

The Reliability and Validity of Sitting Balance Control Tests in Stroke Survivors

X. L. Li¹, Gary K. C. Lau², Carmen K. M. Lo², Sally H. L. Wong², H. T. Zhuo², William W. N. Tsang²

¹Medical School, Yangtze University, Jingzhou, China

²Department of Rehabilitation Sciences, the Hong Kong Polytechnic University, Hong Kong, China

Email: william.tsang@polyu.edu.hk

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Abstract

The purpose of this cross-sectional study was to investigate the reliability and validity of two sitting balance tests, namely limits of stability test (LOS) and sequential weight shifting test (SWS) in stroke survivors. Eleven community-dwelling stroke survivors with onset for at least two years (mean time since stroke = 8.0 years (SD 4.0)) and fifteen healthy subjects were recruited. Reaction time, maximum excursion, directional control of LOS, and total movement time and directional control of SWS were measured. Modified Function Reach Test (MFRT) and Trunk Impairment Scale (TIS) were also conducted to correlate with LOS and SWS. Result demonstrated excellent test-retest reliability in reaction time (ICC [3,8] = 0.760) and maximum excursion (ICC [3,8] = 0.929) of LOS and total movement time of SWS (ICC [3,3] = 0.864) in stroke survivors. Known groups validity was only shown in reaction time of LOS ($p = 0.039$) between the two groups. Reaction time of LOS of stroke subjects was significantly correlated with MFRT ($r = -0.684$, $p = 0.020$), while directional control of LOS was significantly correlated with the dynamic sitting balance score ($r = 0.846$, $p = 0.001$) and total score ($r = 0.817$, $p = 0.002$) of TIS. For SWS, total movement time was significantly correlated with dynamic sitting balance score of TIS ($r = -0.654$, $p = 0.029$). In conclusion, moderate to excellent test-retest reliability was found in LOS and SWS tests in stroke survivors. The convergence and discrimination perspectives of construct validity were established. Further study with a larger sample size and in a frailer stroke population is warranted.

Keywords

Sitting Balance, Stroke, Reliability, Validity

1. Introduction

Stroke survivors may have difficulties to maintain sitting balance due to the im-

paired control of trunk muscles [1]. Sitting balance is important and necessary for safety and functional activities [2] [3]. Good sitting posture and balance control are needed in stroke survivors to perform activities of daily living (ADL) such as feeding, grooming and transferring [4]. Poor sitting control can easily result in falls which may lead to head injury or fractures. Hence, many falls occurred while stroke patients were in sitting position in which they either slid off their chairs due to poor sitting balance or leaned out too far when reaching for objects [5]. Therefore, maintaining good sitting balance should be considered as one of the rehabilitation goals for stroke survivors.

An accurate and coordinated movement in different directions, termed as directional control, can reflect the ability to perform a variety of functional activities which is crucial in ADL. For example, reaching for objects in sitting requires coordinating movement of body segments and balancing [6]. Weakness of hemiplegic side of stroke survivors can affect response, distance and directional control of body movement.

Trunk Impairment Scale, Trunk Control Test, and Postural Assessment Scale for Stroke Patients are typical examples of clinical outcome measures [7]. Scores of these ordinal scales are subjectively obtained by direct observation of an investigator. Modified Functional Reach Test was also proven to be reliable and valid as a useful outcome measure in stroke subjects [8]. However, MFRT was unable to address time domain, diagonal displacements and directional control. Moreover, many studies of standing balance have been done on force platform but very few researches were done in sitting. Method using time domain and movement control to investigate dynamic sitting balance control is not well established yet. Therefore, two balance tests, namely limits of stability test (LOS) and sequential weight shifting test (SWS) were designed. They are laboratory-based tests used in clinical settings to assess dynamic sitting balance in both temporal and spatial domains. The purpose of the study was to investigate the reliability and validity of these two balance tests, LOS and SWS, in sitting. In this first stage of our study, the target group was stroke survivors who are more independent and a more dependent group will be investigated at a second stage.

