural)
Sitting balance measures							
Function in Sitting Test	(Cabanas-Valdés et al., 2017)	TIS 2.0; r_s=0.791			Translated into Spanish		Poor (convergent); Poor (cross-cultural)
	(Ozdil et al., 2019)	Eyes-open and eyes-closed COP deviation; NS	Significant difference between stroke and healthy group				Poor (convergent); Poor (discriminative)
	(Alzyoud et al., 2020)					ES 1.11, SRM 1.49	Poor (responsiveness)
Sitting Balance Scale	(Alzyoud et al., 2020)					ES 1.34, SRM 2.29	Poor (responsiveness)
Trunk Impairment Scale/s *TIS 2.0*	(Cabanas-Valdés et al., 2016)				Translated into Spanish		Poor (cross-cultural)
TIS-I	(Lombardi et al., 2017)	TCT, BI, LIND-MOB, FM-BAL; TCT r_s=0.81; BI r_s=0.63, LIND-MOB r_s=0.79, FM-BAL r_s=0.74			Translated into Italian		Fair (convergent); Poor (cross-cultural)
m-TIS	(Lee et al., 2018)	BBS, TUG, 5mWT, FAC, FM-LE PASS-TC. TCT, modified BI; BBS r_s=0.82; TUG r_s=0.70; 5mWT	Significant differences between stroke survivors and				Poor (convergent); Fair (discriminative)

		r_s=0.73; FAC r_s=0.54; FMA-LE r_s=0.80; PASS-TC r_s=0.55; TCT r_s=0.63; modified BI r_s=0.80	healthy adults				
Original TIS	(Kong & Ratha Krishnan, 2019)			Multivariate logistic regression; admission TIS score most important variable for predicting D/C FIM-motor score (Beta=0.23, p<0.001)			Poor (predictive)
Original TIS	(Monticone et al., 2019)	BI, FIM-motor, TCT pre and post-training; cohort 1 BI r_p=0.67 and 0.70, FIM-motor r_p=0.57 and 0.73, TCT r_p=0.85 and 0.67; cohort 2 BI r_p=0.48 and 0.46, FIM-motor r_p=NS and 0.31, TCT r_p=0.67 sand 0.68			Translated into Italian	ES, SRM; cohort 1 ES 0.99, SRM 1.63; cohort 2 ES 0.63. SRM 0.99	Poor (convergent); Poor (cross-cultural); Poor (responsiveness)
Turkish version of TIS	(Sag et al., 2019)	BBS, RMI, BI; BBS r_p=0.89, RMI r_p=0.78, BI r_p=0.78			Translated into Turkish		Poor (convergent); Poor (cross-cultural);
TIS 2.0	(Karthikbabu & Verheyden, 2021)			stepwise multivariate linear regression; TIS 2.0 total score (partial R^2=0.433) and DSB score (partial R^2=0.376) were strong determinants of balance confidence			Fair (predictive)

5mWT, 5-metre walk test; BI, Barthel Index; BBS, Berg Balance Scale; COSMIN, Consensus-based Standards for selection of health status Measurement Instruments; D/C, discharge; DSB, Dynamic sitting balance subscale; ES, Effect size; FAC, Functional Ambulation Classification; FIM, Functional Independence Measure; FM-BAL, Balance subscore of Fugl-Meyer; FM-LE, Fugl-Meyer Lower Extremity; LIND-MOB, Mobility section of motor assessment chart; m-TIS, modified TIS-Norwegian version; NS, not significant; PASS-TC, Postural Assessment Scale for Stroke-Trunk Control; RMI, Rivermead Motor Index; r_p, Pearson product-moment correlation coefficient; SRM, Standardised response mean; r_s, Spearman's rank correlation coefficient; TCT, Trunk Control Test; TIS, Trunk Impairment Scale; TIS-I, Trunk Impairment Scale-Italian; TUG, Timed Up and Go Test.

*Please note, results are significant unless indicated as not significant (NS).

were scored as poor (66%) to fair (34%). Similar reasons as identified in the original systematic review relating to small sample sizes, completion of inappropriate statistical analyses and insufficient creation of hypotheses prior to data collection contributed to the generally low ratings attributed to the additional studies.

Two of the additionally identified studies investigated aspects of reliability and cross-cultural validity for the Motor Assessment Scale Balance sitting item (Lima et al., 2019) and the sitting items of the Brunel Balance Assessment (Aydoğan Arslan et al., 2020), with the quality of the measurement properties evaluated for these two measures rated as fair and poor respectively. Thus, the key findings of the original systematic review relating to the single item measures as part of functional or motor scales and the sitting items as part of balance measures remain unchanged following the updated search.

For the stand-alone measures of sitting balance, the studies related to two previously identified scales, the Function in Sitting Test and the Trunk Impairment Scale, and one measure, the Sitting Balance Scale, which had not been previously identified. Given only responsiveness has been evaluated for the Sitting Balance Scale with stroke survivors in a study of poor quality (Alzyoud et al., 2020), the use of this scale cannot be recommended. For the seven additional studies identified evaluating varying versions of the Trunk Impairment Scale, including four studies investigating cross-cultural validity, the methodological quality was rated as poor or fair. Despite the methodological flaws of the newly identified studies, the results of the updated search support the findings of the original systematic review. That is, whilst sound psychometric properties exist for the Trunk Impairment Scale, ultimately the scale evaluates sitting balance in regard to trunk impairment, and not through the completion of functional sitting balance tasks.

In the original systematic review, only one study of limited quality evaluated some psychometric properties of the Function in Sitting Test, including the internal consistency, and the content, structural and convergent validity of this scale (Gorman et al., 2010). Three further studies investigating the Function in Sitting Test were identified in the additional search, evaluating different psychometric properties of the measure including the inter-rater and intra-rater reliability (Cabanas-Valdés et al., 2017), discriminative validity (Ozdil et al., 2019), cross-cultural validity (Cabanas-Valdés et al., 2017) and responsiveness (Alzyoud et al., 2020). The poor quality of these additional studies mean that the Function in Sitting Test cannot be recommended as the preferred outcome measure for assessing sitting balance following stroke, despite positive results obtained from the additional studies regarding the various measurement properties investigated. However, the findings support the need for higher quality studies to further explore the psychometric properties of this promising clinical sitting balance measure.

In summary, the results obtained from the updated review predominantly support the findings of the original systematic review presented in this chapter, that there are currently no clinical sitting balance scales with adequate measurement properties to recommend as the chosen measure for use with stroke survivors, and that further studies of higher quality are necessary. However, the Function in Sitting Test was flagged in the updated review as a promising measure of static and dynamic sitting balance that warrants further investigation with higher quality studies.

Chapter 4. Methods

Chapter Outline

This chapter presents an overview of the methods utilised in the feasibility study (Chapter 6) and the main longitudinal study (Chapters 7, 8 and 9) included in this thesis. This chapter includes additional details regarding these studies which could not be included in the individual manuscripts due to word count limitations.

The following areas are described in detail in this chapter for the studies included in this thesis:

1. Research questions
2. Study design
3. Participant inclusion criteria and recruitment
4. Outcome measures
5. Testing procedures

In each of the subsequent chapters relating to the feasibility study (Chapter 6) and the different components of the main longitudinal study (Chapters 7, 8 and 9) only a brief methods section is included within the published or original manuscript.

4.1 Feasibility study methods (see Chapter 6)

4.1.1 Research question

Is it feasible to use the WBB as an instrumented measure of sitting and standing balance in stroke survivors with lateropulsion early after stroke?

4.1.2 Study design

Prospective repeated measures study.

4.1.3 Ethical approval

This study was approved by the human research ethics committees of St Vincent's Hospital Melbourne and Curtin University (LRR 084/13, HR 174/2013; Appendix 1).

4.1.4 Participant inclusion criteria and recruitment

Ten participants were recruited to the feasibility study from admissions to the Stroke Unit and Rehabilitation Units of St. Vincent's Hospital Melbourne between April to December 2014. To ensure testing was conducted with individuals across the continuum of functional abilities, including those with more severe stroke, at least 30% of individuals who were recruited were unable to stand without assistance during the first assessment occasion.

The inclusion criteria included:

- Diagnosis of acute stroke
- Between one and twelve weeks post stroke
- The presence of contraversive lateropulsion (defined as a score greater than or equal to two on the BLS (Babyar et al., 2015, 2017; Babyar et al., 2009; Babyar et al., 2008; Chow et al., 2019)
- Able to sit with back and upper limb support for at least three seconds
- Able to follow at least one stage verbal command with gesture
- Able to complete a 20 minute physiotherapy session
- Able to provide informed consent

Exclusion criteria included:

- Pre-stroke co-morbidity limiting an individual's ability to mobilise independently in the community (Functional Ambulation Classification (FAC) less than six (Holden et al., 1984))
- Weight >112kg (due to weight limitations of the transfer bench which the WBB was securely fastened to for the participant to sit on).

4.1.5 Outcome measures

Instrumented measures

Participants were assessed sitting on a WBB which was securely fastened to a transfer bench. The height of the transfer bench was adjusted for each individual so to achieve 90 degrees of hip and knee flexion (van Nes et al., 2008). With the assistance of the therapist, participants were centred as much as possible on the WBB using coloured lines spaced one centimetre apart, and sat with two thirds thigh support (Genthon & Rougier, 2006; Roerdink et al., 2011), feet hip width apart and shanks vertical (van Nes et al., 2008) (see Figure 4.1 for setup). If necessary, a small footstool or inactive WBB was used under the participants' feet to achieve this alignment, as the minimum height that the transfer bench could be adjusted to was inadequate for many participants.

Participants were initially assessed sitting with and without arm support (Figure 4.1(a) and (b)). If able, participants then performed a number of predominately dynamic balance tasks in sitting, informed by clinical measures (Gorman et al., 2010; Tyson & DeSouza, 2004b). These tasks included shifting weight to the non-paretic side, shifting weight to the paretic side, maintaining balance while closing their eyes, raising their non-paretic arm up and down, reaching to the non-paretic side, and turning and picking up a pen from behind them (Gorman et al., 2010; Tyson & DeSouza, 2004b). A variety of tasks were included in order to determine their appropriateness for assessing postural control when using instrumented measures for individuals with lateropulsion following stroke.

Instrumented measures were also recorded in standing if an individual was able. For the standing tasks, individuals stood on one WBB with their feet positioned with heels hip width apart and nine degrees of toe out (de Haart et al., 2005; de Haart et al., 2004; Roerdink et al., 2009). Coloured toe out lines drawn one centimetre apart on the WBB assisted with achieving and replicating this foot position on subsequent testing occasions. If this degree of toe out could not be achieved with a given individual, the degree of toe out was set by the therapist to the observed resting position of the non-affected foot in sitting. For testing in standing, participants stood next to a plinth on their non-paretic side placed 15 centimetres away from the anterior superior iliac spine on this side, with a plinth behind them (in a low position) which was utilised for seated rests as required (see Figure 4.2 for setup).

(a) Sit with arm support

(b) Sit without arm support

Figure 4.1. Setup of equipment for the static sitting tasks in the feasibility study

As occurred in sitting, participants were initially asked to stand with and without arm support (Figure 4.2(a) and (b)). A number of more complex standing balance tasks were then performed with participants who were able. These included shifting weight to the non-paretic leg, shifting weight to the paretic leg, standing with eyes closed, turning one's head while standing, and standing with feet together (Berg et al., 1992).

Both sitting and standing tasks were performed with individuals barefoot. Demonstration of the required task was performed by the assessor prior to testing of the participant and standardised instructions were used for all tasks. If possible, three trials of each task were performed. If, however, fatigue was identified early in testing as a potential issue, two trials of each task were completed instead in order to maximise the number of different tasks an individual undertook and was able to have data recorded for. For visual analysis of the data, data from all successful trials were utilised. In order to ensure participant safety, individuals were closely supervised by the assisting therapist on their affected side throughout the testing session.

(a) Stand with arm support (b) Stand without arm support

Figure 4.2. Setup of equipment for the static standing tasks in the feasibility study

The WBB was wirelessly connected via Bluetooth to a laptop and controlled by a custom-designed data acquisition and analysis system. The WBB yielded COP measures comparable to those acquired from a laboratory force plate, including total, mediolateral and anteroposterior COP path velocity (Clark et al., 2010).

Clinical measures

In regard to clinical measures, lateropulsion was measured using the BLS (D'Aquila et al., 2004). Postural abilities were measured using the PASS (Benaim et al., 1999). The use of a postural control outcome measure, such as the PASS, in addition to a measure of lateropulsion has previously been recommended in studies involving individuals with lateropulsion following stroke (Clark et al., 2012; Koter et al., 2017).

Active motor control, sensation and neglect were assessed using lower extremity items of the Stroke Rehabilitation Assessment of Movement Instrument (Daley et al., 1999), the lower limb sensory section of the Fugl-Meyer Assessment (Fugl-Meyer et al., 1975) and the

Catherine Bergego Scale (Azouvi et al., 1996) respectively, while the participants' functional abilities were measured using the FIM (motor domain) (Linacre et al., 1994). Psychometric properties of the clinical measures are outlined below, with the exception of the BLS (D'Aquila et al., 2004) (Appendix 2) which has previously been discussed (Assessment of lateropulsion (clinical measures) – see section 2.2.2).

<u>Postural Assessment Scale for Stroke</u>

The PASS (Benaim et al., 1999) (Appendix 3) is a 12-item scale designed to measure postural control with stroke survivors in lying, sitting and standing (Benaim et al., 1999). Items from two domains are incorporated, including items which measure an individual's ability to maintain a given posture, and other items that assess the level of assistance required for an individual to complete specific positional changes. High internal consistency (Benaim et al., 1999; Mao et al., 2002), high inter-rater reliability (Benaim et al., 1999) and high test-retest reliability have been reported for the PASS (Benaim et al., 1999; Mao et al., 2002). High concurrent validity of the PASS with the Berg Balance Scale (Mao et al., 2002), the Balance subscale of the Fugl-Meyer test (Mao et al., 2002) and the Trunk Impairment Scale (Di Monaco et al., 2010), as well as good predictive validity for ambulation independence on discharge from rehabilitation (Huang et al., 2016) have been demonstrated. The PASS has also been found to be moderately to highly responsive within the first three months following stroke (Mao et al., 2002) and with stroke survivors with lateropulsion (Clark et al., 2012).

<u>Lower extremity subscale of the Stroke Rehabilitation Assessment of Movement Instrument</u>

The lower extremity subscale of the Stroke Rehabilitation Assessment of Movement Instrument (Daley et al., 1999) (Appendix 4) assesses voluntary movement of the affected lower extremity using ten three-point items. Scores are converted to a percentage score out of 100 to account for any items that cannot be scored for specific reasons, such as pain or limitations in range of movement (Daley et al., 1999). High inter-rater reliability (Daley et al., 1999; Wang et al., 2002), high test-retest reliability (Hsueh et al., 2008) and excellent internal consistency (Daley et al., 1999) have been demonstrated for the lower extremity subscale of the Stroke Rehabilitation Assessment of Movement Instrument. High concurrent validity with the lower extremity subscale of the Fugl-Meyer motor assessment scale has been established (Wang et al., 2002), whilst the lower limb subscale of the Stroke Rehabilitation Assessment of Movement Instrument has also been found to be responsive to change (Hsueh et al., 2008; Ward et al., 2011).

Lower limb sensory subscale of the Fugl-Meyer Assessment

The lower limb sensory section of the Fugl-Meyer Assessment (Sullivan et al., 2011) (Appendix 5) includes six three-point items; two assessing light touch sensation of the thighs and soles of feet, and four assessing joint position sense at the big toe, ankle, knee and hip, with a maximum score of 12 indicating intact sensation. High internal consistency (Lin et al., 2004) and high intra-rater and inter-rater reliability have been reported for the total sensory score of the Fugl-Meyer Assessment (Sullivan et al., 2011). Poor concurrent validity has been found between scores from the sensory subscale of the Fugl-Meyer Assessment and the Barthel Index and the motor section of the Fugl-Meyer Assessment (Lin et al., 2004). This finding is not surprising given these measures assess different constructs rather than sensory impairment. More recently, high concurrent validity has been observed between the sensory subscale of the Fugl-Meyer Assessment and the Revised Nottingham Sensation Assessment which both assess components of somatosensory function (Wu et al., 2016). Finally, whilst the responsiveness of the sensory subscale of the Fugl-Meyer Assessment has been reported to be moderate to low (Lin et al., 2004), this was not considered to be an issue in the present study, given the measure was only used initially to identify lower limb sensory impairment and not to monitor change over time.

Catherine Bergego Scale

The Catherine Bergego Scale (Azouvi et al., 1996) (Appendix 6) provides a functional assessment of spatial neglect using ten items related to different everyday-life activities (Azouvi et al., 1996). Each item is scored zero to three and items are summed together to provide an overall score of neglect severity. The Catherine Bergego Scale has been found to have good internal consistency (Azouvi et al., 1996), excellent concurrent validity (Azouvi et al., 1996; Azouvi et al., 2003) and is more sensitive to change than commonly used paper-and-pencil tests of neglect (Azouvi et al., 2003). In order to standardise the administration of the Catherine Bergego Scale, the Kessler Foundation Neglect Assessment Process (KF-NAP™), which provides detailed instructions on how to administer the Catherine Bergego Scale, has been developed (Chen et al., 2012).

Functional Independence Measure (motor domain)

The FIM (motor domain) (Linacre et al., 1994) (Appendix 7) is the 13-item component of the 18-item full FIM scale (which also includes the 5-item cognition component). The motor domain of the FIM assesses dependence in self-care, sphincter control, transfer and locomotion to provide an overall measure of physical disability, each on a 1 to 7 point ordinal scale (Linacre et al., 1994). Scores from the FIM (motor domain) range from 13 to 91, with a higher score representing greater functional independence. High internal consistency (Hseuh et al., 2002; Stineman et al., 1996), concurrent validity (Hseuh et al., 2002) and responsiveness (Hseuh et al., 2002) of the FIM (motor domain) have been demonstrated with individuals following stroke undergoing inpatient rehabilitation. The FIM (motor domain) score at admission to rehabilitation has also been identified as a primary predictor of length of stay and discharge to home following rehabilitation (Brown et al., 2015).

4.1.6 Procedures

Participants were recruited to the trial when the inclusion criteria were met. Within a testing session, participants were assessed using the instrumented measures first. This was followed by a 20 minute rest period in supine, and then the clinical measures of lateropulsion and postural control were performed.

In order to reduce the length of testing time and minimise participant fatigue, the BLS and PASS were applied simultaneously. An assessment procedure previously described to perform the BLS and SCP concurrently (Krewer, Rieß, et al., 2013) was adapted instead to include the completion of the PASS with the BLS. The procedure utilised was as follows. Firstly, the participant was assisted to transfer from the wheelchair to the plinth, during which time the participant's reaction to the transfer was assessed (BLS transfers). The participant's ability to move from sitting on the edge of the plinth to supine was then determined (PASS item 9). While in supine, the supine log roll test was completed (BLS), followed by an assessment of the individual's ability to roll to their affected and non-affected sides (PASS items 6 and 7). The participant's ability to move from lying to sitting on the edge of the plinth was then evaluated (PASS item 8). Sitting on the edge of the plinth with their feet touching the ground, sitting ability was assessed (PASS item 1). The plinth was then raised so the participant's feet were off the floor and the sitting item of the BLS was completed. Subsequently sit to stand ability was determined from a plinth 50 centimetres high (PASS item 10). In standing, the standing item of the BLS was assessed, as well as the individual's ability to stand with and without support (PASS items 2 and 3). This was followed by an attempt to walk with assistance, during which the severity of lateropulsion present was measured (BLS walking item), and then the participant's ability to perform standing to sitting was evaluated (PASS item 11). Finally, the participant was assessed standing on their non-paretic leg, standing on their paretic leg and picking up a pencil from the floor from standing to determine their ability to perform these tasks (PASS items 4, 5, and 12 respectively).

In addition to the measures of lateropulsion and postural control, the impairment measures (motor control, sensation and neglect) were administered during the initial testing session. If required, participants were given additional rest periods at specified time periods within a testing session, in order to maximise the amount of testing that occurred within the limits of participant fatigue. The number, timing and duration of any additional rest periods were recorded. Trained assessors (physiotherapists with greater than five years postgraduate experience and at least two years of experience in the areas of rehabilitation or neurology) were used for all tests.

Data collection for the instrumented and clinical measures of lateropulsion and postural control were repeated the following day (day two), and then a fortnight later (day 14 and day 15). Data were collected at these four time points to explore whether issues with consistency of performance were present early following stroke compared with two weeks later. This information was used to inform when data collection for the reliability component of the main study occurred. Demographic information (including date of birth, age, gender, pre-stroke mobility and comorbidities), stroke characteristics (date of stroke, pathology, side of hemiparesis and computed tomography report) and an individual's FIM (motor domain) were recorded initially.

4.2 Longitudinal study methods (see Chapters 7-9)

4.2.1 Research questions

i. What is the relationship between instrumented measures of postural control in sitting and standing and clinical measures of lateropulsion and postural function in individuals with lateropulsion? (Chapters 7-8)
ii. Are measures of COP in sitting and WBA in standing reliable between test occasions in individuals with lateropulsion? (Chapters 7-8)
iii. What mobility and functional outcomes can be achieved by stroke survivors with lateropulsion at six months post stroke? (Chapter 9)
iv. What is the association between baseline lateropulsion scores, and functional outcomes achieved six months post stroke? (Chapter 9)

v. What is the pattern of recovery for lateropulsion and standing symmetry in the subacute phase of stroke? (Chapter 9)

4.2.2 Study design

Prospective repeated measures study.

4.2.3 Ethical approval

This study was approved by the human research ethics committees of St Vincent's Hospital Melbourne and Curtin University (HREC-A 146/15, HR 15/2015; Appendix 1).

4.2.4 Participant inclusion criteria and recruitment

Participants were recruited to the longitudinal study from consecutive admissions to the Stroke Unit and Rehabilitation Units of St. Vincent's Hospital Melbourne between January 2016 to December 2018. The inclusion and exclusion criteria utilised for the longitudinal study were replicated from the feasibility study with the exception of two criteria. Individuals who were unable to consent for themselves were included (see process, described below), whilst individuals with ataxia were excluded from the longitudinal study. Ataxia was added as an exclusion criterion, as in the feasibility study, a participant with ataxia demonstrated distinctly different patterns of variability in their COP measures, compared to the other nine subjects without ataxia. These differences in variability appeared to capture a different phenomenon in postural control when ataxia was present which had been overlooked when determining the inclusion criteria for the feasibility study. Where potential participants did not meet the baseline requirements to be approached regarding participation (i.e. able to sit with back and arm support for more than three seconds), the baseline requirements were reviewed again one or two weeks later, in an attempt to ensure the maximum capture of stroke survivors with more severe lateropulsion were included in the study.

Written consent was obtained from those participants who were able to consent for themselves. For the individuals who were unable to consent due to communication or cognitive deficits, competence to consent was determined by medical staff, in consultation with the speech pathologists and occupational therapists, as commonly occurs in the acute stroke and rehabilitation settings. For the individuals who were deemed unable to consent for themselves, written consent was sought from the individual's Next of Kin or Carer.

4.2.5 Outcome measures

Instrumented measures

The sitting setup utilised within the feasibility study which has previously been outlined (section 4.1.5 Outcome measures: Instrumented measures) was replicated for the longitudinal study. Thus, participants were assessed seated on a WBB securely fastened to a transfer bench with two thirds thigh support (Genthon & Rougier, 2006; Roerdink et al., 2011), 90 degrees of hip and knee flexion, shanks vertical (van Nes et al., 2008) and feet hip width apart (see Figure 4.3 for setup). If required, a small step or inactive WBB was used beneath the participants' feet to attain this position, as the minimum height that the transfer bench could be lowered to was inadequate for many participants.

Participants performed four tasks seated on the WBB if able in the following order. These included: 1) sitting with the use of the non-paretic upper limb holding a rail (Figure 4.3(a)); 2) sitting without upper limb support (Figure 4.3(b)); 3) reaching to pick up a cup in front, within arm's length with the non-paretic hand (Figure 4.3(c)); 4) reaching to pick up a cup on the non-paretic side, beyond arm's length with the non-paretic hand (Figure 4.3(d)). These tasks were chosen based on the results of the feasibility study (Chapter 6) (Birnbaum et al., 2018). Whilst the static sitting tasks were identical to those performed in the pilot study, the reaching tasks were adapted from those completed to involve reaching to an object in a pre-determined position, in an attempt to minimise variability between trials. Given the tasks were performed in order of difficulty, if a participant could not successfully complete a task after three attempts, testing of the sitting tasks was stopped.

The two static sitting tasks were performed for three seconds duration as occurred in the feasibility study (Chapter 6) (Birnbaum et al., 2018). This was to enable data to be collected for individuals across the spectrum of lateropulsion severity, including those with limited sitting ability. For the reaching tasks, the cup was positioned on a tray table adjusted to just below shoulder height at 80% of an individual's trunk length. Only reaching with the non-paretic upper limb was assessed given upper limb deficits may interfere with the performance of this task using the paretic arm. The position of the cup for both reaching tasks was

(a) Sit with arm support

(b) Sit without arm support

(c) Sit reach forwards, within arm's length

(d) Sit reach diagonally to the non-paretic side, beyond arm's length

Figure 4.3. Setup of equipment for the four sitting tasks in the longitudinal study

standardised relative to an individual's non-paretic arm length, measured as the distance from the acromion to wrist crease. For the forward reaching task, the cup was placed in front of the non-paretic side at 100% of an individual's arm length measured from the non-affected anterior superior iliac spine. For reaching to the diagonal, reach was assessed on a 45 degree angle to the non-paretic side at a distance of 140% of an individual's arm length (Dean et al., 2007) from the individual's non-affected anterior superior iliac spine.

For those participants who could stand unsupported using their non-paretic upper limb for greater than three seconds, standing ability was also assessed. Two WBBs were utilised in the longitudinal study for all standing tasks (changed from one WBB in the feasibility study). The use of two WBBs was selected for the longitudinal study to allow information regarding weight bearing symmetry to be collected in preference to COP variables, which could not be investigated in the feasibility study when only one WBB was used. Aside from the addition of an extra WBB, the standing position used in the feasibility study was replicated in the longitudinal study. Thus, individuals stood with their feet positioned with heels hip width apart and nine degrees of toe out (de Haart et al., 2005; de Haart et al., 2004; Roerdink et al., 2009). If this could not be achieved, the degree of toe out was set by the therapist to the observed resting position of the non-affected foot in sitting (see Figure 4.4 for standing position).

For testing in standing participants stood next to a plinth on their non-paretic side positioned at a distance of 20 centimetres away the anterior superior iliac spine, to prevent the plinth from blocking weight shift in standing. The height of the plinth beside the individual was adjusted to the distance measured from wrist crease to heel in supine, plus the height of the WBB to account for the individual standing on them. A plinth was also placed behind the individual (adjusted to sitting height) and was utilised for seated rests as required between tasks (see Figure 4.4 for setup).

The following tasks were performed with participants in standing as able in the order listed: 1) standing with upper limb support, with the non-paretic hand resting on a plinth (Figure 4.4(a)); 2) standing without upper limb support (Figure 4.4(b)); 3) reaching to pick up a cup in front in standing, within arm's length (Figure 4.4(c)); 4) reaching to pick up a cup from the non-paretic side in standing, beyond arm's length (Figure 4.4(d)); 5) sit to stand with upper limb support, with the non-paretic hand resting on a plinth; 6) standing with feet together.

These tasks were selected based on the results of the feasibility study (Chapter 6) (Birnbaum et al., 2018). As occurred in sitting, since the standing tasks were assessed in order of difficulty, testing in standing was ceased if a participant could not successfully complete a task following three attempts. Data collected from the sit to stand with upper limb support and standing with feet together tasks were not analysed, as only 11 and nine of the 33 participants respectively could complete these tasks on the day 1 assessment occasion. Subsequently, these tasks are not elaborated on further in this Methods Chapter nor outlined in Chapter 8 where the results of the standing component of the longitudinal study are presented.

The two static standing tasks (standing with arm support and standing without arm support) were performed for three seconds duration as occurred in the feasibility study. For the standing with arm support task, participants placed their non-paretic hand flat on the plinth beside them in a self-selected position (Figure 4.4(a)). For the reaching tasks, the cup was positioned at 75% of shoulder height using either a step or stacked dense foam placed on an adjustable plinth to achieve the required height. As occurred in sitting, only reaching with the non-paretic upper limb was assessed in standing and the cup position was standardised relative to an individual's non-paretic arm length. For the forward reaching task, the cup was placed on foam that was securely resting 10 centimetres off the supporting plinth on the non-paretic side, at 80% of an individual's arm length measured from the non-affected anterior superior iliac spine (Figure 4.4(c)). For reaching to the diagonal, reach was assessed on a 45 degree angle to the non-paretic side, at a distance of 140% of an individual's arm length from the individual's non-affected anterior superior iliac spine (Figure 4.4(d)).

As occurred in the feasibility study, tasks were assessed with the participants barefoot. Demonstration of each task was performed by the assessor prior to its completion and standardised instructions were used for all tasks. Three trials of each task were performed unless fatigue was identified early in testing as an issue, in which case two trials of each task were completed. For analysis purposes, the median of the successfully completed trials was used. Participants were closely supervised by the assisting therapist on their affected side throughout testing and steadied if required to maintain balance.

(a) Stand with arm support

(b) Stand without arm support

(c) Stand reach forwards, within arm's length

(d) Stand reach diagonally to the non-paretic side, beyond arm's length

Figure 4.4. Setup of equipment for the four standing tasks in the longitudinal study

On each testing occasion, participants with lateropulsion performed the tasks appropriate for their current level of sitting and standing ability. Therefore, some individuals could only perform one or two sitting tasks on the initial testing occasion, whilst others could perform all of the sitting tasks and some tasks in standing. On subsequent testing occasions, relevant tasks in sitting and/or standing were added to the testing battery as they were able to be performed.

For the longitudinal study the WBB(s) were controlled in a similar manner to the feasibility study with the use of a laptop operating a custom-designed data acquisition and analysis system. For the sitting tasks, amplitude, standard deviation (as a measure of COP variability) and path velocity were the COP variables acquired from the WBB which were analysed. Mediolateral amplitude and mediolateral standard deviation were identified in the feasibility study as variables of interest in individuals with lateropulsion following stroke (Chapter 6) (Birnbaum et al., 2018). For the standing tasks involving two boards, mean and absolute WBA were examined.

Clinical measures

The clinical measures used within the longitudinal study were replicated from the feasibility study with the completion of an additional measure, the FAC. Thus, the BLS (D'Aquila et al., 2004) was utilised to measure lateropulsion, while the PASS was used to assess postural abilities (Benaim et al., 1999). Active motor control, sensation and neglect were assessed using lower extremity items of the Stroke Rehabilitation Assessment of Movement Instrument (Daley et al., 1999), the lower limb sensory section of the Fugl-Meyer Assessment (Fugl-Meyer et al., 1975) and the Catherine Bergego Scale (Azouvi et al., 1996) respectively, while the participants' functional abilities were measured using the FIM (motor domain) (Linacre et al., 1994). The FAC (Holden et al., 1984) was utilised as an additional measure of functional ambulation within the longitudinal study. Psychometric properties of the FAC are outlined below.

<u>Functional Ambulation Category</u>

The FAC (Holden et al., 1984) (Appendix 8) assesses functional ambulation by classifying walking ability into one of six categories, based on the amount of physical assistance an individual requires to walk and the environment the individual is able to negotiate. The FAC has excellent test-retest and inter-rater reliability and concurrent validity with the Rivermead Mobility Index, walking velocity, step length and distance walked during the six-minute walk test when used with individuals following stroke who could not walk without help at the start of their inpatient rehabilitation (Mehrholz et al., 2007); as is often the case with individuals with lateropulsion following stroke. Good predictive validity and responsiveness of the FAC have also been found (Mehrholz et al., 2007).

4.2.6 Procedures

Following recruitment to the trial and the day prior to data collection commencing (day zero), participants undertook a 10 minute familiarisation session with the technology task setup. During this session the sitting and standing tasks relevant to an individual's level of ability were demonstrated, and participants were given an opportunity to perform the tasks using the technology task setup. The aim of the familiarisation session was to reduce any learning effect that may have occurred between day one and day two assessments.

Within a testing session the instrumented measures were assessed first, followed by a 10 minute rest period in supine if required, and then the clinical measures were assessed. As occurred in the feasibility study, the BLS and PASS were applied simultaneously using the method outlined (section 4.1.6 Procedures) in order to reduce the length of testing and minimise participant fatigue. Trained assessors (physiotherapists with greater than five years postgraduate experience and at least two years experience in the areas of rehabilitation or neurology) were used for all testing.

Data collection was performed at day one following recruitment to the trial and completion of the familiarisation session (day zero), at day two and then every two weeks following the initial testing session to a maximum of six testing occasions (eight weeks from first assessment) for the instrumented measures and clinical scales for lateropulsion and postural abilities. Impairment measures of motor control, sensation and neglect were completed at the first assessment. Measures of community ambulation and functional ability were taken at the first assessment and at six months post stroke. In order to maximise the dataset collected at six months, the six-month FIM motor and FAC scores were obtained either in person or via telephone (Smith et al., 1996). The measures undertaken at each time point in the longitudinal study are summarised in Table 4.1. Demographic information (including date of birth, age, gender, pre-stroke mobility, handedness and comorbidities), stroke characteristics (date of stroke, pathology, side of hemiparesis and computed tomography report) were also recorded.

Table 4.1. Measures used at each time point with the different groups in the longitudinal and healthy control studies

Measurements	Participants with lateropulsion							Healthy controls
	Day 1	*Day 2*	*Week 2*	*Week 4*	*Week 6*	*Week 8*	*6 months*	*Day 1*
Instrumented measures								
Sitting tasks (as able)	✓	✓	✓	✓	✓	✓		✓
Standing tasks (as able)	✓	✓	✓	✓	✓	✓		✓
Clinical Measures								
BLS	✓	✓	✓	✓	✓	✓		
PASS	✓	✓	✓	✓	✓	✓		
STREAM LL items	✓							
FMA LL sensory section	✓							
Catherine Bergego Scale	✓							
FIM (motor domain)	✓						✓	
FAC	✓						✓	

Abbreviations: BLS, Burke Lateropulsion Scale; FAC, Functional Ambulation Classification; FIM, Functional Independence Measure; FMA, Fugl Meyer Assessment; LL, lower limb; PASS, Postural Assessment Scale for Stroke; STREAM, Stroke Rehabilitation Assessment of Movement Instrument.

4.2.7 Sample size

The sample size calculations for the different components of the longitudinal study are reported in the respective chapters (Chapters 7, 8 and 9).

4.3 Healthy controls methods (see Chapters 7-8)

4.3.1 Research question

What differences exist when comparing instrumented measures of postural control in sitting and standing in stroke survivors with lateropulsion relative to healthy controls? (Chapters 7-8)

4.3.2 Study design

A cross-sectional comparison of WBB-derived COP and WBA measures obtained from individuals with lateropulsion following stroke (using data from the longitudinal study outlined above) were compared with healthy controls.

4.3.3 Ethical approval

This study was approved by the human research ethics committees of St Vincent's Hospital Melbourne and Curtin University (LNR 158/15, HR 55/2016; Appendix 1).

4.3.4 Participant inclusion criteria and recruitment

Forty-eight healthy control participants were recruited as a sample of convenience from the staff, family and friends of St Vincent's Hospital Melbourne. The healthy participants were intentionally recruited across 12 five year age ranges from 25 to 85 years, with two male and two female participants recruited per age range. Following completion of data collection for both the longitudinal and healthy control studies, 35 sex- and aged matched (±5 years) healthy controls were matched with the lateropulsion sample from the longitudinal study for comparison purposes.

Inclusion criteria for the control participants were:

- Individuals without a health condition affecting their mobility
- The ability to walk independently with no aids in the community.

Exclusion criteria included:

- History of trauma or surgery to the lower limbs or back
- Use of foot or ankle orthotic support
- History of neurological conditions that affect balance or walking
- Under medical management for a serious medical condition
- Weight >112kg (due to weight limitations of the transfer bench which the WBB was securely fastened to for the participant to sit on).

4.3.5 Outcome measures

Instrumented measures

The healthy control participants performed the same instrumented measures as those completed by the stroke participants with lateropulsion in the longitudinal study. Thus, the protocol for the instrumented measures has been outlined previously (see section 4.2.5 Outcome measures). For tasks requiring use of the non-paretic arm for stroke participants, the healthy control participants were randomly allocated a side with which to perform all of the included tasks.

4.3.6 Procedures

As occurred in the longitudinal study with the stroke participants, a 10 minute familiarisation session with the technology task setup was undertaken by the healthy controls. However, for the healthy control participants this occurred at the beginning of the data collection session, rather than the day prior to the first testing occasion as occurred with the stroke participants. For the healthy control participants, data collection occurred on one occasion only (see Table 4.1). Demographic information including date of birth, age, gender, and comorbidities was recorded.

4.3.7 Sample size

The sample size calculations for between group comparisons are reported in the respective chapters (Chapters 7 and 8).

Chapter 5. Rasch analysis of the Burke Lateropulsion Scale (BLS)

Chapter Outline

The BLS has previously been recommended as the preferred clinical scale for measuring lateropulsion following stroke. However, the internal validity of the BLS has not previously been examined. The aim of this study was to investigate the internal validity of the BLS with Rasch analysis using data from 132 participants following stroke.

This chapter is presented in its original manuscript format. Details of the publication are: Birnbaum M, Brock K, Parkinson S, Burton E, Clark R & Hill K (2021): Rasch analysis of the Burke Lateropulsion Scale (BLS). *Topics in Stroke Rehabilitation* 28(4): 268-275, https://doi.org/10.1080/10749357.2020.1824724.

