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Original Article

Reliability and validity of the sequential weight-shifting test: a new functional approach to the assessment of the sitting balance of older adults

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Abstract. [Purpose] The evaluation of sitting balance is important for the prevention of falls in older adults, especially those who have a disability involving the lower extremities. However, no studies have been designed to assess a patient's dynamic sitting balance using a sequential protocol. The objective of this study was to investigate the psychometric properties of the sequential weight-shifting (SWS) test. [Subjects and Methods] Twenty-three older adults who were physically dependent with regard to ambulation were recruited by convenience sampling. In study 1, 10 participants performed the SWS test and repeated the procedure 1 week later. In study 2, 23 participants were assessed using the SWS test, forward and lateral reach tests in a sitting position, tests of shoulder flexor and hand grip strength, an eye-hand coordination test, mobility tests, and pulmonary function tests. The test-retest reliability of the SWS test and its correlations with the different physical dimensions were examined. [Results] The intraclass correlation coefficient (3,1) of the SWS test was 0.67. The results of the SWS test correlated significantly with forward reach in the sitting position, arm muscle strength, eye-hand coordination, mobility, and pulmonary function (all $p<0.05$). [Conclusion] The SWS test demonstrated satisfactory psychometric properties and can be considered a useful functional approach for the measurement of sitting balance.
Key words: Geriatric assessment, Disability evaluation, Balance

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INTRODUCTION

The population is aging worldwide[1)], and approximately one-third of people aged 65 years or above fall at least once a year. Studies show that the older the person, the more likely that a fall will result in an injury[2)]. One of the major consequences of falls by older adults is lower extremity fracture, which can lead to significant disability.

Although much of the research on falls has focused on falls that occur while standing or walking, falls from a seated position are of special concern for those with a disability involving the lower extremities. These individuals often need to perform functional activities from a sitting position; therefore stability of movement in multiple directions is crucial for their safety and movement efficiency. Indeed, simple daily tasks such as transferring or reaching can result in a fall, and one of the causes is a loss of sitting balance[3)]. Although epidemiological information about the incidence of falls from a sitting position among older adults is still lacking, about one-third of wheelchair users were found to have one or more falls over the course of a year, and 14% of patients with spinal cord injury were injured further as a result of falls[4)]. It is generally believed that the

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Table 1. Characteristics of the subjects of studies 1 and 2

Demographic variables	Study 1 (n = 10)	Study 2 (n = 23)
Age (years)	88.0 ± 7.8	85.6 ± 8.0
Weight (kg)	48.3 ± 8.4	52.3 ± 10.7
Body height (cm)	150.5 ± 7.6	149.1 ± 9.5
Sitting height (cm)	63.6 ± 8.5	64.8 ± 7.4
Arm length (cm)	66.2 ± 4.0	65.0 ± 6.3
EMS score	11.0 ± 2.6	9.7 ± 4.1
Barthel index	66.6 ± 12.4	67.9 ± 15.4
MMSE score	19.9 ± 6.9	19.0 ± 7.0

Values are mean ± SD.
EMS: elderly mobility scale; MMSE: mini-mental status examination

older adult population has a similar or higher incidence of injury from falls. Hence, strategies for the assessment of dynamic sitting balance are needed.

Previously, most sitting balance tests have been constructed around reaching abilities[5, 6]. However, such measurements have their limitations. The reaching ability only measures the spatial domain without consideration of the temporal domain (i.e., the time needed to complete the test) or the quality of movement. Indeed, the time to complete functional activities could reflect the efficiency of subjects with ambulation difficulties in accomplishing tasks, like the timed-up-and-go test. Moreover, differences in anthropometrics between sitting heights and arm lengths also make comparisons between individuals difficult. Most importantly, they involve only one orthogonal movement plane for each measure, which is not functionally adequate because many daily activities, such as putting on a sock located beside oneself, involve sequential diagonal movements of the trunk.

In view of these limitations, functional or task-oriented approaches to the assessment of sitting balance have been suggested[7, 8]. Nevertheless, these types of performance-based measures may be difficult for the tester to score or judge. Moreover, no standardized or sequential protocol for the assessment of sitting balance has been explored.

This study was conducted to determine the test-retest reliability of a newly developed test of dynamic sitting balance, the sequential weight-shifting (SWS) test. The SWS test is more functional in nature than previous tests and specifically incorporates the temporal domain without imposing a floor effect. The study was also designed to evaluate the relationships among different physical capabilities.