2. Methods

2.1. Subjects and Study Design

Eleven community-dwelling stroke survivors (8 men and 3 women, mean age 61.7 years (standard deviation (SD) 7.3)) and fifteen healthy subjects (6 men and 9 women, mean age 54.3 years (SD 6.2)) were recruited by convenience sampling in this cross-sectional study. All stroke subjects had survived a stroke for a minimum of 2 years (mean time since stroke 8.0 years (SD 4.0)). The inclusion criteria for stroke subjects were able to sit unsupported independently for at least 2 minutes; able to perform shoulder flexion for at least 90°; previously fully independent in ADL; and able to communicate and follow instructions. For healthy subjects, the inclusion criteria were independent in ADL; outdoor walkers; and able to communicate and follow instructions. The exclusion criteria for both

groups were orthopedic or other neurological diseases affecting balance, hemianopia, visuo-spatial neglect, marked hypertonicity of muscles, unstable medical conditions, and unable to sit. Written informed consent was obtained from all subjects. The study was approved by the ethics committee of The Hong Kong Polytechnic University.

2.2. Test Procedures

Two dynamic sitting balance tests which measured both temporal and spatial domains were developed, namely limits of stability test (LOS) and sequential weight shifting test (SWS). Each subject came in 2 sessions which were held in the same day. Four sitting balance tests, LOS, SWS, Modified Functional Reach Test (MFRT) and Trunk Impairment Scale (TIS), were conducted in the first session while only LOS and SWS were conducted in the second session. The first session lasted for one hour and the second for half an hour.

The set-up included a tailor-made wooden force platform (90 cm × 76 cm) and a visual display unit (VDU) with adjustable height placed 1.5 m in front of the subjects. The centre of pressure (COP) of subjects was shown on the screen continuously and it was measured by 4 load cells (SBDEG, Measurement Specialties Inc., Schaevitz) mounted in the force platform. The measurement range of the load cells was 40 to 400-pound force. All data from the force platform were converted and digitized via a Multifunction Data Acquisition USB (National Instrument NI USB-6009, USA) with an 8-channel analog-to-digital converter at a sample rate of 1000 Hz. It was connected to a computer which was programmed using tailored LabView software (version 8.6, National Instrument, USA) to display and store the COP data during the sitting balance tests.

For limits of stability test (LOS), subjects were required to sit independently without support on a standardized stool with adjustable seat height. Their hips, knees and ankles were kept at approximately 90° of flexion with feet shoulder-width apart resting on the force platform. There was one palm width between the popliteal fossa and the edge of the stool. Subjects were asked to cross their arms over the chest and they were not allowed to lift up their buttock and feet during the test. An investigator stood behind the subjects for safety concern throughout the testing period. One practice trial was given for familiarization and three trials were then conducted. There was a 2-second baseline measurement of the COP before the appearance of visual target. The initial COP was displayed in the centre together with 8 targets, positioned at front, right front, right, right back, back, left back, left and left front, on a VDU, which was placed in front of the subjects at their eye-level. Visual feedback of the subjects' COP was given on the VDU so that they could weight-shift according to the location of targets. Once 1 of the 8 selected visual targets appeared, subjects were instructed to move their COP towards it to their limit of stability as quickly, accurately and furthest as possible. A 20-second resting period was given between each trial to minimize any fatigue. The mean of 3 trials was calculated for subsequent analyses.

The sitting position of sequential weight shifting test (SWS) was the same as

in LOS. Subjects were asked to shift their COP sequentially to trace a total of 12 targets appearing on the VDU as quickly as possible without losing balance. Once a target was hit, it would disappear and another would be shown. The distance from the centre to each target was 75% of the maximum excursion in LOS of each individual. The trajectory of the targets is shown in **Figure 1**.

The outcome measures of LOS were mean of the eight directions in reaction time, maximum excursion and directional control while those of SWS were the total movement time and directional control. Reaction time was the time of the appearance of the visual target to the onset of voluntary shifting of COP towards the target. Maximum excursion was the maximum displacement of COP in the eight directions. It was normalized with subject's sitting height in statistical analysis as it would be affected by sitting height. Directional control was a comparison between the amount of COP movement in the on-target direction (towards the target) and that in the off-target direction (deviated from the target). Total movement time was the time used for completing the task by hitting all the 12 targets.