5.1 Abstract

Background: Lateropulsion is a common problem following stroke. Whilst the Burke Lateropulsion Scale (BLS) is recommended in the literature as the outcome measure of choice for measuring lateropulsion, the internal validity of the BLS has not been investigated.
Objectives: To evaluate the internal validity of the BLS for use in evaluating the effectiveness of therapies aimed at reducing lateropulsion.
Methods: Rasch analysis procedures were undertaken including assessment of overall model fit, item and person fit, threshold ordering, differential item functioning, internal consistency, targeting and dimensionality.
Results: Data from 132 participants were utilised to perform Rasch analysis of the BLS. In this preliminary study, overall model fit and individual item and person fit were found to be good using fit residual statistics and chi-square probability values. The BLS was found to be unidimensional and have good internal consistency (Person Separation Index 0.867). Thresholds for four of the five items were found to be only marginally disordered and were subsequently not modified. Non-uniform differential item functioning was detected for age for the transfers item; however, this item did not display item misfit and was therefore not removed.
Conclusions: This study supports the internal construct validity of the BLS as a measure of lateropulsion following stroke. Further use of Rasch analysis on the BLS using a larger sample is recommended to confirm these preliminary findings and allow transformation into an interval level scale.

5.2 Introduction

Stroke is a leading cause of disability worldwide (WHO, 2012). The effects of stroke differ from one individual to another, depending on the area of the brain affected and the severity of damage. Common signs of stroke include weakness or numbness of one side of the body, difficulty speaking or understanding speech, difficulty swallowing, and loss of balance or incoordination. Contraversive lateropulsion is another common problem post stroke, where individuals display a distorted perception of postural vertical (Karnath et al., 2000b; Pérennou et al., 2002; Pérennou et al., 2008). This postural control disorder is characterised by patients pushing toward their paretic side with their non-paretic arm and leg, and resisting movement of the altered posture back to and past vertical (Davies, 1985; Pérennou et al., 2008). The prevalence of lateropulsion in acute stroke survivors has been reported to be 9-10% (Abe et al., 2012; Pedersen et al., 1996) and much higher in rehabilitation settings (Baccini et al., 2008; Chow et al., 2019; Clark et al., 2012; Krewer, Luther, et al., 2013). Lateropulsion has been associated with longer hospital stays (Clark et al., 2012; Danells et al., 2004; Pedersen et al., 1996) and poorer outcomes in terms of functional recovery (Babyar et al., 2008; Pedersen et al., 1996).

A number of clinical scales for assessing lateropulsion, including the Burke Lateropulsion Scale (BLS), have been described in the literature (Chow et al., 2019; D'Aquila et al., 2004; Hallin et al., 2008; Karnath et al., 2000b; Lagerqvist & Skargren, 2006). The BLS contains five items which assess for the presence of lateropulsion across different positions or tasks, including supine, sitting, standing, transfers and walking (D'Aquila et al., 2004). The scale measures the resistance present when the rater attempts to correct a tilted posture to or past midline, with a higher score reflecting the presence of greater or earlier resistance and therefore more severe lateropulsion.

The BLS has been shown to have high inter-rater and intra-rater reliability and concurrent validity, with moderate correlations demonstrated between the BLS and measures of balance and functional ability (D'Aquila et al., 2004). High levels of responsiveness have also been reported with individuals with lateropulsion post stroke (Clark et al., 2012). The BLS has previously been recommended as the outcome measure of choice for measuring lateropulsion following stroke (Koter et al., 2017). However, no study to date has investigated the internal validity of the BLS.

According to the authors, a total BLS score out of 17 can be calculated by summing the individual item scores together (D'Aquila et al., 2004). However, this is problematic given the ordinal nature of the BLS. Whilst a higher score represents more severe lateropulsion than a lower score on the BLS, the difference between scores may not be consistent. Thus, whilst two individuals may have the same change score (e.g. 2) from different points on the scale, it may not indicate the same amount of progress. This becomes an issue when attempting to evaluate the effectiveness of therapies aimed at reducing lateropulsion. Rasch analysis is a statistical method that can provide estimates of the size of each step and the improvement in ability for each person. The use of Rasch analysis to develop precision rehabilitation outcome measures is strongly advocated (Malec, 2020).

The aim of this preliminary study was to use Rasch analysis to evaluate the internal validity of the BLS. This will then determine if further larger studies are warranted to investigate if the BLS can be transformed into an interval-level scale for measuring change or responsiveness to therapies targeting lateropulsion.

5.3 Materials and Methods

Setting

This study involves secondary analysis of data collected for two other studies investigating different aspects of the measurement of lateropulsion following stroke. One study was conducted in the acute stroke and inpatient rehabilitation units of a tertiary hospital in Melbourne, Australia (paper in preparation) and the other study in the stroke rehabilitation unit of a tertiary hospital in Perth, Australia (Chow et al., 2019).

Participants

For the study undertaken by Chow and colleagues, adults admitted for neurological inpatient rehabilitation who were less than two months post stroke were prospectively considered for inclusion. Patients who were unable to consent, medically unstable, had no motor impairments from their stroke, and/or had severe pre-morbid orthopaedic problems were excluded from the study (Chow et al., 2019). For the study conducted in Melbourne, participants were recruited from consecutive admissions to the participating units if the following inclusion criteria were met: between one and twelve weeks post stroke, the presence of contraversive lateropulsion as defined by a BLS score of greater than or equal to two (Babyar et al., 2015, 2017; Babyar et al., 2009; Babyar et al., 2008; Chow et al., 2019), able to sit with back and arm support with feet touching the floor for more than three seconds, able to follow a one stage command, and able to complete a 20 minute physiotherapy session (Chapter 6) (Birnbaum et al., 2018). Exclusion criteria were limited ability to mobilise independently in the community prior to the stroke (Functional Ambulation Classification less than six) (Holden et al., 1986), weight >112kg and cerebellar ataxia. In total, 132 participants were included in this secondary data analysis with 85 participants involved from Perth (Chow et al., 2019), including those with (n = 44) and without (n = 41) lateropulsion, and 47 participants from Melbourne, all of whom had lateropulsion.

Procedures

In both studies, the BLS was administered by trained physiotherapists alongside other outcome measures investigating the measurement of lateropulsion following stroke (Chow et al., 2019). The BLS is a 5-item scale measuring the presence of lateropulsion across different activities (D'Aquila et al., 2004). The scale encompasses both the amount of resistance present when the assessor attempts to correct a tilted posture and when the resistance occurs. Items are either scored from zero to three or zero to four. The maximum score of the BLS is 17, which reflects the presence of severe lateropulsion. For both studies, a cut-off BLS score of two or more was used to determine the presence of lateropulsion (Chow et al., 2019) as has been used in the literature previously (Babyar et al., 2015, 2017; Babyar et al., 2009; Babyar et al., 2008). The BLS has been shown to be reliable, responsive and have good concurrent validity with measures of balance and functional abilities (Clark et al., 2012; D'Aquila et al., 2004). The Functional Independence Measure (motor domain) scores were also recorded in both studies as a global measure of functional ability (Linacre et al., 1994).

Data Analysis

Rasch analysis of the BLS was performed using the partial credit model in RUMM2030 (Andrich et al., 2009). The statistical procedures undertaken as part of the Rasch analysis process have previously been described in detail (Hagquist et al., 2009; Pallant & Tennant, 2007). The procedures included assessment of overall model fit, item fit, person fit, threshold ordering, differential item functioning (DIF), internal consistency, targeting and dimensionality.

To assess overall model fit three summary statistics were used. These included the summary fit residual statistics for both items and persons and the chi-square item-trait interaction statistic. For the summary fit residual statistics, a fit residual standard deviation of less than 1.5 is considered to indicate adequate fit of items or persons, with a fit residual standard deviation of 1 indicating perfect fit (Shea et al., 2009). For the chi-square item-trait interaction statistic, a non-significant result using a Bonferroni adjusted alpha value (p = 0.01) is indicative of good overall fit (Tennant & Conaghan, 2007). Individual item and person fit were also examined using fit residual values (where values between ± 2.5 indicate adequate fit), as well as by using chi-square probability values (Pallant & Tennant, 2007).

Response category structure was initially examined by using the threshold map to detect the presence of disordered thresholds. Disordered thresholds arise when persons inconsistently use item response categories (Pallant & Tennant, 2007). Item category probability curves were subsequently inspected visually to ascertain the degree of any threshold disordering present (Tennant & Conaghan, 2007). Differential item functioning was assessed to determine if potential test item bias was present in the sample on the basis of gender, age (less than 60 years or ≥ 60 years) and site (Melbourne or Perth). To assess DIF, analysis of variance was performed using a Bonferroni adjusted alpha level.

Internal consistency of the scale was examined using the Person Separation Index (PSI). The PSI is interpreted in a similar way to Cronbach's alpha coefficient where values greater than 0.70 are regarded as adequate (Pallant & Tennant, 2007). Targeting of the scale was assessed through inspection of the person-item threshold distribution map. For a scale to be well targeted to the population being measured, it should contain items that extend over the entire range of person estimates (Ramp et al., 2009).

To evaluate the dimensionality of the scale, principal component analyses of residuals were performed to identify subsets of items with positive and negative loadings on the first principal component (Smith, 2002). Using independent t-tests, Rasch-derived person estimates from these subsets were compared. The unidimensionality of the scale was confirmed if less than 5% of the t-test comparisons were significant at $p < 0.05$, or the lower bound of the confidence interval is less than 5% (Tennant & Conaghan, 2007).

The sample size needed to determine stable person and item estimates using Rasch analysis is based on the margin of error anticipated. A sample size of 100 is thought to be adequate to provide item calibration stability within ± 0.5 logits with a 95% confidence interval, whilst a sample of 150 is required for a 99% confidence interval (Linacre, 1994). Thus, a sample size of n = 132, whilst considered a small sample size, is appropriate to use for Rasch analysis to gain preliminary results regarding the BLS and inform whether future larger studies are justified.

5.4 Results

Data from 132 participants were included in the Rasch analysis, including 85 participants from Perth (51.8% with BLS ≥ 2) (Chow et al., 2019) and 47 participants from Melbourne (100% with BLS ≥ 2). Of these participants, there were 82 men (62.1%) and 50 women (37.9%), ranging in age from 18 to 91 years with a mean age of 58.5 years (SD 14.0 years). The median time post stroke was 16 [interquartile range (IQR) 10 – 23] days and the median Functional Independence Measure (motor domain) score was 29.5 [IQR 21 – 48.5], out of a maximum possible score of 91. The participant characteristics for both sites are summarised in Table 5.1. Scoring of the entire sample for each of the five BLS items is reported in Table 5.2.

In terms of overall model fit, the mean fit residual value for items was -0.18 (SD = 0.63) and the mean fit residual value for persons was -0.30 (SD = 0.61) (Table 5.3). These values indicate good item and person fit to the Rasch model. The chi-square item-trait interaction statistic for the BLS also displayed good model fit (p = 0.725) (Table 5.3). In terms of the individual item and individual person fit statistics for the BLS, adequate fit was displayed for all statistics (the individual item fit statistics are presented in Table 5.4).

Table 5.1. Characteristics of participants

Variable	Melbourne (n = 47)	Perth (n = 85)	Overall (n = 132)
Age (years)			
Mean (SD)	66.4 (14.7)	54.2 (11.4)	58.5 (14.0)
Range	35-91	18-74	18-91
Sex, men, n (%)	27 (57.4%)	55 (64.7%)	82 (62.1%)
Time post stroke (days)			
Median [IQR]	22 [13-34]	13 [9-21]	16 [10-23]
Range	8-63	5-61	5-63
BLS scores, /17			
Median [IQR]	8 [4-10]	2 [0-11]	5.5 [0-10]
Range	2-17	0-17	0-17
FIM Motor scores, 13-91			
Median [IQR]	22 [17-30]	36 [23-61.5]	29.50 [21-48.5]
Range	13-62	13-91	13-91

NB. All participants from the Melbourne study had lateropulsion (BLS ≥ 2), whilst in the Perth sample, 44 out of the 85 participants (51.8%) had lateropulsion.

Table 5.2. Frequency table of scores for each item of the Burke Lateropulsion Scale for the entire sample

Item	Score frequency				
	0	1	2	3	4
Supine	90 (68%)	14 (11%)	13 (10%)	10 (7%)	5 (4%)
Sitting	90 (68%)	15 (12%)	11 (8%)	16 (12%)	
Standing	45 (34%)	23 (17%)	13 (10%)	13 (10%)	38 (29%)
Transfers	48 (36%)	28 (21%)	17 (13%)	39 (30%)	
Walking	41 (31%)	17 (13%)	10 (7%)	64 (49%)	

NB. Items are scored from 0 to 3 or 0 to 4, with a higher score on a given item reflecting the presence of greater or earlier resistance and subsequently more severe lateropulsion.

Table 5.3. Model fit statistics for the Burke Lateropulsion Scale

Overall model fit	**Item fit residual** Mean (SD)	**Person fit residual** Mean (SD)	**PSI**	**% Significant t-tests**	
				n	%
χ^2 = 7.00, p = 0.725	-0.18 (0.63)	-0.30 (0.61)	0.87	2	(2.2%)

Notes: χ^2, chi-square; PSI, Person Separation Index.
NB. The χ^2 item-trait interaction statistic and the mean fit residual values for items and persons indicate good model fit. Unidimensionality of the Burke Lateropulsion Scale was supported as less than 5% of the *t*-test comparisons were significant.

Table 5.4. Individual item fit statistics for the Burke Lateropulsion Scale

Test item	**Location** (logits)	**Standard error** (logits)	**Fit residual**	**χ^2 statistic**	***p*-value**
1- Supine	2.224	0.159	0.428	0.875	0.646
2- Sitting	1.614	0.169	0.487	2.263	0.323
3- Standing	-0.818	0.138	-0.277	0.277	0.871
4- Transfers	-0.803	0.162	-0.914	1.577	0.455
5- Walking	-2.216	0.182	-0.629	2.012	0.366

Notes: χ^2 statistic, chi-square statistic.
NB. For the chi-square statistic, non-significant results using a Bonferroni adjusted alpha value (p = 0.01) are indicative of good overall fit. Thus, adequate fit was displayed for all individual items.

The threshold map for the five items of the BLS showed that four items (supine, sitting, standing and walking items) had some degree of threshold disordering. Visual inspection of the item category probability curves for these four items found that the thresholds were only marginally disordered and were subsequently not altered (Figure 5.1). No DIF was found for sex or site (Melbourne or Perth). Non-uniform DIF was detected for age (less than 60 years /

≥ 60 years) for the transfers item (where p = 0.001, less than the Bonferroni adjusted alpha value of 0.003), as shown in Figure 5.2. Given the item did not show misfit no action was taken to address this.

Adequate internal consistency was found with a PSI of 0.867. The targeting map for the BLS showed that the items and thresholds adequately spanned the full range of person scores (Figure 5.3). This suggests that the BLS is well targeted for the current sample of stroke patients. Thirty-eight participants (28.8%) scored zero on all test items (i.e. no lateropulsion present), whilst four participants (3%) scored the maximum score on all test items (representing the presence of severe lateropulsion). Unidimensionality of the BLS was supported as only 2 (2.2%) of the t-test comparisons performed were significant (refer to t-test results, Table 5.3).

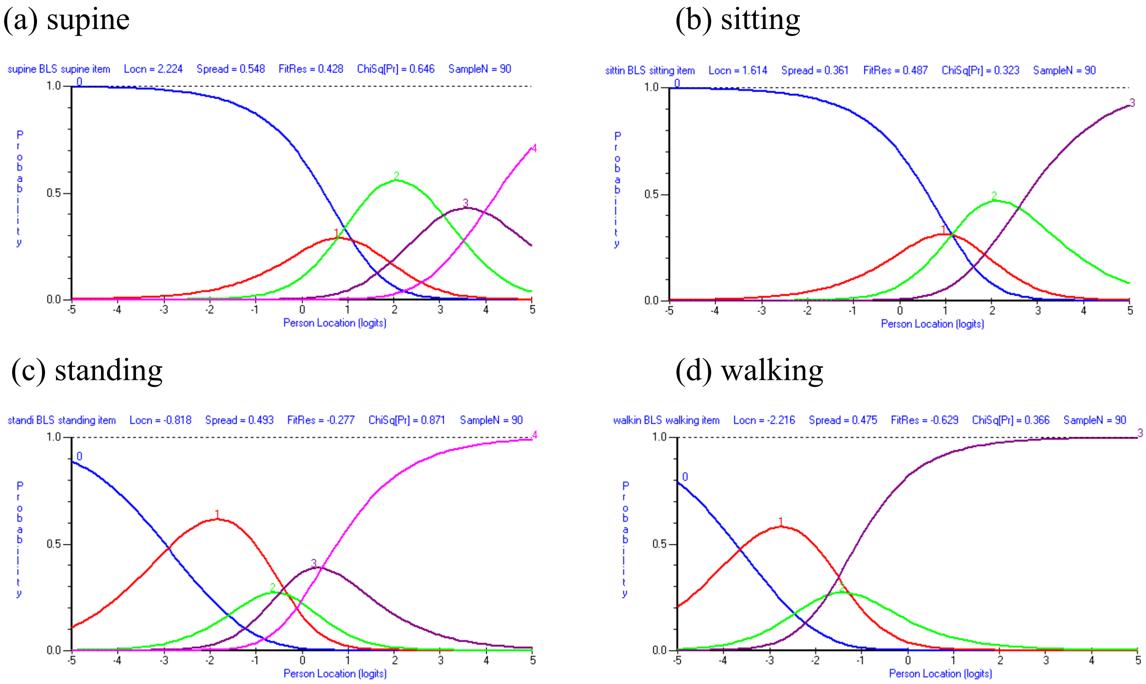

Figure 5.1. Category probability curves for Burke Lateropulsion Scale items identified as having some degree of threshold disordering

NB. The coloured lines represent the different possible scores for a given item and are defined by the number accompanying each line.

Note the thresholds for these four items are only marginally disordered and were subsequently not altered.

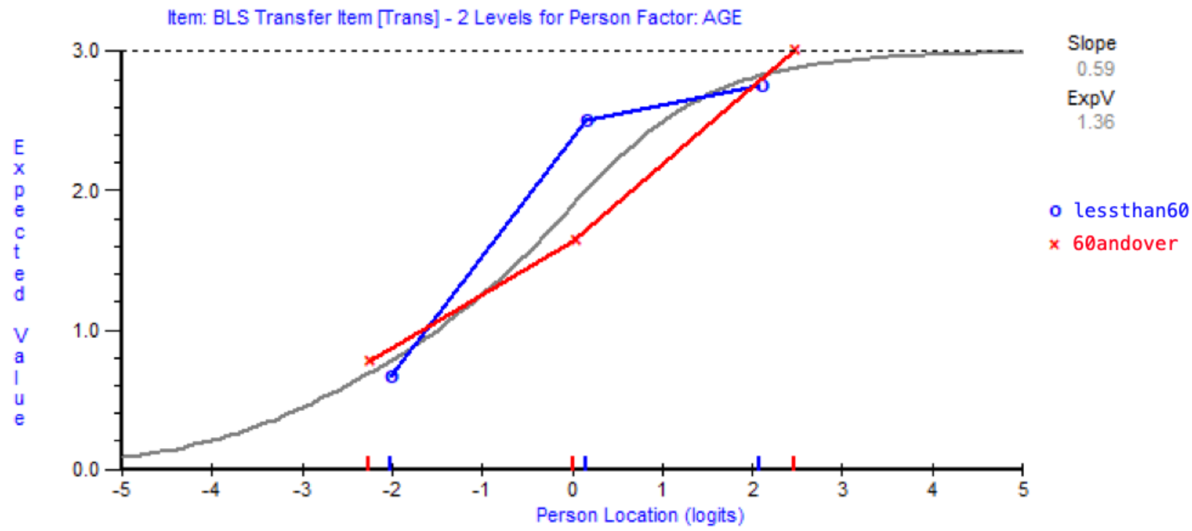

Figure 5.2. Differential item functioning graph of age for the transfers item

As this figure depicts, non-uniform differential item functioning (DIF) was detected for age (<60 years / ≥60 years) for the transfers item.

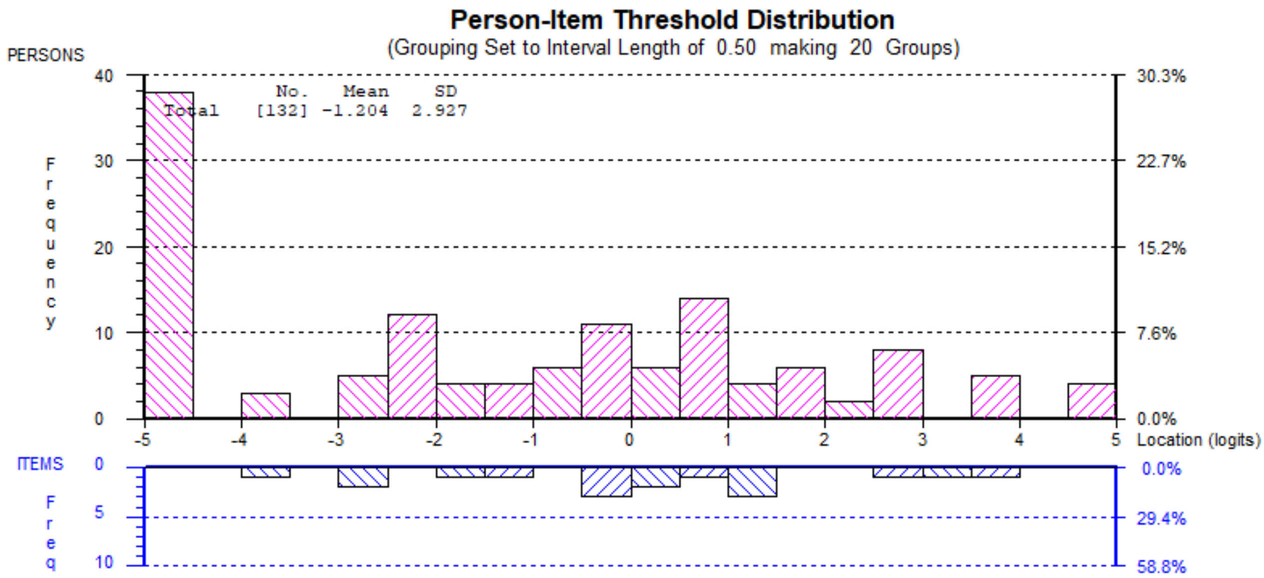

Figure 5.3. Targeting map for the Burke Lateropulsion Scale (n=132)

As the targeting map demonstrates, items and thresholds spanned the full range of person scores sufficiently.

5.5 Discussion

To the authors' knowledge, this is the first study to examine the measurement properties of the BLS using Rasch analysis. The BLS was found to be unidimensional and have adequate internal consistency. Internal validity of the BLS was also supported, with the BLS items showing good fit to the Rasch model. It is important to recognise that given the small sample size utilised, the chi-square probability values were underpowered to detect misfit. The fit residual statistics, however, which are less impacted by sample size, did support good item and person fit to the Rasch model.

Adequate targeting of the BLS was demonstrated through the person-item threshold distribution map. The ceiling effect of the BLS was found to be minimal, with only four participants (3%) scoring the maximum score on all test items. Thirty-eight participants (28.8%) scored zero on all test items (i.e. no lateropulsion present). Whilst this could potentially highlight a marked floor effect of the BLS, it instead reflects the inclusion of individuals following stroke without lateropulsion (BLS score of zero or one) within the Perth study sample.

The presence of minor threshold disordering for four of the BLS items, and evidence of non-uniform DIF for age for the transfers item were found during the Rasch analysis process. However, no actions were taken to address these. The threshold disordering was considered to be marginal and given rescoring may adversely impact the discriminative ability of the BLS, it was not undertaken. In terms of the non-uniform DIF, given the transfers item did not display misfit, the item was not removed. It is likely that in both cases, these findings may be present due to the limited sample size used in the current study. The decision to leave the BLS unaltered therefore should be verified using Rasch analysis of the BLS in a larger sample.

The combination of data from the two different studies, one which included stroke survivors with and without lateropulsion, and the other for which all participants had lateropulsion, appeared to be a successful sampling strategy in gaining a representative sample of individuals across the entire spectrum of lateropulsion severity. However, the study population used for the Rasch analysis was characterised by younger age (especially in the Perth study sample) and more severe disability (particularly in the Melbourne study sample where only individuals with lateropulsion were included) than may be commonly found in inpatient rehabilitation settings. This potentially limits the generalisability of these results to broader stroke inpatient rehabilitation populations and forms a limitation of the current study. Ideally future studies should include individuals from different inpatient rehabilitation units across the entire spectrum of lateropulsion severity so the results can be more easily generalisable to broader inpatient rehabilitation populations.

This is the first study to use Rasch analysis to investigate the psychometric properties of a clinical scale measuring lateropulsion. Comparison with other studies is therefore limited. The Postural Assessment Scale for Stroke patients (PASS) (Benaim et al., 1999) is a measure of postural function commonly utilised with individuals following stroke which has been found to be moderately correlated with the BLS (Clark et al., 2012). The measurement properties of a modified version of the PASS (SwePASS) have previously been examined using Rasch analysis (Persson et al., 2014). The preliminary findings of the current study are comparable to those obtained from the study investigating the SwePASS (Persson et al., 2014), with the exception that small adjustments were made to the SwePASS in order to achieve good model fit, whereas adjustment of the BLS was not deemed necessary in the present study.

Finally, the combined dataset of 132 individuals following stroke, whilst small, was thought to be appropriate for preliminary Rasch analysis of the BLS (Linacre, 1994). With the use of the relatively small sample, this study has demonstrated some promising results in terms of the internal construct validity of the BLS. If the results of this study are confirmed in future studies using larger sample sizes, the ordinal scaling of the BLS may be able to be transformed into interval scaling. This is turn would support a total score being summated from the interval scaling, which could subsequently be used to evaluate the effectiveness of therapies aimed at reducing lateropulsion in future intervention studies.

5.6 Conclusion

These preliminary results support the use of the BLS for the measurement of lateropulsion following stroke. However, these findings need to be verified in a study utilising Rasch analysis with a larger sample size. If confirmed, the BLS could be transformed into an interval-level scale and used to measure the effectiveness of therapies targeting lateropulsion.

Chapter 6. Measuring lateropulsion following stroke: a feasibility study using Wii Balance Board technology

Chapter Outline

As outlined in the literature review, the postural dysfunction observed in sitting and standing in individuals with lateropulsion following stroke has received little investigation to date. The use of a WBB with custom-designed software provides a means by which COP variables can be obtained within the clinical environment. This chapter outlines a pilot study which was undertaken with ten stroke survivors with lateropulsion to determine the feasibility and utility of using WBB-derived COP variables as a measure of postural control in sitting and standing in individuals with lateropulsion following stroke.

This chapter is presented in its published format:
Birnbaum M, Brock K, Clark R, Hill K (2018) Measuring lateropulsion following stroke: a feasibility study using Wii Balance Board technology. *New Zealand Journal of Physiotherapy* 46(1): 36-42. https://doi.org/10.15619/NZJP/46.1.06

This study has also been presented at the following conference:
Measuring lateropulsion following stroke in the clinical setting: a feasibility study using Wii technologies. Australian Physiotherapy Association Conference, Gold Coast, 2015.

6.1 Published paper

RESEARCH REPORT

Measuring lateropulsion following stroke: a feasibility study using Wii Balance Board technology

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ABSTRACT

The aim of this pilot study was to determine the feasibility and utility of using Wii Balance Board-derived centre of pressure data as measures of balance in people with lateropulsion following stroke. Ten individuals with lateropulsion, between one and twelve weeks post stroke, participated in this study. Participants were assessed on four occasions over a two-week period, performing a number of tasks sitting and standing on the Wii Balance Board, in addition to clinical measures. Feasibility was determined by participant retention and the percentage of testing occasions ceased prematurely. Clinical utility was explored through visual analysis of the Wii Balance Board-derived data. Participant retention was 100%. Cessation of testing due to discomfort or fatigue occurred 20% of the time. For the static balance tasks, mediolateral amplitude emerged as a variable of interest. Wii Balance Board-derived centre of pressure data from static sitting and standing tasks appeared to capture useful information about individuals with varying degrees of lateropulsion and displayed change over time. The use of Wii Balance Board technology as a measure for balance in individuals with lateropulsion appears feasible. A larger measurement study is required to establish the reliability and validity of this technology in this important clinical sub-group.

Birnbaum, MA., Brock, K., Clark, RA., Hill, KD. (2018) Measuring lateropulsion following stroke: a feasibility study using Wii Balance Board technology. New Zealand Journal of Physiotherapy 46(1): 36-42. doi:10.15619/NZJP/46.1.06

Key words: Lateropulsion, Stroke, Feasibility, Centre of pressure.

INTRODUCTION

Lateropulsion following stroke is a distinct disorder of postural control, where individuals have an altered perception of body verticality (Perennou et al., 2008). People with lateropulsion push themselves toward their paretic side, and actively resist passive correction of the altered posture back to or beyond midline (Davies, 1985; Perennou et al., 2008). At its most severe, lateropulsion prevents individuals from being able to sit independently and can affect rehabilitation outcomes (E. Clark, Hill, & Punt, 2012; Danells, Black, Gladstone, & McIlroy, 2004).

There is limited research about the measurement and rehabilitation of individuals with lateropulsion following stroke. Measurement scales have primarily been used to assess postural control in this patient population (Koter et al., 2017). While force platforms are considered the gold standard for measuring postural control in various clinical groups, these are not readily available within the clinical environment.

The Nintendo Wii Balance Board (WBB) is a portable, inexpensive device, which when operated with customised software, may be used to capture data such as centre of pressure (COP) in the clinical setting. The main advantage of the WBB over laboratory-based systems is the ability for it to be taken to individuals with lateropulsion early following stroke. The WBB has been shown to be reliable (Chang, Levy, Seay, & Goble, 2014; R. A. Clark et al., 2010; Scaglioni-Solano & Aragon-Vargas, 2014), can acquire comparable data to a laboratory force platform when assessing standing balance (Chang et al., 2014; R. A. Clark et al., 2010; Scaglioni-Solano & Aragon-Vargas, 2014), and has been used to assess seated postural control in people with severe knee osteoarthritis (Pua et al., 2013). Whilst no studies have investigated the use of WBB technology with stroke survivors with lateropulsion, the use of this technology with this patient population may provide a greater understanding of the postural control deficits experienced by individuals with lateropulsion. This would enable physiotherapists to focus therapy targeting the identified postural control deficits with stroke survivors with lateropulsion. The delivery of more effective physiotherapy for recovery of lateropulsion has the potential to promote better outcomes, decrease hospital length of stay and reduce long term dependency in the community.

Given lateropulsion significantly impacts on an individual's balance abilities in sitting and standing, it is important to establish the feasibility of using WBB technology to capture COP data with these individuals prior to undertaking a longitudinal measurement study. The purpose of this study was to investigate the feasibility and utility of using a WBB to assess postural control in sitting and standing in individuals with lateropulsion early following stroke. This will then inform a larger longitudinal study with the aim to establish the reliability and validity of this novel technology in this important subgroup of stroke survivors.

METHODS

Participants

Individuals between one and twelve weeks post stroke who demonstrated signs of lateropulsion (score of two or more on the Burke Lateropulsion Scale) (Babyar, White, Shafi, & Reding, 2008) were recruited following admission to the Stroke and Rehabilitation Units of St. Vincent's Hospital Melbourne. Other inclusion criteria were: (1) able to sit with back and arm support for three seconds; (2) follow at least a one stage command verbally or with gesture; (3) tolerate a 20 minute physiotherapy session; and (4) provide informed consent. Exclusion criteria were pre-existing co-morbidity limiting community mobility (defined as a Functional Ambulation Classification of less than six) (Holden, Gill, & Magliozzi, 1986) and weight greater than 112 kilograms due to weight restrictions of the transfer bench utilised for the sitting tasks. To ensure testing occurred with individuals across a spectrum of functional abilities, ten participants were recruited, including at least three individuals with more severe stroke who were unable to stand at the first assessment. The study was approved by the human research ethics committees of participating institutions. Written consent was obtained from all participants prior to inclusion.

Procedures

Participants were assessed sitting on a WBB that was securely fastened to a transfer bench. Individuals were initially assessed sitting with and without arm support. If able, participants then performed a series of dynamic sitting balance tasks, including reaching sideways and picking up an object from behind (Gorman, Radtka, Melnick, Abrams, & Byl, 2010). For participants who could stand, balance was also assessed standing on a WBB. Standing tasks included standing with and without arm support, and a number of dynamic tasks such as looking behind while standing (Berg, Maki, Williams, Holliday, & Wood-Dauphinee, 1992). A full list of the included tasks in sitting and standing can be found in Table 1.

Table 1: Balance tasks performed in feasibility study, and an abbreviated assessment suite for future research

Tasks performed in feasibility study	Recommended future abbreviated task set
Sitting	Sitting
• Sit with arm	• Sit with arm
• Sit without arm	• Sit without arm
• Shift weight to non-paretic side	• Reach for cup in front within arm's length
• Shift weight to paretic side	• Reach for cup on non-paretic side beyond arm's length
• Sitting eyes closed	
• Arm raise test	
• Reaching sideways	
• Picking up object from behind	
Standing	Standing
• Stand using arm	• Stand using arm
• Stand without arm	• Stand without arm
• Shift weight to non-paretic leg	• Reach for cup in front within arm's length
• Shift weight to paretic leg	• Reach for cup on non-paretic side beyond arm's length
• Standing eyes closed	• Sit to stand
• Turning head while standing	• Standing feet together
• Standing feet together	

The WBB yields measures of COP similar to those obtained from a laboratory force platform (R. A. Clark et al., 2010). Centre of pressure is defined as the location of the vertical ground reaction force from a platform and is considered the neuromuscular response to movement of the centre of mass (Winter, 2009). The WBB was wirelessly connected to a laptop via Bluetooth, controlled by custom-programmed software similar to a freely available version (www.rehabtools.org) and sampled COP data at the native frequency of approximately 40Hz. Data were acquired from each of the four load sensors, lowpass filtered at 10Hz, resampled to 100Hz using spline interpolation, and lowpass filtered again at 6.25Hz to attenuate signal noise as per Clark et al. (2017). Prior to testing, the Wii Balance Board was calibrated by placing a series of known loads on each of the four load sensors, creating the force calibration, then applying loads at known positions to calibrate for the centre of pressure positions. This was done in accordance with a previously described protocol (Clark, RA. et al., 2010). The WBB generated a number of output variables of interest, including total, mediolateral and anteroposterior COP path velocity.

In addition to the instrumented measures, a series of clinical measures were performed including the Burke Lateropulsion Scale (D'Aquila, Smith, Organ, Lichtman, & Reding, 2004), the Postural Assessment Scale for Stroke (Benaim, Perennou, Villy, Rousseaux, & Pelissier, 1999) and the Functional Independence Measure (motor domain) (Dodds, Martin, Stolov, & Deyo, 1993). Instrumented and clinical measures of lateropulsion and postural control were taken on day one and day two, and then repeated a fortnight later (day 14 and day 15).

Outcomes

Feasibility was assessed by participant retention, and adherence to assessment procedures, with thresholds set at 80% (Oxford Centre for Evidence-Based Medicine. Levels of Evidence, 2009). Occasions where testing was required to be stopped prematurely at the request of patients (e.g. fatigue or discomfort) were also recorded. Wii Balance Board-derived COP data were analysed visually by graphing performance for each condition and individual over the four testing occasions to investigate clinical utility, and as a first step examination of responsiveness.

Data analysis

Demographic data of participants was presented using descriptive statistics including median, interquartile range and frequency. For centre of pressure variables, including anteroposterior amplitude, mediolateral amplitude and total path velocity, median and interquartile range were calculated for each task for day 1 and day 15 data. Percentage change was also calculated and is the difference between day 15 and day 1 scores divided by the day 1 score. Statistical analyses could not be performed due to the small sample size included in this study.

RESULTS

Ten individuals participated in this study between April and November 2014, including three individuals who were unable to stand initially. The median (range) age of participants was 66.5 (42-89) years and the time of the initial assessment post stroke was 24 (15-44) days. Three of the 10 participants had Burke Lateropulsion Scale scores indicating moderate (n=2) or severe (n=1) lateropulsion. The median Functional Independence Measure (motor domain) score at initial assessment was 32. Other baseline characteristics for participants are summarised in Table 2.

Participant retention for the study was 100%, with all 10 participants completing data collection on all four testing occasions. The median time taken to complete the instrumented measures was 27.5 minutes for both day 1 (range 5-45 minutes) and day 15 (range 5-35 minutes) assessment occasions. Testing was ceased prematurely due to discomfort sitting on the WBB for a prolonged period of time (two participants, 7.5% of assessment occasions) and due to fatigue (two participants; 12.5% of assessment occasions). Table 3 outlines the participants' ability to complete each test item during the day 1 assessment session.

