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Original Article

Concurrent and discriminant validity of Nintendo Wii Fit *exergame* for the assessment of postural sway

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Abstract. [Purpose] The purpose of this study was to determine the concurrent validity of Wii Fit center-of-pressure parameters with Clinical Test of Sensory Integration for Balance and to evaluate the discriminant validity of the Wii Fit center-of-pressure parameters for adults and the elderly for the assessment of postural sway. [Participants and Methods] This study used an observational cross-sectional correlational design. All 70 participants were required to complete a questionnaire for eligibility screening, followed by a center-of-pressure assessment using three Wii Fit balance activities (snowboard slalom, ski slalom, and balance bubble) and Clinical Test of Sensory Integration for Balance using a force platform. [Results] For center-of-pressure assessment, our results showed there was concurrent validity of Wii Fit ski slalom and balance bubble with Clinical Test of Sensory Integration for Balance conditions 6 and 4, respectively. Our results also demonstrated that the three Wii Fit balance activities selected in this study could be used to discriminate between adults and the elderly. [Conclusion] Our results suggest that Wii Fit is a viable and affordable alternative method for center-of-pressure assessment.
Key words: Wii Fit, Centre of pressure, Validity

INTRODUCTION

Adequate balance function is necessary to successfully accomplish most activities of daily living such as sitting, standing and walking, especially among the elderly population[1, 2]. In the United States, the incidence of falls among community dwellers at least once a year was reported as 33% and 50% for those above 65 and 80 years respectively[3]. In Japan, however, the reported annual incidence of falls is comparatively lower for those between 65 to 84 years at 13% and 22% for men and women respectively[4]. Therefore, it is important to initiate quick and timely assessment of balance function to decrease the risk and incidence of falls by implementing strategies to prevent further deterioration.

The assessment of balance function can be categorized into three types:

(1) Assessment of impairments related to balance function such as decreased range of motion in the lower limbs[5] and decreased muscle strength of the anti-gravity muscles[6].

(2) Assessment of postural alignment[7] and postural sway, such as the various iterations of the Romberg test[8], and the Clinical Test of Sensory Integration for Balance or CTSIB[9].

(3) Assessment of functional tasks such as sitting and standing (e.g. Berg Balance Scale)[10] and reaching forward in sitting or standing[11].

The assessment of postural sway by measurement of the body's center of pressure (COP) using computerized systems was introduced by Nashner in 1970[12]. Since then, conventional force platforms are usually considered as the gold standard for assessment of COP which is defined as "an approximation of the body's center of mass (or balance point) projected vertically

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onto the floor below"[13]. In addition to conventional force platforms[14], dedicated systems such as the Balance Master (Natus Medical Inc., San Carlos, CA, USA)[15, 16] have also been used to assess COP in research laboratories or rehabilitation centers. More affordable alternatives are available such as those being used in gaming technology e.g. Wii Balance Board (WBB) which was introduced in 2007 as an exercise accessory to the Wii game console (Nintendo Co., Ltd, Kyoto, Japan). The WBB is a portable platform with built-in pressure sensors at each of the four corners which can measure, track and display the COP of the user in real-time[17]. When the WBB is used in conjunction with dedicated software such as Wii Fit (Nintendo Co., Ltd, Kyoto, Japan), it enables the system to assess postural alignment and sway, as well as challenging the user's balance ability through games (also known as *exergames*) with different levels of difficulties. These *exergames* can be divided into four categories: yoga, strength training, aerobics and balance.

The yoga and strength training categories consist of 15 activities each. At the end of each activity, the users are scored based on how well they were able to maintain their COP within a certain threshold indicated by a yellow circle. The aerobics and balance categories consist of 9 activities each. Only the balance category is directly related to how the user controls his COP. Two activities require the user to control his COP in the anterior-posterior direction (ski jump, snowboard slalom), four in the medial-lateral direction (ski slalom, soccer heading, tightrope walk, penguin slide), and two in a combination of both (table tilt, balance bubble). The ninth activity requires the user to sit motionless on the WBB and is related more to sitting rather than standing postural sway.

Various studies have been conducted to evaluate the effectiveness of Wii Fit *exergames* for improving balance function in various population groups[17–20]. In addition to *exergaming*, the WBB can also be used to assess postural sway through measurement of the COP. However, compared with conventional force platforms, the WBB is limited by its sampling frequency (30 to 50 Hz) and its maximum load (150 kg). Nevertheless, the cost-performance benefit from using an affordable and portable device has prompted several investigations into its validity and reliability for COP assessment of postural control. According to Horak[9], the postural control system can be divided into three components for testing: biomechanical, motor coordination and sensory organization components. Only the last component is related to COP, and has been described as the Sensory Organization Test (SOT) or the CTSIB[21]. The CTSIB involves measuring the COP under six different conditions by combining two different surfaces (somatosensory normal and conflicted) and three different visual conditions (vision normal, absent, and conflicted)[21]. To test under somatosensory conflicted conditions, a soft foam cushion is used for the participant to stand on. To test under vision conflicted conditions, a dome or surround screen is used to always maintain the participant's visual field at the same distance from the visual target. The validity and reliability of CTSIB have been investigated in healthy children (concurrent validity, Pearson's r=0.681 to 0.799)[22] and in patients with vestibular dysfunction (reliability, ICC=0.74)[23], among others.