SUBJECTS AND METHODS

Older adults with physical dependence were recruited from four residential care homes in Hong Kong by convenience sampling. The participants' characteristics are shown in Table 1. Their ambulation level as assessed by the Functional Ambulation Classification (FAC)[9] was used as one of the selection criteria: only older adults with FAC scores of between 0 and 2 were included. These scores indicate a need for physical assistance for ambulation[10], and the candidates mainly remained sitting when performing daily activities. The candidates were excluded if they: had a progressive neurological disease or any unstable medical condition; had any signs or symptoms consistent with major unstable cardiopulmonary disease (i.e., ischemic chest pain, unaccustomed shortness of breath, shortness of breath with mild exertion, recurrent episodes of syncope, orthopnea, paroxysmal nocturnal dyspnea, palpitations, tachycardia, claudication, or ankle edema with severe pitting); were unable to follow instructions; or had a terminal disease. This study was approved by the ethics committee of The Hong Kong Polytechnic University. All of the participants signed an informed consent form before participating in the study.

The assessments used in this study included the newly developed sequential weight-shifting (SWS) test, a reaching test in the sitting position (forward and lateral reach), tests of arm muscle strength (shoulder flexor strength and hand grip strength), an eye-hand coordination test, a mobility test, and a pulmonary function test.

In the SWS test, two force platforms (Model 9286AA, Kistler, Gommiswald, Switzerland) were placed under the participants' buttocks and feet to measure shifts in the resultant center of pressure (COP) while sitting. The force platforms were connected to a computer with LabView software (version 8.6; National Instruments) customized to display and store in real time the motion of the resultant COP during the sitting balance test. The participants initially sat on the force platform with their arms crossed on their chests and their hips and knees at approximately 90 degrees of flexion. Their feet were placed shoulder-width apart and rested completely on the second force platform. The participants were required to sit quietly before the dynamic test began to record their baseline body sway. The test began when a target appeared on a visual display unit (VDU) in front of the participant; the VDU also displayed the current position of the participant's COP. The participants were asked to shift their center of mass (COM) as quickly as possible without losing their balance in order to propel the COP trace to reach 10 targets that appeared sequentially on the VDU. When each target was hit, it disappeared and the next target

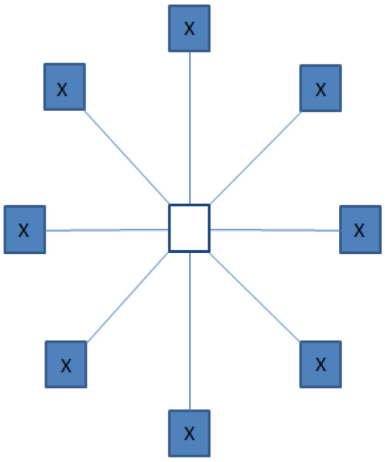

Fig. 1. Distribution of targets. The unfilled square denotes the center of pressure of the subject at rest, filled squares denote the target locations

Fig. 2. Equipment setup for the sequential weight-shifting (SWS) test

appeared. The 10 targets appeared in eight locations (Fig. 1). The distance from the center to each target was normalized according to the participant's individual height and was determined using the normalized body sway angle. The normalized body sway angles were calculated from the data of 22 older adults of similar mobility level (FAC=0–2), collected in a previous study, and twenty-fifth percentiles of their limits of stability were chosen to position the target locations.

Visual feedback regarding the participants' COP was provided continuously on the VDU as the participants adjusted their COM to reach the targets. The total time required to hit all 10 targets was recorded. Each participant performed the test only once, but a familiarization trial was performed to ensure that the participants fully understood the testing procedure. Figure 2 shows the equipment setup for the SWS test.

The forward reach test in a sitting position (sit-and-reach) has been shown to be reliable (test-retest reliability intraclass correlation coefficient [ICC], 0.79)[5]. Tests of lateral reaching in a sitting position have also reported that it has excellent intrarater reliability (ICC, 0.96)[6].

In the forward reach test, a measuring tape was secured horizontally on a wall at the level of the participants' acromion process. The participants sat on a wooden stool with their hips, knees, and ankles positioned at approximately 90 degrees of flexion, with about 5 cm (2 inches) of clearance between the popliteal fossa and the edge of the stool[11]. Foot support was provided if necessary.