Table 2: Baseline characteristics of participants

Variable*	
Age (years)	66.5 [59-75]
Time post stroke (days)	24 [20-30]
Gender, male	4 (40%)
Side of hemiparesis, left	7 (70%)
Pathology	
Infarct	4 (40%)
Haemorrhage	2 (20%)
Both	4 (40%)
Severity of lateropulsion (BLS scores)	4.5 [3-11.5]
Mild (2-8)	7 (70%)
Moderate (9-12)	2 (20%)
Severe (13-17)	1 (10%)
PASS scores	21.5 [11-24]
FIM Motor scores	32 [24-38]

Notes: BLS, Burke Lateropulsion Scale; D1, Day 1; FIM, Functional Independence Measure; PASS, Postural Assessment Scale for Stroke. *Values are median [interquartile range] or frequency (percentage) unless specified

Sitting using arm support was the only task that could be completed by all participants on each testing occasion. Two participants with moderate lateropulsion were unable to complete all of the dynamic sitting tasks initially but could do so by day 15. The participant with severe lateropulsion was unable to perform any dynamic tasks nor sit without arm support over the two week testing period. The seven individuals with mild lateropulsion could successfully perform all sitting tasks on each testing occasion. Six of these individuals could also be assessed standing at initial assessment. No participants could perform all of the included standing tasks day one, however five individuals could do so by day 15. Overall, nine participants progressed to being able to perform tasks on day 15, which they could not complete initially. No adverse events or falls occurred during the testing sessions.

Centre of pressure data is presented in Table 4. For the static sitting and standing tasks, mediolateral amplitude displayed greatest capacity for change over the study period. Visual examination of the COP graphs revealed that pronounced COP variability was observed when individuals were performing balance tasks at the upper end of their level of ability. Three participants showed instability with static sitting initially, with COP variability reducing two weeks later. An example of this for a participant with moderate lateropulsion sitting without arm support is provided in Figure 1(a). Of the six participants who could perform the static standing tasks initially, four displayed marked instability on day one, which improved by day 15. An example of this for a participant with mild lateropulsion standing unsupported can be found in Figure 1(b). As these figures

Table 3: Participants' ability to complete each test item (✓) or not (×) (day 1)

		Sitting test number†								Standing test number‡						
Participant number	Severity*	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7
1	Mild	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	x	x	x
2	Mild	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x
3	Mild	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	x	x	x
4	Moderate	✓	✓	x	x	x	x	x	x	x	x	x	x	x	x	x
5	Mild	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	x	x
6	Mild	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x
7	Moderate	✓	✓	✓	✓	✓	✓	x	✓	x	x	x	x	x	x	x
8	Severe	✓	x	x	x	x	x	x	x	x	x	x	x	x	x	x
9	Mild	✓	✓	✓	✓	✓	✓	✓	x	x	x	x	x	x	x	x
10	Mild	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x

Notes: * Rated by BLS scores; † Sitting test 1=sit with arm support; test 2=sit no arm support; test 3=sit shift weight non-paretic; test 4=sit shift weight paretic; test 5=sit eyes closed; test 6=sit arm raise test; test 7=sit reaching sideways; test 8=sit pick up object from behind; ‡ Standing test 1=standing with arm support; test 2=standing without arm support; test 3=stand shift weight to non-paretic leg; test 4=stand shift weight to paretic leg; test 5=stand eyes closed; test 6=turn head while standing; test 7=standing feet together.

demonstrate, the mediolateral COP amplitude measure showed a greater level of initial variability and displayed a greater capacity for change over time compared to the anteroposterior COP amplitude measure for both the static sitting and standing tasks. The variability observed for the dynamic tasks in both positions was more difficult to interpret in the absence of normative data. This was further confounded by the nature of some of the included dynamic tasks. For example, participants were asked to reach sideways as far as possible in sitting. The use of maximal reach rather than reach to a pre-determined target was found to introduce further variability between trials. Weight bearing symmetry could not be measured due to difficulty accurately aligning the participants to the centre of the WBB for testing.

DISCUSSION

The aim of this study was to determine the feasibility of using WBB technology as a novel measure of postural control in individuals with varied severity of lateropulsion. The use of the WBB for this purpose was shown to be feasible with no drop-outs. However, the higher rate of premature cessation of testing from fatigue or discomfort indicates that the number of tasks could be reduced to minimise this and optimise data completeness. Based on the study findings, an abbreviated task set for future research using the WBB for stroke survivors with lateropulsion has been recommended (Table 1).

The WBB-derived mediolateral COP variability measures obtained from the static sitting and standing tasks appeared to capture useful information regarding postural control for individuals with varying degrees of lateropulsion and detect change over time. The COP data reveals that the balance control mechanisms are very active in these individuals in balance tasks that are possible but difficult, without the individual finding a stable balance point. As they improve, they are able to achieve improved balance stability in the task.

Use of WBB technology for this purpose is not without its limitations. These include the need for specific equipment and training, including a computer, customised software and modified transfer bench, and the cost associated with this; as well as the potential issues that may arise when utilising Bluetooth and battery operated systems. Force platforms are considered a gold standard for measuring postural alignment in static and dynamic tasks. However they are expensive, and generally not available in rehabilitation in-patient and out-patient services for patients with stroke. The WBB as utilised in this study, is cheap, (less than $AUD 200), portable, easily stored, and requires minimal training for use compared to standard types of force platforms.

A number of limitations need to be considered when interpreting the results of this pilot study. Firstly, the small sample size restricted the ability to perform statistical analyses

Table 4: Centre of pressure data (median [interquartile range] or median (range))

Task		D1				D15			Percentage change		
	n	AP amplitude	ML amplitude	Total path velocity	n	AP amplitude	ML amplitude	Total path velocity	AP amplitude	ML amplitude	Total path velocity
SITTING TASKS											
Sit with arm support	10	0.46 [0.22,0.73]	0.47 [0.25,0.92]	0.72 [0.58,1.54]	9	0.33 [0.24,0.44]	0.35 [0.22,0.52]	0.56 [0.44,0.69]	-28% [9%,-39%]	-25% [-13%,-44%]	-22% [-24%,-55%]
Sit no arm support	9	0.38 [0.32,1.54]	0.75 [0.39,3.43]	0.69 [0.49,2.57]	8	0.38 [0.32,0.56]	0.48 [0.31,0.60]	0.47 [0.40,0.68]	-1% [-2%,-64%]	-36% [-20%,-82%]	-32% [-18%,-74%]
Shift weight- NP	8	1.18 [0.87,1.32]	5.62 [4.10,7.02]	1.65 [1.42,2.43]	8	1.42 [0.63,1.66]	6.34 [4.66,8.50]	1.76 [1.06,2.03]	20% [-27%,26%]	13% [14%,21%]	6% [-26%,-17%]
Shift weight- P	8	1.43 [0.86,1.01]	5.86 [2.98,4.26]	1.35 [1.24,1.31]	7	1.69 [0.76,2.62]	8.26 [3.41,8.81]	1.52 [0.94,2.10]	18% [-12%,159%]	41% [15%,107%]	12% [-24%,61%]
Sitting eyes closed	7	0.50 [0.43,0.62]	0.72 [0.61,1.15]	0.60 [0.51,0.79]	8	0.33 [0.28,0.55]	0.52 [0.44,1.01]	0.55 [0.48,0.61]	-34% [-35%,-12%]	-28% [-28%,-12%]	-8% [-6%,-22%]
Arm raise test	7	1.47 [0.93,1.52]	2.47 [1.06,3.72]	1.89 [1.38,3.63]	8	1.54 [0.85,2.20]	2.54 [1.50,3.94]	2.69 [1.32,4.48]	5% [-8%,44%]	3% [42%,6%]	42% [-4%,24%]
Reaching sideways	6	1.38 [0.77,1.82]	7.41 [5.58,9.03]	1.72 [1.60,2.28]	7	1.69 [1.00,2.18]	7.88 [5.94,11.29]	1.74 [0.94,2.10]	22% [30%,19%]	6% [6%,25%]	1% [-41%,-8%]
Pick up object	7	2.01 [1.17,2.44]	3.38 [2.63,4.89]	1.80 [1.31,2.76]	8	1.49 [1.03,2.16]	4.08 [3.20,5.17]	1.74 [1.25,2.46]	-26% [-13%,-11%]	21% [21%,6%]	-3% [-4%,-11%]
STANDING TASKS											
With arm support	6	2.03 [1.30,2.23]	1.89 [1.02,2.17]	1.31 [1.25,1.49]	7	1.59 [1.05,1.80]	0.87 [0.57,1.10]	1.10 [0.89,1.33]	-22% [-19%, -19%]	-54% [-44%,-50%]	-16% [-29%,-10%]
Without arm support	6	2.80 [2.61,3.34]	4.00 [2.27,5.09]	2.70 [2.24,2.92]	7	2.89 [2.35,3.45]	2.55 [1.61,4.13]	2.92 [1.63,3.07]	3% [-10%,3%]	-36% [-29%,-19%]	8% [-27%,5%]
Shift weight- NP	6	3.51 [3.03,4.74]	4.27 [3.68,5.14]	3.01 [2.82;3.88]	7	3.97 [2.33,6.61]	5.63 [3.34,7.05]	2.91 [2.45,4.13]	13% [-23%,39%]	32% [-9%,37%]	-3% [-13%,6%]
Shift weight- P	4	4.88 [3.69,6.24]	6.94 [4.77,8.62]	3.88 [3.31,4.67]	7	3.72 [2.28,5.11]	8.22 [4.97,9.05]	3.65 [2.87,4.96]	-24% [-38%,-18%]	18% [4%,5%]	-6% [-13%,6%]
Eyes closed	3	4.13 [2.91,5.34]	3.37 [1.47,3.73]	3.16 [3.16,5.85]	7	3.52 [2.76,3.86]	2.50 [2.08,3.21]	3.21 [2.39,3.77]	-15% [-5%,-28%]	-26% [41%,-14%]	1% [-24%,-36%]
Turn head	3	6.14 [3.00,9.58]	2.50 [2.42,10.05]	3.64 [2.87,11.94]	7	6.86 [3.72,7.49]	6.03 [3.01,6.45]	5.35 [3.68,6.77]	12% [24%,-22%]	142% [25%,-36%]	47% [28%,-43%]
Feet together	0				7	2.91 (2.49,4.00)*	3.52 (2.86,4.42)*	3.41 (2.62,4.06)*			

Notes: AP, Anteroposterior; D, Day; ML, Mediolateral; NP, non-paretic side; n, number, P, paretic side;
Values are median [interquartile range] or (range); Percentage change calculated by $\frac{D15 - D1}{D1}$

* only three measures available

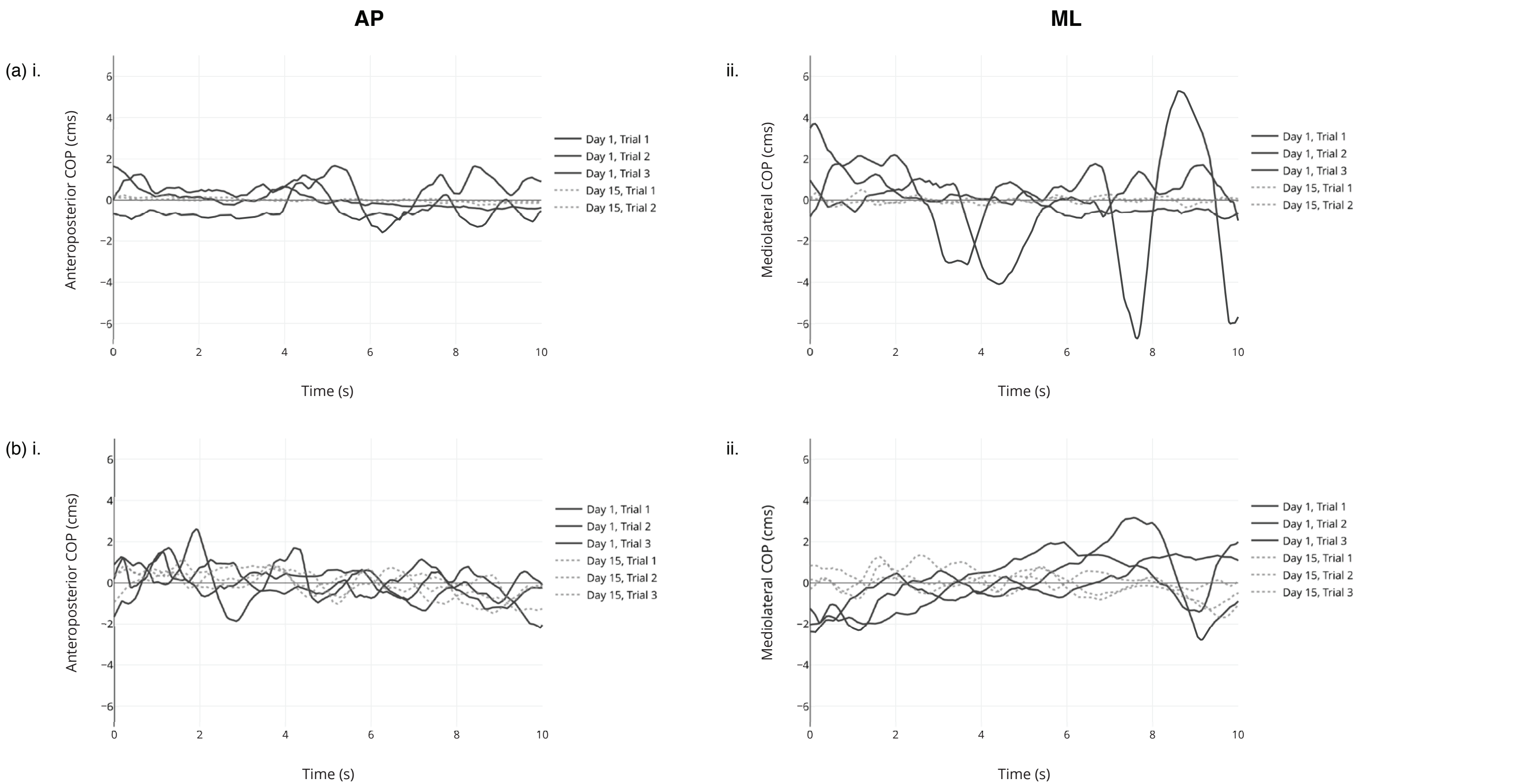

Figure 1: Centre of pressure (COP) movement variability over time (seconds) for (a) task of sitting without arm support for a participant with moderate lateropulsion; (b) standing unsupported for a participant with mild lateropulsion. Interactive versions of these figures are available to view online at http://www.rehabtools.org/pusher-syndrome-balance.html.
(a) Sitting without arm support for a participant with moderate lateropulsion:
i. Anteroposterior (AP) COP movement variability Day 1 (average AP amplitude 2.65; average AP path velocity 1.20) and Day 15 (average AP amplitude 0.38; average AP path velocity 0.29)
ii. Mediolateral (ML) COP variability Day 1 (average ML amplitude 8.27; average ML path velocity 2.74) and Day 15 (average ML amplitude 0.76; average ML path velocity 0.60)
(b) Standing unsupported for a participant with mild lateropulsion:
i. AP COP movement variability Day 1 (average AP amplitude 3.64; average AP path velocity 1.92) and Day 15 (average AP amplitude 2.42; average AP path velocity 1.27)
ii. ML COP movement variability Day 1 (average ML amplitude 4.61; average ML path velocity 1.40) and Day 15 (average ML amplitude 2.19; average ML path velocity 0.99)
As these figures demonstrate, postural instability was present for both individuals on day one for the different tasks, particularly in the mediolateral plane. The postural instability observed improved for both participants in both directions over the two-week period. This corresponded with an improvement in the individuals' lateropulsion measures."

in this study. Secondly, although 100% retention was achieved, some participants did find the tasks fatiguing, and / or caused discomfort, which may limit the utility of this approach in some patients with stroke. Thirdly, the nature of some of the included dynamic tasks introduced further variability between trials, which had not been anticipated. The abbreviated task set developed for future research includes standardised tasks with pre-determined targets in order to minimise this (Table 1). Finally, the absence of normative values for the balance tasks included also made it difficult to interpret the WBB-derived data, particularly for the dynamic tasks. Given the promising results of the feasibility study, the research team have commenced a normative data collection project with the abbreviated task set presented in Table 1 to address this need.

CONCLUSIONS

The use of WBB technology appears feasible to assess sitting and standing balance in individuals following stroke with lateropulsion using a reduced number of modified tasks, structured to minimise variability between trials due to task performance. A larger longitudinal measurement study is required to establish the reliability and validity of this technology in this important clinical sub-group. Given laboratory-based systems are often inaccessible to this patient population, use of WBB technology may provide a greater insight into the postural control deficits experienced by individuals with lateropulsion, which cannot be obtained from clinical measures alone.

KEY POINTS

1. The use of Wii Balance Board technology appears feasible to assess sitting and standing balance in individuals following stroke with lateropulsion undergoing rehabilitation.
2. Using Wii Balance Board technology as a research tool may capture useful information about balance in individuals with lateropulsion, and inform future physiotherapy trials investigating the effectiveness of specific interventions targeting lateropulsion.

DISCLOSURES

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PERMISSION

The study was approved by the human research ethics committees of St. Vincent's Hospital Melbourne (LRR 084/13) and Curtin University (HR 174/2013). Written informed consent was obtained from all participants prior to inclusion.

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Chapter 7. Postural control strategies in sitting are highly variable in people with lateropulsion post stroke

Chapter Outline

Based on the outcomes obtained from the feasibility study (Chapter 6) (Birnbaum et al., 2018), a larger main observational study was undertaken to further investigate the use of instrumented measures to quantify the postural control dysfunction observed in sitting and standing in stroke survivors with lateropulsion. The outcomes of the feasibility study resulted in some minor changes to the methods used, in particular abbreviating the overall number and duration of the assessment procedures. The sitting component of the main observational study is presented in this chapter.

This study involves 46 individuals with lateropulsion and 35 healthy controls. The study aims to 1) compare WBB-derived COP data acquired in sitting in people with lateropulsion to healthy controls; 2) investigate the relationship between seated COP variables and clinical measures of lateropulsion and postural function; and 3) determine the test-retest reliability of seated WBB-derived COP variables in individuals with lateropulsion.

The study reported within this chapter is presented in manuscript format.

7.1 Abstract

Background: Lateropulsion following stroke is characterised by an impaired postural orientation to vertical and can impact an individual's ability to sit unsupported. Little is known regarding postural control recovery in sitting in stroke survivors with lateropulsion.
Research Questions: (1) What differences are present when comparing instrumented measures of postural control in sitting in people with lateropulsion to healthy controls; (2) What is the relationship between these measures and non-instrumented clinical assessments of lateropulsion and postural function; and (3) Do instrumented measures of postural control in sitting have adequate test-retest reliability.
Methods: Forty six individuals with lateropulsion post stroke and 35 healthy controls participated in this study. For the participants with lateropulsion, instrumented measures of static and dynamic sitting balance tasks (using Wii Balance Boards) and non-instrumented clinical assessments of lateropulsion and postural function were taken when able to sit with back and arm support for three seconds and then fortnightly over eight weeks.
Results: Differences in postural control for mediolateral and anteroposterior stability in sitting were found in people with lateropulsion compared to healthy controls, with higher centre of pressure amplitudes demonstrated ($p<0.01$). However postural control performance was inconsistent, with some participants demonstrating high levels of mediolateral amplitude and variability, while others were within the healthy control range. A moderate positive correlation was found between mediolateral and anteroposterior amplitude and the Burke Lateropulsion Scale for the task of sit unsupported ($r=0.548$ and 0.571 respectively, $p<0.001$).
Significance: This study demonstrated that stroke survivors with lateropulsion display different and mixed postural control strategies to maintain balance in sitting as a group and compared to healthy controls. This may have implications for treatment strategies and warrants further investigation.

7.2 Introduction

Lateropulsion following stroke is a unique disorder characterised by individuals displaying impaired postural orientation to vertical (Karnath et al., 2000b; Pérennou et al., 2008). Individuals with lateropulsion typically adopt a tilted body posture and use their non-paretic extremities to push towards the paretic side, actively resisting correction of this alignment back to vertical (Davies, 1985). The incidence of lateropulsion following acute stroke in rehabilitation settings is 18-25% (Baccini et al., 2008; Clark et al., 2012). Compared to stroke survivors without lateropulsion, individuals with lateropulsion have a longer length of stay (Clark et al., 2012; Danells et al., 2004) and/or achieve a lower functional level upon discharge (Babyar et al., 2008; Danells et al., 2004).

Stroke survivors with severe lateropulsion are often unable to sit independently. This in turn affects their ability to perform basic self-care tasks, such as toileting. Achievement of independent sitting balance is one of the first goals of rehabilitation for these individuals. While many studies have investigated the sensory/perceptual disorder underlying lateropulsion (Karnath et al., 2000b; Pérennou et al., 2008), little is known about the motor execution/efferent postural control aspects of lateropulsion. The use of instrumented measures to acquire COP data in sitting may assist to quantify the postural dysfunction observed in lateropulsion and subsequently guide treatment.

Previous studies have investigated using COP variables obtained from force platforms as measures of seated postural control in stroke survivors (Genthon et al., 2007; Näf et al., 2020; Tessem et al., 2007; van Nes et al., 2008). For static sitting, individuals following stroke have displayed greater postural instability compared with healthy controls (Genthon et al., 2007; van Nes et al., 2008). For seated reaching tasks, greater variability in COP patterns and differences in lateral displacement have been demonstrated (Tessem et al., 2007). Two small studies have attempted to quantify postural dysfunction in sitting in individuals with lateropulsion. In a sample of stroke survivors including seven participants with lateropulsion, centre of gravity was shifted towards the paretic side when lateropulsion was present (Lafosse et al., 2007). In a pilot study involving 10 individuals with lateropulsion, mediolateral COP variability during seated balance tasks was identified as a variable of interest (Chapter 6) (Birnbaum et al., 2018).

This study had three aims: (1) to establish what parameters in sitting differed between individuals following stroke with lateropulsion and healthy controls using instrumented measures of postural control; (2) to determine the relationship between these instrumented measures and non-instrumented clinical assessments of lateropulsion and postural function with individuals following stroke with lateropulsion; and (3) to evaluate the test-retest reliability of COP variables acquired from the WBB with individuals following stroke with lateropulsion.

7.3 Method

Study design

For the lateropulsion cohort, a longitudinal observational study with repeated measures was undertaken. A separate, concurrent observational study was completed for the healthy control cohort investigating healthy control values for the same instrumented WBB-derived measures of sitting. The studies were approved by the relevant human research ethics committees (HREC-A 146/15, HR15/2015; LNR 158/15, HR55/2016). Written consent was obtained from all participants, or the Next of Kin if individuals were unable to consent for themselves.

Setting

Participants

Participants with lateropulsion were recruited from consecutive admissions to the Stroke and Rehabilitation Units of St. Vincent's Hospital Melbourne, Australia between January 2016 and December 2018.

The inclusion criteria for the lateropulsion group were:

- Between one and 12 weeks post-acute stroke
- The presence of contraversive lateropulsion (BLS score ≥2) (Babyar et al., 2017; Babyar et al., 2008)
- Able to sit with back and arm support for >3 seconds
- Able to follow a one stage command with gesture
- Able to undertake 20 minutes of physiotherapy (Chapter 6) (Birnbaum et al., 2018).

Exclusion criteria were:

- Pre-stroke co-morbidity limiting community mobility (Chapter 6) (Birnbaum et al., 2018)

- Weight >112kg (Chapter 6) (Birnbaum et al., 2018)
- Cerebellar ataxia.

Healthy control participants were identified from a concurrent study investigating healthy control values for various postural control tasks, inclusive of the tasks utilised in this study. Participants for the concurrent study were recruited from staff, family and friends of St Vincent's Hospital Melbourne. Inclusion criteria for this group were individuals without a health condition affecting their mobility, independent community ambulation with no aids and weight <112kg. Forty-eight healthy participants were intentionally recruited across 12 five year age brackets from 25 to 85 years, with two male and two female participants recruited per bracket. Following completion of data collection for both groups, only 35 sex- and aged matched (±5 years) healthy controls were able to be matched with the lateropulsion sample from the concurrent study.

Measures

Participants performed three trials of four tasks sitting on a Nintendo WBB if able, in the following order: 1) sitting with the non-paretic arm holding a rail (or the randomised arm for healthy controls) for three seconds; 2) sitting without arm support for three seconds; 3) reaching to pick up a cup in front, within arm's length; 4) reaching to pick up a cup diagonally on the non-paretic side, beyond arm's length (Chapter 6) (Birnbaum et al., 2018) (or randomised side for healthy controls). In order to gain insight into the challenging impairment of lateropulsion across its entire spectrum, the short test length for the static sitting tasks (three seconds) was selected to include participants with severe lateropulsion who could only sit unsupported for a very short period of time. Task setup and testing procedures are outlined in section 4.2.5 Outcome measures: Instrumented measures.

The WBB was used with a custom-designed data acquisition system comparable to prior seated postural control studies, yielding COP measures similar to those obtained by a force platform (Clark et al., 2010; Pua et al., 2013). The WBB sampled COP data at the native frequency of approximately 40Hz, which is set by the WBB and not adjustable without hardware modification. Data were acquired from each of the four strain gauge-based load cells located in each corner of the platform, lowpass filtered at 10Hz using a 1-level Coiflet-5 discrete wavelet transform with the details levels removed (Clark et al., 2017). To perform the discrete wavelet transform analysis data were resampled to 100Hz using spline interpolation, and lowpass filtered again at 6.25Hz using a 3-level Coiflet-5 discrete wavelet transform with the details levels removed to attenuate signal noise as per Clark et al (2017). This resampling and filtering allowed for the cascading discrete wavelet filter banks to achieve the desired frequency bandwidths of interest (Clark et al., 2017).

Of the WBB-derived COP variables yielded, amplitude, path velocity and standard deviation were examined (Chapter 6) (Birnbaum et al., 2018; Clark & Pua, 2018). Centre of pressure amplitude for each axis (mediolateral and anteroposterior) is defined as the largest range that the COP trace moved during a trial on a given axis and is determined by calculating the distance between the maximum and minimum COP position on each axis (Clark et al., 2017). A larger amplitude indicates increased COP sway range of motion (Clark et al., 2017). Centre of pressure path velocity (mediolateral and anteroposterior) (cm/seconds) is a commonly reported COP variable and is defined as the total distance (cm) that the COP trace moves during the trial along a given axis divided by the trial length (seconds) (Clark et al., 2010). Standard deviation (SD) of the COP trace on each axis (mediolateral and anteroposterior) is determined from the COP position data for each axis independently, and quantifies the motion occurring about the mean COP position during the trial (Clark et al., 2017). A larger value represents greater exploration around the centre position (Clark et al., 2017). Standard deviation was added to the variables examined in the feasibility study (Chapter 6) as a measure of COP variability given the pronounced COP movement which was observed when individuals were performing tasks at the upper end of their ability level (Birnbaum et al., 2018). For data analysis, the median score of successful trials was utilised.

Along with the instrumented measures, participants following stroke completed a series of non-instrumented clinical assessments. The BLS (D'Aquila et al., 2004) was used to assess lateropulsion severity, while postural abilities were measured using the PASS (Benaim et al., 1999). Active motor control, sensation and neglect were assessed using lower extremity items of the Stroke Rehabilitation Assessment of Movement Instrument (Daley et al., 1999), the lower limb sensory section of the Fugl-Meyer Assessment (Fugl-Meyer et al., 1975) and the Catherine Bergego Scale (Azouvi et al., 1996) respectively. The participants' Functional Independence Measure (motor domain) scores were recorded to provide a global measure of functional ability (Linacre et al., 1994). These clinical scales are reliable and valid outcome measures for use with stroke survivors.

Procedures

Participants with stroke were recruited on the latter of either day seven post stroke, or when all inclusion criteria were met. On the day prior to commencing data collection, participants undertook a 10 minute familiarisation period with the technology task setup (online supplementary material). The aim of the familiarisation period was to reduce any practice effect between day one and day two testing. For the participants with stroke, data collection for the instrumented measures, BLS and PASS was performed for a maximum of six testing occasions. This included; day one following the familiarisation session, day two, week two from the first assessment, week four, week six and week eight, unless discharged from hospital prior to this time. In order to maximise the dataset, the WBB measures for each task were recorded from the first occasion that task could be successfully performed by a given participant, and so the time of measurement (and therefore time post stroke) differed within participants for some tasks (e.g. for sit with and without arm support, the measures may have been taken from the first assessment, but for forward reach the assessment may have occurred two weeks later), as well as between participants (Figure 7.1). Measures of motor control, sensation, neglect and functional ability were completed at baseline only. For healthy controls, data collection occurred on one occasion.

Statistical Analysis

Descriptive statistics were used to present demographic data. Distribution of the WBB-derived COP variables were examined for normality using the Shapiro-Wilk test. The majority of COP variables were not normally distributed (15/16 variables; 94%). Therefore, non-parametric statistics were utilised. To identify any COP variables that may be redundant, correlations between COP variables for each task were examined using Spearman rho. A Spearman rho value of 0.75-1 is regarded as excellent; 0.50-0.74, a moderate correlation; 0.25-0.49, a fair correlation and 0-0.24, weak or no correlation (Portney & Watkins, 2009).

Mann-Whitney U Tests were performed for between group comparisons. Effect size (ES)(r) was calculated for each Mann-Whitney U Test using the relevant z value divided by the square root of the total number of cases (Pallant, 2016). For the Mann-Whitney U Test, an effect size of 0.1-0.29 is considered small; 0.3-0.49, medium; and greater than 0.50, a large effect (Cohen, 1988). These values were utilised to interpret effect size as the novel nature of the included tasks meant it was difficult to interpret the results in the context of prior research (Durlak, 2009).

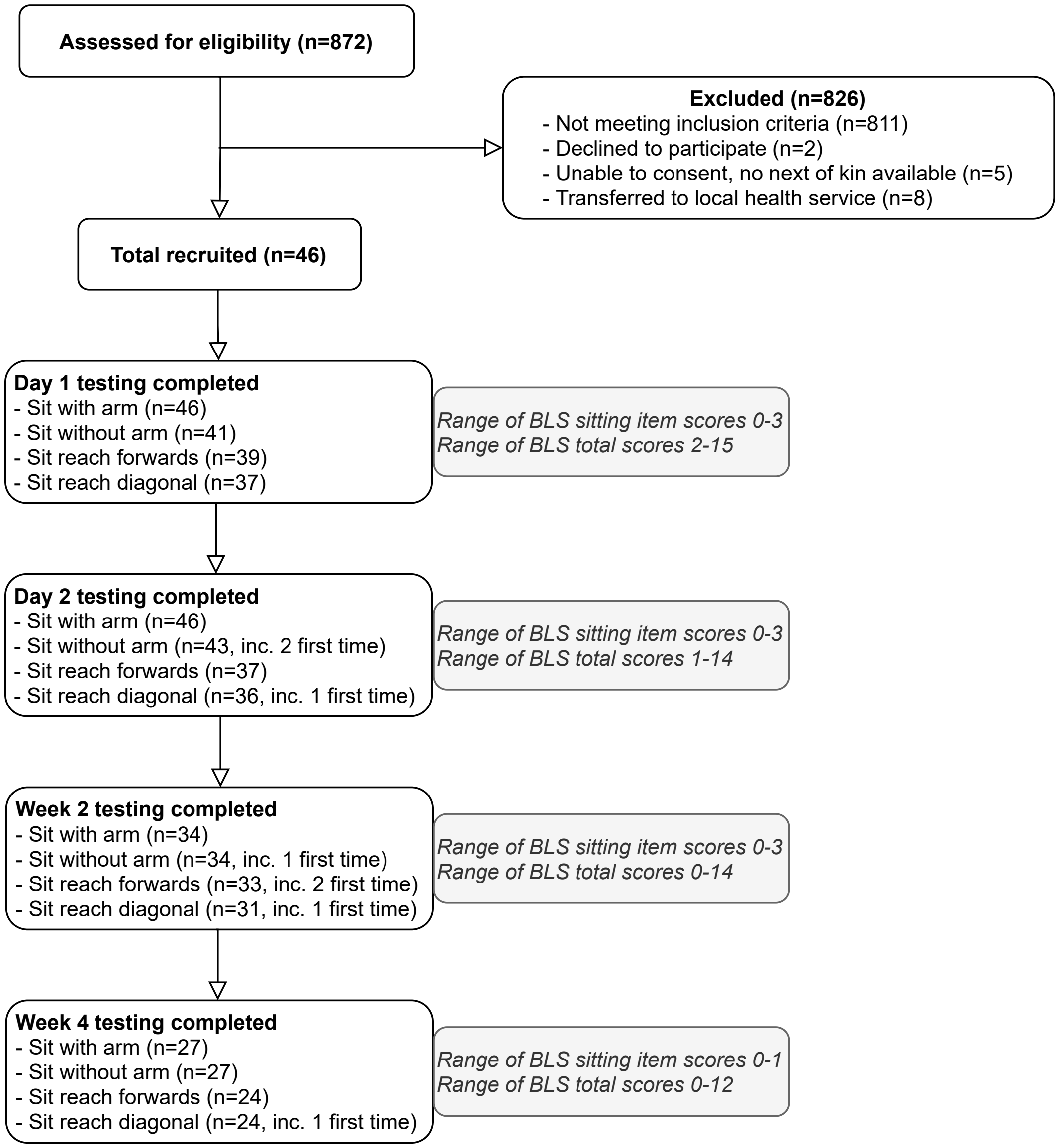


Figure 7.1. Flow diagram outlining the testing completed for recruited participants including when new participants completed a task for the first time and the range of Burke Lateropulsion Scale sitting item and total scores on each testing occasion

Abbreviations: BLS, Burke Lateropulsion Scale; inc., including; n, number.

For those COP variables where a significant difference was identified between groups, correlations between the significant COP scores and the non-instrumented clinical assessments of lateropulsion and postural control (total BLS and PASS scores) were investigated using Spearman rho and bivariate scattergrams. For between group comparisons and correlations between COP variables and non-instrumented clinical assessments, data were used from when an individual with lateropulsion could first complete a given task in order to maximise the dataset size.

Test-retest reliability of COP variables was assessed between Day 1 and Day 2, with Spearman rho utilised given the included COP variables were not normally distributed. Additional analysis was conducted using the Wilcoxon signed-rank test and bivariate scattergrams to determine if there was systematic variability observed between Day 1 and Day 2 scores.

Significance for statistical analyses was set at $p<0.05$. In order to adjust for multiple comparisons, a family-wise Bonferroni error correction for the various analyses undertaken was applied. Adjusted p values are reported in the relevant tables of data for each group of data where family-wise Bonferroni error corrections have been made.

Power analyses utilising data from a feasibility study (Chapter 6) (Birnbaum et al., 2018) were performed to calculate the sample size required for between group comparisons of mediolateral standard deviation and mediolateral path velocity for the sitting tasks. With alpha set at 0.05, power at 0.8, and a two-tailed test based on a 20% difference between groups, at least 12 participants per group were needed. For analysis of the psychometric properties of the instrumented tests, the COSMIN guidelines recommend a good sample size contains >50 subjects (Mokkink, Terwee, Patrick, et al., 2010). A sample size of 60 participants was planned allowing for an anticipated dropout rate of 20% given the longitudinal nature of the study.

7.4 Results

Forty-six participants with lateropulsion, including 26 men (57%) (mean (standard deviation (SD)) age of 66.8 (±14.6) years) participated in this study and completed Day 1 and Day 2 testing. This was the available number of participants who volunteered and were eligible during the nominated duration of the study. For Day 2 testing, 87% (n=40) of assessments were completed as scheduled, 6.5% (n=3) were delayed by one day and 6.5% (n=3) were completed three or four days later than planned. The median [interquartile range] time post stroke to initial assessment was 22 [13-33] days. Thirty-five healthy controls participated in this study, including 19 men (53%) (mean (SD) age of 62.0 (±13.7) years). Baseline characteristics for both healthy controls and participants with stroke are summarised in Table 7.1.

Correlations between COP variables

For the sitting tasks in the lateropulsion group, mediolateral amplitude and standard deviation (r=0.948-0.973, p<0.001), as well as anteroposterior amplitude and standard deviation (r=0.969-0.987, p<0.001), were highly correlated and therefore deemed redundant (Barfod et al., 2019). Correlations between mediolateral amplitude and path velocity (r=-0.027-0.777, p=0.000-0.865) for the sitting tasks in the lateropulsion group, as well as correlations between anteroposterior amplitude and path velocity (r=-0.003-0.894, p=0.000-0.983) for the four tasks in this group were generally lower, and in some cases weak. Thus, amplitude and path velocity in both directions were selected to be reported for each sitting task in the subsequent analyses.

Lateropulsion compared to healthy controls

For the two static tasks of sit with and without arm support, COP amplitude in both directions were greater for participants with stroke compared with healthy controls (p<0.01; Table 7.2, Figure 7.2a(i)-b(i)). This was particularly evident in the mediolateral direction when sitting without arm support (U=223, z=-5.399, p<0.001, ES=0.607), where 10 cases (23%) had scores outside 1.96SD (i.e. the 95% reference range (Whitley & Ball, 2002)) of the healthy controls (Figure 7.2b(i)). Path velocity was significantly different for mediolateral COP path velocity only for the sit without arm task, with greater path velocity in those with lateropulsion.

For the sit reach forwards within arm's length task, participants with stroke displayed more lateral movement, with higher mediolateral amplitude (U=422, z=-3.202, p<0.001, ES=0.365), however only seven cases (16%) scored outside 1.96SD of the healthy controls. In contrast, for the sit reaching diagonally beyond arm's length task, participants with stroke had less lateral movement with reduced mediolateral amplitude (U=986, z=2.798, p=0.005), with seven cases (17%) scoring outside 1.96SD of the healthy controls. Decreased COP mediolateral path velocity (U=1203, z=5.060, p<0.001) was observed for the sit reach diagonal task with six cases (15%) scoring outside 1.96SD of the healthy controls.