Modified Functional Reach Test (MFRT) was shown to have excellent test-retest reliability in healthy population (ICC = 0.94 - 0.96) and stroke survivors (ICC = 0.92 - 0.96) [8]. It was also found to significantly correlate with the Functional Independence Measure ($r = 0.49$, $p < 0.05$) [8]. Subjects were asked to sit on a wooden stool with hips, knees, and ankles at approximately 90° of flexion and feet on the ground. There was one palm width between the popliteal fossa and the edge of stool. A measuring tape was mounted on the wall at the height of the subject's acromion level in sitting. Ulnar styloid process was used as the anatomical landmark to measure the reaching distance. This landmark was used since it would not be affected by the wrist angle. Subjects were instructed to sit upright with shoulder flexed to approximately 90° and reach forward as far as possible without losing balance. Subjects were not allowed to rotate their trunk, lift up their buttock and feet, lean against the wall or hold onto surrounding objects for weight bearing. There were 1 practice trial and 3 testing trials. The

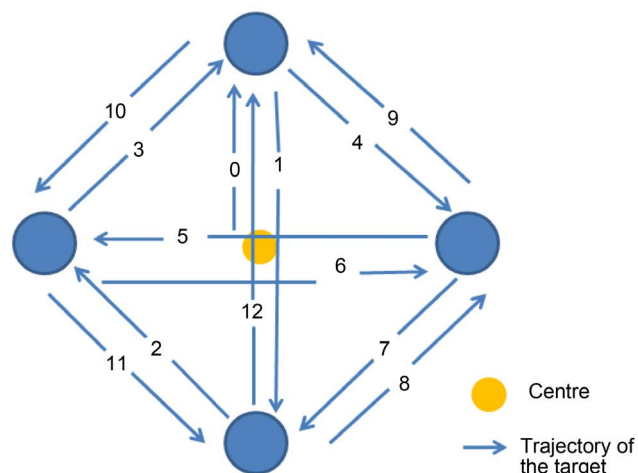


Figure 1. The trajectory of the targets in SWS.

difference between the starting position and maximally reached distance in centimeters was recorded. The average of the 3 testing trials was calculated for data analysis.

Trunk Impairment Scale (TIS) is an objective clinical measurement tool for testing the quality of trunk performance of stroke survivors [9]. The scale was proven to have high test-retest reliability (ICC = 0.93 - 0.96) and inter-rater reliability (ICC = 0.97 - 0.99), high construct validity ($r = 0.86$ with Barthel Index) and concurrent validity ($r = 0.83$ with Trunk Control Test), and good internal consistency (Cronbach's alpha = 0.89) [10]. The scale consists of 3 components including static sitting balance, dynamic sitting balance and trunk coordination. The 3 items of static sitting balance with score ranging from 0 to 7 assessed the ability of subjects in maintaining an erect and stable sitting posture, with both feet on the ground and legs crossed. The 10 items of dynamic sitting balance with score ranging from 0 to 10 tested the competence of subjects in achieving adequate trunk elongation or shortening of both sides of the body, and any compensatory movements were observed. Lastly, the 4 items of trunk coordination with score ranging from 0 to 6 evaluated the capability of subjects in trunk rotation, while any asymmetrical and compensatory movements were noted. The total score of TIS varies from 0 to 23. A higher score shows better trunk performance. Every item was performed for 3 times with best score taken and the score was obtained by direct observation of the investigator.

2.3. Statistical Analysis

Intraclass correlation coefficient (ICC 3, k) was used to assess the test-retest reliability of LOS and SWS, with "k" denoting the number of trials used in different tests. The ICC values were interpreted as follows: <0.40 for poor reliability, 0.40 - 0.75 for fair to good reliability and >0.75 for excellent reliability [11]. Independent t-test was employed to examine the difference of sitting balance performance in LOS, SWS and MFRT between the healthy subjects and stroke survivors to investigate the known groups validity using the known groups method [12]. Pearson's product moment coefficient of correlation was applied to analyze the correlation of LOS and SWS with MFRT and TIS to see the construct validity, both convergence or discrimination perspectives [12]. Results were considered statistically significant if p-value was <0.05. All statistical analyses were performed with SPSS for Windows (version 18).

3. Results

3.1. Subjects

Demographic data describing the 26 subjects (healthy = 15, stroke = 11) are presented in **Table 1**. Significant difference was found in subjects' age ($p = 0.010$) and weight ($p = 0.005$).

3.2. Test-Retest Reliability

For LOS, the data demonstrated excellent reliability in reaction time (ICC [3,8]:

Table 1. Demographic data.