Each participant was requested to sit up straight, make a fist with the dominant hand, straighten the elbow, and flex the shoulder to 90 degrees. The participants were allowed to use their other arm for counterbalance only (i.e., they were not allowed to hold on to the chair or to bear weight with their other arm). The placement of the end of the third metacarpal along the tape was recorded as the initial position. The participant then reached as far forward as possible without rotating the trunk or losing balance. The position of the end of the third metacarpal was then recorded as the final position. The distances achieved in the reaching test were defined as the difference between the initial and final positions. If the participant touched the wall or lost his or her balance during the test, the trial was repeated. The investigator sat beside the participants to record the measurements and to help prevent them from falling.

The tests of lateral reach to the left and right were performed in a manner similar to that of the forward reach test by asking the participants to reach to the side using the left and right arms, respectively, with the shoulder abducted at 90 degrees. The participants were not permitted to lift their heels or any portion of their feet off the floor. If the feet moved, the trial was repeated. Each participant was allowed to practice these two tests twice before performing the three test trials. The mean of the three test trials was used in the analysis[6].

Shoulder flexor strength was measured with a Nicholas MMT hand-held dynamometer (Model 01160, Lafayette Instrument, Lafayette, IN, USA). The participants were asked to sit with the tested arm at approximately 90 degrees of shoulder flexion with the elbow extended[12]. The force pad of the hand-held dynamometer was always held perpendicular to the arm being tested. For the participants' comfort and because of the fragility of their skin, a towel was placed between the force pad and the arm being tested. The participants were then asked to flex their shoulder against the device, which was placed just proximal to the epicondyles of the humerus.

The mean value of three trials was computed for the strength tests, because the use of three trials was shown to have greater test-retest reliability than the use of one trial or the use of the highest of the three scores[13]. The duration of the contraction was 3 seconds, which was usually sufficient to register a maximum reading[14]. The participants were given consistent verbal encouragement during each trial. The measurements were then repeated on the alternate side.

Hand grip strength was measured with a Jamar hydraulic hand dynamometer (Sammons Preston, AbilityOne Co., Bolingbrook, IL, USA). The reliability and high test-retest reliability of the Jamar dynamometer have been confirmed[13]. The participants were asked to adduct the shoulder in neutral rotation with the elbow flexed at 90 degrees, the forearm in a neutral position, and the wrist between 0 and 30 degrees of extension and between 0 and 15 degrees of ulnar deviation[13]. For standardization, the apparatus was set at the second handle position for all participants[15]. The grip strength was measured to the nearest kilogram.

For the eye-hand coordination test, a VDU (ClearTek 3000; Capacitive Touchscreens, MicroTouch Systems Inc., Methuen, MA, USA) and a force-sensing resistor were used, and the data were collected using customized tailored LabView software (LabView, version 7.0, National Instruments, Budapest, Hungary). The participants were seated on a chair with the seat height adjusted so that the upper edge of the screen was at each participant's eye level. The hips, knees, and ankles were in approximately 90 degrees of flexion, and the feet were placed completely on the floor. The participants were instructed to sit erect with the trunk supported throughout the test. A mark was positioned at the center of the upper edge of the display unit, and the participants were asked to fix their eyes on it at the beginning and during the entire test. At the beginning of the test, the participants' hands were positioned on hand-like markers on a table 10 cm from the screen. The force-sensing resistor connected to the computer system was located underneath the "thumb" of the hand-like marker for the participant's dominant hand (i.e., the side used for writing and for holding chopsticks). In each trial, the participants were instructed to point to the visual signal as quickly and as accurately as possible. Spoken encouragement was delivered (in Cantonese) at the middle of each set of tests to counter any decrease in attention span. Trial runs were performed for each protocol to familiarize subjects with the procedure.

The visual target was an image of a ball (1.2 cm diameter) on the VDU. The participants were required to touch the ball with the index finger of their dominant hand. The target appeared sequentially in different positions on the VDU. Each of the 20 targets appeared as soon as the participant had touched the previous ball. The participants were asked to touch the visual targets as quickly and as accurately as possible. The movement time was measured from the time the participant's hand left the force-sensing resistor and the time the hand touched the 20th target. Each participant performed two trials, and the average time was calculated. The test-retest reliability was evaluated using 20 individuals in a previous study[16], and the ICCs for reaction time, movement time, and accuracy were 0.70, 0.68, and 0.71, respectively.

The Elderly Mobility Scale (EMS) was used to assess locomotion, balance (functional reach), and key position changes (sitting to standing, lying to sitting, sitting to lying, and standing with and without support). Each item is measured on an ordinal scale. The maximum score possible, which represents independent mobility, is 20, and the minimum score is 0. Individuals with a score below 10 on the EMS are likely to need help with mobility and ADL, whereas those with a score or 14 or more are likely to be independent in mobility. The EMS has concurrent validity, exhibits high correlation with the Barthel index and the Functional Independence Measure, and demonstrates good inter-rater reliability, as no significant difference was found between testers[17].