Table 7.1. Baseline characteristics for stroke participants and healthy controls

Variable	Stroke participants (n=46)	Healthy controls (n=35)
Age (years), mean (SD) [range]	66.8 (14.6) [35-91]	62.0 (13.7) [36-83]
Male sex, n (%)	26 (57)	19 (53%)
Time post stroke (days), median [IQR] (n=46)	22 [13-33]	
Side of hemiparesis (n=46)		
Left, n (%)	19 (41)	
Right, n (%)	26 (57)	
Both, n (%)	1 (2)	
Pathology (n=46)		
Infarct, n (%)	22 (48)	
Haemorrhage, n (%)	19 (41)	
Both, n (%)	5 (11)	
Lateropulsion severity (BLS scores), median [IQR] (n=46)	8 [4-10]	
Mild (2-8), n (%)	25 (54.4)	
Moderate (9-12), n (%)	14 (30.4)	
Severe (13-17), n (%)	7 (15.2)	
BLS sitting item scores (n=46)		
0, n (%)	33 (72%)	
1, n (%)	8 (17%)	
2, n (%)	0 (0%)	
3, n (%)	5 (11%)	
PASS scores, median [IQR] (n=46)	15 [12-23]	
Active Motor Control (LL items of STREAM) (n=44)		
Scores, median [IQR]	32 [0-63]	
Not tested , n (%)	2 (4)	

***Table 7.1 is continued on the next page*

Table 7.1. Baseline characteristics for stroke participants and healthy controls (continued)

Variable	Stroke participants (n=46)	Healthy controls (n=35)
Sensation (LL sensory section of FMA) (n=37)		
Impaired, n (%)	25 (54)	
Intact, n (%)	12 (26)	
Not tested, n (%)	9 (20)	
Neglect (Catherine Bergego Scale) (n=44)		
No neglect, n (%)	13 (28)	
Mild, n (%)	15 (33)	
Moderate, n (%)	11 (24)	
Severe, n (%)	5 (11)	
Not tested, n (%)	2 (4)	
FIM score (motor), median [IQR] (n=46)	22 [17-30]	

Abbreviations: BLS, Burke Lateropulsion Scale; FIM, Functional Independence Measure; FMA, Fugl Meyer Assessment; IQR, interquartile range; LL, lower limb; PASS, Postural Assessment Scale for Stroke; STREAM, Stroke Rehabilitation Assessment of Movement Instrument.

NB. For some participants, measures for active motor control, sensation and neglect were 'not tested'. The main reason for these not being completed was the presence of language deficits limiting the ability to do so accurately.

Correlation between COP and non-instrumented clinical assessments for individuals following stroke with lateropulsion

The correlations found for the stroke participants between the selected COP variables and the total BLS and PASS scores, varied depending on the sitting task (Table 7.3). The highest correlation between COP variables and the total BLS score was for the sitting without arm support task (mediolateral amplitude r=0.548, p<0.001; anteroposterior amplitude r=0.571, p<0.001) with larger amplitudes observed in those with more severe lateropulsion.

Table 7.2. Between group comparisons, participants with lateropulsion (the first time they could complete each task) and healthy controls, for centre of pressure variables

	LP N	LP Median	LP IQR	HC N	HC Median	HC IQR	U	z	p	ES
SITTING TASKS (family-wise Bonferroni correction)										
Sit with arm support (4 variables 0.05/4=0.013)										
ML COP amplitude, cm	46	0.215	0.159-0.340	35	0.144	0.124-0.202	427.5	-3.599	<0.001*	0.4
ML COP velocity, cm/s	46	0.382	0.342-0.458	35	0.363	0.310-0.440	677	-1.22	0.222	0.136
AP COP amplitude, cm	46	0.146	0.094-0.219	35	0.087	0.077-0.105	370.5	-4.143	<0.001*	0.46
AP COP velocity, cm/s	46	0.25	0.199-0.312	35	0.235	0.200-0.269	628	-1.688	0.092	0.188
Sit without arm support (4 variables 0.05/4=0.013)										
ML COP amplitude, cm	44	0.297	0.202-0.516	35	0.152	0.114-0.174	223	-5.399	<0.001*	0.607
ML COP velocity, cm/s	44	0.437	0.376-0.609	35	0.37	0.322-0.436	469.5	-2.966	0.003*	0.334
AP COP amplitude, cm	44	0.142	0.099-0.213	35	0.087	0.077-0.110	362.5	-4.022	<0.001*	0.453
AP COP velocity, cm/s	44	0.24	0.195-0.298	35	0.218	0.186-0.271	634	-1.342	0.18	0.151
Sit reach forwards (within arm's length) (4 variables 0.05/4=0.013)										
ML COP amplitude, cm	42	0.946	0.758-1.421	35	0.738	0.616-0.919	422	-3.202	0.001*	0.365
ML COP velocity, cm/s	42	0.968	0.826-1.269	35	1.018	0.736-1.240	685	-0.512	0.609	0.058
AP COP amplitude, cm	42	0.788	0.593-1.116	35	0.714	0.507-1.073	688	-0.481	0.631	0.055
AP COP velocity, cm/s	42	0.647	0.485-0.757	35	0.598	0.472-0.846	743	0.082	0.935	0.009
Sit reach diagonal (beyond arm's length) (4 variables 0.05/4=0.013)										
ML COP amplitude, cm	41	6.359	4.858-8.449	35	7.988	7.233-8.704	986	2.798	0.005*	0.321
ML COP velocity, cm/s	41	3.197	2.580-3.939	35	4.817	3.902-5.433	1203	5.06	<0.001*	0.58
AP COP amplitude, cm	41	2.99	2.326-4.348	35	3.18	2.476-3.977	752.5	0.365	0.715	0.042
AP COP velocity, cm/s	41	1.477	1.091-1.919	35	1.97	1.559-2.428	1016	3.111	0.002*	0.357

Abbreviations: AP, anteroposterior; cm, centimetres; cm/s, centimetres per second; COP, centre of pressure; ES, effect size; HC, healthy control; IQR, interquartile range; LP, lateropulsion; ML, mediolateral; N, number; p, p value; U, Mann-Whitney U; Z, Z value.
*Significant at p<0.013 after Bonferroni adjustment

Table 7.3. Correlations between centre of pressure variables and non-instrumented clinical assessments of lateropulsion and postural control

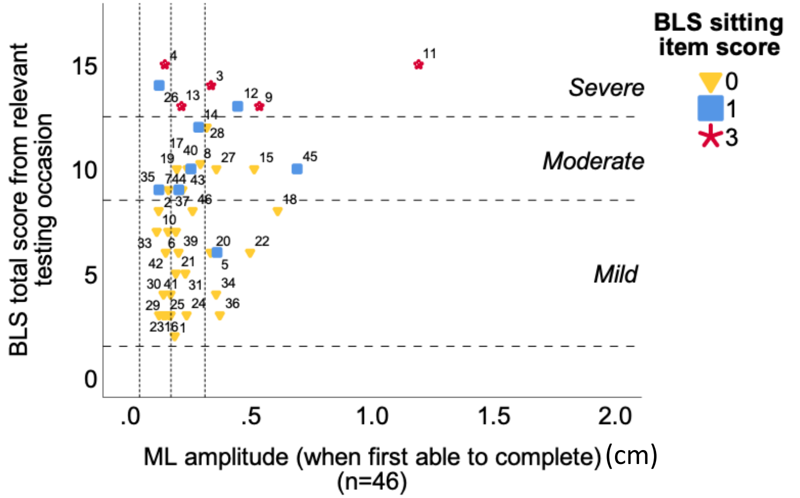
	BLS total Spearmans rho	p	PASS Spearmans rho	p
SITTING TASKS (family-wise Bonferroni correction)				
Sit with arm, n = 46 (2 variables 0.05/2=0.025)				
ML COP amplitude, cm	0.351	0.017*	-0.298	0.044
AP COP amplitude, cm	0.396	0.006*	-0.278	0.062
Sit without arm, n = 44 (2 variables 0.05/2=0.025)				
ML COP amplitude, cm	0.548	<0.001*	-0.501	0.001*
ML COP velocity, cm/s	0.412	0.005*	-0.435	0.003*
AP COP amplitude, cm	0.571	<0.001*	-0.517	<0.001*
Sit reach forwards (within arm's length), n = 42 (1 variable at 0.05)				
ML COP amplitude, cm	0.364	0.018*	-0.383	0.012*
Sit reach diagonal (beyond arm's length), n = 41 (3 variables 0.05/2=0.017)				
ML COP amplitude, cm	-0.145	0.365	0.32	0.042
ML COP velocity, cm/s	-0.211	0.184	0.369	0.018
AP COP velocity, cm/s	-0.241	0.128	0.287	0.069

Abbreviations: AP, anteroposterior; BLS, Burke Lateropulsion Scale; cm, centimetres; cm/s, centimetres per second; COP, centre of pressure; ML, mediolateral; n, number; p, p value; PASS; Postural Assessment Scale for Stroke.
*Significant at corrected p-value after Bonferroni adjustment.

Either weak or fair correlations were found between the total BLS score and COP measures for the other sitting tasks (Table 7.3, Figure 7.2). Examination of Figure 7.2a(i) indicates that participants with moderate to severe lateropulsion potentially demonstrated different postural control strategies. Some participants with stroke had similar scores to healthy controls (n=12) and others showed marked mediolateral amplitude beyond 1.96SD above healthy controls (n=7). Similarly, for those with mild lateropulsion, both mediolateral amplitudes within and outside the normal range were observed. This pattern was observed for all sitting tests (Figure 7.2b(i)-d(i)). For the sitting without arm support task, the three participants who had BLS sitting item scores of two or three displayed mediolateral amplitude scores outside the normal range (Figure 7.2a(i)).

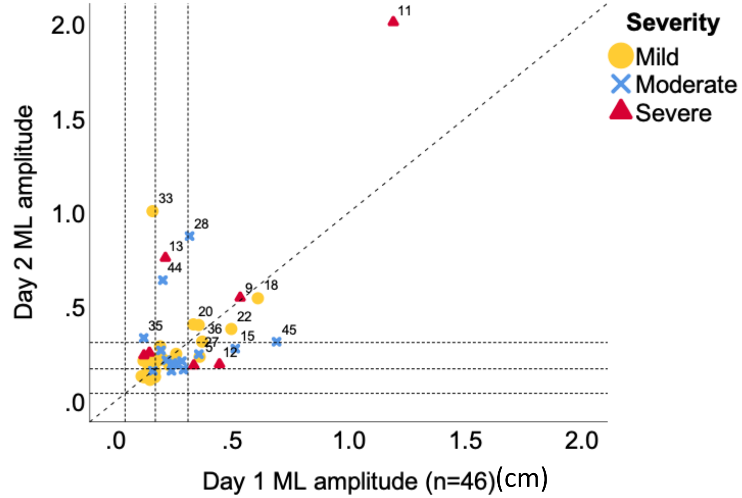
(a) Sit with arm

i.



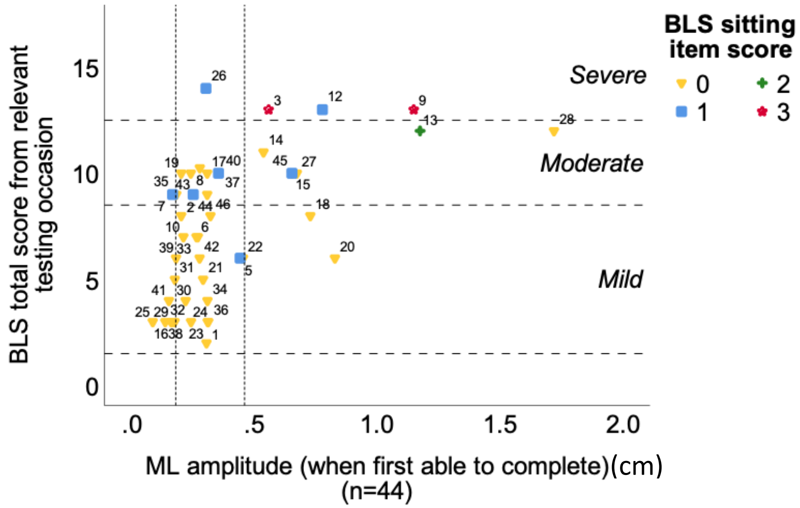
**The Day 2 ML amplitude value for Participant 11 was 3.01, it is represented as

ii. 2.01 on this graph to maintain a consistent axis range for the static sitting tasks

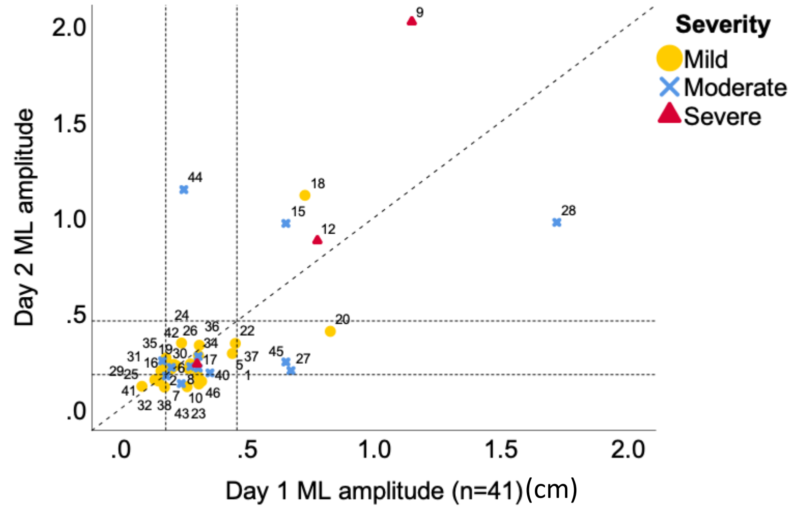


(b) Sit without arm

i. **1.96SD below the mean=-0.10, therefore omitted

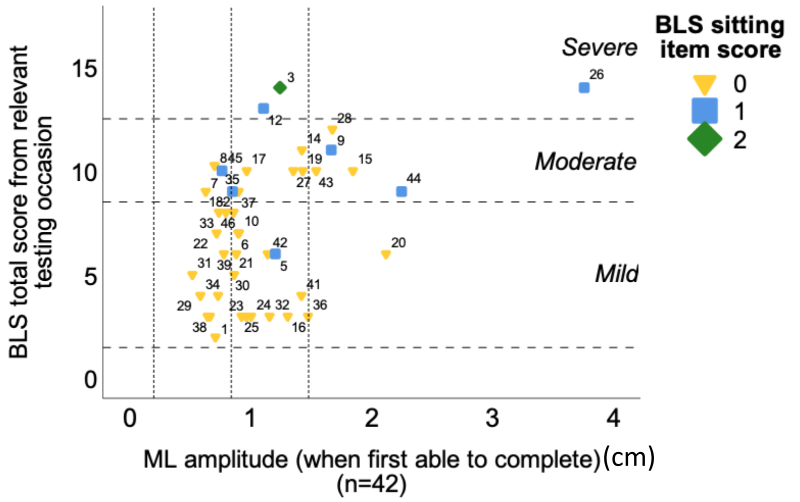


ii. **1.96SD below the mean=-0.10, therefore omitted

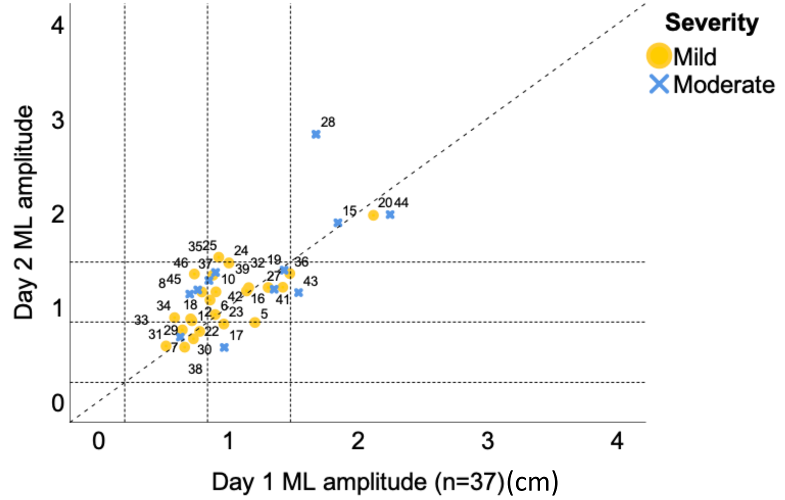


(c) Sit reach forwards (within arm's length)

i.

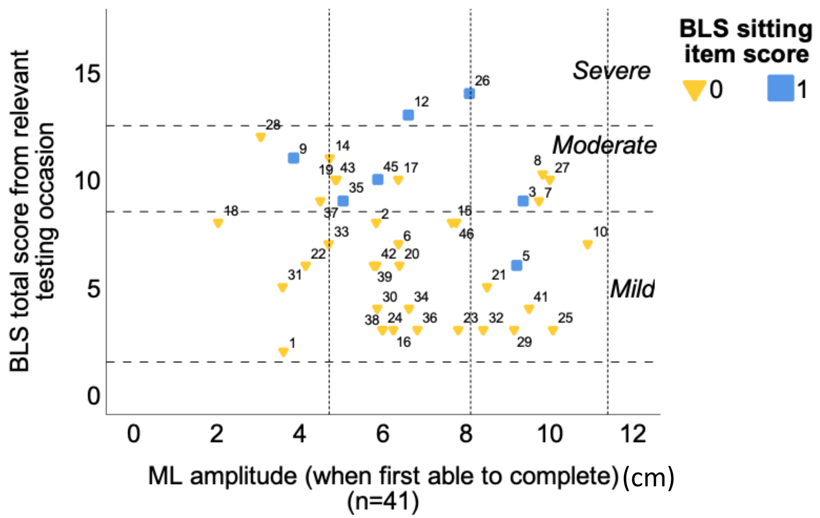


ii.



(d) Sit reach diagonal (beyond arm's length)

i.



ii.

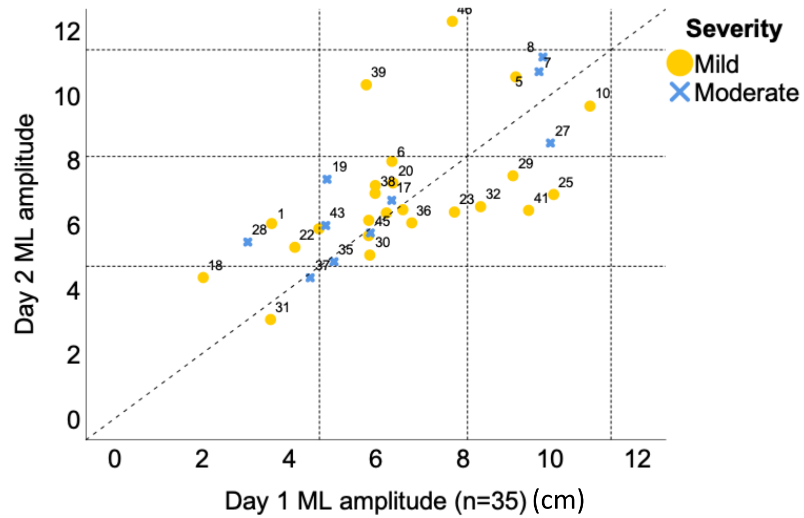


Figure 7.2. Mediolateral amplitude results for all sitting tasks

i. Scatterplot of relationship between mediolateral amplitude variable and the Burke Lateropulsion Scale for stroke participants with the symbols utilised representing the BLS sitting item score from the same testing occasion; ii. Scatterplot of Day 1 and Day 2 data for stroke participants. Normative value lines from healthy control data (mean +/- 1.96SD) are included on all scatterplots.

Abbreviations: BLS, Burke Lateropulsion Scale score; mild, mild lateropulsion severity (BLS 2-8); ML, mediolateral; moderate, moderate lateropulsion severity (BLS 9-12); n, number; severe, severe lateropulsion severity (BLS 13-17).

Table 7.4. Test-retest reliability for Day 1 and Day 2 centre of pressure data

	Day 1 Median [IQR]	Day 2 Median [IQR]	Test-retest reliability r_s	*p*	Wilcoxon signed-rank test *Z*	*p*
SITTING TASKS (family-wise Bonferroni correction)						
Sit with arm, n = 46 (4 variables 0.05/4=0.013)						
ML COP amplitude, cm	0.22 [0.16 – 0.34]	0.22 [0.18 – 0.32]	0.435	0.003*	-0.300	0.764
ML COP velocity, cm/s	0.38 [0.34 - 0.46]	0.42 [0.35 – 0.52]	0.481	0.001*	-1.262	0.207
AP COP amplitude, cm	0.15 [0.09 – 0.22]	0.14 [0.11 – 0.24]	0.649	<0.001*	-0.213	0.831
AP COP velocity, cm/s	0.25 [0.20 – 0.31]	0.25 [0.21 – 0.32]	0.418	0.004*	-1.153	0.249
Sit without arm, n = 41 (4 variables 0.05/4=0.013)						
ML COP amplitude, cm	0.28 [0.19 - 0.40]	0.22 [0.18 - 0.31]	0.559	<0.001*	-1.477	0.140
ML COP velocity, cm/s	0.41 [0.38 - 0.61]	0.44 [0.36 - 0.49]	0.675	<0.001*	-1.050	0.294
AP COP amplitude, cm	0.13 [0.10 - 0.19]	0.12 [0.10 - 0.20]	0.655	<0.001*	-1.237	0.216
AP COP velocity, cm/s	0.24 [0.19 - 0.29]	0.24 [0.21 - 0.29]	0.746	<0.001*	-0.758	0.448
Sit reach forwards (within arm's length), n = 37 (4 variables 0.05/4=0.013)						
ML COP amplitude, cm	0.90 [0.73 – 1.33]	1.16 [0.85 – 1.35]	0.673	<0.001*	-1.810	0.070
ML COP velocity, cm/s	0.95 [0.82 – 1.25]	1.05 [0.89 - 1.25]	0.566	<0.001*	-1.018	0.309
AP COP amplitude, cm	0.79 [0.57 – 1.10]	0.73 [0.51 – 1.18]	0.626	<0.001*	-0.400	0.689
AP COP velocity, cm/s	0.61 [0.47 - 0.75]	0.57 [0.52 – 0.82]	0.635	<0.001*	-0.913	0.361
Sit reach diagonal (beyond arm's length), n = 35 (4 variables 0.05/4=0.013)						
ML COP amplitude, cm	6.24 [4.87 – 8.50]	6.43 [5.67 – 7.50]	0.694	<0.001*	-0.884	0.376
ML COP velocity, cm/s	3.20 [2.67 – 3.72]	3.28 [2.64 – 4.24]	0.652	<0.001*	-1.245	0.213
AP COP amplitude, cm	2.92 [1.92 – 4.43]	3.55 [2.08 – 4.34]	0.675	<0.001*	-0.328	0.743
AP COP velocity, cm/s	1.45 [1.12 – 1.91]	1.47 [1.00 – 2.01]	0.687	<0.001*	-0.541	0.589

Abbreviations: AP, anteroposterior; cm, centimetres; cm/s, centimetres per second; COP, centre of pressure; ML, mediolateral; n, number; p, p value; r_s, Spearman's rho; Z, Z value.
*Significant at p<0.013 after Bonferroni adjustment

Test-retest reliability

For the sit with arm support task, fair to moderate correlations were found between Day 1 and Day 2 COP variables (r=0.418-0.649, p=0.000-0.004; Table 7.4, Figure 7.2a(ii)). For the remaining tasks, moderate correlations were found for all COP variables (r=0.559-0.746, p<0.001; Table 7.4, Figure 7.2b(ii)-d(ii)). No systematic differences were identified between Day 1 and Day 2 testing occasions for the COP variables, given the non-significant findings of the Wilcoxon signed-rank test (Table 7.4). Examination of the individual scores for the sit with arm support task showed varying patterns; individuals within healthy stability values on both occasions, those who were unstable on both occasions and those who were stable (within the healthy group's stability range) on one occasion and unstable on the other. This was less apparent during the other tasks.

7.5 Discussion

This study investigated postural dysfunction in people with lateropulsion after stroke by examining COP in sitting for both static and dynamic tasks. The study demonstrated differences in postural control in sitting, with higher COP amplitudes and velocity observed in people with lateropulsion compared to healthy controls.

Static tasks

The instrumented measures of postural stability in static sitting tasks were compared with non-instrumented clinical assessments of lateropulsion and postural ability, yielding fair to moderate correlations. Examining individual scores for the static sitting tests demonstrated that the COP patterns observed across people with moderate to severe lateropulsion (total BLS score 9-15) were not consistent. High levels of instability during static sitting tasks were observed for some participants (as previously reported (Chapter 6) (Birnbaum et al., 2018)), whereas others were within the healthy control range. These results suggest that even individuals with similar lateropulsion severity scores (moderate to severe) utilise different postural control strategies to one another, rather than one consistent strategy across this subgroup. For example, those with similar mediolateral COP scores to healthy controls and marked lateropulsion may be holding themselves relatively still, either by finding an equilibrium point or perhaps using fixation strategies as observed by La Fosse et al. to enable maintenance of a position (Lafosse et al., 2007). In contrast, larger mediolateral amplitudes may indicate a more fluctuating postural control strategy with continual readjustments.

Interestingly, for the three individuals able to perform the sitting without arm support task with BLS sitting item scores of two or three (indicating a greater severity of lateropulsion in sitting), all demonstrated larger mediolateral amplitudes, thus swaying excessively in sitting. For the participants with mild lateropulsion (total BLS score 2-8), the majority demonstrated similar mediolateral COP scores to the healthy controls. This was also the case for individuals who could complete the sitting unsupported task and only scored zero or one on the BLS sitting item. However, lateropulsion remained present during more demanding tasks such as standing and walking (as demonstrated by the BLS scores). It appears that recovery from lateropulsion may be posture and task specific.

It is unknown whether these different strategies can be distinguished by the clinician using visual observation. In the experience of the investigators, participants were observed to have high inter-subject variability, with noticeable excessive sway in some participants, but not others. Given the postural control strategies of participants differed, there may be benefit in using different treatment approaches to address the specific postural dysfunction observed. Perhaps those swaying excessively would benefit from the clinician providing support to reference and stabilise body alignment centrally in preparation for building stability. For those who are more static, potentially fixating through compensatory strategies, facilitation to reduce fixation through larger range movement and then building stability in midline without fixation may be more beneficial. Treatment of this type is utilised for lateropulsion in the Bobath Concept (Gjelsvik & Syre, 2016). Further research is warranted to increase understanding of these different postural strategies for individuals with lateropulsion.

Dynamic reaching tasks

In the dynamic tasks, significant differences were observed between COP measures in people with lateropulsion and healthy controls. Examining individual data, most participants could organise their postural control to reach for a defined target in a similar way to healthy controls. In contrast, some participants displayed greater mediolateral displacement when reaching forwards and reduced lateral movement when reaching diagonally. Similar findings regarding displacement during reaching have previously been observed with stroke survivors in the subacute phase (lateropulsion status unspecified) (Tessem et al., 2007).

The dynamic sitting tasks' COP measures had lower (or nonsignificant) correlations with the BLS total scores, compared to the static tasks. These findings were surprising; we anticipated that more instability may be observed with increased challenge, particularly with the large displacement required by the diagonal reach task, and that instability would correlate with lateropulsion severity. In contrast, the results suggest that once a person with lateropulsion has overcome the verticality impairment to successfully complete a dynamic task in sitting, they are likely to be stable in performing that task. This is supported by the finding that all bar one participant who could perform the dynamic reaching tasks scored zero or one for the sitting item of the BLS. Therefore, practicing reaching towards the non-paretic side in sitting, an intervention recommended for lateropulsion (Broetz & Karnath, 2005), once successfully and consistently achieved, may be of limited benefit as preparation for more difficult postural tasks in standing.

Test-retest reliability

The test-retest analysis revealed fair to moderate correlations (0.44-0.75), despite the previous familiarisation session, with variability in performance between Day 1 and Day 2 testing for all sitting tasks. The findings of this study suggest that the use of COP measures in sitting as a single-occasion assessment in studies evaluating interventions targeting lateropulsion early following stroke may be limited. There may be improved confidence in these measures in early stages of recovery after stroke if undertaken as serial measures over time. Interestingly, the day-to-day variability observed was not the result of a learning effect, with no systematic differences identified.

The variability observed in this study is in agreement with previous studies in stroke. Moderate test-retest reliability has been reported for COP velocity during quiet sitting in stroke survivors (Näf et al., 2020). Tessem and colleagues previously found COP pattern variability during seated reaching tasks within a testing session for stroke survivors, hypothesising that this variability may signify difficulty in generating appropriate postural adjustments following stroke (Tessem et al., 2007). Whilst different factors such as participant fatigue or distractibility may have contributed to the variability observed, the variability itself may represent underlying postural control dysfunction in participants with lateropulsion.

Prior to this study, we conducted a feasibility study for the use of instrumented measures in people with lateropulsion (Chapter 6) (Birnbaum et al., 2018). The study revealed the feasibility of collecting COP data using the WBBs, even with patients with severe lateropulsion, however some data was difficult to interpret because there were no normative data available for the majority of the posture and movement tasks utilised in this study. Therefore, in conjunction with the current study, we investigated these tasks in healthy controls. Without these data, it would not have been possible to identify participants with

COP values outside a normative range. This study highlights the importance of establishing normative data for assessment of tasks using instrumented measures.

Limitations

This study compared data from people with lateropulsion following stroke and healthy controls. The study did not include stroke survivors without lateropulsion as it was beyond the project resources to do so. Other studies have identified postural instability in participants with stroke, who may or may not have had lateropulsion. Future studies investigating lateropulsion should consider including stroke survivors without lateropulsion for comparison purposes. People with severe lateropulsion such that they could not sit with arm and back support were not included, excluding the most severe cases (e.g. BLS of 16 and 17). The study also does not examine the sitting tasks in individuals with lateropulsion who were unable to perform a given task without assistance.

An additional limitation of the study was the short test duration of the static sitting balance tasks which may have contributed to the variability in performance observed between Day 1 and Day 2 testing (Carpenter et al., 2001). The short test length was selected in order to include participants with severe lateropulsion who could only sit unsupported for a very short period of time. It has previously been acknowledged that studies must balance the limitations of participants, with the benefits of collecting a test period of longer duration (Carpenter et al., 2001). The inclusion of these individuals was considered to be essential to gain insight into this challenging impairment across its entire spectrum. Further studies investigating the repeated measurement of the COP variables over multiple time points to establish a variability baseline would be beneficial.

Another limitation of the study was the absence of data evaluating symmetry. In a pilot study, we attempted to seat participants centred on the WBB using line markers (Chapter 6) (Birnbaum et al., 2018). However, it was not possible to accurately place the person in the middle, readjust their position easily, or record their position on the surface, particularly for more disabled participants requiring equipment (e.g. hoist) to assist positioning or movement. A method of assessing weight-bearing asymmetry in sitting in people with lateropulsion would be valuable, and hence systems incorporating grid-type pressure mats may be beneficial. Likewise, data regarding body alignment and muscular activity were not recorded. Changes in neck and trunk alignment have previously been reported in individuals with lateropulsion (Lafosse et al., 2007). The collection of kinematic and electromyography data in future studies may provide insight as to how individuals with lateropulsion maintain sitting.

For this study, the reaching tasks used a constrained environment where participants reached towards a cup. This was chosen to represent daily life postural control requirements and enable comparison of COP values with a defined reach length and direction. This is a different task to those utilised in other studies, such as reaching or leaning as far as possible (Näf et al., 2020; Tessem et al., 2007). Therefore the results are not directly comparable.

7.6 Conclusion

This study demonstrated that stroke survivors with lateropulsion utilised different postural control strategies compared to healthy controls to maintain static sitting. Variability in postural control strategies was observed within the lateropulsion group. Once a stroke survivor could perform a dynamic task, severity of lateropulsion was not strongly related to COP variables. Day-to-day variability in COP measures was evident, limiting the utility of these variables as single-occasion assessments early following stroke.

Chapter 8. Standing weight-bearing asymmetry in adults with lateropulsion following stroke

Chapter Outline

It has previously been postulated that stroke survivors with lateropulsion may stand with greater weight through their paretic lower limb, given individuals with lateropulsion are often tilted towards this side. The results from two preliminary studies undertaken to date have not supported this notion, however, both studies have only included a small subset of participants with lateropulsion. The study presented in this chapter is the standing component of the main observational study (with the sitting component presented in Chapter 7). The standing component aims to 1) further explore the weight-bearing strategies used by individuals with lateropulsion to maintain balance in standing; 2) investigate the relationship between these weight-bearing strategies and clinical measures of lateropulsion and postural function; and 3) determine the test-retest reliability of the WBA variables collected.

This chapter is presented in its original manuscript format. Details of the publication are: Birnbaum M, Brock K, Clark R, Muir S, Burton & Hill K (2021) Standing weight-bearing asymmetry in adults with lateropulsion following stroke. *Gait & Posture*, advance online publication, https://doi.org/10.1016/ j.gaitpost.2021.09.172.

8.1 Abstract

Background: Weight-bearing asymmetry biasing the non-paretic leg is common following stroke. However, little is known as to how lateropulsion impacts on the weight-bearing patterns adopted in standing by individuals following stroke.

Research Questions: (1) Are there differences in weight-bearing asymmetry patterns observed in standing in people with lateropulsion relative to healthy controls; (2) What is the relationship between weight-bearing asymmetry and clinical measures of lateropulsion and postural function; and (3) Are measures of weight-bearing asymmetry reliable between test occasions.

Methods: Thirty-three individuals with lateropulsion and 35 healthy controls participated in this study. For the participants with lateropulsion, weight-bearing asymmetry during standing tasks (measured using two Wii Balance Boards) and clinical measures of lateropulsion (Burke Lateropulsion Scale) and postural function (Postural Assessment Scale for Stroke) were assessed initially and fortnightly over eight weeks.

Results: Individuals with lateropulsion displayed marked weight-bearing asymmetry in standing compared to healthy controls. This asymmetry was predominantly towards their non-paretic leg when standing unsupported, and mixed presentation of weight-bearing asymmetry directions when standing with arm support. No significant correlations were observed between directional weight-bearing asymmetry and the Burke Lateropulsion Scale. A moderate correlation was found between absolute weight-bearing asymmetry for the stand with arm support task and the Postural Assessment Scale for Stroke (r=-0.608). The weight-bearing asymmetry variables for the standing with arm support task were found to be highly reliable between test occasions (ICC 0.915-0.972) and the standard error of measurement was 8.2% to 9.3% body mass.

Significance: Individuals following stroke with lateropulsion demonstrate marked and varied patterns of asymmetry in standing. Weight-bearing asymmetry when standing with arm support may be an appropriate outcome measure for use with patients with lower functional abilities.

8.2 Introduction

Standing ability is commonly impaired following stroke. Compared to healthy controls, individuals following stroke stand with greater WBA and display increased postural sway, particularly in the frontal plane (de Haart et al., 2005; Kamphuis et al., 2013). Many factors may contribute to standing difficulty following stroke, including motor impairment (Barra et al., 2009; Genthon et al., 2008), sensory deficits (Barra et al., 2009), spatial neglect (Barra et al., 2009; Genthon et al., 2008) and spasticity (de Haart et al., 2004; Genthon et al., 2008).

Lateropulsion is a distinct postural control disorder where individuals have an impaired perception of postural verticality which can negatively impact an individual's standing ability (Pérennou et al., 2008). Individuals with lateropulsion following stroke often display three distinctive features - a tilted body posture to the paretic side, use of non-paretic extremities to push towards the non-paretic side, and active resistance to passive correction of the tilted posture back to vertical (Davies, 1985). These features are thought to be exhibited in an attempt to align body position in space with an altered perception of postural verticality (Pérennou et al., 2008). Up to a quarter of individuals following stroke undergoing rehabilitation may present with lateropulsion (Clark et al., 2012; Krewer, Luther, et al., 2013), with the posterolateral thalamus (Karnath, 2005; Karnath et al., 2000a; Pérennou et al., 2008) and the superior (Johannsen et al., 2006; Pérennou et al., 2008 and inferior {Babyar, 2019 #380) parietal cortex identified as key structures commonly affected. Individuals with lateropulsion have longer hospital stays (Clark et al., 2012; Danells et al., 2004) and poorer functional outcomes compared to individuals following stroke without lateropulsion (Babyar et al., 2008; Danells et al., 2004). However, despite the difficulty individuals following stroke with lateropulsion have standing, minimal research has been conducted investigating standing ability and the potential strategies utilised by these individuals to maintain balance.

Standing WBA has been extensively studied following stroke (Barra et al., 2009; Bower et al., 2014; de Haart et al., 2004; Mansfield et al., 2013; Marigold & Eng, 2006; Martins et al., 2011; Pereira et al., 2010), particularly in the chronic (>6 months) phase following stroke {Bower, 2014 #228;Eng, 2002 #324;Mansfield, 2013 #307;Marigold, 2006 #309;Martins, 2011 #310;Pereira, 2010 #313}, but also in the early (7 days – 3 months) (de Haart et al., 2004) and late sub-acute (3 - 6 months) phases (Barra et al., 2009; Hesse et al., 1994). Most commonly, individuals following stroke have been found to take more weight through their non-paretic leg, during static (Barra et al., 2009; de Haart et al., 2004; Eng & Chu, 2002; Mansfield et al., 2013; Marigold & Eng, 2006; Martins et al., 2011; Pereira et al., 2010) and dynamic (Hesse et al., 1994) standing tasks. Weight-bearing asymmetry loading the paretic leg has also been described in 12-37% of individuals following stroke (Hesse et al., 1994; Mansfield et al., 2013; Martins et al., 2011; Pereira et al., 2010). It has been hypothesised that individuals with lateropulsion may exhibit WBA towards their paretic leg, given these individuals are often tilted towards this side (Mansfield et al., 2013; Pereira et al., 2010). However, preliminary studies have not supported this hypothesis (Barra et al., 2009; Mansfield et al., 2013). Mansfield and colleagues investigated WBA in 147 chronic stroke survivors including 13 participants with a history of lateropulsion (Mansfield et al., 2013). Whilst three distinct weight-bearing patterns were identified (symmetrical, loading non-paretic leg, loading paretic leg), no significant differences were found between groups when lateropulsion was considered (Mansfield et al., 2013). Barra et al. found that more severe lateropulsion (as defined by the SCP (Pérennou et al., 2008)), was unexpectedly associated with greater loading of the non-paretic leg (Barra et al., 2009). The results of these studies should be interpreted cautiously given the small sample sizes (13 (Mansfield et al., 2013) and 11 (Barra et al., 2009)) of participants with lateropulsion. Trials with larger samples are clearly warranted. Understanding how individuals with lateropulsion stand in terms of WBA may provide valuable information into the strategies adopted by these individuals to maintain balance in standing, and subsequently guide treatment of this challenging disorder.