	Healthy group (n = 15)	Stroke group (n = 11)	p-value
Gender (men/ women), n	6/9	8/3	0.105
Age in years, mean (SD)	54.2 (6.2)	61.7 (7.3)	0.010*
Height in cm, mean (SD)	160.8 (6.6)	163.9 (7.8)	0.284
Sitting height in cm, mean (SD)	90.3 (3.3)	90.2 (3.3)	0.976
Weight in kg, mean (SD)	55.9 (10.3)	68.4 (10.2)	0.005*
Years since stroke, mean (SD)	/	8 (4.0)	/
Type of stroke (hemorrhagic/ischaemic), n	/	3/8	/
Hemiplegic side (left/right), n	/	7/4	/

SD, standard deviation. *statistically significant difference at $p < 0.05$.

healthy = 0.799, stroke = 0.760) and maximum excursion (ICC [3,8]: healthy = 0.940, stroke = 0.929) in both groups. Excellent reliability was also shown in directional control of healthy subjects (ICC [3,8] = 0.901), but only fair reliability was found in stroke subjects (ICC [3,8] = 0.446).

For SWS, the data of both groups demonstrated excellent reliability in total movement time (ICC [3,3]: healthy = 0.849, stroke = 0.864). Excellent reliability was also shown in directional control of healthy subjects (ICC [3,3] = 0.899), but only fair reliability was found in stroke subjects (ICC [3,3] = 0.548).

The ICC values of test-retest reliability for LOS and SWS are summarized in **Table 2**.

3.3. Construct Validity

As there was statistically significant difference in age between the healthy and stroke groups, age was treated as a covariate in the statistical test when comparing difference between groups.

Table 3 summarizes the difference between the two subject groups in LOS, SWS and MFRT. Significant difference was shown only in reaction time of LOS ($p = 0.039$). However, significant difference was neither found in maximum excursion and directional control of LOS, nor in any parameters of SWS and MFRT.

For LOS, there was a significant negative correlation between reaction time and MFRT of stroke subjects ($r = -0.684$, $p = 0.020$; refer to **Table 4**). Directional control of the stroke subjects was also significantly correlated with their dynamic sitting balance score ($r = 0.846$, $p = 0.001$) and total score ($r = 0.817$, $p = 0.002$) of TIS. Maximum excursion, however, was neither correlated with MFRT nor TIS. There was also no significant correlation found between reaction time and TIS, and similar result was found between directional control and MFRT.

For SWS, significant correlation was only shown between total movement time and dynamic sitting balance score of TIS ($r = -0.654$, $p = 0.029$; **Table 4**). Both total movement time and directional control were not significantly correlated with MFRT and total TIS score. There was also no significant correlation

Table 2. Test-retest reliability of LOS and SWS.

	Healthy group (n = 15)	Stroke group (n = 11)
LOS		
Reaction time	0.799	0.760
Maximum excursion	0.940	0.929
Directional control	0.901	0.446
SWS		
Total movement time	0.849	0.864
Directional control	0.899	0.548

LOS, limits of stability; SWS, sequential weight shifting.

Table 3. Difference between healthy and stroke subjects in LOS, SWS and MFRT.

	Healthy group (n = 15)	Stroke group (n = 11)	p-value
LOS			
Reaction time in ms, mean (SD)	608.7 (158.2)	833.8 (235.9)	0.039*
Maximum excursion, in %, mean (SD)	13 (2.5)	11.7 (2.5)	0.549
Directional control in %, mean (SD)	80.7 (5.3)	77.2 (7.6)	0.538
SWS			
Total movement time in ms, mean (SD)	37,045.7 (5640.3)	51,086.8 (22716.5)	0.271
Directional control in %, mean (SD)	59.4 (15.0)	69.8 (4.7)	0.109
MFRT			
MFRT in %, mean (SD)	41.6 (9.5)	38.2 (9.3)	0.309

LOS, limits of stability; SWS, sequential weight shifting; MFRT, modified functional reach test. *statistically significant difference at $p < 0.05$.

Table 4. Correlation of LOS and SWS with MFRT and TIS in subjects with stroke.

	MFRT	TIS (total score)	TIS (dynamic sitting balance score)
LOS			
Reaction time	$r = -0.684$	$r = -0.517$	$r = -0.436$
	$p = 0.020^*$	$p = 0.104$	$p = 0.180$
Maximum excursion	$r = 0.187$	$r = 0.209$	$r = 0.362$
	$p = 0.582$	$p = 0.537$	$p = 0.274$
Directional control	$r = 0.063$	$r = 0.817$	$r = 0.846$
	$p = 0.853$	$p = 0.002^{**}$	$p = 0.001^{**}$
SWS			
Total movement time	$r = -0.539$	$r = -0.523$	$r = -0.654$
	$p = 0.087$	$p = 0.099$	$p = 0.029^*$
Directional control	$r = 0.219$	$r = 0.196$	$r = 0.258$
	$p = 0.517$	$p = 0.564$	$p = 0.443$

LOS, limits of stability; SWS, sequential weight shifting; MFRT, modified functional reach test; TIS, trunk impairment scale. *statistically significant correlation at $p < 0.05$. **statistically significant correlation at $p < 0.01$.

found between directional control and dynamic sitting balance score of TIS.