Pulmonary function tests were performed with a spirometer (MicroLab 3500 v6, Micro Medical Ltd., Basingstoke, UK) with the participant in a sitting position. The participants were asked to inhale a maximal breath and then to exhale into a mouthpiece as hard, as fast, and for as long as they could, so that the entire exchangeable gas volume was emptied from their lungs as quickly as possible. They then inhaled fully immediately after the expiratory maneuver. The values for forced vital capacity, forced expiratory volume in the first second, and peak expiratory flow were recorded. The best values of three attempts were used in the analysis[18].

In study 1, the participants repeated the SWS test 1 week after first performing it under similar conditions. In study 2, the participants underwent a series of physical and mobility assessments that included the SWS test, forward and lateral reach tests in a sitting position, shoulder flexor and hand grip strength tests, an eye-hand coordination test, a mobility test, and pulmonary function tests.

The results were entered into a database for analysis using the Statistical Package for the Social Sciences (SPSS) version 17 for Windows. The test-retest reliability was determined using the intraclass correlation coefficient (ICC) with trial as the random factor and rater as the fixed factor in a two-way mixed ANOVA model. In the results, the notation ICC (3,1) signifies that model 3 was used for the assessment of test-retest reliability, and "1" represents the number of trials used in the dynamic sitting balance test, in this case, a single rating. The correlations between the SWS test results and the physical data were analyzed using Pearson's product-moment coefficient of correlation. An α value of less than or equal to 0.05 was considered significant in all statistical analyses.

RESULTS

No adverse events occurred as a result of the aforementioned tests. All of the data obtained were used for the subsequent analyses.

Table 2. Pearson correlations between the physical measures and sequential weight shifting times

Physical dimension	R (95% CI)
Sitting balance	
Forward reach test	–0.740** (–0.897 to –0.417)
Right reach test	–0.533* (–0.789 to –0.118)
Left reach test	–0.522* (–0.789 to –0.089)
Shoulder flexor strength	
Left	–0.456* (–0.731 to –0.054)
Right	–0.472* (–0.740 to –0.074)
Hand grip strength	
Left	–0.615** (–0.819 to –0.272)
Right	–0.666** (–0.846 to –0.350)
Eye-hand coordination	
Time to complete the sequential target pointing task	0.458* (0.045 to 0.737)
Physical mobility	
Elderly mobility scale	–0.529** (–0.773 to –0.149)
Pulmonary function	
Forced expiratory volume in 1 second	–0.544** (–0.781 to –0.170)
Forced vital capacity	–0.594** (–0.808 to –0.241)
Peak expiratory flow	–0.442* (–0.723 to –0.036)

*Indicates significance at the p≤0.05 (**p≤0.01) level of confidence

Ten older adults were recruited for the test-retest reliability trials. After administration of the SWS test, the procedure was repeated 1 week later under similar conditions. The ICC (3,1) value was found to be 0.67 (95% confidence interval, 0.12 to 0.91), which suggests moderate reliability of the SWS test has moderate reliability within this population with a mean age of 88 years[19].

Table 2 shows the correlation coefficients between the results of the SWS test and the physical data and the results of the mobility tests. All of the correlations among the tests were significant (p≤0.05). The parameters that had the strongest correlations with the results of the SWS test were the forward reach test (r=−0.74), the two tests of hand grip strength (right, r=−0.666; left, r=−0.615), and forced vital capacity (r =−0.594).

DISCUSSION

A new sequential weight-shifting test of sitting balance was developed and its psychometric properties were established in this study. The sequential weight-shifting test has acceptable test-retest reliability and correlations with forward reach in the sitting position, arm muscle strength, eye-hand coordination, mobility, and pulmonary function.

The moderate reliability of the SWS test can be considered to be acceptable among this population of older adults with a mean age of 88 years and some physical disability. A similar reliability (ICC=0.69) was reported in another study with a similar assessment protocol, i.e., an investigation of the dynamic sitting balance control of subjects with spinal cord injury[20]. The lack of familiarity with the equipment setup and testing procedures may have affected the reliability result even though familiarization trials were conducted before the actual testing. Moreover, greater inconsistencies in physical and cognitive performance among the old-old population may also contribute to the variable responses. Furthermore, a more physical challenging test in the dynamic mode may contribute to the variations as more sensorimotor processing is required to maintain control of the balance. It is also worthwhile noting that only one SWS test trial was conducted in this study in order to avoid fatigue among the older adults.