This study had three aims. To: (1) investigate WBA patterns in standing in individuals following stroke with lateropulsion, relative to healthy controls; (2) examine the relationship between WBA and clinical measures of lateropulsion and postural function; and (3) assess the test-retest reliability of WBA variables with individuals following stroke with lateropulsion.

8.3 Method

Study design

For the lateropulsion cohort, a repeated measures observational study was completed. A separate, concurrent observational study was undertaken with the healthy control cohort to obtain healthy normative values for various tests of balance, inclusive of the standing tests used in this study. Ethical approval was obtained from the relevant human research ethics committees (HREC-A 146/15, HR 15/2015; LNR 158/15, HR55/2016). Prior to inclusion, participants gave written consent, or for individuals unable to provide written consent, this was obtained from the Next of Kin.

Setting

Participants

Participants following stroke were recruited by consecutive sampling from the Stroke and Rehabilitation Units of St. Vincent's Hospital Melbourne, Australia between January 2016 and December 2018. The inclusion criteria were being between one and 12 weeks post ischaemic or haemorrhagic stroke, presence of contraversive lateropulsion (Burke Lateropulsion Scale (BLS) score ≥2) (Babyar et al., 2017; Babyar et al., 2008), able to sit on a transfer bench with back and arm support for >3 seconds (Chapter 6) (Birnbaum et al., 2018), able to follow a one stage verbal command with gesture and able to undertake 20 minutes of physiotherapy (Chapter 6) (Birnbaum et al., 2018). This experiment formed part of a larger study, with sitting tasks reported elsewhere. Additionally, for this standing component, participants needed to be able to stand with arm support for >3 seconds (see Figure 4.4(a). The exclusion criteria included inability to mobilise independently in the community premorbidly (Chapter 6) (Birnbaum et al., 2018), weight >112kg (Chapter 6) (Birnbaum et al., 2018) and a history of or current cerebellar ataxia.

Healthy control participants were identified from a concurrent study determining healthy normative values for various tests of balance, inclusive of the standing tasks performed in this study. Participants for the concurrent study were recruited from the staff, family and friends of St Vincent's Hospital Melbourne. Inclusion criteria for this group were individuals without a health condition impacting their mobility, able to walk with no aids independently outdoors and weight <112kg. Forty-eight healthy controls were recruited across 12 five-year age brackets from 25 to 85 years, with two male and two female participants recruited in each bracket. At the conclusion of data collection for both groups, 35 gender- and aged matched (±5 years) healthy controls were able to be age and gender-matched with the lateropulsion sample.

Measures

Participants were assessed standing on two Wii Balance Boards placed side by side, one under each foot, performing three trials of four tasks if able. Using two Wii Balance Boards with custom-designed software allowed WBA measures to be collected in a similar way as occurs using force platforms (Clark et al., 2011). The tasks were performed in the following order: 1) standing with arm support for three seconds, with the non-paretic hand resting on a plinth (or the randomised hand for healthy controls); 2) standing without arm support for three seconds; 3) reaching to pick up a cup on a table in front in standing with the non-paretic arm, within arm's length; and 4) reaching to pick up a cup on a table positioned diagonally from the non-paretic side in standing, beyond arm's length, using the non-paretic arm (or the randomised side for healthy controls) (Chapter 6) (Birnbaum et al., 2018). The arm used by the healthy controls in a given task was randomised so that some healthy controls used their dominant arm and others used their non-dominant arm, as occurred in the lateropulsion group where the non-affected arm was utilised. The short test length for the static standing tasks (three seconds) was utilised in order to capture data from individuals who were just able to stand without assistance, given this data may have provided a vital insight into the lateropulsion phenomena. Task setup is shown in Figure 4.4 and testing procedures are outlined in section 4.2.5 Outcome measures: Instrumented measures. Absolute WBA and directional WBA as a percentage of body mass were examined for all tasks. Absolute WBA quantifies in kilograms the WBA observed between the two legs during the completion of a task, with a value of zero indicating equal weight-bearing through both legs. Absolute WBA, does not however, indicate which leg took the greater load. Directional WBA does this, through positive and negative values, with a positive value representing greater loading of the non-paretic leg and a negative value indicating greater load through the paretic leg. For the healthy controls, directional WBA was calculated according to the randomisation of the arm used, with a positive value representing greater loading of the leg on the randomised side. The median score of successful trials (ie. task completed independently with no steadying assistance required) was used in data analysis. This measure of central tendency was chosen to prevent the possibility of outlying data impacting the results obtained (Clark et al., 2010). If a participant could not complete a given task independently or steadying assistance was provided, only data from trials where overbalancing occurred, or steadying was required were excluded. Where a participant was unable to complete a task on a testing occasion, the task was attempted again at the next testing occasion in a fortnights time.

In addition to the WBA measures, a number of clinical scales were performed. Lateropulsion severity was measured using the Burke Lateropulsion Scale (BLS) (D'Aquila et al., 2004), and postural function was assessed using the Postural Assessment Scale for Stroke (PASS)

(Benaim et al., 1999). Motor control and sensation of the affected lower limb as well as neglect were measured using lower extremity items of the Stroke Rehabilitation Assessment of Movement Instrument (Daley et al., 1999), the lower limb sensory section of the Fugl-Meyer Assessment (Fugl-Meyer et al., 1975) and the Catherine Bergego Scale (Azouvi et al., 1996) respectively. Functional ability was determined using the Functional Independence Measure (motor domain) (Linacre et al., 1994). These clinical measures have demonstrated good reliability and validity for use with individuals following stroke(Azouvi et al., 1996; Benaim et al., 1999; D'Aquila et al., 2004; Daley et al., 1999; Fugl-Meyer et al., 1975; Linacre et al., 1994).

Procedures

Participants with lateropulsion were recruited on day seven post stroke, or when all inclusion criteria were met. For the participants with lateropulsion, data collection occurred on day one following recruitment to the study, day two and then fortnightly (every 14 days) to a maximum of six testing occasions (eight weeks from initial assessment). A familiarisation session with the test setup occurred on the day prior to day one (online supplementary material). Testing occurred in standing from the first session when a stroke participant could stand for three seconds with arm support. This means that the results reported for these tasks varied within and between participants in terms of when each task could initially be performed (for example standing with and without arm support may have been able to be measured at week 4, the reaching forward task at week 6, and the reaching diagonally task at week 8) and between participants (for example, there may have been participants contributing data to the standing and reaching forwards task from any of the two-weekly measurement occasions over the 8 week period, depending on when each participant was able to perform the task initially) (Figure 8.1). Standing WBA, BLS and PASS were evaluated on each testing occasion. Measures including the lower extremity items of the Stroke Rehabilitation Assessment of Movement Instrument, the lower limb sensory section of the Fugl-Meyer Assessment, the Catherine Bergego Scale and the Functional Independence Measure (motor domain) were performed in the order listed on the day one testing occasion only. Data collection only occurred once for the healthy controls.

Statistical Analysis

Demographic data were summarised using descriptive statistics. Weight-bearing asymmetry variables were assessed for normality using the Shapiro-Wilk test. Parametric statistics were utilised except for ordinal variables, variables not normally distributed or when unequal variance was present between groups. In these cases, non-parametric statistics were used. To identify any WBA variables that may be redundant, correlations between directional WBA and absolute WBA variables for each task were determined using Spearman's rho.

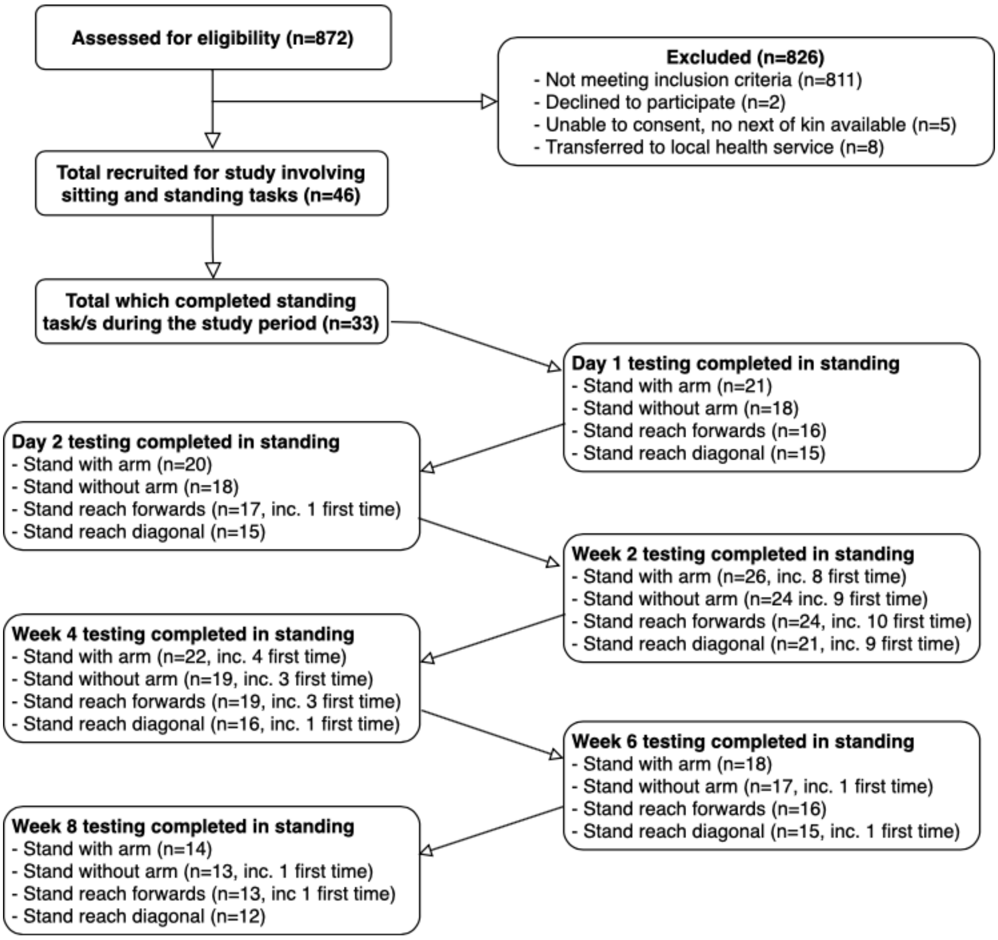


Figure 8.1. Flow diagram outlining the testing completed for recruited participants at each time point in standing including when new participants completed a task for the first time

The range for the number of testing sessions completed in standing for the 33 participants was one to six sessions.

Abbreviations: inc., including; n, number.

For between group comparisons, Mann-Whitney U Tests were used due to unequal variance. Effect size (ES)(*r*) was calculated for each Mann-Whitney U Test by dividing the relevant z value with the square root of the total number of cases (Pallant, 2016). For the WBA variables where a significant difference was found between groups, correlations between the

significant WBA variables and the BLS and PASS were examined using bivariate scattergrams and Spearman rho. For the between group comparisons and correlations with clinical measures, data were utilised from whichever assessment a stroke participant could first successfully complete the task, in an attempt to maximise the dataset size.
Test-retest reliability of the Wii Balance Board-derived WBA variables was assessed between Day 1 and Day 2 median scores using a two-way, random-effects, single measures intraclass correlation coefficients ($ICC_{(2,1)}$) model and standard error of measurement (SEM). Statistical significance for the analyses was set at $p<0.05$. For Spearman rho, values of 0.75-1 are considered excellent; 0.50-0.74, moderate; 0.25-0.49, fair; and 0-0.24, weak or no correlation (Portney & Watkins, 2009). For the Mann-Whitney U Test, an effect size of 0.1-0.29 is indicative of a small effect; 0.3-0.49, a medium effect; and >0.50, a large effect (Cohen, 1988). For the ICC values, >0.90 is considered excellent test-retest reliability, 0.75-0.90 good reliability, 0.50-0.75 moderate reliability and <0.50 poor reliability (Portney & Watkins, 2009).

Sample size calculations for between group comparisons of instrumented standing measures were obtained by performing power analyses utilising data from a feasibility study (Chapter 6) (Birnbaum et al., 2018). With alpha set at 0.05, power at 0.8, and a two-tailed test based on a 20% difference between groups, at least 15 participants per group were required.

8.4 Results

Thirty-three participants with lateropulsion, including 19 males (58%) (mean (SD) age of 66.8 (±16.1) years) participated in the standing arm of the study, with 20 of these participants completing Day 1 and Day 2 testing for at least one standing task. Next of kin written consent was obtained for 16 of the 33 participants. The median [interquartile range] time following stroke to the initial assessment was 22 [13-32] days. Table 8.1 summarises the other baseline characteristics for the participants with lateropulsion. Thirty-five healthy controls participated in this study, including 19 males (53%) (mean (SD) age of 62.0 (±13.7) years).

Correlation between directional WBA and absolute WBA

The directional WBA variables for all tasks met the assumptions of normality, whereas the absolute WBA variables did not; therefore Spearman rho [r_s] was used to determine

Table 8.1. Stroke participant characteristics at baseline

Variable	n=33
Age (years), mean (SD)	66.8 (16.1)
Time following stroke (days), median [IQR]	22 [13-32]
Male gender, n (%)	19 (58)
Body mass, mean (SD), kg	70.1 (15.7)
Side of hemiparesis	
Left, n (%)	12 (36)
Right, n (%)	20 (61)
Both, n (%)	1 (3)
Pathology	
Infarct, n (%)	19 (58)
Haemorrhage, n (%)	12 (36)
Both, n (%)	2 (6)
Severity of lateropulsion (BLS scores), median [IQR]	6 [3-9]
Mild (2-8), n (%)	24 (72.7)
Moderate (9-12), n (%)	9 (27.3)
Severe (13-17), n (%)	0 (0)
PASS scores, median [IQR]	19 [14.5-27]
Active Motor Control (Lower extremity items of STREAM)	
Scores, median [IQR]	43 [10-71]
Not tested, n (%)	2 (6)
Sensation (Lower limb sensory section of FM Assessment)	
Impaired, n (%)	17 (52)
Intact, n (%)	11 (33)
Not tested, n (%)	5 (15)
Neglect (Catherine Bergego Scale)	
No neglect, n (%)	11 (33)
Mild, n (%)	13 (39)
Moderate, n (%)	7 (21)
Severe, n (%)	1 (3)
Not tested, n (%)	1 (3)

***Table 8.1 is continued on the next page*

Table 8.1. Stroke participant characteristics at baseline (continued)

Variable	n=33			
FIM (motor) score, median [IQR]	23 [20.5-34.5]			
Time from recruitment to first able to perform test (weeks)	*0*	*2*	*4*	*>4*
Stand with arm, n	21	8	4	0
Stand without arm, n	18	9	3	2
Stand reach forwards (within arm's length), n	17	10	3	1
Stand reach diagonal (beyond arm's length), n	15	9	1	1

Abbreviations: BLS, Burke Lateropulsion Scale; FIM, Functional Independence Measure; FM, Fugl Meyer; IQR, interquartile range; n, number; PASS, Postural Assessment Scale for Stroke; STREAM, Stroke Rehabilitation Assessment of Movement Instrument.
NB. As outlined in the table, assessments of active motor control, sensation and neglect were 'not tested' for between one to five participants. The main reason for these not being completed was the presence of language deficits which limited the ability to complete the measures accurately.

redundancy. For the task of standing with arm support, no significant correlation was found between directional WBA and absolute WBA (r_s=0.179). Both directional WBA and absolute WBA are subsequently reported for the stand with arm support task. For the other three standing tasks, the WBA variables were highly correlated (r_s=0.935-0.996). In order to capture different patterns of WBA, the directional WBA variable was selected for examination and absolute WBA was removed for these three standing tasks to avoid redundancy.

Lateropulsion compared to healthy controls

The median and interquartile scores for WBA variables for the healthy controls and participants with lateropulsion are presented in Table 8.2. For the absolute WBA variable for the stand with arm support task, compared with healthy controls, the participants with lateropulsion were found to be significantly more asymmetrical (*p value<0.001*, effect size (ES) 0.789; Table 8.2, Figure 8.2a(i)). There was no significant difference in directional WBA between groups for the stand with arm support (*p=0.65*), however, for 28 participants following stroke (85% of cases), the directional WBA score was outside 1.96SD of the healthy controls (Figure 8.2a(i)). Fourteen of these cases loaded their paretic leg more (represented by negative directional WBA values) and 14 cases took greater weight through their non-paretic leg (represented by positive directional WBA values).

Compared with healthy controls, the directional WBA variables for the remaining tasks (stand without arm support, stand reach forwards and stand reach diagonally) were significantly more asymmetrical for participants with lateropulsion (*p values<0.001*, ES 0.603-0.708; Table 8.2, Figure 8.2). For these tasks, 24 cases (77%) had directional WBA scores outside 1.96SD of the healthy controls for the stand without arm task, 21 cases (70%) for the stand reach forwards task and 13 cases (52%) for the stand reach diagonally task, nearly all with greater weight through the non-paretic leg (Figure 8.2b(i)-8.2d(i)). For the four participants who loaded their paretic leg more during these tasks, only two participants had scores which fell outside 1.96SD of the healthy controls (see Figure 8.2b(i)-8.2d(i)).

Table 8.2. Between group comparisons, participants with lateropulsion and healthy controls, for weight-bearing asymmetry variables

	Lateropulsion			Healthy controls						
	N	Median	IQR	N	Median	IQR	U	Z	p	ES
STANDING TASKS										
Stand with arm support										
Directional WBA, %BM	33	11.0	-45.2 – 57.2	35	1.5	-3.3 – 9.0	540	-0.460	0.645	0.056
Absolute WBA, %BM	33	49.5	22.9 - 81.8	35	6.2	2.2 –10.4	47	-6.510	<0.001**	0.789
Stand without arm support										
Directional WBA, %BM	32	32.1	16.4 – 63.8	35	3.2	-3.2 – 8.9	147	-5.184	<0.001**	0.633
Stand reach forwards (within arm's length)										
Directional WBA, %BM	31	30.2	12.8 – 54.6	35	3.4	-1.8 – 8.0	161	-4.902	<0.001**	0.603
Stand reach diagonal (beyond arm's length)										
Directional WBA, %BM	26	44.6	26.9 – 59.3	35	19.0	10.9 – 22.3	76	-5.527	<0.001**	0.708

Abbreviations: BM, body mass; ES, effect size; IQR, interquartile range; n, number; p, p value; U, Mann-Whitney U; WBA, weight-bearing asymmetry; Z, Z value.
Notes: Directional WBA as a percentage of body mass indicates through positive and negative values, which leg took greater load, with a positive value representing greater loading of the non-paretic leg.
***Significant at p<0.01*

Correlation between WBA and clinical measures

Correlations between the directional WBA variable for the standing tasks and the BLS (Table 8.3, Figure 8.2) were not statistically significant, indicating that severity of lateropulsion was not associated with degree of WBA. For postural function, a moderate correlation was found between absolute WBA while standing with arm support and the PASS for this task (r_s=-0.608, *p=0.001*; Table 8.3, Figure 8.2a(iii)), meaning the greater the WBA (no matter what direction), the lower an individual's postural function. Similarly, a fair correlation (r_s=-0.423 --0.498, *p=0.004-0.035*; Table 8.3, Figure 8.2b(iii)) was shown between directional WBA for the other standing tasks (stand without arm support, stand reach forwards and stand reach diagonally) and the PASS.

Table 8.3. Correlations between weight-bearing asymmetry variables and clinical measures of lateropulsion and postural control

	BLS r_s	**p**	**PASS r_s**	**p**
STANDING TASKS				
Stand with arm support, n = 33				
Directional WBA, %BM	0.095	0.599	-0.118	0.512
Absolute WBA, %BM	0.396	0.023*	-0.608	<0.001**
Stand without arm support, n = 31				
Directional WBA, %BM	0.259	0.159	-0.498	0.004**
Stand reach forwards (within arm's length), n = 30				
Directional WBA, %BM	0.221	0.241	-0.429	0.018*
Stand reach diagonal (beyond arm's length), n = 25				
Directional WBA, %BM	0.185	0.377	-0.423	0.035*

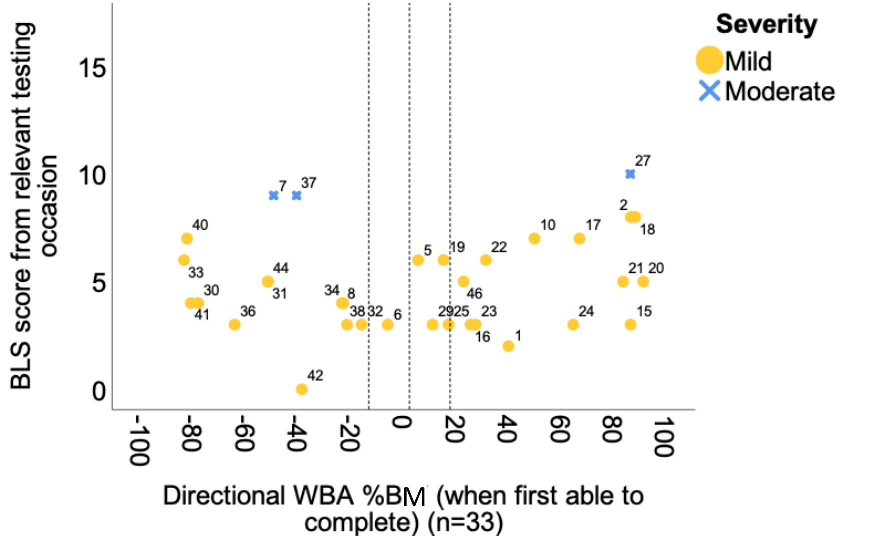
Abbreviations: BLS, Burke Lateropulsion Scale; BM, body mass; n, number; p, p value; PASS, Postural Assessment Scale for Stroke; $r_{s,}$ Spearmans rho; WBA, weight-bearing asymmetry.

Notes: Directional WBA as a percentage of body mass indicates through positive and negative values, which leg took greater load, with a positive value representing greater loading of the non-paretic leg.

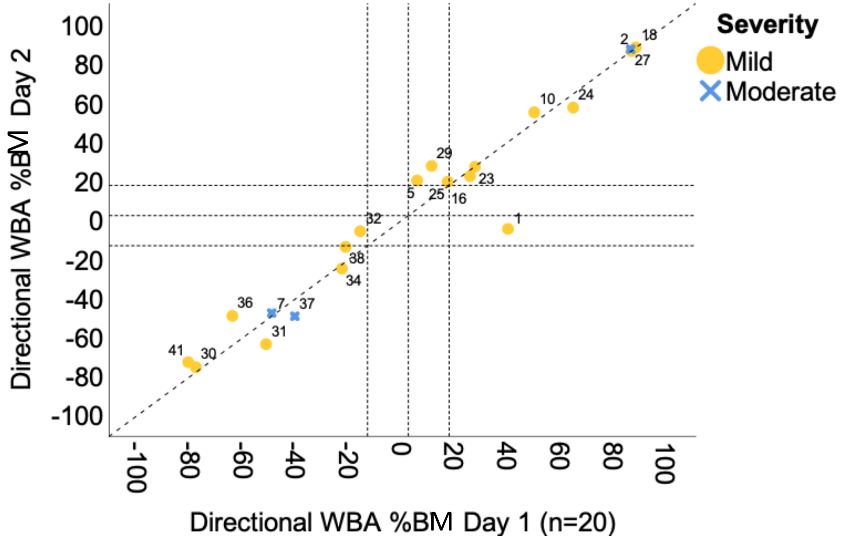
*Significant at *p<0.05*; **Significant at *p<0.01*

(a) Stand with arm support

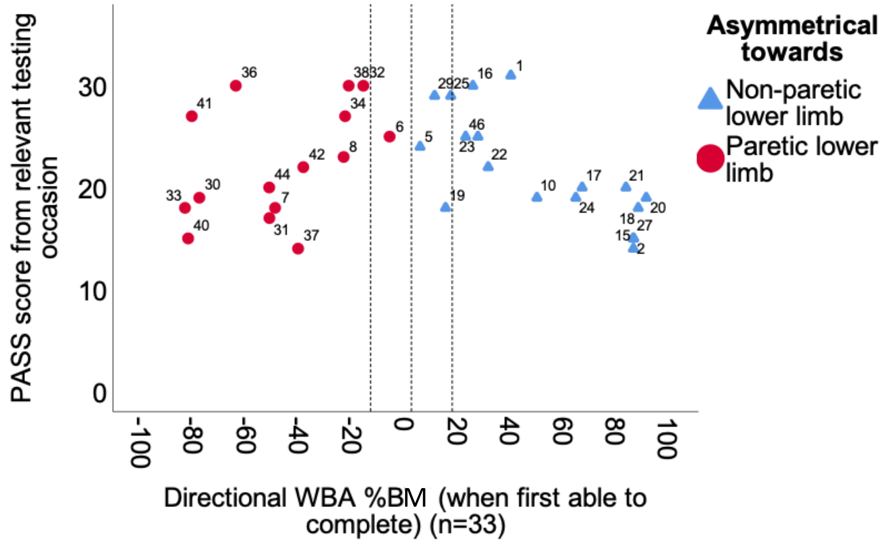
i.



ii.

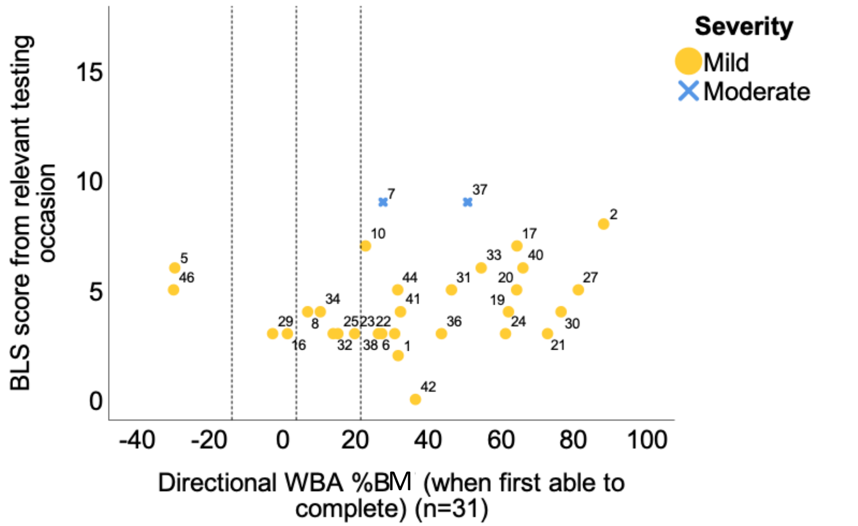


iii.

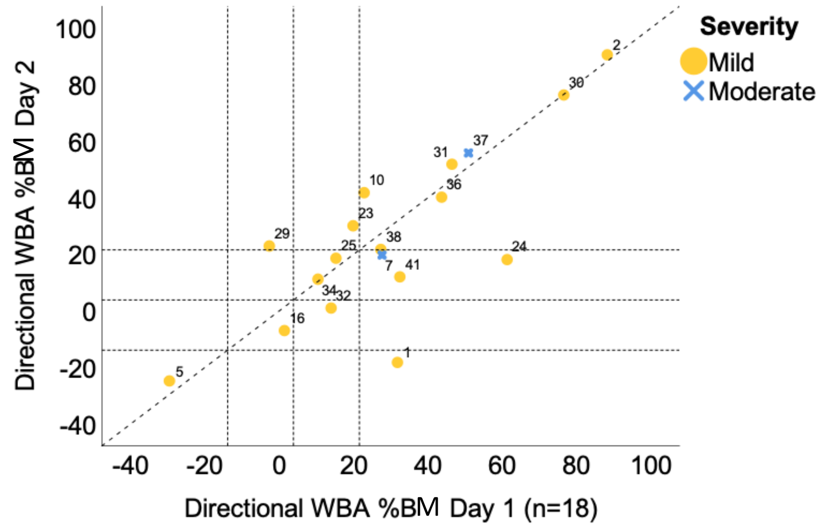


(b) Stand without arm support

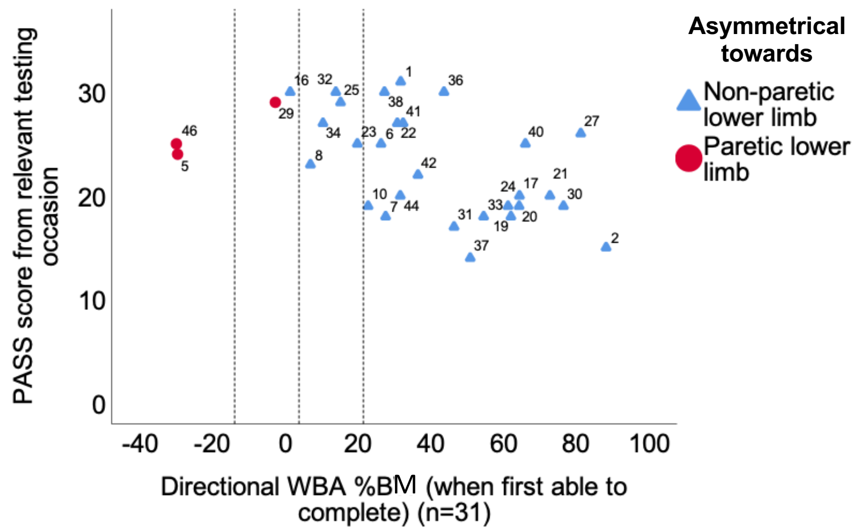
i.



ii.

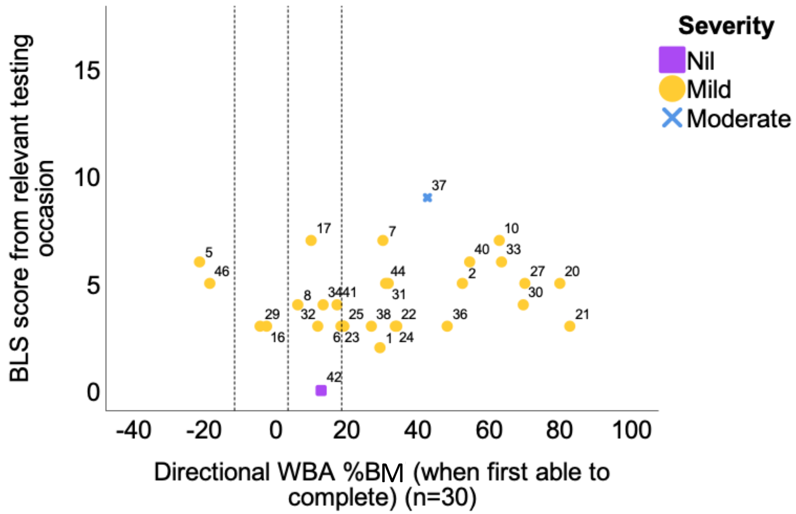


iii.

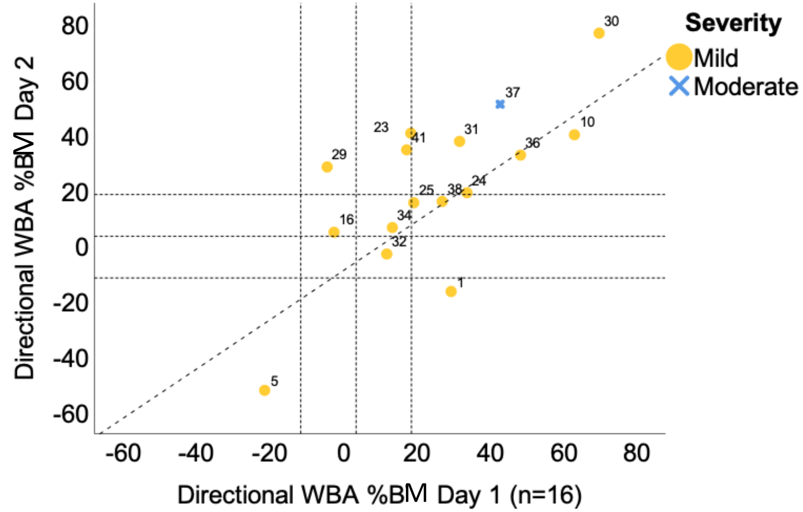


(c) Stand reach forwards

i.

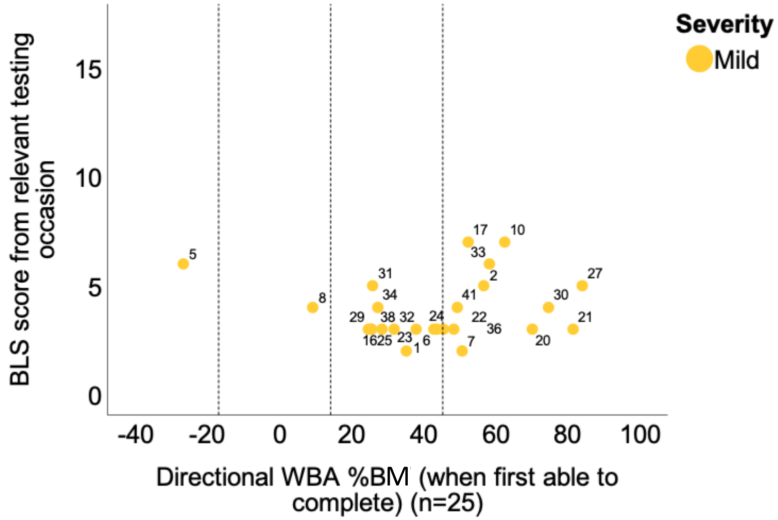


ii.



(d) Stand reach diagonal

i.



ii.

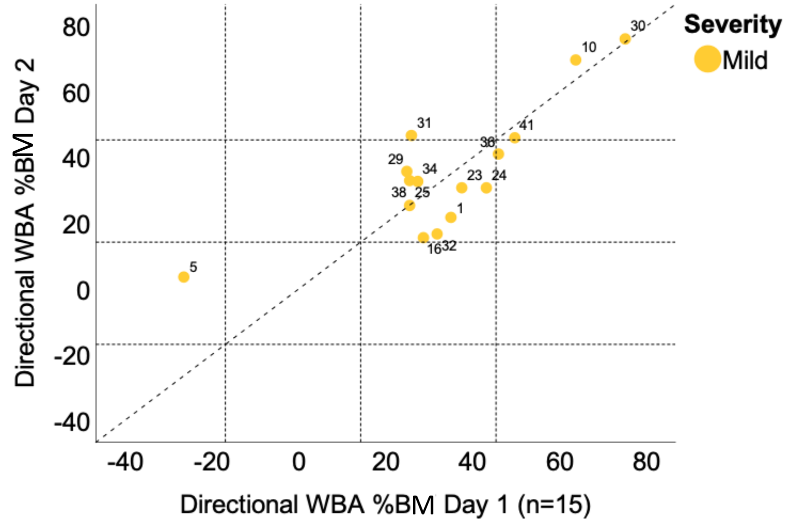


Figure 8.2. Directional weight-bearing asymmetry results for the standing tasks involving two Wii Balance Boards

i. Scatterplot of relationship between directional WBA %BM variable and the Burke Lateropulsion Scale for stroke participants; ii. Scatterplot of Day 1 and Day 2 data for stroke participants for directional WBA %BM variable; iii. Scatterplot of relationship between directional WBA %BM variable and the Postural Assessment Scale for Stroke for stroke participants. Normative value lines from healthy control data (mean +/- 1.96 SD) are included on all scatterplots.

Abbreviations: BLS, Burke Lateropulsion Scale score; BM, body mass; n, number; PASS, Postural Assessment Scale for Stroke; WBA, Weight-bearing asymmetry.

Notes: Directional WBA as a percentage of body mass indicates through positive and negative values, which leg took greater load, with a positive value representing greater loading of the non-paretic leg.

Table 8.4. Test-retest reliability for Day 1 and Day 2 weight-bearing asymmetry data

	Retest Reliability Day 1 Mean (SD)	 Day 2 Mean (SD)	ICC (95% CI)	SEM
STANDING TASKS				
Stand with arm support, n = 20				
Directional WBA, %BM	3.77 (54.99)	4.18 (53.79)	0.971 (0.928 - 0.988)	9.26
Absolute WBA, %BM	46.42 (27.75)	45.05 (27.85)	0.915 (0.799 - 0.966)	8.11
Stand without arm support, n = 18				
Directional WBA, %BM	29.85 (28.61)	25.63 (30.26)	0.796 (0.534 - 0.918)	13.29
Stand reach forwards (within arm's length), n = 16				
Directional WBA, %BM	24.82 (24.02)	20.86 (29.76)	0.715 (0.355 - 0.890)	14.36
Stand reach diagonal (beyond arm's length), n = 15				
Directional WBA, %BM	34.18 (22.48)	35.00 (19.26)	0.806 (0.516 - 0.931)	9.19

Abbreviations: BM, body mass; ICC, intraclass correlation coefficient; n, number; SEM, standard error of measurement; WBA, weight-bearing asymmetry.
Notes: Directional WBA as a percentage of body mass indicates through positive and negative values, which leg took greater load, with a positive value representing greater loading of the non-paretic leg.