4. Discussion

From past researches, the reliability and validity of LOS were established on standing balance. This test was examined using computerized dynamic posturography devices such as the PRO balance master system [13] [14] [15]. There is a lack of studies in examining the reliability and validity of LOS and SWS on sitting balance. Therefore, our investigation was to establish the reliability and validity of these two tests on sitting balance of stroke survivors. The tests consisted of temporal and spatial domains, which involved diagonal and orthogonal displacements.

4.1. Test-Retest Reliability

The dynamic sitting balance tests showed excellent test-retest reliability in healthy subjects. In stroke subjects, excellent test-retest reliability was found in reaction time and maximum excursion in LOS and total movement time in SWS, while fair to good test-retest reliability was found in directional control in both LOS and SWS. Possible explanation was that the endurance of stroke subjects might not be adequate, resulting in fatigue as the tests were conducted in the same day.

In SWS, the distance from the centre to each target was set at 75% of subject's maximum excursion as determined in LOS. This allowed subjects to complete the test and challenged them sufficiently while avoiding any ceiling effects and fatigue. Hence, this may result in good test-retest reliability.

4.2. Construct Validity

Statistically significant difference between groups was found only in reaction time, but not in maximum excursion and directional control in LOS, nor total movement time and directional control in SWS. This shows that known groups validity was high in reaction time in LOS but not in other items. The difference in balance performance was reflected by temporal domain in LOS but not spatial domain. Possible explanation was that the stroke subjects were quite independent in mobility. Most of them could walk either with stick or unaided independently, while only two required supervision when walked unaided. This might reduce the difference in sitting balance ability between healthy and stroke subjects. Also, 75% of the subject's maximum excursion might not be demanding enough for the stroke subjects. Moreover, rehabilitation programs usually train balance in spatial domain but not in temporal domain, so the stroke survivors might perform better in spatial domain [16]. However, significant difference was not shown in temporal domain in SWS. This may be due to small sample size.

The temporal domain of LOS showed significant correlation with MFRT. That is, subjects with better balance could react faster and reach further. This indicates that reaction time is vital for stroke survivors in maintaining balance. However, there was no significant correlation between maximum excursion and directional control in LOS and MFRT. This may be because in LOS, the average of maximum excursion was calculated from 8 different directions, while only

forward direction was tested in MFRT. The degree of excursion and movement control in LOS may be affected by movement in other directions, especially those in backwards, which were considered as the most difficult directions to move. This shows that conventional MFRT may be inadequate to reflect functional sitting ability which is important in daily function. Besides, directional control of LOS showed significant correlation with TIS. That is, subjects with better balance could control movement better and have higher TIS score. Therefore, spatial domain of balance performance can be well-tested by LOS.

For SWS, no significant correlation with MFRT was found. This may be because subjects were required to move in only one direction once in MFRT while in SWS, they had to keep shifting weight in different directions. Nevertheless, there was significant correlation between total movement time in SWS and dynamic sitting balance score in TIS. This may be due to the fact that both SWS and dynamic sitting balance tests in TIS involve weight-shifting to both hemiplegic and non-hemiplegic sides.

4.3. Limitations of the Study

This study showed no difference in most items in LOS and SWS between healthy and stroke subjects. This might be due to small sample size. Besides, subjects were recruited by convenience sampling and the stroke subjects were all community-dwelling. They suffered from only minor stroke and could walk independently. They could achieve a relatively high level of functioning and leading to a good sitting balance control. Therefore, a more disabled population of stroke survivors will be recruited in the next stage of reliability and validity study of the two dynamic sitting balance tests.

5. Conclusion

Good test-retest reliability of the two dynamic sitting balance tests, LOS and SWS, has been shown. Also, the convergence and discrimination perspectives of the construct validity with traditional sitting balance tests were demonstrated. Further study with a larger sample size and on frail stroke survivors will be conducted. Moreover, the reliability and validity of these sitting balance tests at the sub-acute stage can be investigated.

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