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.

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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

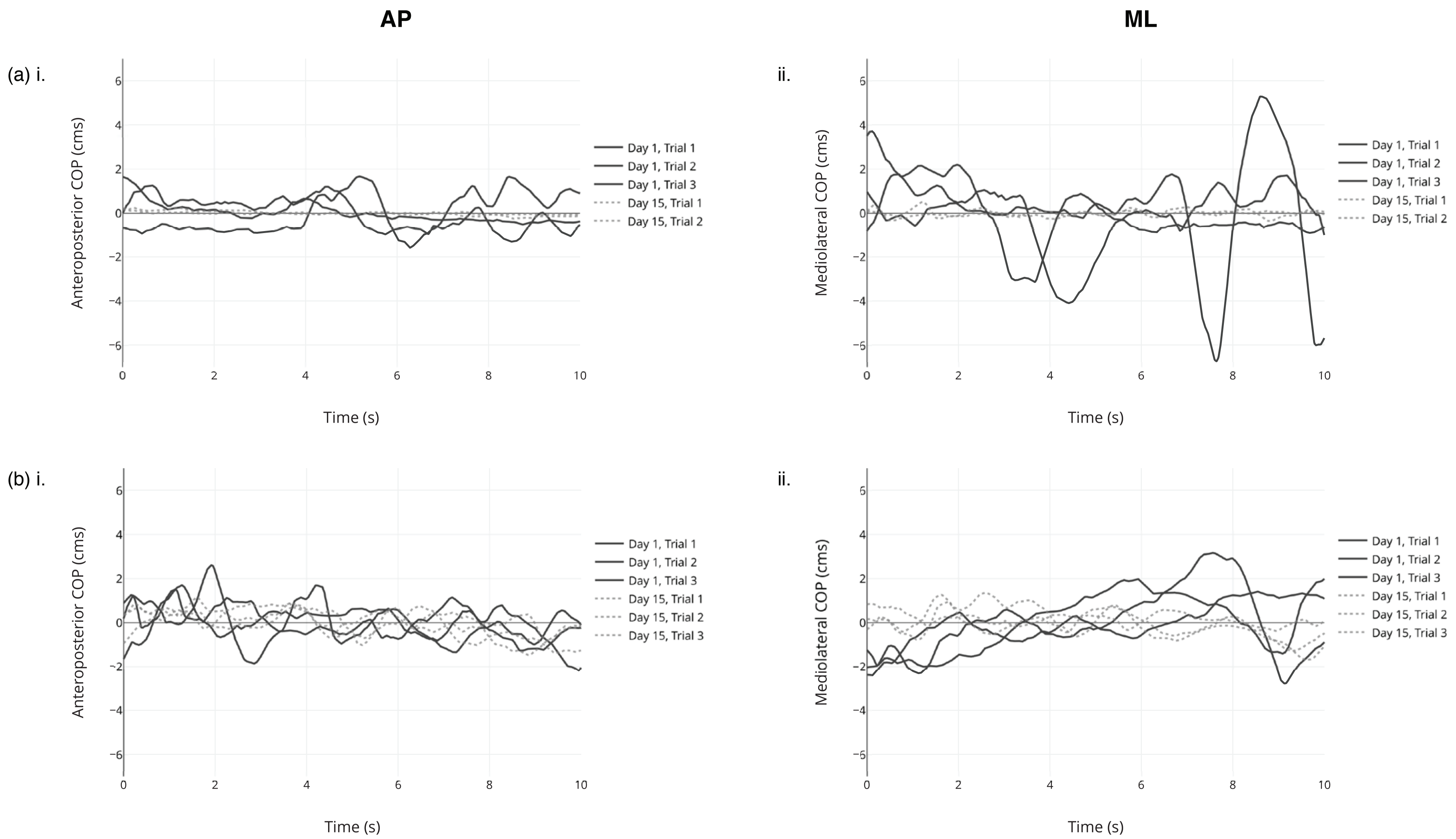

Figure 1: Centre of pressure (COP) movement variability over time (seconds) for (a) task of sitting without arm support for a participant with moderate lateropulsion; (b) standing unsupported for a participant with mild lateropulsion. Interactive versions of these figures are available to view online 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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