Test-retest reliability

Excellent test-retest reliability was found for the WBA variables for the task of stand with arm support (ICC=0.915-0.971; Table 8.4, Figure 8.2a(ii)). Moderate to good test-retest reliability was demonstrated for the WBA variables of the other standing tasks (ICC=0.715-0.806; Table 8.4, Figure 8.2b(ii)-8.2d(ii)). The SEM values ranged from 8.1 to 14.4% of body mass (Table 8.4).

8.5 Discussion

This study has investigated the postural control disorders observed in people with lateropulsion after stroke by investigating WBA in static and dynamic standing tasks. The study examined static standing with and without arm support, finding markedly different weight-bearing patterns for these tasks (Figure 8.2a-b). For standing with arm support, 85% of cases recorded directional WBA outside the healthy control range, with nearly equal numbers weight-bearing on the paretic and non-paretic legs (Figure 8.2a(i)). This task is relevant in rehabilitation because the use of non-paretic arm support, both for balance and weight relief, is necessary in the early recovery of standing ability in people with moderate to severe stroke. In contrast, for unsupported standing, directional WBA beyond the healthy control range was towards the non-paretic leg in all except two participants (6% of cases) (Figure 8.2b(j)).

It has previously been hypothesised that lateropulsion may lead to WBA towards the paretic leg (Mansfield et al., 2011; Pereira et al., 2010), as the individual seeks to align themselves in space either with a disturbed perception of postural verticality (contralesional tilt) (Pérennou et al., 2008) or as a compensatory strategy to resolve conflict between a mismatch of visual vertical and postural vertical orientation (Bergmann et al., 2016; Karnath et al., 2000a). This hypothesis is partially supported in our study for standing with arm support, with 42% of cases demonstrating directional WBA to the paretic side beyond healthy control values (Figure 8.2a(i)). This finding indicates that, when support for balance and weight relief was provided, nearly half of the present cohort with lateropulsion preferentially biased weight-bearing towards the paretic leg. It is important to highlight that greater loading of the paretic leg in this scenario may not only be due to passive loading of the lower limb secondary to the presence of lateropulsion, but may also result from atypical force generation through the paretic limb as has been described previously (Vaughan-Graham et al., 2019).

In contrast, when balance and weight relief support was not provided (ie. standing without arm support), almost all participants with lateropulsion (94%) who were able to maintain standing loaded the non-paretic leg, likely as part of a necessary strategy to maintain balance and not fall (Barra et al., 2009). The proportion of participants with lateropulsion loading the paretic leg (6%) in the standing without arm support task is less than what has been previously described following stroke (12-37%) (Hesse et al., 1994; Mansfield et al., 2013; Martins et al., 2011; Pereira et al., 2010), but similar to the findings of Barra and colleagues, where one of 11 cases with lateropulsion favoured their paretic leg (Barra et al., 2009). It is important to recognise that the WBA results obtained in this current study only represent data from successful trials, where the stroke participant maintained their balance independently (ie. for day 1 testing, only data from 55% of participants were included for the stand without arm support task). As postulated by Barra and colleagues, the achievement of standing unsupported for individuals with lateropulsion may be the result of a learnt strategy of loading the non-paretic leg to maintain balance (Barra et al., 2009). Without this strategy, the person is likely to fall towards their paretic side (as observed clinically), and subsequently fail the trial, resulting in the data being excluded. Interestingly in the current study, while this learnt strategy enabled achievement of static standing balance, almost all participants (30/31) still demonstrated lateropulsion in walking, as demonstrated by their BLS scores (BLS median [interquartile range] score of 4 [3-6]). Recovery from lateropulsion appears to be posture and task specific.

In the standing reaching tasks, participants with lateropulsion demonstrated greater directional WBA than healthy controls with a large effect size, almost always towards the non-paretic leg and with some participants, minimal weight-bearing on the paretic leg (Figure 8.2c-d). For the most difficult task of reaching diagonally beyond arm's length, a higher proportion of patients recorded directional WBA scores within the healthy range, indicating they were able to find an appropriate weight-bearing strategy to allow successful task performance (Figure 8.2d).

No significant correlations were identified between lateropulsion severity and the directional WBA variable for the static standing tasks, indicating that the directional asymmetry magnitude was not affected by severity of lateropulsion (Table 8.3). Interestingly, 10 participants with lower levels of lateropulsion (BLS scores$\leq$5), therefore less verticality disturbance, showed significant asymmetry towards the paretic leg in the easier supported standing task, switching their asymmetry towards the non-paretic leg when standing unsupported (Figure 8.2a-b). This suggests that for some participants, the preference for vertical orientation towards the paretic side is retained and does not reduce even though functional limitations from lateropulsion are less. The lack of significant correlation between BLS scores and directional WBA for unsupported standing (*p=0.16*) found in this study contrasts with Barra and colleagues, who found a fair correlation between lateropulsion severity and WBA, however their sample also included individuals following stroke without lateropulsion (Barra et al., 2009). This may partly explain the different outcomes obtained. The use of different measures of lateropulsion, as well as differences in other characteristics of the included participants (e.g. level of motor and sensory impairment) which influence standing WBA [3-5] may have also contributed to this. Directional weight-bearing asymmetry for the reaching tasks was not associated with lateropulsion severity in the current study (Table 8.3). There were moderate correlations found between the PASS and absolute WBA for stand with arm support (r_s=-0.608) and fair correlations (r_s=-0.423 –0.498) with the

PASS and directional WBA variable for the remaining three standing tasks, demonstrating that WBA is associated with postural abilities, as has previously been reported (Barra et al., 2009).

Weight-bearing asymmetry in standing displayed high consistency using ICC metrics over two days, with ICC's ranging from 0.72-0.97 however the SEM values were relatively large (>8% body mass) (Table 8.4). These results are comparable to previous research investigating the test-retest reliability of WBB derived-WBA with individuals following stroke (lateropulsion status unknown) (Bower et al., 2014). The high consistency in absolute WBA and directional WBA when standing with arm support demonstrated by the ICC metrics, both in terms of leg preference and degree of asymmetry, suggests that the postural systems are reflecting the sensory integration and perceptual disturbances experienced in lateropulsion in terms of aligning the body in space along an altered reference of postural verticality (Pérennou et al., 2008), rather than a more random alignment.

Traditionally, WBA is assessed in individuals following stroke who can stand unsupported for 30 seconds (Barra et al., 2009; Bower et al., 2014; Genthon et al., 2008; Mansfield et al., 2011; Marigold & Eng, 2006). Findings from this study suggest WBA may be reliably assessed in acute lower level patients, such as individuals with lateropulsion, and may be a useful evaluation tool in clinical trials investigating interventions at the early stage of achieving standing balance. However, it must be noted that the sample sizes for the test-retest reliability component of this study are small; therefore results can be considered as pilot data only (Mokkink, Terwee, Patrick, et al., 2010).

Limitations

As outlined, weight-bearing asymmetry results obtained in this study only represent data from successful trials where participants (n=33) maintained their balance independently. For participants who were unable to stand unsupported, instead falling towards the paretic side, data were excluded. Therefore, this study may understate the problem of WBA to the paretic side as only successful trials were examined.

Whilst WBA variables provide useful information in terms of postural control strategies utilised to maintain balance, these measures do not evaluate the body alignment or the muscular activity used by an individual to stabilise, which may be compensatory in nature.

For example, a learnt strategy of loading the non-paretic leg does not necessarily mean the individual is optimally aligned or utilising appropriate muscular activity to achieve stability. Compensatory strategies, such as trunk lateral flexion on the non-paretic side to increase weight-bearing on the non-paretic leg, may be utilised. This strategy may inhibit normal balance responses, increasing the risk of falling. Future studies investigating kinematic and electromyography data in individuals with lateropulsion are required to explore this further. Quantifying the amount of force taken through the arm during the stand with arm support task may also provide useful information regarding the postural control strategies utilised to maintain balance during this task, given this was not recorded in the current study.

This study explored the WBA patterns adopted in standing by people with lateropulsion following stroke, relative to healthy controls. Individuals following stroke without lateropulsion were not included in this study. Other studies have demonstrated that WBA is commonly observed towards the non-paretic side following stroke in unsupported standing (in individuals with and without lateropulsion). However, to the investigators' knowledge, WBA when standing with arm support has not previously been investigated in individuals following stroke without lateropulsion. Future studies investigating WBA when standing with and without arm support in individuals following stroke with lateropulsion should consider including individuals following stroke without lateropulsion for comparison purposes. In addition, the role of stroke characteristics including side and severity of stroke and motor and sensory impairments on WBA in individuals with lateropulsion should be evaluated.

Finally, the healthy control participants were only assessed on one testing occasion in this study. Therefore, it is unknown whether the healthy controls were also consistent across testing sessions. Establishing test-retest reliability in future studies with healthy control participants would be beneficial to determine this.

Clinical Implications

From a clinical perspective, these results raise some interesting points. Analysis of task performance rather than task completion (Vaughan-Graham et al., 2017) may be critical to inform treatment when individuals with lateropulsion commence standing, given the different directional WBA patterns observed for the standing with arm support task. For those individuals loading their paretic leg more when standing with arm support, therapeutic interventions may need to orientate the individual towards their non-paretic side, given standing unsupported biasing the non-paretic leg appears to be a necessary learnt strategy for maintaining standing balance (Barra et al., 2009). For individuals weight-bearing excessively through their non-paretic limb (i.e. greater than 1.96SD of the healthy control scores or in this case approximately 22% body mass), interventions aimed at bringing the weight-bearing pattern back towards symmetry may be indicated given WBA has been found to be associated with decreased postural abilities (Barra et al., 2009).

8.6 Conclusion

Individuals following stroke with lateropulsion demonstrate marked asymmetry in unsupported static and dynamic standing tasks. Asymmetry is towards the non-paretic side in almost all individuals in unsupported standing. In contrast, when standing with arm support, WBA is pronounced, with few individuals having symmetry within the healthy control range, and approximately half favouring their paretic leg, and half their non-paretic leg.

Preliminary testing of WBA while standing with arm support demonstrated promising results for test-retest reliability and a moderate association with postural abilities. This may be a useful measure for individuals following stroke with lower levels of function, such as individuals with lateropulsion. However, these results should be reproduced with a larger sample and other measurement properties, such as responsiveness (ability to detect change, for example, over time), need to be investigated before these tools are used in clinical trials to evaluate interventions targeting lateropulsion.

Chapter 9. Six-month outcomes and patterns of recovery for people with lateropulsion following stroke

Chapter Outline

The longer-term outcomes of individuals with lateropulsion after stroke, as well as individual recovery patterns of lateropulsion severity and postural function for this patient cohort over time have not been a focus of previous research. The longitudinal study presented in this chapter is another component of the main observational study undertaken, in addition to the sitting and standing components outlined in Chapters 7 and 8. The aims of the longitudinal component of this study were to 1) explore the six-month outcomes of stroke survivors with lateropulsion; and 2) examine the individual recovery patterns for different variables, such as lateropulsion severity for these individuals.

The study reported within this chapter is presented in manuscript format.

9.1 Abstract

Background and Purpose: Longer-term outcomes for individuals with lateropulsion following stroke have received little investigation previously. Likewise, the contribution of baseline lateropulsion scores to six-month functional outcomes have not been reported before. The purpose of this study was to investigate six-month outcomes of individuals with lateropulsion, examine the relationship between baseline measures and six-month functional abilities, and explore the recovery patterns for lateropulsion and other postural control variables in stroke survivors with lateropulsion.

Methods: Forty one individuals with lateropulsion participated in this study. Measures of lateropulsion, postural function and weight bearing asymmetry (WBA) in standing were taken initially and fortnightly over eight weeks. Measures of functional and walking abilities were performed at six months post stroke.

Results: Individuals with mild lateropulsion achieved high levels of functional ability at six months. For individuals with moderate to severe lateropulsion, lower functional ability levels were achieved, however there was a wide range of scores present within these groups. A linear regression model for functional ability at six months identified baseline lateropulsion scores as a significant predictor ($p=.009$), but not baseline functional scores. In terms of recovery patterns, participants displayed good recovery from lateropulsion over time, whilst WBA patterns in standing were more variable, particularly when standing unsupported.

Conclusions: Individuals with lateropulsion can make meaningful functional gains at six months post stroke, including some individuals with more severe lateropulsion. Baseline lateropulsion scores were more predictive of functional ability at six months post stroke than baseline functional scores. This highlights the effect that lateropulsion may have on longer term functional outcomes.

9.2 Introduction

Lateropulsion following stroke is a postural control disorder, where individuals present with a distorted perception of body orientation in relation to vertical (Karnath et al., 2000b; Pérennou et al., 2002; Pérennou et al., 2008). The incidence of lateropulsion in acute settings has been reported as 9-10% (Abe et al., 2012; Pedersen et al., 1996), and up to 17-25% in rehabilitation settings (Baccini et al., 2008; Clark et al., 2012; Krewer, Luther, et al., 2013). At its most severe, lateropulsion adversely affects an individual's ability to sit, whilst at a milder level, it may impact transfer and walking ability.

Length of hospital stay and functional level at discharge from rehabilitation have been investigated in a number of studies, demonstrating that individuals with lateropulsion spend longer in rehabilitation (Clark et al., 2012; Danells et al., 2004) and/or achieve a lower functional level at discharge (Babyar et al., 2008; Krewer, Luther, et al., 2013). Three studies have found that lateropulsion had resolved by discharge from inpatient rehabilitation for between 46-50% of individuals (Babyar et al., 2015, 2017; Clark et al., 2012). Clark et al investigated the pattern of recovery during rehabilitation in people with lateropulsion, measuring every two weeks, showing a steady reduction in lateropulsion and improvement in postural control (Clark et al., 2012). Factors which have been shown to negatively influence recovery from lateropulsion include right cerebral hemisphere damage (Abe et al., 2012), older age (Babyar et al., 2017; Danells et al., 2004), the presence of three additional deficits (Babyar et al., 2015), poor limb proprioception (Babyar et al., 2017), poor admission motor status (Babyar et al., 2017) and cognitive impairment (Babyar et al., 2017).

However, whilst outcomes on discharge from rehabilitation have previously been investigated, longer term outcomes of stroke survivors with lateropulsion have received little attention to date. Danells and colleagues investigated three-month outcomes post stroke and found that individuals with lateropulsion had significantly lower levels of motor recovery and functional abilities compared to individuals without lateropulsion, although the degree of change from baseline measures at one week post stroke were similar in each group (Danells et al., 2004). Karnath and colleagues previously reported transfer status at six months following stroke in 12 participants with lateropulsion, with eight participants able to transfer between bed and chair without assistance at the follow-up assessment occasion (Karnath et al., 2002). Further studies investigating longer term mobility and functional outcomes for individuals with lateropulsion following stroke, including the relationship of these outcomes to baseline measures are clearly warranted.

Along with measures of lateropulsion and postural function, WBA is another potential variable of interest in this patient population (Barra et al., 2009; Mansfield et al., 2013; Pereira et al., 2010). Previously it has been hypothesised that individuals with lateropulsion may stand with greater weight through their paretic leg, given these individuals often fall towards their paretic side (Mansfield et al., 2013; Pereira et al., 2010). Recent data has shown that whilst this may be the case for some individuals with lateropulsion when first starting to stand with arm support (Chapter 8), this is not the case when standing unsupported, where individuals with lateropulsion have been shown to predominately bias their weight towards their non-paretic leg (Barra et al., 2009; Mansfield et al., 2013). Recovery of standing balance over time in terms of WBA has been reported for individuals following stroke within an inpatient rehabilitation setting (de Haart et al., 2004). It has not previously been investigated for individuals with lateropulsion. Information regarding WBA over time in individuals with lateropulsion may further our understanding of this postural control disorder and direct treatment targeting lateropulsion.

The aims of this study were to (1) examine the six-month mobility and functional outcomes of individuals with lateropulsion following stroke; (2) explore the relationship between baseline measures of lateropulsion and function, and six-month functional ability; and (3) investigate patterns of recovery for lateropulsion, postural function and WBA in a cohort of individuals with lateropulsion following stroke.

9.3 Method

Design

The study is a longitudinal study with multiple time points of assessment during in-patient rehabilitation, and follow-up assessment at six-months post stroke. This study is part of a concurrent study undertaken to investigate the use of instrumented measures in sitting and standing in individuals with lateropulsion following stroke described in detail elsewhere (Chapter 7 and 8).

Participants

Individuals with lateropulsion (score of ≥2 on the BLS (Babyar et al., 2015, 2017; Babyar et al., 2009; Babyar et al., 2008; Chow et al., 2019)) were recruited from consecutive admissions to the Stroke and Rehabilitation Units of St. Vincent's Hospital Melbourne between January 2016 and December 2018. Other inclusion criteria were to be able to: (1) sit with back and arm support for three seconds; (2) follow a one stage command (with or without gesture); and (3) participate in physiotherapy for 20 minutes duration (Chapter 6) (Birnbaum et al., 2018). Exclusion criteria were pre-existing conditions limiting walking ability in the community (FAC less than six pre-stroke) (Holden et al., 1986), weight over 112 kilograms (due to limitations of the instrumented device used for assessments in the concurrent study) (Chapter 6) (Birnbaum et al., 2018) and cerebellar ataxia. The study was approved by the human research ethics committees of St. Vincent's Hospital Melbourne and Curtin University. Written consent was obtained for all participants prior to inclusion. If an individual was unable to consent due to communication or cognitive impairment, consent was obtained from an individual's Next of Kin.

Measures

A number of clinical measures were performed with participants across a six month assessment period. Lateropulsion severity was assessed using the BLS (D'Aquila et al., 2004). The BLS assesses for the presence of lateropulsion across five tasks including rolling, sitting, standing, transfers and walking (D'Aquila et al., 2004). The scale measures how much resistance is present when a rater attempts to correct a tilted posture and when the resistance occurs. Scoring for the BLS ranges from zero to 17 with a higher score reflecting greater resistance. The BLS was utilised in preference to the Scale of Contraversive Pushing, as recommended by Koter and colleagues, due to the limitations of the Scale of Contraversive Pushing for measuring milder lateropulsion (Bergmann et al., 2014; Koter et al., 2017). The BLS has strong measurement properties regarding inter-rater and intra-rater reliability (D'Aquila et al., 2004), internal validity (Chapter 5) (Birnbaum et al., 2020), concurrent validity (D'Aquila et al., 2004) and responsiveness (Clark et al., 2012). Postural function was determined using the PASS (Benaim et al., 1999). The PASS is a 12-item scale designed to measure postural control with stroke survivors in lying, sitting and standing. Scores from the PASS span from zero to 36, with a higher score representing greater postural abilities. The PASS has demonstrated high reliability, validity and responsiveness with stroke survivors, including those with lateropulsion (Benaim et al., 1999; Clark et al., 2012; Mao et al., 2002).

The FIM (motor domain) (Linacre et al., 1994) was used as a measure of functional ability. The FIM motor is a 13-item scale which assesses dependence in self-care, sphincter control, transfer and locomotion to provide an overall measure of physical disability (Linacre et al., 1994). The scoring range of the FIM motor is 13 to 91, with a higher score signifying greater functional independence. Summed, raw FIM motor scores were transformed into Rasch transformed interval scores for statistical analysis (Fielder, 1993). Finally, walking ability was classified using the FAC (Holden et al., 1984). The FAC assesses functional ambulation by classifying walking ability into one of six categories, based on the amount of physical assistance an individual requires to walk and the environment in which they can walk, with higher scores indicating greater independence and terrains able to be negotiated.

In addition to the clinical measures, WBA was assessed with participants standing with and without arm support for three seconds duration with a WBB under each foot. The WBBs were operated with a custom-designed acquisition and analysis system which allows WBA measures to be collected similar to force platform methods (Clark et al., 2011). The setup and testing procedures of these tasks have been described in-depth previously (see section 4.4 Longitudinal study methods). For both tasks, directional WBA was examined. Directional WBA quantifies in kilograms and through positive and negative values the magnitude and direction of the WBA, where a positive value represents a greater load being placed through the non-paretic leg. Good to excellent test-retest reliability of WBA for these tasks in individuals with lateropulsion has been demonstrated (Chapter 8). Active motor control, sensation and neglect were assessed using lower extremity items of the Stroke Rehabilitation Assessment of Movement Instrument (Daley et al., 1999), the lower limb sensory section of the Fugl-Meyer Assessment (Fugl-Meyer et al., 1975) and the Catherine Bergego Scale (Azouvi et al., 1996) respectively.

Participants were assessed day 1 following recruitment to the study when the above criteria were met, and then fortnightly until eight weeks from initial assessment, and at six months post stroke. Both the clinical scales of lateropulsion and postural function were performed on the initial testing occasion and fortnightly until the eight-week assessment. Weight bearing asymmetry in standing with and without arm support was also assessed during the same testing sessions if able (i.e. when a participant could stand for three seconds with arm support). The FIM motor and FAC were recorded at the time of initial assessment and six months post stroke. The six-month FIM motor and FAC were either acquired in person or via telephone (Smith et al., 1996) in order to maximise the dataset obtained. The measures of motor control, sensation and neglect were performed at the initial assessment occasion only. The full testing procedures have been described previously (Chapter 4).

Statistical Analysis

Demographic data, baseline measures and six-month post stroke outcomes are reported using descriptive statistics. Variables were assessed for normality through the inspection of histograms and by using the Shapiro-Wilk test.

The relationships between baseline measures (BLS, PASS, FIM motor) and WBA in standing with and without arm support (when first able to complete) with the six-month motor FIM were examined using bivariate scattergrams and the Spearman's rank-order correlation or Pearson product-moment correlation depending on the nature of the measure and whether data were normally distributed or not. For Pearson's r and Spearman rho, values between 0.9-1 are considered a very high correlation, 0.7-0.9, a high correlation; 0.5-0.7, a moderate correlation; and 0.3-0.5, low correlation and 0-0.3, a negligible correlation (Mukaka, 2012).

To determine the association of the baseline lateropulsion and functional ability measures to functional outcomes at six months in a sample of individuals with lateropulsion, linear regression was performed using FIM motor score at six months as the dependent variable. Variables including BLS, PASS and FIM motor were investigated for collinearity before conducting the linear regression.

Patterns of recovery in terms of lateropulsion, postural function and WBA in standing with and without arm support were depicted using spaghetti plots from the initial to eight-week testing occasion. Statistical significance of $p<0.05$ was used for all analyses.

9.4 Results

Over the study period of 36 months, 872 patients were consecutively assessed for eligibility including 743 patients in the acute stroke unit. Of the patients assessed in the acute stroke unit, 11.3% had lateropulsion as determined by a BLS score ≥2. Participant recruitment is outlined in Figure 9.1. In total, 46 individuals participated in this study with follow up six-month data (FIM motor and FAC) acquired for 41 participants. The mean (SD) age of participants was 66.8 (±14.6) years and the median [interquartile range (IQR)] time post stroke until initial assessment completion was 22 [13-33] days. Baseline characteristics are presented in Table 9.1, both for those whom follow up data were obtained (*n*=41) and for those missing to follow up (*n*=5). For the five participants without six-month data, all were male and had more mild lateropulsion (median BLS three compared to eight) and higher functional level at baseline (median FIM motor 35 compared to 22) compared with the follow up data group (Table 9.1).

Six-month outcomes

The six-month data were collected in person for 10 participants, via telephone for 30 participants, whilst data for one participant who was uncontactable at six months were brought forward from completion of outpatient rehabilitation given this occurred greater than four months post stroke. If required, for the 30 participants contacted via telephone, the FIM motor at discharge from rehabilitation was used as a basis for discussion, particularly for those in care facilities. Six-month outcomes are reported in Table 9.2. Individuals with mild lateropulsion (BLS 2-8) achieved a high level of functional ability, with a median [IQR] six-month FIM motor score of 85 [70-89] out of 91. Sixteen (76.2%) participants with mild lateropulsion achieved independent walking (including both on level surfaces only (FAC of 5) and on level and non-level surfaces (FAC of 6)). Comparatively, individuals with moderate and severe lateropulsion achieved a lower level of functional ability with a median [IQR] six-month FIM motor score of 43 [26.5-76.8] and 27.5 [16-82.5] respectively, however there was a wide range of scores within these groups. Of those classified as having either moderate or severe lateropulsion, six (30%) individuals achieved independent walking (including both on level surfaces only (FAC of 5) and on level and non-level surfaces (FAC of 6)).

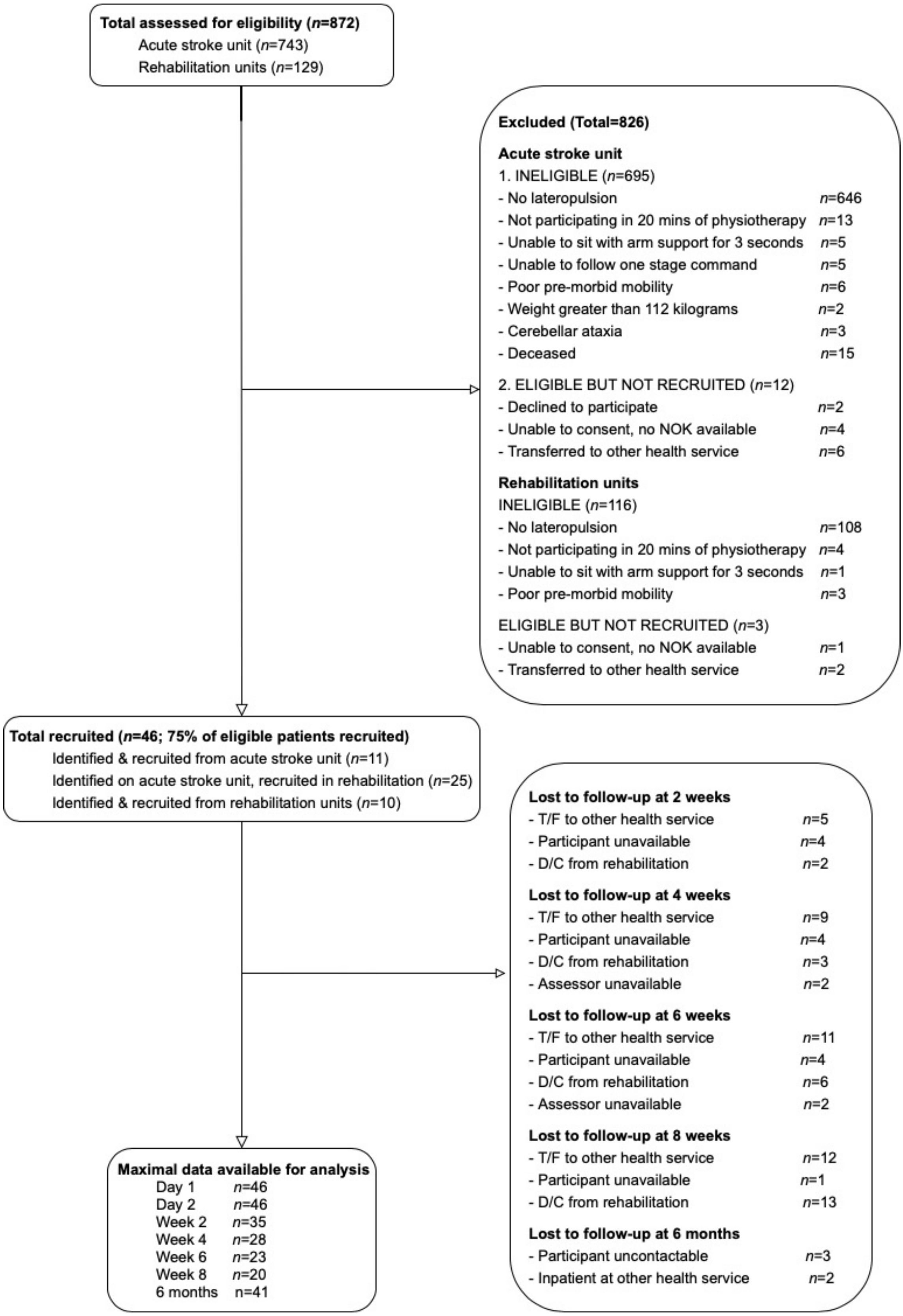


Figure 9.1. Flow diagram of participant recruitment

Abbreviations: D/C, discharge; NOK, Next of Kin; n, number; T/F, transfer.

Table 9.1. Baseline characteristics

Variable	Follow up data (n=41)	Missing follow up data (n=5)
Age (years), mean (SD)	67.0 (14.9)	65.2 (13.0)
Time post stroke (days), median [IQR]	22.0 [13.5 – 33.5]	19.0 [8.0 – 40.0]
Male sex, n (%)	21 (51.2%)	5 (100%)
Side of hemiparesis		
Left, n (%)	22 (53.7%)	4 (80%)
Right, n (%)	18 (43.9%)	1 (20%)
Both, n (%)	1 (2.4%)	0 (0%)
Pathology		
Infarct, n (%)	19 (46.3%)	3 (60%)
Haemorrhage, n (%)	17 (41.5%)	2 (40%)
Both, n (%)	5 (12.2%)	0 (0%)
Severity of lateropulsion (BLS scores), median [IQR]	8.0 [5.5 – 10.0]	3.0 [3.0 – 10.0]
Mild (2-8), n (%)	21 (51.2%)	4 (80%)
Moderate (9-12), n (%)	14 (34.1%)	0 (0%)
Severe (13-17), n (%)	6 (14.6%)	1 (20%)
PASS scores, median [IQR]	15.0 [12.0 – 19.0]	30.0 [13.0 – 30.0]
Active Motor Control (Lower extremity items of STREAM)		
Scores, median [IQR]	26.8 [0 – 57.1]	53.6 [8.9 – 89.1]
Not tested	1 (2.4%)	1 (20%)
Sensation (Lower limb sensory section of FM Assessment)		
Impaired	22 (53.7%)	3 (60%)
Intact	11 (26.8%)	1 (20%)
Not tested	8 (19.5%)	1 (20%)

***Table 9.1 is continued on the next page*

Table 9.1. Baseline characteristics (continued)

Variable	Follow up data (n=41)	Missing follow up data (n=5)
Neglect (Catherine Bergego Scale)		
No neglect	11 (26.8%)	2 (40%)
Mild	14 (34.1%)	1 (20%)
Moderate	10 (24.4%)	1 (20%)
Severe	4 (9.8%)	1 (20%)
Not tested	2 (4.9%)	0 (0%)
FIM (motor) score at baseline, median [IQR], 13-91	22.0 [17.0 – 28.5]	35.0 [17.0 – 51.0]
FAC score at baseline, median [IQR]	1 [1-1]	1 [1-3.5]

Abbreviations: BLS, Burke Lateropulsion Scale; FAC, Functional Ambulation Classification; FIM, Functional Independence Measure; FM, Fugl Meyer; IQR, interquartile range; PASS, Postural Assessment Scale for Stroke; STREAM, Stroke Rehabilitation Assessment of Movement Instrument.

NB. For some participants, measures for active motor control, sensation and neglect were 'not tested'. The main reason for these not being completed was the presence of language deficits limiting the ability to do so accurately.

Univariate relationships between baseline measures and six-month FIM motor scores

A moderate correlation was found between both baseline BLS and PASS scores and the six-month FIM motor scores (Spearman's rho -0.526 and 0.620, $p<0.001$ respectively)(Figure 9.2(a)). A low correlation was found between baseline FIM motor and the six-month FIM motor scores (Spearman's rho 0.384, $p=0.013$)(Figure 9.2(b)). Negligible, non-significant correlations were found between the six-month FIM motor and WBA directional variable for either standing task from when an individual was first able to complete the given task (Figure 9.2(c) and (d)).

Table 9.2. Six-month outcomes

Variable (n=41)	All participants (n=41)	Mild (n=21)	Moderate (n=14)	Severe (n=6)
Time post stroke to six month assessment (days), median [IQR]	188 [183-195]	189 [183-193]	188 [184-198]	182.50 [180-189]
Six-month FIM motor score, median [IQR]	74.0 [34.0-87.0]	85.0 [70.0-89.0]	43.0 [26.5-76.8]	27.5 [16.0-82.5]
Six-month FAC score, median [IQR]	5 [1-6]	5 [4.5-6]	1 [1-5.3]	1 [1-5.3]
1 Nonfunctional, n (%)	13 (31.7)	1 (4.8)	8 (57.2)	4 (66.6)
2 Dependent, Level II, n (%)	1 (2.4)	0 (0)	1 (7.1)	0 (0)
3 Dependent, Level I, n (%)	0 (0)	0 (0)	0 (0)	0 (0)
4 Dependent, Supervision, n (%)	5 (12.2)	4 (19.0)	1 (7.1)	0 (0)
5 Independent, Level surfaces only, n (%)	10 (24.4)	8 (38.1)	1 (7.1)	1 (16.7)
6 Independent, Level and non-level surfaces, n (%)	12 (29.3)	8 (38.1)	3 (21.5)	1 (16.7)

Abbreviations: FAC, Functional Ambulation Classification; FIM, Functional Independence Measure; IQR, interquartile range.

Multivariate analysis for FIM motor outcomes

In terms of collinearity, a high correlation was found between baseline BLS and baseline PASS (n=41, Spearmans rho -0.854, p<0.001), whilst moderate correlations were found between these measures and the baseline FIM motor (n=41, Spearman rho -0.655 and 0.662 respectively, p<0.001). Thus, due to the collinearity identified between the BLS and PASS, and the need to limit the number of variables included because of the small sample size, linear regression for FIM motor score at six months was completed with the variables of baseline FIM motor score and baseline BLS score being utilised. The model accounted for 26% of the observed variability (Adjusted R square). In this model only baseline BLS score provided statistically significant predictive value (*p*=.009)(Table 9.3).

Table 9.3. Linear model predicting Functional Independence Measure motor score at six months

Variable	B	p
Baseline FIM motor	0.025	0.944
Baseline BLS score	-3.517	0.009

Abbreviations: BLS, Burke Lateropulsion Scale; FIM, Functional Independence Measure.

Recovery pattern of lateropulsion, postural function and WBA in standing over eight weeks

The individual patterns of recovery for lateropulsion and postural function for 46 participants over the eight-week testing period are displayed in Figure 9.3(a) and (b). At an individual level there was generally good recovery from lateropulsion for participants over time with a decrease in BLS scores, including for some individuals with moderate (BLS 9-12) and severe (BLS 13-17) lateropulsion. Improvement in PASS scores for most participants over time was also observed. However, for some participants there was minimal change in PASS scores over the study period, and for two participants a substantial reduction in PASS scores occurred, demonstrating deterioration in function (one had a fall [unrelated to the study] causing bruising and loss of confidence, the other participant had fluctuating fatigue that may have influenced performance).

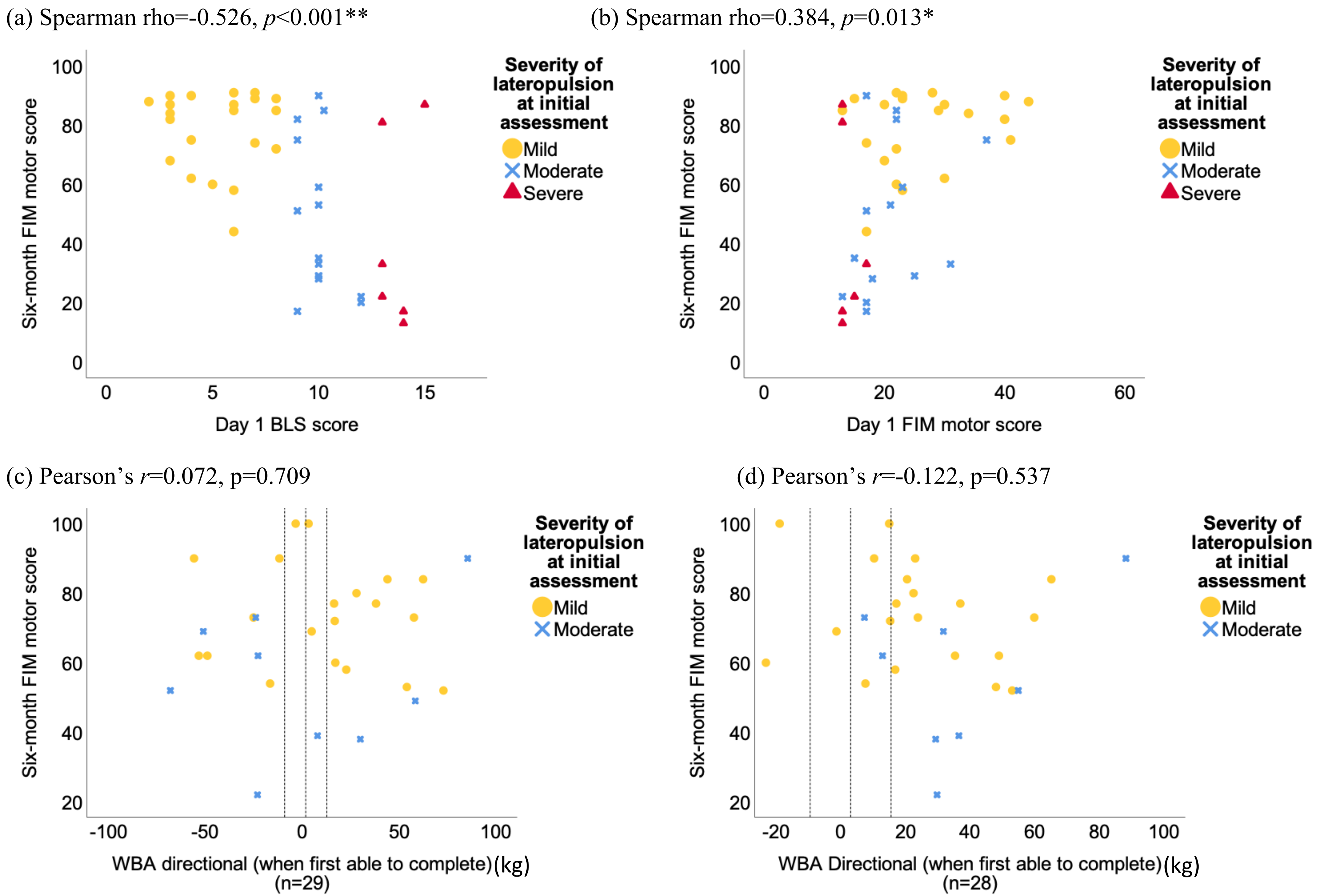

(a) Spearman rho=-0.526, p<0.001**
Six-month FIM motor score
Day 1 BLS score
Severity of lateropulsion at initial assessment
Mild
Moderate
Severe
(b) Spearman rho=0.384, p=0.013*
Six-month FIM motor score
Day 1 FIM motor score
Severity of lateropulsion at initial assessment
Mild
Moderate
Severe
(c) Pearson's r=0.072, p=0.709
Six-month FIM motor score
WBA directional (when first able to complete)(kg) (n=29)
Severity of lateropulsion at initial assessment
Mild
Moderate
(d) Pearson's r=-0.122, p=0.537
Six-month FIM motor score
WBA Directional (when first able to complete)(kg) (n=28)
Severity of lateropulsion at initial assessment
Mild
Moderate

Figure 9.2. Relationship between baseline clinical measures or standing weight-bearing asymmetry measures when first able to complete and six-month Functional Independence Measure motor

(a) Baseline BLS; (b) Baseline FIM motor; (c) Directional WBA for stand with arm support task when first able to complete; (d) Directional WBA for stand without arm support task when first able to complete. For WBA directional measures normative value lines from healthy control data (mean +/- 1.96SD) are included on the scatterplots.