The results show that the participants who had better performance in the tests of physical function were able to complete the SWS test more quickly. The significant correlations of the times achieved in the SWS test with the results of other dynamic sitting balance tests, such as the forward reach test in a sitting position, support its convergent validity. The analysis also found that the time domain (as revealed in the SWS test) correlated with the spatial domain of balance control in a sitting position, particularly the forward reach test. A possible explanation for this is that stronger neck and trunk muscles were needed in the sagittal plane, than in the coronal plane, for greater excursion in the anteroposterior direction as well as the faster movement required by the SWS test. However, further study of the muscles involvement is warranted.

Significant correlations of the SWS test with both shoulder flexor strength and hand grip strength were found in this study. Traditional tests of balance control have shown it correlates with physical functioning[21], and with both shoulder flexor strength[22] and hand grip strength[23]. An individual's arm strength may reflect the general muscle strength of their entire body, which determines balance control while sitting. Indeed, a positive correlation has been reported between lower extremity strength and standing balance control[24]. The significant correlation between arm muscle strength and dynamic sitting balance control revealed by this study is a novel observation.

A significant correlation was also found between eye-hand coordination and performance in the SWS test. It has been shown that eye-hand coordination is one of the fitness components that is most strongly associated with the functional performance of older adults[25]. As previously mentioned, balance control correlates with physical performance[21]. Subjects who have better balance while sitting may have better functional capability. Specifically, the coordination of eye-hand movements requires coordinated truncal movement and stable sitting balance control, which are reflected in the SWS test.

The significant correlation of the SWS test results with cardiopulmonary function is noteworthy. This correlation may be the result of the positive relationship between pulmonary function and general physical fitness[26] being reflected in sitting balance control[27].

The time domain of the SWS test significantly correlated with muscle strength, eye-hand coordination, mobility, and pulmonary function. This may imply that the SWS test is to some extent functional in nature and that it involves many sensorimotor systems such as dynamic balance control, eye-head-trunk coordination, muscle strength (especially that of the trunk muscles), and general mobility. This body of evidence makes it clear that all of these physical components are interrelated. In fact, the relationships between physical parameters and functional abilities have been studied and evidence is accumulating.

The results of this study are of great clinical importance, because the overall correlation of the SWS test results with many physical parameters further confirms that the SWS test can assess many physical states ranging from impairment to a certain degree of functional capability. The results of this study suggest the potential use of the SWS test both as a specific assessment of dynamic sitting balance, which doesn't impose floor effects, and as a more generic assessment of general physical fitness.

There are, however, several limitations to the use of the SWS test in a clinical setting. The major limitations of this test are the involvement of sophisticated instruments which are expensive in terms of equipment (e.g. force platforms) and the necessity of technical expertise in clinical settings, even though the SWS test can provide time domain and diagonal measurements. The force platform could possibly be tailored to purpose using four load cells mounted on the platform to reduce the cost. Also, the size of the platform could be adjusted to suit different sizes of chair and even wheelchair[20]. Another issue is that it may be difficult for older adults with cognitive impairment to perform the SWS test. The mini-mental status examination scores of the subjects were 19.9 and 19.0 in study 1 and study 2, respectively. However, the cut-off point for the test remains to be determined. This study included a small sample size with convenience sampling rather than probability sampling. It is possible that some older adults who met the selection criteria and were representative of critical differences were not recruited. Thus, a large random sample is suggested for future studies to avoid selection bias and to increase the generalizability of the study results. Furthermore, the protocol tested here emphasized the time domain. The spatial domain of this test (i.e., different starting and ending locations and control of COP trajectory) remains to be explored, and the test's psychometric properties also need to be explored further in different populations, such as patients who have experienced stroke or spinal cord injury.

Finally, the establishment of cutoff points for the results of the SWS test may provide more information for the prediction of fall risk of chair-bound older adults.

In conclusion, this study was designed to generate valuable, previously unavailable information regarding the measurement of dynamic sitting balance using a sequential protocol. The SWS test was shown to provide a functional approach to the assessment of sitting balance control, with multidirectional and sequential movement components. The continuous scale of measurement is applicable to a wide range of capabilities and is not sensitive to floor effects. The SWS protocol demonstrated satisfactory psychometric properties, including acceptable test-retest reliability and convergent validity with the forward reach test. It also showed correlation with arm muscle strength, eye-hand coordination, and pulmonary function. Therefore, an aggregation of measures from various physical function domains may provide the initial screening criteria for exercise training for older adults.

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