Abbreviations: BLS, Burke Lateropulsion Scale; FIM, Functional Independence Measure; n, number; p, p value; WBA, weight bearing asymmetry.

*Significant at $p<0.05$; **Significant at $p<0.01$

Figure 9.3(c) and (d) shows the individual patterns of recovery for WBA for participants able to stand with and without arm support over the eight-week repeated testing period. For the task of *standing with arm support*, the weight bearing pattern utilised changed for the majority of participants over the testing period (n=20, 80% of participants with repeated measures)(Figure 9.3(c)). Four participants started within the directional WBA healthy control range (+/-1.96SD represented by dashed grey lines), including one participant who was only tested initially. Nine participants (36%) swapped from weight bearing excessively on their paretic leg to excessively weight bearing through their non-paretic leg. Eight participants (32%) stood more symmetrically over the testing period, with the values for three of these participants (12%) moving to within the healthy control range (+/-1.96SD).

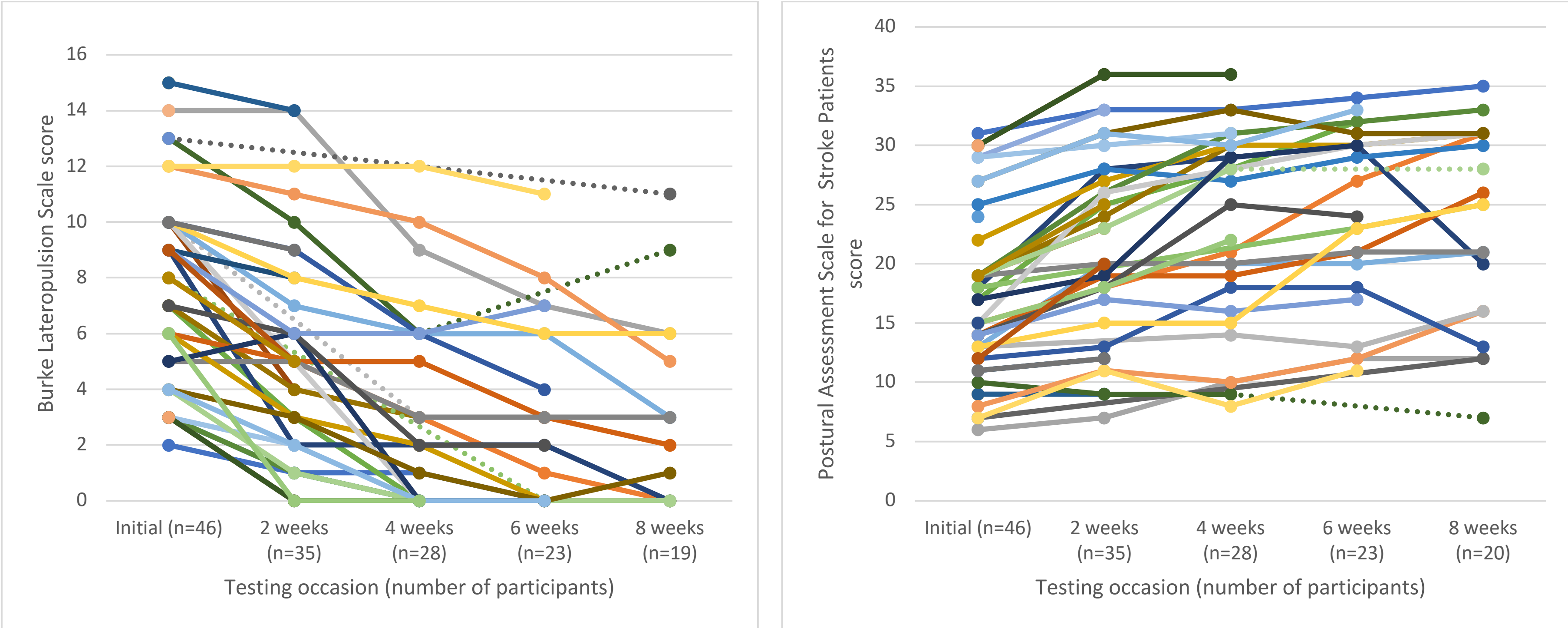
For the task of *standing without arm support*, eight participants started within the directional WBA healthy control range (+/-1.96SD represented by dashed grey lines), including two participants who were tested on one occasion only (Figure 9.3(d)). Of the 23 participants with repeated measures for the *stand without arm support task*, 10 participants (43%) were relatively stable in their WBA patterns when standing unsupported over the testing occasions (with three participants (13%) remaining within the healthy control range throughout). There were six participants (26%) who had WBA scores outside the healthy control range and then came back towards symmetry to within the healthy control range (+/-1.96SD), and another four participants (17%) who came back more towards symmetry but not within the healthy range. Three participants were quite variable in terms of their weight bearing pattern over the testing period (13%).

9.5 Discussion

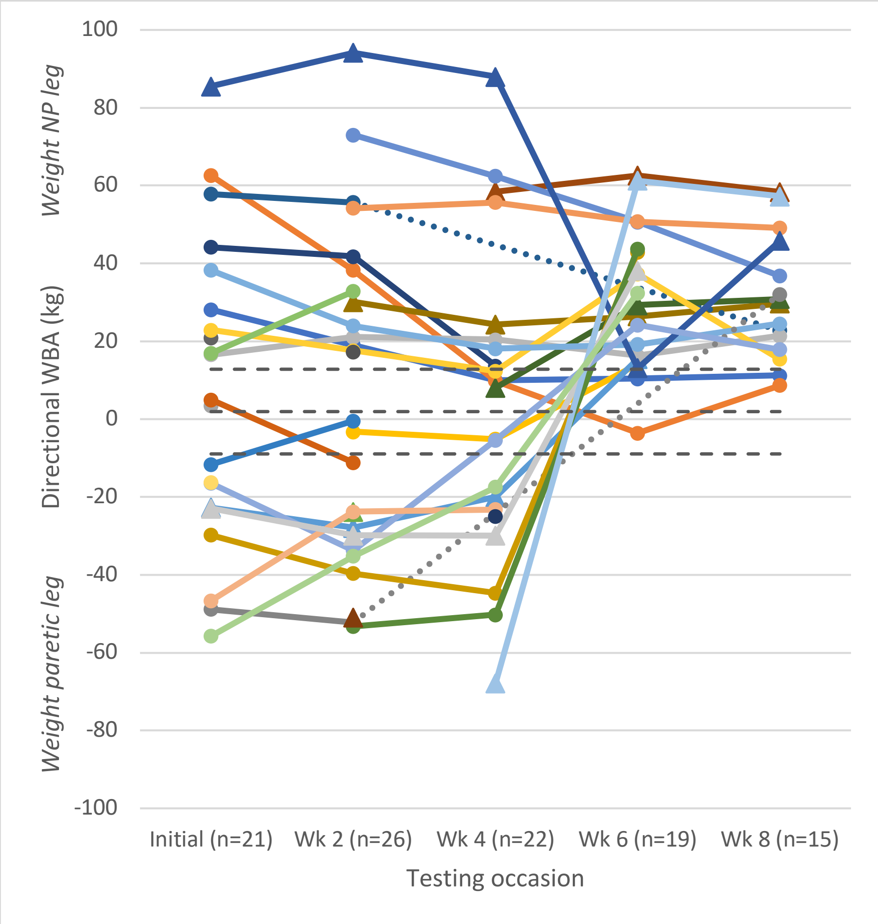
This study investigated the six-month mobility and functional outcomes of individuals with lateropulsion following stroke, demonstrating that marked mobility and functional independence improvements can be achieved over this timeframe. For individuals with mild lateropulsion, 72.2% (16 of 21) achieved independent walking (as evidenced by a score of 5 or 6 on the FAC), whereas of those with moderate to severe lateropulsion, 30% (6 of 21) achieved independent walking. Prior research has demonstrated significant functional improvements during inpatient rehabilitation for individuals with lateropulsion (Babyar et al., 2015; Krewer, Luther, et al., 2013; Pedersen et al., 1996) however, previous studies have not reported outcomes in terms of lateropulsion severity. The six-month outcomes reported in the

(a) *BLS<2 considered to have no lateropulsion

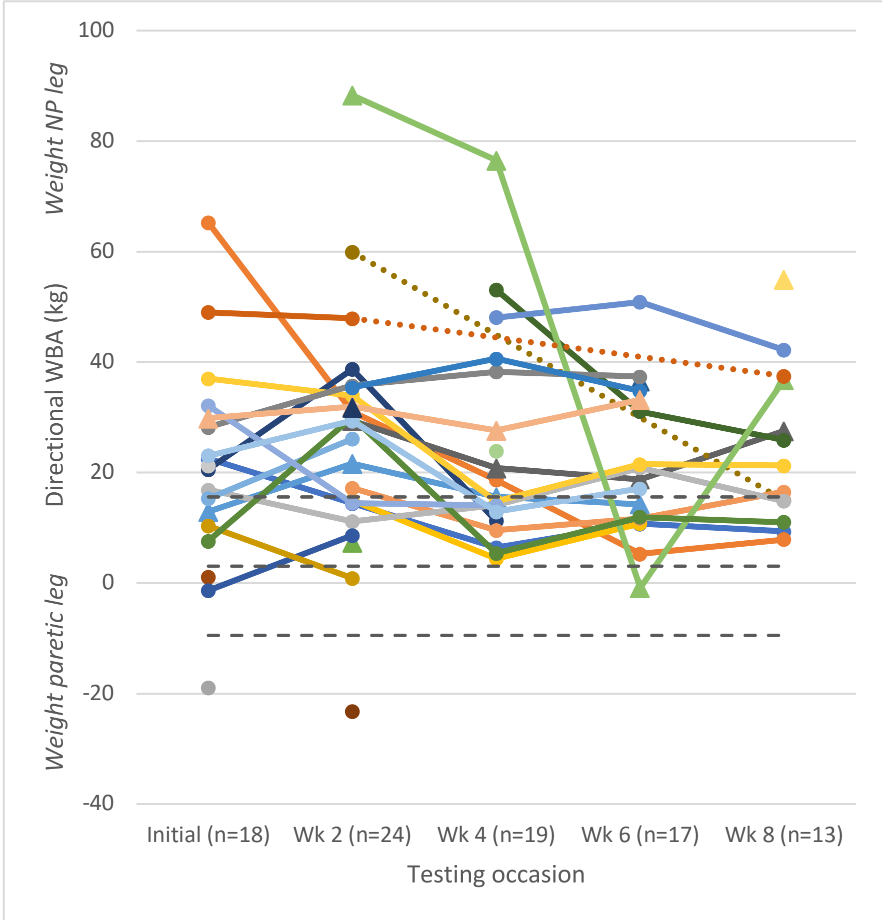
(b)



(c)


100
80
60
40
20
0
-20
-40
-60
-80
-100
Weight NP leg
Directional WBA (kg)
Weight paretic leg
Initial (n=21)
Wk 2 (n=26)
Wk 4 (n=22)
Wk 6 (n=19)
Wk 8 (n=15)
Testing occasion

(d)


100
80
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-20
-40
Weight NP leg
Directional WBA (kg)
Weight paretic leg
Initial (n=18)
Wk 2 (n=24)
Wk 4 (n=19)
Wk 6 (n=17)
Wk 8 (n=13)
Testing occasion

Figure 9.3. Patterns of recovery over time

(a) Burke Lateropulsion Scale overtime from initial to eight weeks; (b) Postural Assessment Scale for Stroke overtime from initial to eight weeks; (c) Directional weight bearing asymmetry (WBA) variable for Stand with arm task overtime from initial to eight weeks; (d) Directional WBA variable for Stand without arm task overtime from initial to eight weeks.

Abbreviations: n, number; NP, non-paretic; WBA, weight bearing asymmetry; wk, week.

NB. Circles markers indicate participant had mild lateropulsion at baseline (BLS 2-8), whilst triangle markers indicate a participant had moderate lateropulsion at baseline (BLS 9-12). Dotted lines are used between data points when missing data exists.

current study further support that individuals with lateropulsion can make clinically important gains in terms of independence in mobility and functional abilities post stroke, including some individuals with moderate to severe lateropulsion.

The second aim of the study was to explore the relationships between baseline measures of lateropulsion and function and six-month functional outcomes. A moderate correlation was found between baseline BLS scores and six-month functional ability measured using the FIM motor scores. Baseline BLS scores contributed significantly to the model of predicting the FIM motor score at six months, whereas the baseline FIM motor score did not. These results were unanticipated given admission FIM scores have previously been shown to strongly predict discharge FIM score in a general stroke sample (Lin et al., 2003). The findings of baseline BLS scores contributing to prediction of FIM motor score at six months provide further support for the use of this measure of lateropulsion in stroke evaluation throughout the episode of care.

Although the BLS and PASS were highly correlated at baseline, examination of the recovery patterns of the BLS and PASS scores over time revealed distinctly different patterns. For the BLS there was generally a consistent decrease in scores over the testing period, demonstrating recovery from lateropulsion, even for participants presenting with moderate to severe lateropulsion at baseline, whereas a lower rate of change was observed for the PASS. These findings suggest that initially the presence of lateropulsion may markedly impact postural function, however over time, as the lateropulsion resolves, other impairments such as motor control and sensation may adversely affect an individual's postural function.

The time course of the individual WBA patterns for the *stand with arm support task* provides some interesting findings. Whilst initially just under half of the participants were weight bearing more through their paretic leg, this weight bearing pattern changed overtime towards greater weight taken through the non-paretic leg. This supports the notion that individuals with lateropulsion acquire a learnt strategy of loading their non-paretic leg over time in order to overcome their verticality impairment and maintain balance in standing (Barra et al., 2009). For those individuals weightbearing excessively through their non-paretic leg initially, many came back more towards symmetry over the testing occasions. These two scenarios reinforce the need for therapists to carefully analyse the weight bearing pattern which individuals with lateropulsion adopt when starting to stand without therapist assistance, and to subsequently tailor treatment to target this. For example, if the weight bearing pattern when standing with hand support is biased towards the affected side, then the focus of treatment may be to orientate the individual towards their non-paretic leg. Whereas, if an individual is excessively biasing their non-paretic leg when standing with light touch contact, then the aim of treatment may be to bring them back more towards symmetry (Chapter 8).

For the task of *stand without arm support*, the time course of individual WBA patterns was much more variable. The high inter-subject variability further supports the need for individualised treatment based on an individual's presentation. Overall, fewer participants changed their adopted weight bearing pattern over time for the *stand without arm support task*, than for the *stand with arm support task*. Thus, for a proportion of stroke survivors with lateropulsion, the weight bearing pattern which was adopted when they were first able to stand without arm support and overcome their verticality impairment, was the pattern which continued to be adopted over the study period. Previously in a study undertaken with a cohort of individuals following stroke undergoing inpatient rehabilitation (lateropulsion status unknown), WBA was found to decrease over the first four weeks and then persisted following this (de Haart et al., 2004). This appears more variable in our current study that only included patients with lateropulsion. Interestingly, both the weight bearing pattern adopted by individuals when first able to stand both with and without arm support, and how asymmetrical an individual was did not relate to functional ability at six months.

Limitations

As mentioned, this study forms part of a larger study undertaken to investigate the use of instrumented measures in individuals with lateropulsion following stroke (Chapters 7 and 8). Therefore, a limitation of the acquired baseline measures is that these were not taken at a specific time point post stroke, but instead when a participant met the inclusion criteria to enter the main study including being able to sit with back and arm support and participate in 20 minutes of physiotherapy. As a result, the baseline measures do not represent the participants' initial impairment scores (with the initial testing occasion occurring a median [IQR] of 22 [13.5-33.5] days post stroke). Also, individuals with BLS scores of 16 and 17, whilst not excluded on the basis of BLS score, were unlikely to be able to sit with arm and back support for three seconds and subsequently did not meet the study inclusion criteria. Future studies should address both of these limitations by performing baseline measures at a consistent time point post stroke (ie. seven days post) as well as including those more severe cases with BLS scores of 16 and 17.

Data capture was complete for all occasions of testing for 30% of participants, with 25 participants (54%) discharged home or transferred to another hospital prior to testing completion. This resulted in missing data points for the time course series and subsequently limits the interpretation of the patterns of recovery data. In addition, six month follow-up assessments were conducted by telephone limiting the outcome variables assessed. Further studies are required to assess the impact that persistent lateropulsion has on longer term outcomes.

Finally, the current sample size limited the statistical analyses which could be performed on the data acquired. Subsequently, whilst a number of different factors have been shown to influence functional recovery following stroke (Nijboer et al., 2013; Langhorne et al., 2011; Patel et al., 2000; Sennfalt et al., 2019), including the presence of other impairments such as neglect (Nijboer et al., 2013), these could not be factored into the predictive model undertaken within this current study.

9.6 Conclusion

This study demonstrated that individuals with lateropulsion can make clinically meaningful gains in terms of mobility and functional independence at six months following stroke, including some stroke survivors with more severe lateropulsion. Participants generally displayed a reduction in lateropulsion over time. The baseline BLS scores were shown to be predictive of functional impairment at six months post stroke compared to baseline FIM motor scores, supporting the use of the BLS as a scale for measuring lateropulsion following stroke and also highlighting the effect that lateropulsion has on longer term functional outcomes.

Chapter 10. Discussion and Conclusion

Chapter Outline

This chapter summarises and integrates the results of the different studies presented in this thesis. The specific discussion of each study in the context of relevant literature is reported in each chapter previously, so is not repeated here. The chapter includes a discussion of the clinical implications of the different studies, the strengths and limitations of the studies undertaken, and also outlines some recommendations for future research.

10.1 Discussion

This thesis explored the measurement of lateropulsion following stroke in clinical research, extending our knowledge about the nature and recovery of this distinct postural control disorder. The thesis focused on three main areas:

(1) the measurement properties of clinical lateropulsion and sitting balance measures in individuals following stroke, encompassing the following questions:

i. What are the psychometric properties of current clinical assessment scales used to measure sitting balance after stroke?

ii. Does the BLS demonstrate internal validity using Rasch analysis?

iii. What is the association between baseline lateropulsion scores, and functional outcomes achieved six months post stroke?

(2) the use of WBB(s) as an instrumented measure of postural control in sitting and standing in individuals with lateropulsion, encompassing the following questions:

iv. Is it feasible to use the WBB as an instrumented measure of sitting and standing balance in stroke survivors with lateropulsion early after stroke?

v. What differences exist when comparing instrumented measures of postural control in sitting and standing in stroke survivors with lateropulsion relative to healthy controls?

vi. What is the relationship between instrumented measures of postural control in sitting and standing and clinical measures of lateropulsion and postural function in individuals with lateropulsion?

vii. Are measures of COP in sitting and WBA in standing reliable between test occasions in individuals with lateropulsion?

(3) the longer-term outcomes and individual recovery patterns of lateropulsion and postural control over time of individuals following stroke with lateropulsion, encompassing the following questions:

viii. What mobility and functional outcomes can be achieved by stroke survivors with lateropulsion at six-months post stroke?

ix. What is the pattern of recovery for lateropulsion and standing symmetry in the subacute phase of stroke?

The first key focus of this thesis was to explore the measurement properties of available sitting balance measures in individuals following stroke, as well as of the BLS, as the preferred clinical measurement scale of lateropulsion (Koter et al., 2017). As recognised in the literature review, sitting balance measures for use with individuals following stroke have not been investigated as extensively as standing balance measures. This is despite the fact that some stroke survivors, such as those with severe lateropulsion, have great difficulty in maintaining their balance in sitting. A systematic review was performed to address this by examining the available clinical sitting balance measures (until December 2015) (Research question i; Chapter 3). The review included 39 articles evaluating 14 different clinical sitting balance measures that include dynamic sitting tasks. The review could not distinguish any measures with adequate psychometric properties to recommend as a favoured tool, given the poor to fair methodological quality of the included studies. Another 12 articles were identified when the updated search was undertaken until September 2020. The results of the additionally identified studies predominantly supported the findings obtained from the original systematic review described above, with one exception. The Functional in Sitting Test was flagged as a clinical sitting balance measure with promising psychometric properties that deserves further investigation through the completion of higher quality studies.

Along with investigating the measurement properties of sitting balance measures with individuals following stroke, further psychometric properties of the BLS were explored in this thesis. In the Rasch analysis study utilising data from 132 participants (Research question ii; Chapter 5), the BLS was found to be unidimensional and possess good internal consistency. The internal validity of the BLS was also supported, with the BLS items demonstrating good fit to the Rasch model. In the longitudinal component of the observational study which involved 41 participants with lateropulsion, a moderate correlation was demonstrated between baseline BLS scores and functional ability at six months (Research question iii; Chapter 9). Additionally, baseline BLS scores were found to contribute significantly to the model of predicting FIM motor score at six months, whereas baseline FIM motor scores were not. This is a surprising finding given that baseline function is well established as strongly associated with functional outcome (Lin et al., 2003). The results of these two studies provide further support for the validity of the BLS and its utilisation as the preferred scale for assessing lateropulsion after stroke (Koter, 2019; Koter et al., 2017).

While the BLS presents as a strong clinical measure of lateropulsion, the literature review in Chapter 2 revealed that there are very few studies investigating postural control dysfunction in this patient population using instrumented measures. The second focus of this thesis was to investigate the utilisation of WBB(s) as an instrumented measure of postural control in sitting and standing in individuals with lateropulsion following stroke. In the pilot study undertaken with ten stroke survivors with lateropulsion, the use of a WBB for this purpose was found to be feasible, with mediolateral amplitude identified as a variable of interest for the static balance tasks (Research question iv; Chapter 6). The utility of the testing procedures implemented was limited with some participants, with testing ceased on 20% of assessment occasions. This finding was foreshadowed with the completion of the feasibility study, given individuals with severe lateropulsion can often only sit unsupported for very short periods of time, if at all. The feasibility study results supported the completion of a larger observational study to further investigate the use of this technology in this patient population, but with a number of protocol adaptations. These included a reduction in the number of tasks performed, the use of dynamic tasks that involved reaching to a pre-determined target in order to minimise variability between trials and also the use of a healthy control group to assist with interpretation of the data obtained, particularly for the dynamic tasks where it was unknown as to how much COP movement was to be expected. The potential benefit of acquiring data regarding WBA was also identified during the completion of the feasibility study, as well as on further reflection of the literature (Barra et al., 2009; Lafosse et al., 2007; Mansfield et al., 2013). However, the difficulties encountered when attempting to place participants accurately in the middle of the WBB in sitting during the feasibility study meant COP variables remained the outcome measure chosen for the sitting tasks. In standing however, the one WBB was replaced with two WBBs (one under each foot) to enable WBA data to be captured in preference to COP variables. Subsequently, COP variables were acquired in sitting and WBA variables in standing in the larger observational study undertaken.

The larger observational study subsequently completed involved 46 participants with lateropulsion following stroke and 35 gender- and aged matched healthy controls. The aims of the sitting and standing components of the larger observational study (Chapters 7 and 8) were to 1) compare instrumented measures of postural control in sitting and standing in people with lateropulsion to healthy controls; 2) investigate the relationship between these measures and clinical measures of lateropulsion and postural function; and 3) determine the test-retest reliability of the instrumented measures. These aims relate to research questions v-vii of the thesis.

As may be expected, a number of differences were found in the postural control strategies utilised in sitting and standing by stroke survivors with lateropulsion relative to healthy controls (Research question v). In terms of the sitting tasks (Chapter 7), reduced mediolateral and anteroposterior stability was demonstrated for people with lateropulsion compared to healthy controls. What was unanticipated however, was the inconsistency present in the postural control performance in sitting of participants with lateropulsion, with some individuals displaying high levels of mediolateral instability, and other individuals performing the task with COP variable scores within the healthy control range. For the standing tasks, individuals with lateropulsion stood with marked WBA compared to the healthy controls. This asymmetry was largely towards the non-paretic leg when standing unsupported, backing the previous hypothesis that individuals with lateropulsion acquire this learnt strategy to maintain their balance in standing (Barra et al., 2009). Interestingly, when standing with arm support, two different weight-bearing patterns were observed in the individuals with lateropulsion, with half of the participants with lateropulsion favouring their paretic leg, and the other half their non-paretic leg. The results for both the sitting and standing tasks highlight that different treatment approaches may be required to address the different postural control strategies observed with specific individuals.

The WBA results from the standing unsupported task for the individuals with lateropulsion must not be interpreted in isolation, as the question may be asked as to whether lateropulsion is a distinct postural control disorder, given the results of taking greater loading through the non-paretic leg are similar to those of other studies investigating WBA more broadly following stroke (Barra et al., 2009; de Haart et al., 2004; Eng & Chu, 2002; Mansfield et al., 2013; Marigold & Eng, 2006; Martins et al., 2011; Pereira et al., 2010). Instead, it is important to highlight that only 18 of 46 (39%) individuals with lateropulsion recruited to the repeated measures observational study could stand unsupported on day 1 of testing (with day one testing occurring a median of 22 days post stroke). Thus, greater than 60% of participants could either not stand or required assistance to stop falling towards their paretic side in standing due to lateropulsion. Previous research has reported the median time to achieve unsupported standing following stroke is three days (interquartile range 0 to 14 days) (Smith & Baer, 1999). Thus, whilst it appears that individuals with lateropulsion learn to orientate themselves towards their non-paretic leg in order to avoid falling as those without lateropulsion commonly do, the underlying postural control disorder of lateropulsion remains distinctively different to other postural control disorders experienced following stroke.

The relationships between the instrumented measures of postural control in sitting and standing and clinical measures of lateropulsion and postural function (Research question vi; Chapters 7 and 8), or lack thereof, were not unexpected given low correlations between static WBA variables in standing and clinical tests have been previously reported in stroke survivors (Bower et al., 2014). Whilst a moderate correlation was found between mediolateral and anteroposterior amplitude and the BLS for the task of sit without arm support, when individual performance was evaluated, it was observed that some participants with mild lateropulsion displayed considerable instability, while others with more severe lateropulsion were within the healthy range. In standing, lateropulsion severity was not associated with the directional weight-bearing pattern an individual adopted while performing the different tasks. However, WBA was found to be moderately correlated with postural function when standing with arm support, as has previously been reported (Barra et al., 2009). This correlation supports the use of the WBB as a means of acquiring associated but unique quantitative information regarding postural control in individuals with lateropulsion following stroke in addition to clinical measures (Bower et al., 2014).

Interestingly, the findings relating to test-retest reliability of the WBB-derived variables of postural control varied greatly between sitting and standing positions (Research question vii; Chapters 7 and 8). For all of the sitting tasks, variability in performance between Day 1 and Day 2 testing was evident, with test-retest reliability in the fair to moderate range, despite the completion of a familiarisation session. The variability observed in this study is in agreement with previous studies in stroke (Näf et al., 2020; Tessem et al., 2007). When looking at individual performance, some participants were highly unstable on one testing occasion and within healthy control range on the other, other participants were unstable on both testing occasions and some participants displayed COP variables within the healthy control range on both occasions. Comparatively, the WBA variables for the standing tasks demonstrated moderate to excellent test-retest reliability between measurement occasions, with excellent test-retest reliability found for the task of standing with arm support. These results are comparable to previous research investigating the retest reliability of WBB derived-WBA with individuals following stroke (lateropulsion status unknown) (Bower et al., 2014). The consistency of asymmetry in standing contrasts strongly with the variability in postural control in sitting. This raises the question of what would occur if the opposite variables were assessed in each position, that is, the testing of asymmetry in sitting and COP in standing. It is unknown based the findings of the current thesis as to whether the same results would be observed, or if the results are a consequence of the context of the task being performed.

Another gap which was identified in the literature review was that little is known about the longer-term outcomes of individuals with lateropulsion. Likewise, whilst Clark and colleagues demonstrated a steady reduction in lateropulsion and improvement in postural control measured every two weeks during rehabilitation in cohort of stroke survivors with lateropulsion (Clark et al., 2012), individual recovery patterns of lateropulsion using the BLS or weight-bearing patterns in standing have not previously been reported. Forty-one participants with lateropulsion completed the six-month assessment follow-up in the longitudinal component of the observational study (Research question viii; Chapter 9). The results revealed that individuals with mild lateropulsion attained high levels of functional ability and that greater than 75% achieved independent walking. For individuals with moderate to severe lateropulsion, lower functional ability levels were reached and 30% reached independence with mobility. Whilst functional improvements for stroke survivors with lateropulsion have previously been reported during inpatient rehabilitation (Babyar et al., 2015; Krewer, Luther, et al., 2013; Pedersen et al., 1996), to the author's knowledge, this is the first study that has reported longer-term outcomes for these individuals in terms of baseline lateropulsion severity. The study highlighted that stroke survivors with lateropulsion can make clinically significant gains in terms of mobility and functional abilities at six months post stroke, including some with greater lateropulsion severity.

For the individual recovery pattern data (Research question ix; Chapter 9), the study demonstrated that participants displayed good recovery from lateropulsion over time (supporting previous findings (Clark et al., 2012; Danells et al., 2004)). The WBA recovery patterns observed in standing differed for the two tasks of standing with and without arm support. For the standing with arm support task, the WBA pattern adopted by participants generally evolved over time towards increasing symmetry, no matter whether an individual was initially asymmetrical towards the paretic or non-paretic leg. The WBA patterns observed over time for the standing without arm support task were more variable, however overall, less participants altered their adopted weight-bearing pattern when standing unsupported compared to standing with arm support. Previous research has demonstrated WBA in unsupported standing to decrease over the first four weeks and then persist following this period in stroke survivors undertaking inpatient rehabilitation (lateropulsion status unknown) (de Haart et al., 2004). Results from this thesis suggest the recovery patterns for WBA when standing unsupported may be more variable in individuals with lateropulsion following stroke.

As outlined, this thesis focused on three main areas, including the measurement properties of clinical sitting and lateropulsion scales, the utilisation of WBBs as an instrumented measure of postural control in sitting and standing and the longer-term outcomes and individual recovery patterns of lateropulsion and other postural control variables in individuals with lateropulsion. Unexpectedly, the findings of this thesis provided a greater insight into this unique postural control disorder. Firstly, the study demonstrated that in sitting, stroke survivors with lateropulsion display differing and mixed postural control strategies to maintain balance as a group and compared to healthy controls. In standing, the participants with lateropulsion also utilised marked and varied patterns of asymmetry depending on the standing task undertaken. These findings support the importance of analysing how a task is being performed (Vaughan-Graham et al., 2017), and the need for treatment to be tailored to address the different postural control strategies being utilised. The results also indicated that the recovery of lateropulsion appears to be specific to the posture and task being undertaken. Finally, the standing component results support the previous hypothesis that stroke survivors with lateropulsion learn to compensate for their verticality impairment in standing by loading their non-paretic leg to stop falling (Barra et al., 2009). These key findings and their clinical implications are presented as part of the following section (10.2 Clinical implications).

10.2 Clinical implications

The findings from the series of studies included in this thesis have significantly contributed to the knowledge base regarding the measurement, nature and recovery of lateropulsion and raise a number of clinical implications worthy of consideration when working clinically with individuals with lateropulsion. In particular, the sitting and standing components of the larger observational study investigating the use of instrumented measures of postural control in people with lateropulsion generated many clinically relevant findings, some consistent across both postures, and others specific to either sitting or standing. As mentioned, these findings unexpectedly provided an important insight into the nature of the lateropulsion phenomena and how treatment may best be directed when working with individuals with lateropulsion.

In terms of the measurement of lateropulsion, results from two of the completed studies provide support for the use of the BLS for assessing lateropulsion within the clinical environment. Utilising Rasch analysis, the BLS was identified as having good psychometric properties, supporting the internal validity of the scale. Furthermore, baseline BLS scores were found to be moderately associated with functional ability at six months. The BLS has previously been recommended as the preferred measure for assessing lateropulsion following stroke (Koter et al., 2017). The findings from the current study further support this recommendation and also suggest that the BLS should be considered as a core element of assessment for all acute stroke patients on admission to acute and / or rehabilitation hospitals. Routine screening for lateropulsion in these settings has previously been proposed (Clark et al., 2012; Dai et al., 2021).

Both the sitting and standing components of the observational study demonstrated that different postural control and weight-bearing strategies were utilised within the lateropulsion cohort, particularly for the static sitting and standing tasks. This finding highlights the importance of analysing how a task is performed when working with stroke survivors with lateropulsion clinically, rather than just whether the task is completed (Vaughan-Graham et al., 2017). Therapists should consider tailoring their treatment based on how an individual presents in terms of the strategies utilised to sit and stand. For example, different postural control strategies were observed for the static sitting tasks for participants with moderate to severe lateropulsion, with some participants displaying high levels of instability, and others holding themselves relatively still, potentially through the use of fixation strategies (Lafosse et al., 2007). It is likely these contrasting strategies may benefit from different treatment approaches. Individuals swaying excessively may benefit from the therapist providing body support and referencing of the individual in a more centralised body alignment, in preparation for creating stability. For individuals who may be using fixation strategies to stay still, treatment may need to involve larger range movements to reduce the fixation, prior to building active stability around midline (Gjelsvik & Syre, 2016; Raine et al., 2009).

Another finding which was consistent across both the sitting and standing components of the observational study was that recovery of lateropulsion seems to be specific to the posture and task being performed. That is, even if an individual can appropriately maintain their stability whilst performing a dynamic task in sitting or standing, lateropulsion appears to remain present in a more demanding activity such as walking (as evident from individuals' BLS scores). From a clinical perspective, it is important that clinicians consider this finding when formulating their treatment plan. For example, performing the previously proposed task of reaching towards the non-paretic side in sitting (Broetz et al., 2004; Broetz & Karnath, 2005) may be of minimal benefit once an individual can consistently perform the reaching task successfully. Instead, interventions targeting the more difficult postural tasks for the individual, be it standing, transferring or walking, may be of more benefit.

This thesis also provides some interesting insights into the learnt strategies that individuals with lateropulsion appear to adopt in order to overcome their verticality impairment in standing. When standing with arm support initially, approximately half of the participants with lateropulsion took greater weight through their paretic leg. Over time, this weight bearing pattern was observed to change towards greater weight taken through the non-paretic leg. Conversely, when standing unsupported initially, the majority of participants with lateropulsion took greater weight through their non-paretic leg. These findings support the theory that people with lateropulsion often learn to compensate for their verticality impairment in standing by loading their non-paretic leg, in order to be able to maintain balance and avoid falling (Barra et al., 2009). From a clinical perspective, for individuals loading their paretic leg more initially, treatment may need to focus on orientating the individual back towards their non-paretic side, in order to assist in the development of this necessary strategy. Standing with the use of the non-paretic upper limb, both for the purposes of assisting balance and relieving some weight, is commonly used in therapy with people following moderate to severe stroke as a means of aiding the early recovery of standing ability.

The preliminary findings from the standing component of the observational study suggest that WBA may be reliably assessed in patients with lower functional abilities, such as individuals with lateropulsion who have just commenced standing with arm support. Use of WBA in standing with arm support as an outcome measure early following stroke may be a useful evaluation tool to assist clinicians in analysing task performance and subsequently guide treatment for a given individual. Furthermore, the high day-to-day consistency demonstrated in the WBA variables for the stand with arm support task, both in regard to leg favoured and the degree of asymmetry observed, may suggest that the postural systems are displaying the sensory integration and perceptual disturbances experienced in lateropulsion (Pérennou et al., 2008) through the weight-bearing pattern adopted, and not a random alignment.

The longitudinal component of this thesis demonstrated that individuals with lateropulsion can make substantial gains in terms of mobility and functional abilities at six months post stroke, including some individuals displaying moderate to severe lateropulsion initially. Previous studies have similarly highlighted that individuals with lateropulsion can make significant functional gains during rehabilitation (Babyar et al., 2015; Krewer, Luther, et al., 2013; Pedersen et al., 1996), but may need prolonged rehabilitation in order to maximise these (Babyar et al., 2015, 2017; Babyar & Reding, 2019; Nolan et al., 2021). From a clinical perspective the outcomes of the longitudinal component of the observational study support these findings, providing further justification for the provision of adequate rehabilitation to stroke survivors with lateropulsion in order to augment the functional abilities able to be achieved.

10.3 Strengths of this thesis

This thesis has explored the measurement of lateropulsion in stroke survivors within the clinical setting, furthering our understanding of the nature and recovery of this challenging disorder of verticality. The thesis included a feasibility study and a main longitudinal study containing a series of different components which investigated the measurement of lateropulsion using both clinical and instrumented measures, as well the longer-term outcomes of stroke survivors with lateropulsion. Through the various components of the main study, a number of insights were gained into the nature of this distinct postural control disorder, which have implications for both clinical practice and future research.

Two of the strengths of this thesis are that all of the included stroke survivors within the studies had lateropulsion at baseline and that performance was initially evaluated within the first few weeks following stroke. Previously published work investigating the use of instrumented measures in stroke survivors has often been undertaken with individuals months or years post stroke (Barra et al., 2009; Lafosse et al., 2007; Mansfield et al., 2013; Marigold & Eng, 2006; Martins et al., 2011; Nardone et al., 2009; Pereira et al., 2010; Tessem et al., 2007) and has either included a small subset of individuals with lateropulsion (Barra et al., 2009; Lafosse et al., 2007; Mansfield et al., 2013) or alternatively in most cases lateropulsion status has not been reported (de Haart et al., 2004; Genthon et al., 2007; Marigold & Eng, 2006; Martins et al., 2011; Näf et al., 2020; Nardone et al., 2009; Pereira et al., 2010; Tessem et al., 2007; van Nes et al., 2008). Subsequently, the postural control strategies utilised by individuals with lateropulsion to maintain balance in sitting and standing early following stroke have received little investigation to date. The recruitment of a moderate sample of stroke survivors with lateropulsion from acute stroke and inpatient rehabilitation settings enabled the postural control strategies utilised by this patient population early following stroke to be explored more fully in the current thesis.

Another strength of this thesis is that the completed studies included stroke survivors across the spectrum of lateropulsion from mild to severe. This included individuals with limited sitting and standing ability who are traditionally excluded from instrumented studies due to an inability to sit or stand unsupported for a prolonged length of time, i.e. 30 seconds. Where potential participants did not meet the baseline requirements to participate (i.e. Able to sit with back and arm support for three seconds), this was trialled again one or two weeks later ensuring maximum capture of more individuals with more severe lateropulsion. Likewise, individuals with communication and cognitive deficits were also included through Next of Kin consent in the main study, provided the individual could follow a one stage command with gesture in order to enable testing to occur. This has meant that the findings presented in this thesis are likely to reflect the lateropulsion phenomena more broadly, rather than if more restrictive criteria were used to assess eligibility and a discrete subset of individuals with lateropulsion had been recruited.

Completion of the feasibility study enabled a number of limitations of the initial study protocol to be identified and subsequently altered in the main observational study. Thus, the inclusion of the feasibility study formed a further strength of this thesis. This included the identification that data from a healthy control group would be critical to the appropriate interpretation of data obtained from stroke survivors with lateropulsion in the main observational study, both for between group comparisons, as well as for interpreting individual lateropulsion participant data against normative values.

A final strength of the thesis was the inclusion of a longer-term follow-up component which allowed six-month mobility and functional ability data to be presented. Longer-term outcomes in this patient population have received little examination previously. Furthermore, the use of telephone follow-up to obtain six-month data regarding mobility and functional abilities minimised participant loss at six months to five participants (11%). This was significantly less than what would have occurred without this strategy, given only 10 participants (22%) attended the six-month assessment in person.

10.4 Limitations of this thesis

A limitation of this thesis was the relatively small sample size of 46 participants who participated in the main observational study. For analysis of the psychometric properties of reliability and validity, the COSMIN guidelines consider a sample size as ‘good’ when it contains greater than 50 subjects (Mokkink, Terwee, Patrick, et al., 2010). Additionally, not all of the participants following stroke could complete all of the sitting and standing tasks on recruitment to the study. For example, only 20 participants (43%) could stand with arm support on the initial testing occasion. This meant the sample for these tasks was even smaller. Despite this, these preliminary results indicate excellent retest reliability was achieved for the WBA variables for the stand with arm support task, and moderate to good retest reliability for the other standing tasks.

Sample size was also a limitation in the Rasch analysis study. A sample of 132 participants is considered small for Rasch analysis (Linacre, 1994). As a result, the chi-square probability values were likely underpowered to detect misfit, whilst some issues identified within the Rasch analysis process including the presence of minor threshold disordering for four of the BLS items, and evidence of non-uniform DIF for age for the transfers item may have been due to the limited sample size rather than issues with the BLS itself.

For the longitudinal component of the main observational study, 70% of participants were lost to follow-up at one or more assessment occasions. Subsequently, a number of data points were missing from the time course series, limiting the interpretation of the recovery data in this thesis. Sample size also limited the statistical analyses that could be performed in terms of predictive validity, with only linear regression with baseline BLS and FIM motor scores being performed. Previously a number of different factors which influence lateropulsion recovery have been identified (Abe et al., 2012; Babyar et al., 2015, 2017; Danells et al., 2004), which may also impact longer term mobility and functional outcomes. The association between six-month lateropulsion scores and six-month mobility and functional outcomes following stroke could also not be explored in the current thesis, given six-month lateropulsion scores were not recorded.

Another limitation of this thesis was that stroke survivors without lateropulsion were not included in the feasibility or main observational studies. Previously, studies have identified postural instability and varying WBA patterns in participants with stroke, who may or may not have had lateropulsion. It is unknown how the postural instability and WBA observed in individuals with lateropulsion in this thesis differs to that observed previously in stroke survivors without lateropulsion. Future studies investigating lateropulsion should consider including participants following stroke without lateropulsion for comparison purposes.

It should be recognised that whilst this thesis provides some interesting insights into the postural control strategies which individuals with lateropulsion following stroke present with, limitations exist in terms of the instrumented testing undertaken. Firstly, people who were unable to sit with arm and back support over several testing occasions due to severe lateropulsion (BLS of 16 and 17) were not included. The studies also did not investigate the sitting and standing tasks in individuals with lateropulsion who were unable to perform a given task without assistance, with only data from successful trials where participants maintained their balance independently being included. Whilst these limitations may be difficult to avoid, it is important to acknowledge that this thesis may subsequently understate the postural control dysfunction observed in this patient population.

An additional limitation relating to the instrumented testing was the short duration which the static balance tasks were performed for. The short test length may have contributed to the variability in performance observed between Day 1 and Day 2 testing in the main observational study for the COP variables of the static sitting tasks (Carpenter et al., 2001). The three second test length was chosen to allow the inclusion of individuals with severe lateropulsion who could only sit unsupported for a very short period of time. It has previously been recognised that studies should consider the limitations of participants, with the advantages of using a longer test duration (Carpenter et al., 2001). The inclusion of participants with severe lateropulsion in the studies undertaken as part of this thesis was deemed to be essential to gaining a greater insight into this challenging postural control disorder across its entire spectrum.

10.5 Recommendations for further research

Three studies of this thesis (feasibility study and the sitting and standing components of observational study) explored the use of WBBs as an instrumented measure of postural control in sitting and standing in individuals with lateropulsion, with the feasibility study results informing the protocol for the observational study.

The sitting component of the study compared COP variables in sitting in people with lateropulsion to healthy controls and investigated the relationships between these variables and clinical measures of lateropulsion and postural function. Further research is required to explore the different postural strategies utilised in sitting by stroke survivors with lateropulsion identified in this study, given a greater understanding of these strategies may assist to tailor therapeutic interventions. Future studies should include stroke survivors both with and without lateropulsion in order to determine if the postural control strategies utilised in sitting by individuals with lateropulsion differ to those used by individuals without lateropulsion as may be anticipated, and if so how. A method of assessing WBA in sitting in people with lateropulsion would also be valuable, potentially utilising systems that incorporate grid-type pressure mats. Furthermore, the collection of concurrent kinematic data and electromyography activity to provide information regarding body alignment and the muscular activity used in conjunction with COP measures would provide a more complete picture in terms of the postural control strategies utilised by individuals with lateropulsion to stabilise. Importantly, given the day-to-day variability present in the sitting COP measures, these measures should not be used as single-occasion measures in clinical studies evaluating interventions targeting lateropulsion early following stroke. The use of serial measures over time to establish a variability baseline may be a means by which confidence in these measures may be increased when utilising them in the acute and early subacute phases of recovery following stroke.

The standing component of the observational study examined the weight-bearing patterns adopted by individuals with lateropulsion during static and dynamic standing tasks when these individuals just started to stand. Additional research is needed to determine whether the weight-bearing patterns observed in stroke survivors with lateropulsion differ to those adopted in stroke survivors without lateropulsion. Future studies may look to reduce the number of tasks performed with the instrumented measures and predominantly focus on the tasks of standing with and without support given the associations demonstrated with postural abilities. The collection of COP variables in addition to WBA in these standing tasks, along with an assessment of body alignment and the muscular activity used, would build on the findings of the present study and further our understanding of this distinct postural control disorder. For patients with lower levels of function, such as individuals with lateropulsion who have just started to stand, WBA in standing with arm support may be a useful instrumented measure for use in clinical trials evaluating therapeutic interventions. However, whilst promising findings in terms of the test-retest reliability of these measures and associations with postural abilities were demonstrated in the current study, it would be beneficial if these results were reproduced with a larger sample and other psychometric properties such as responsiveness evaluated. Likewise, determining the test-retest reliability of these measure with healthy controls in future studies would be useful.

Another study in this thesis evaluated the internal construct validity for the BLS utilising Rasch analysis. The preliminary findings of this study support using the BLS for measuring lateropulsion after stroke. Further research could verify these findings with a larger sample size (>250) (Linacre, 1994). If confirmed, the BLS could be converted into an interval-level scale. This Rasch transformed version of the BLS could then be used as a primary outcome measure in future clinical trials evaluating the effectiveness of interventions targeting lateropulsion.

The final study in this thesis investigated the six-month mobility and functional outcomes of individuals with lateropulsion following stroke. Further research could expand on this work by completing an assessment of lateropulsion severity and postural function at six months post stroke using the BLS and PASS with a larger number of participants, along with the performance of instrumented measures of WBA in standing. This would allow exploration of the potential impact that persistent lateropulsion, postural control deficits and excessive WBA in standing may have on the longer-term outcomes of stroke survivors with lateropulsion. Use of a larger sample would be beneficial to investigate the predictive validity of the BLS more fully and allow for other variables that have previously been reported to influence time to recovery from lateropulsion (Abe et al., 2012; Babyar et al., 2015, 2017; Danells et al., 2004) to be considered in any modelling performed. Future studies would also benefit from the inclusion of individuals with severe lateropulsion (BLS scores of 16 and 17), as well as the collection of baseline measures at a consistent time point early following stroke (i.e. seven days post). Finally, it is important to acknowledge that many of the individuals with moderate to severe lateropulsion still had significant functional and mobility limitations at six months. Therefore, the need exists to explore different treatment approaches with these individuals in order to achieve improved longer-term outcomes for this group of stroke survivors.

10.6 Conclusion

Overall, the studies included in this thesis highlight that stroke survivors with lateropulsion utilise different postural control and weight-bearing strategies to maintain stability in sitting and standing as a group and compared with healthy controls. These findings emphasise the importance of analysing task performance when working with individuals with lateropulsion, and the potential need to tailor therapeutic interventions to address the different postural control and weight-bearing strategies observed. The findings also provide preliminary evidence to support the use of WBA in standing with arm support as an outcome measure early following stroke when individuals are just starting to stand. The studies reinforce that the BLS is the outcome measure of choice for assessing lateropulsion within the clinical environment. Finally, the findings demonstrate that individuals with lateropulsion can make meaningful functional and mobility gains at six months following stroke, including some individuals with moderate to severe lateropulsion initially.

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Appendices

Appendix 1. Ethics approval letters

ST VINCENT'S HOSPITAL
MELBOURNE
A FACILITY OF ST VINCENT'S HEALTH AUSTRALIA

St Vincent's Hospital
(Melbourne) Limited
ABN 22 052 110 755

41 Victoria Parade Fitzroy VIC 3065
PO Box 2900 Fitzroy VIC 3065

Telephone 03 9288 2211
Facsimile 03 9288 3399
www.svhm.org.au

22 July 2013

Ms Melissa Thompson
Physiotherapy
St Vincent's Hospital (Melbourne)

Dear Ms. Thompson,

LRR:084/13 - 'Measuring lateropulsion following stroke the clinical setting: a feasibility study using Wii and Kinect technologies.'

Thank you for submitting your Low Risk Research activity for approval. The Low Risk Research Sub-committee of Human Research Ethics Committee (HREC)-A has approved the above mentioned project at the following sites:

1. St Vincent's Hospital (Melbourne)
2. St George's Hospital (Kew)

This approval will be ratified by St Vincent's Hospital (Melbourne) HREC-A at the next meeting. Ethics approval is granted for a period of 4 years from the date of this letter.

The project complies with the principles of the *National Statement on the Ethical Conduct of Human Research* (NHMRC; 2007).

Approved documents
The following documents have been reviewed and approved:

Document	Version	Date
LRR Application	2	14/07/2013
Participant Information Consent Form	2	14/07/2013
Project Proposal	1	13/06/2013

Terms of approval:

1. It is the responsibility of the Principal Researcher to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as specified in the application.
2. You should notify the Research Governance Unit immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
3. Amendments to the approved project: Changes to any aspect of the project require the submission of a Request for Amendment to the Low Risk Research Sub-committee and must not begin without written approval. Substantial variations may require a new application.

4. Future correspondence: Please quote the reference number and project title above in any further correspondence.
5. Annual Reports: An Annual Report is due on the anniversary of the date of approval
6. Final report: A Final Report must be provided at the conclusion of the project.
7. Monitoring: Projects may be subject to an audit or any other form of monitoring by the Research Governance Unit at any time.

We wish you well with your project.

Yours sincerely,

Adele Sergeant
Administration Officer
Research Governance Unit
St Vincent's Hospital (Melbourne)

Curtin University

Memorandum

To	Professor Keith Hill, Physiotherapy and Exercise Science
From	Professor Stephan Millett, Chair, Human Research Ethics Committee
Subject	Protocol Approval **HR 174/2013**
Date	13 November 2013
Copy	Ms Melissa Thompson, Physiotherapy and Exercise Science, Dr Kim Brock, Physiotherapy Department, St Vincent's Hospital, Dr Ross Clark, Faculty of Health Sciences, Australian Catholic University

Office of Research and Development
Human Research Ethics Committee

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for your application submitted to the Human Research Ethics Committee (HREC) for the project titled *"Measuring lateropulsion following stroke in the clinical setting: a feasilibity study using Wii and Kinect technologies"*. The Committee notes the prior approval by St Vincent's Hospital Melbourne HREC (LRR:084/13) and has reviewed your application consistent with Chapter 5.3 of the *National Statement on Ethical Conduct in Human Research.*

- You have ethics clearance to undertake the research as stated in your proposal.
- The approval number for your project is **HR 174/2013.** *Please quote this number in any future correspondence.*
- Approval of this project is for a period of four years **14-11-2013** to **14-11-2017**.
- Annual progress reports on the project must be submitted to the Ethics Office.
- If you are a Higher Degree by Research student, data collection must not begin before your Application for Candidacy is approved by your Faculty Graduate Studies Committee.

- The following standard statement **must be** included in the information sheet to participants:
  This study has been approved by the Curtin University Human Research Ethics Committee (Approval Number HR 174/2013). The Committee is comprised of members of the public, academics, lawyers, doctors and pastoral carers. If needed, verification of approval can be obtained either by writing to the Curtin University Human Research Ethics Committee, c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth, 6845 or by telephoning 9266 2784 or by emailing hrec@curtin.edu.au.

Applicants should note the following:

It is the policy of the HREC to conduct random audits on a percentage of approved projects. These audits may be conducted at any time after the project starts. In cases where the HREC considers that there may be a risk of adverse events, or where participants may be especially vulnerable, the HREC may request the chief investigator to provide an outcomes report, including information on follow-up of participants.

The attached **Progress Report** should be completed and returned to the Secretary, HREC, C/- Office of Research & Development annually.

Our website https://research.curtin.edu.au/guides/ethics/non_low_risk_hrec_forms.cfm contains all other relevant forms including:

- Completion Report (to be completed when a project has ceased)
- Amendment Request (to be completed at any time changes/amendments occur)
- Adverse Event Notification Form (If a serious or unexpected adverse event occurs)

Yours sincerely

Professor Stephan Millett
Chair Human Research Ethics Committee

ST VINCENT'S HOSPITAL
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05 January 2015

Ms Melissa Birnbaum
Physiotherapy Department
St Vincent's Hospital, (Melbourne)

Dear Ms Birnbaum,

HREC-A Protocol number: HREC-A 146/14

'Measuring lateropulsion following stroke in the clinical setting: a longitudinal study using Wii & Kinect technologies.'

The St Vincent's Hospital (Melbourne) Human Research Ethics Committee-A has reviewed and approved the aforementioned study.

Approval Status: FINAL

Period of Approval: 05 January 2015 – 05 January 2019

Ethical and governance approval is given in accordance with the research conforming to the *National Health and Medical Research Council Act 1992* and the *National Statement on Ethical Conduct in Human Research (2007).*

Ethical and governance approval is given for this research project to be conducted at the following sites:

- St Vincent's Hospital (Melbourne)

Approved documents

The following documents have been reviewed and approved:

Document	Version	Date
National Ethics Application Form (NEAF)	2.2	05/01/2014
Victorian Specific Module (VSM)	2	18/11/2014
Study Protocol	1	17/10/2014
Participant Information and Consent Form (PICF) Patient	2	10/12/2014
Participant Withdrawal of Consent Form	2	10/12/2014

Participant Information and consent Form (PICF) NOK/Carer	2	10/12/2014
Participant Withdrawal of Consent Form	2	10/12/2014

St Vincent's HREC-A Protocol number: HREC-A 146/14
Please quote these numbers on all Correspondence

Approval is subject to:

- The Principal Researcher is to ensure that all associate researchers are aware of the terms of approval and to ensure the project is conducted as specified in the application and in accordance with the National Statement on Ethical Conduct in Human Research (2007).
- Immediate notification to the Research Governance Unit of any serious adverse events on participants.
- Immediate notification of any unforeseen events that may affect the continuing ethical acceptability of the project;
- Notification and reasons for ceasing the project prior to its expected date of completion;
- Notification of proposed amendments to the study;
- Submission of an annual report, due on the anniversary date of approval, for the duration of the study.
- Submission of reviewing HREC approval for any proposed modifications to the project;
- Submission of a final report and papers published on completion of project;
- Projects may be subject to an audit or any other form of monitoring by the Research Governance Unit at any time.

The HREC wishes you and your colleagues every success in your research.

Yours sincerely,

L. Clinch

Ms Leanne Clinch
Senior Administrative Officer and HREC-A Secretary
Research Governance Unit
St Vincent's Hospital (Melbourne)

MEMORANDUM

Curtin University

To:	Professor Keith Hill
	School of Physiotherapy and Exercise Science
CC:	Professor Keith Hill
From	Prof Peter O'Leary, Chair HREC
Subject	Amendment approval Approval number: HR15/2015
Date	02-Jul-15

Office of Research and Development
Human Research Ethics Office

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for submitting an amendment to the Human Research Ethics Office for the project:

HR15/2015 Measuring lateropulsion following stroke in the clinical setting: a longitudinal study using Wii & Kinect technologies

The Human Research Ethics Office approves the amendment to the project.

Amendment number: HR15/2015/AR1

Approval date: 02-Jul-15

The following amendments were approved:

Addition of another reaching task 'reaching to pick up a cup in front, within arm's length' to be performed in sitting and standing
Change of weight shift task in standing to non-paretic side to a reaching task in standing to the non-paretic side, beyond arm's length.
Use of a tilt sensor placed on the sternum in addition to the Wii Balance Boards and Microsoft Kinect to provide additional information about trunk angle.

Please ensure that all data are stored in accordance with WAUSDA and Curtin University Policy.

Yours sincerely,

Professor Peter O'Leary
Chair, Human Research Ethics Committee

ST VINCENT'S HOSPITAL
MELBOURNE

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30 October 2015

Mrs Melissa Birnbaum
Department of Physiotherapy
St Vincent's Hospital Melbourne

Dear Mrs Birnbaum

St Vincent's reference number: 158/15
Study Title: 'Establishing normative values for balance tasks using Wii and Kinect technologies'

Approval is given in accordance with the research conforming to the *National Health and Medical Research Council Act 1992* and the *National Statement on Ethical Conduct in Human Research (updated March 2014).*

This HREC is organised and operates in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Research Involving Humans (updated 2014), and all subsequent updates, and in accordance with the Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95), the Health Privacy Principles described in the Health Records Act 2001 (Vic) and Section 95A of the Privacy Act 1988 (and subsequent Guidelines).

Ethical and governance approval is given for this research project to be conducted at the following site:

- St Vincent's Hospital Melbourne

This approval will be ratified by St Vincent's Hospital (Melbourne) HREC at the next meeting. Ethical and Governance approval is granted for a period of 4 years from the date of this letter.

Approved documents
The following documents have been reviewed and approved:

Document	Version	Date
Low Negligible Risk Application	1	5 October 2015
Project Protocol	1	5 October 2015
Participant Information and Consent Form	2	27 October 2015
Study Advertisement	1	September 2015
Letter of Support	-	8 October 20145

Terms of approval:

1. It is the responsibility of the Principal Researcher to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as specified in the application.
2. You should notify the Research Governance Unit immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
3. Amendments to the approved project: Changes to any aspect of the project require the submission of a Request for Amendment to the Low Risk Research Sub-committee and must not begin without written approval. Substantial variations may require a new application.
4. Future correspondence: Please quote the reference number and project title above in any further correspondence.
5. Annual Reports: An Annual Report is due on the anniversary of the date of approval
6. Final report: A Final Report must be provided at the conclusion of the project.
7. Monitoring: Projects may be subject to an audit or any other form of monitoring by the Research Governance Unit at any time.

We wish you well with your project.

Yours sincerely,

Ms Eleisha Taylor
Administrative Assistant
Research Governance Unit
St Vincent's Hospital (Melbourne)

MEMORANDUM

Curtin University

To:	Professor Keith Hill School of Physiotherapy and Exercise Science
CC:	
From	Professor Peter O'Leary, Chair HREC
Subject	Reciprocal ethics approval Approval number: HR55/2016
Date	24-Mar-16

Office of Research and Development
Human Research Ethics Office

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for your application submitted to the Human Research Ethics Office for the project: 6267
Establishing normative values for balance tasks using Wii and Kinect technologies

Your application has been approved through Curtin University Human Research Ethics Committee (HREC) through a reciprocal approval process with the lead HREC.

The lead HREC for this project has been identified as St. Vincent's Hospital HREC

Approval number from the lead HREC is noted as: LRR 158/15

Please note the following conditions of approval:

1. Approval is granted from **24-Mar-16** to **30-Oct-19**
2. Research must be conducted as stated in the approved protocol.
3. Any amendments to the approved protocol must be approved by the Ethics Office.
4. An annual progress report must be submitted to the Ethics Office annually, on the anniversary of approval.
5. All adverse events must be reported to the Ethics Office.
6. A completion report must be submitted to the Ethics Office on completion of the project.
7. Data must be stored in accordance with WAUSDA and Curtin University policy.
8. The Ethics Office may conduct a randomly identified audit of a proportion of research projects approved by the HREC.

Should you have any queries about the consideration of your project please contact the Ethics Support Officer for your faculty, or the Ethics Office at hrec@curtin.edu.au or on 9266 2784. All human research ethics forms and guidelines are available on the ethics website.

Yours sincerely,

Professor Peter O'Leary
Chair, Human Research Ethics Committee

Appendix 2. Burke Lateropulsion Scale
Supine
Use 'log roll' technique to test patient's response. Roll first towards the *affected* side then towards the *unaffected* side. Circle the side to which the resistance is most prominent. Score below the maximum resistance felt and add one point if resistance is noted in both directions. (Patients with marked lateropulsion may resist rolling to either side, hence an extra point is added if resistance is noted with rolling both towards and away from the affected side).

0= No resistance to passive rolling
1= Mild resistance
2= Moderate resistance
3= Strong resistance
1= Add one point if resistance noted in both directions

Sitting
Score with the patient seated, feet off floor, with both hands in lap. The expected hemiplegic response is for patient to carry his weight towards the unaffected side. Some patients will passively fall towards their paretic side when placed in true vertical position by the examiner. This will not be scored as 'lateropulsion'. Position the patient with their trunk 30 degrees off true vertical towards their affected side, then score the patient's response to your attempts to bring them back to vertical. The 'lateropulsion' phenomenon is an active attempt by the patient to keep their centre of gravity towards their impaired side as they are brought to true vertical.

0 = No resistance to passive return to true vertical sitting position
1 = Voluntary or reflex resistive movements in trunk, arms or legs noted only in the last five degrees approaching vertical.
2 = Resistive movements noted but beginning within 5 to 10 degrees of vertical
3 = Resistive movements noted more than 10 degrees off vertical.

Standing
Score with the patient standing with whatever support is needed. The expected hemiplegic response is for the patient to carry their weight toward the unaffected side or to passively fall towards their paretic side when placed in true vertical position by the examiner. This will not be scored as 'lateropulsion.' Position the patient with their trunk 15 to 20 degrees off true vertical towards their affected side then score the patient's response to your attempts to bring them back to vertical, then 5 to 10 degrees past vertical toward the intact side. The 'lateropulsion' phenomenon is a voluntary or reflexive response in the trunk or limbs to keep the centre of gravity towards the impaired side e.g., forced trunk curvature towards the paretic side, flexion of affected hip or knee, shifting weight to the lateral aspect of the unaffected foot.

0 = Patient prefers to place his centre of gravity over the unaffected leg.
1 = Resistance is noted when attempting to bring the patient 5 to 10 degrees past midline.
2 = Resistive voluntary or reflex equilibrium responses noted, but only within 5 degrees of approaching vertical.
3 = Resistive reflex equilibrium responses noted, beginning 5 to 10 degrees off vertical.

4 = Resistive voluntary or reflex equilibrium responses noted, more than 10 degrees off vertical.

Transfers

Score this function by transferring the patient from the seated position first to the unaffected side, then if possible, to the affected side. The expected hemiplegic response would be for the patient to require more assistance to transfer towards the affected side (use a sit pivot, modified stand pivot, or stand pivot transfer, depending on the patient's functional level).

0 = No resistance to transferring to the unaffected side is noted.
1 = Mild resistance to transferring to the unaffected side.
2 = Moderate resistance to transferring is noted. Only one person is required to perform the transfer.
3 = Significant resistance is noted with transferring to the unaffected side. Two or more people are required to transfer the patient due to the severity of lateropulsion.

Walking

Score lateropulsion by noting active resistance by the patient to efforts by the therapist to support the patient in true vertical position. Do not score passive falling or leaning to the paretic side. Score lateropulsion as follows:

0 = No lateropulsion noted.
1 = Mild lateropulsion noted.
2 = Moderate lateropulsion noted with walking.
3 = Strong lateropulsion noted, takes two individuals to walk with the patient, or unable to walk because of severity of lateropulsion.

Circle most prominent direction of lateropulsion: left, right, posterior-left, posterior-right.

Note: Some patients may show such marked lateropulsion that they cannot be assessed while standing or walking. In such cases they are scored as having a maximum deficit for those tasks not testable due to the severity of their lateropulsion.

TOTAL SCORE = SUM OF THE ABOVE _____ (Max = 17)

Appendix 3. The Postural Assessment Scale for Stroke Patients

Maintaining a Posture

1. Sitting without support (sitting on the edge of a 50-cm-high examination table [a Bobath plane, for instance] with the feet touching the floor)
    - 0 = cannot sit
    - 1 = can sit with slight support, for example, by 1 hand
    - 2 = can sit for more than 10 seconds without support
    - 3 = can sit for 5 minutes without support

2. Standing with support (feet position free, no other constraints)
    - 0 = cannot stand, even with support
    - 1 = can stand with strong support of 2 people
    - 2 = can stand with moderate support of 1 person
    - 3 = can stand with support of only 1 hand

3. Standing without support (feet position free, no other constraints)
    - 0 = cannot stand without support
    - 1 = can stand without support for 10 seconds or leans heavily on 1 leg
    - 2 = can stand without support for 1 minute or stands slightly asymmetrically
    - 3 = can stand without support for more than 1 minute and at the same time perform arm movements above the shoulder level

4. Standing on nonparetic leg (no other constraints)
    - 0 = cannot stand on nonparetic leg
    - 1 = can stand on nonparetic leg for a few seconds
    - 2 = can stand on nonparetic leg for more than 5 seconds
    - 3 = can stand on nonparetic leg for more than 10 seconds

5. Standing on paretic leg (no other constraints)

    Same scoring as item 4

Changing Posture

Scoring of items 6 to 12 is as follows (items 6 to 11 are to be performed with a 50-cm-high examination table, like a Bobath plane; items 10 to 12 are to be performed without any support; no other constraints):

- 0 = cannot perform the activity
- 1 = can perform the activity with much help
- 2 = can perform the activity with little help
- 3 = can perform the activity without help

6. Supine to affected side lateral
7. Supine to nonaffected side lateral
8. Supine to sitting up on the edge of the table
9. Sitting on the edge of the table to supine
10. Sitting to standing up
11. Standing up to sitting down
12. Standing, picking up a pencil from the floor

Appendix 4. Stroke Rehabilitation Assessment of Movement Instrument Lower Extremity

Item	Score
Flexes hip and knee in supine	0 1a 1b 1c 2 Not tested: ________________
Flexes hip in sitting	0 1a 1b 1c 2 Not tested: ________________
Extends knee in sitting	0 1a 1b 1c 2 Not tested: ________________
Flexes knee in sitting	0 1a 1b 1c 2 Not tested: ________________
Dorsiflexes ankle in sitting	0 1a 1b 1c 2 Not tested: ________________
Plantarflexes ankle in sitting	0 1a 1b 1c 2 Not tested: ________________
Extends knee & DF ankle in sitting	0 1a 1b 1c 2 Not tested: ________________
Abducts affected hip with knee extended in standing	0 1a 1b 1c 2 Not tested: ________________
Flexes affected knee with hip extended in standing	0 1a 1b 1c 2 Not tested: ______________
DF affected ankle with knee extended in standing	0 1a 1b 1c 2 Not tested: ______________
TOTAL	

0	**unable** to perform the test movement through any appreciable range (includes flicker or slight movement)
1	**a**. able to perform only **part** of the movement, and with **marked deviation** from normal pattern
	b. able to perform only **part** of the movement, but in a manner that **is comparable to the unaffected side**
	c. able to complete the movement, but only with marked deviation from normal pattern
2	able to complete the movement in a manner that is comparable to the unaffected side
X	*activity not tested (specify why;* ROM, Pain, Other (reason))

Appendix 5. Lower extremity section of Fugl Meyer Sensory Assessment

TYPE OF SENSATION	AREA	SCORE			SCORING CRITERIA
1. Light Touch	Thigh	0	1	2	0-Anesthesia
	Sole of Foot	0	1	2	1-Hyperesthesia / dysesthesia
	Total				2-Normal
2. Proprioception	Hip	0	1	2	0-No Sensation
	Knee	0	1	2	1-75% of answers are correct, but considerable difference in sensation relative to the unaffected side
	Ankle	0	1	2	
	Toe	0	1	2	
	Total				2-All answers are correct, little or no difference
	OVERALL TOTAL				Maximum = 12

Appendix 6. Catherine Bergego Scale

Item	0 no neglect	1 mild neglect	2 moderate neglect	3 severe neglect	NA (provide reasons)
1. Grooming					
2. Dressing					
3. Eating					
4. Cleaning after meal					
5. Gaze orientation					
6. Limb awareness					
7. Auditory attention					
8. Collisions					
9. Navigation					
10. Personal belongings					

Neglected side (circle one): ***left-sided*** spatial neglect ***right-sided*** spatial neglect

$\frac{\text{Sum of individual scores of valid questions}}{\text{No of valid questions}}$ ______ x 10 = **Final score**

Neglect Classification (circle one):
Absent (0) Mild (1–10) **Moderate** (11–20) Severe (21–30)

Notes:

- A score of 0 is given if no left neglect is observed;
- A score of 1 is given if a mild neglect is observed, with the patient always exploring right hemi-space first, and going slowly and hesitating towards the left; at this level, left-sided omissions or collisions are rare and inconsistent, and fluctuations are observed, with fatigue and emotions;
- A score of 2 is given in case of moderate neglect, with constant and clear left-sided omissions or collisions; at this level, patients are still able to cross the midline, but performance in the left hemi-space is incomplete and ineffective.
- A score of 3 (severe neglect) is given if the patient is only able to explore the right hemi-space.
- In most severely impaired cases, some items of the Catherine Bergego Scale may be been impossible to score, because patients are still highly dependent. If an item is impossible to score, it is considered invalid, and is not included in the total score, which is calculated using the formula outlined above.

Appendix 7. Functional Independence Measure (motor domain)

SELF-CARE		
1. Eating		
2. Grooming		
3. Bathing		
4. Dressing - Upper Body		
5. Dressing - Lower Body		
6. Toileting		
SPHINCTER CONTROL		NO HELPER
7. Bladder Management		7 complete independence (timely, safely)
8. Bowel Management		6 modified independence (device)
TRANSFERS		HELPER
9. Bed, Chair, Wheelchair		<u>Modified dependence</u>
10. Toilet		5 supervision
11. Tub, Shower		4 minimal assistance (subject 75%+)
LOCOMOTION		3 moderate assistance (subject 50%+)
12. Walk, Wheelchair	W/WC	<u>Complete dependence</u>
13. Stairs		2 maximal assistance (subject 25%+) 1 total assistance (subject <25% or requires more than one person to assist)
TOTAL SCORE		

Appendix 8. Functional Ambulation Classification (FAC)

FAC Level	Ambulation Description	Definition
1	**Non-functional**	Unable to ambulate Ambulates only in parallel bars Requires supervision or physical assistance from > 1 person
2	**Dependent, Level II**	Requires manual contact of one person during ambulation on level surfaces Manual contact is continuous and necessary to support body weight and/or to maintain balance or assist coordination
3	**Dependent, Level I**	Requires manual contact of one person during ambulation on level surfaces Manual contact is continuous or intermittent light touch to assist balance or coordination
4	**Dependent, Supervision**	Ambulation occurs on level surfaces without manual contact of another person Requires stand-by guarding of one person because of poor judgment, questionable cardiac status, or the need for verbal cuing to complete the task
5	**Independent, Level Surfaces Only**	Ambulate is independent on level surfaces Requires supervision/physical assistance to negotiate stairs, inclines, or unlevel surfaces.
6	**Independent, Level and Non-Level Surfaces**	Ambulation is independent on unlevel and level surfaces, stairs, and inclines.

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Dear Melissa A Birnbaum

Melissa Birnbaum, Keith Hill, Rita Kinsella, Susan Black, Ross Clark & Kim Brock (2018) Comprehensive clinical sitting balance measures for individuals following stroke: a systematic review on the methodological quality, Disability and Rehabilitation, 40:6, 616-630

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Appendix 10. Search strategy

1. stroke/
2. balance/
3. postural control/
4. equilibrium/s
5. or/2-4
6. sit/
7. sitting/
8. trunk/
9. or/6-8
10. motor/
11. mobility/
12. or/10-11
13. reliability/
14. validity/
15. internal consistency/
16. responsiveness/
17. specificity/
18. sensitivity/
19. predict*
20. or/13-19
21. 1 and 5 and 20 (limited to English language)
22. 1 and 9 and 20 (limited to English language)
23. 1 and 12 and 20 (limited to English language)

Appendix 11. Author contribution statement 1 (Chapter 3)

Birnbaum M, Hill K, Kinsella R, Black S, Clark R, Brock K. (2018). Comprehensive clinical sitting balance measures for individuals following stroke: a systematic review on the methodological quality. *Disability and Rehabilitation* 40(6): 616-630, https://doi.org/ 10.1080/09638288.2016.1261947.

	Conception and Design	Acquisition of Data and Method	Data Conditioning and Manipulation	Analysis and Statistical Method	Interpretation and Discussion	Final Approval	Total % contribution
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Co Author 1 Acknowledgment: I acknowledge that these represent my contribution to the above research output Signed:							
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Co-Author 3: Rita Kinsella		✓	✓	✓			10%
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Co-Author 6: Kim Brock	✓	✓	✓	✓	✓	✓	15%
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Total %							**100%**

Appendix 12. Author contribution statement 2 (Chapter 5)

Birnbaum M, Brock K, Parkinson S, Burton E, Clark R & Hill K (2020): Rasch analysis of the Burke Lateropulsion Scale (BLS). *Topics in Stroke Rehabilitation.* Advance online publication. https://doi.org/10.1080/10749357.2020.1824724.

	Conception and Design	**Acquisition of Data and Method**	**Data Conditioning and Manipulation**	**Analysis and Statistical Method**	**Interpretation and Discussion**	**Final Approval**	**Total % contribution**
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Appendix 13. Author contribution statement 3 (Chapter 6)

Birnbaum M, Brock K, Clark R, Hill K (2018) Measuring lateropulsion following stroke: a feasibility study using Wii Balance Board technology. *New Zealand Journal of Physiotherapy* 46(1): 36-42. https://doi.org/10.15619/NZJP/46.1.06

	Conception and Design	Acquisition of Data and Method	Data Conditioning and Manipulation	Analysis and Statistical Method	Interpretation and Discussion	Final Approval	Total % contribution
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Appendix 14. Author contribution statement 4 (Chapter 7)

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Appendix 15. Author contribution statement 5 (Chapter 8)

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Co-Author 5: Keith Hill	✓			✓	✓	✓	15%
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Total %							**100%**