The validity and reliability of the Wii Fit has also been investigated by several authors with conflicting results. Wikstrom investigated the concurrent validity of Wii Fit scores with a 30 second single limb stance and the Star Excursion Balance Test[24]. Although he reported poor validity when compared with Wii Fit body tests and yoga activities, it is doubtful that the parameters used in this study were appropriate since body tests and yoga activities are not good measures for postural sway. In addition, his adult participants ranged from 18 to 57 years, which may have affected his results as the validity of Wii Fit could be age dependent. Liuzzo et al reported that Wii Fit was moderately reliable for the elderly above 65 years (ICC 0.59), and for adults and elderly with stroke from 54 to 80 years (ICC 0.60)[25]. However, the only Wii Fit parameter that they measured was percentage of left and right weightbearing which is more indicative of static alignment, rather than postural sway. Hall et al reported that in women above the age of 60 years, the validity of Wii Fit ski slalom was significantly correlated with SOT (Spearman's rho −0.67), while table tilt was not[26]. They concluded that ski slalom may be used to assess balance in community dwelling elderly. However, only two of the eight Wii Fit balance activities were investigated, and balance activities in the anterior-posterior direction was not assessed. Hence, due to inadequate or inappropriate Wii Fit parameters being assessed, as well as restrictions in the age range of participants, the validity of Wii Fit to assess COP is still not sufficiently evaluated. Therefore, the purpose of this study was to determine the concurrent validity of Wii Fit COP parameters with CTSIB, and to evaluate the discriminant validity of Wii Fit COP parameters for adults (18 to 64 years) and the elderly (65 years and above) for the assessment of postural sway.

PARTICIPANTS AND METHODS

This investigation employed an observational correlational cross-sectional study design. Ethical approval was obtained from the university's ethical review board (ISU No. 19-09) before the commencement of the study.

Recruitment of participants was carried out using word-of-mouth and through posters distributed at four cities in the Kanto-Tohoku region in Japan. The inclusion criteria were: aged between 18 and 90 years old; community dwelling; independent in daily activities; no previous experience with Wii Fit; and body weight less than 150 kg. The exclusion criteria were: unable to stand independently for 20 minutes; unable to walk without a cane; pain in joints when weight bearing; progressive neurological symptoms; visual or hearing impairment or vestibular disorders. A total of 70 volunteers agreed to participate in this study. The study's protocol was explained to them and written informed consent was obtained.

This research was conducted from September 2019 to February 2020. The entire session lasted for about one hour starting with a questionnaire, followed by (in random sequence) balance assessments using Wii Fit and CTSIB, and evaluation of

muscle strength and range of motion.

All 70 participants were required to complete a questionnaire regarding their age, gender, height, weight, any co-morbidities, past medical history, visual impairment, and any incidence of falls within the past year.

For the Wii Fit assessments, three balance activities were selected for COP assessment. Prior to testing, participants were given a verbal explanation and a live demonstration. Participants were then instructed to stand barefoot on the WBB which was positioned 2 meters away from the image projected on a screen. The sequence for testing was randomized and performed only once to minimize the learning effects. The three balance activities were as follows:

a. Snowboard slalom: The game scenario is to snowboard down a mountain slope while passing through a series of flags positioned along the slope. The WBB is placed on the floor and perpendicular to the screen as if snowboarding. The goal for this activity is to pass through as many flags as quickly as possible on the way down the slope. The score is calculated based on the time taken, with 7 seconds added for each missed flag. The shorter the time, the better the performance.

b. Ski slalom: The game scenario, goal and scoring for this are similar to that of snowboard slalom. The only difference is that the WBB is placed on the floor parallel to the screen as if skiing.

c. Balance bubble: The game scenario is to move an avatar through a maze without touching the sides of the wall. The WBB is positioned parallel to the screen. The goal for this activity is to move the avatar as far as possible without hitting the wall. The score is calculated based on the distance travelled. The longer the distance, the better the performance.

For the CTSIB assessments, the participants stood bare feet on a force plate (JK-101III, UNIMEC Co., Ltd, Tokyo, Japan) and their COP was measured under six conditions at 100 Hz sampling rate for 30 seconds each as follows: 1. eyes open-firm surface; 2. eyes closed-firm surface; 3: eyes conflicted-firm surface; 4. eyes open-foam surface; 5. eyes closed-foam surface; 6. eyes conflicted-foam surface. The eyes conflicted conditions were performed with the participants wearing a virtual reality goggle (VR-Box, Samonic, Shenzhen, China) which had a static picture of a target in the center of their field of view. The somatosensory conflicted conditions were performed with the participants standing on a 6 cm foam (shock absorbing) placed over the force plate. Each condition was measured once, and the COP sway area was recorded. The smaller the sway area, the better the performance.

For the isometric knee extension muscle strength evaluation, participants sat on a special chair with the knee and hip joints at 90-degrees flexion. The lower leg was attached to the dynamometer (model T.K.K.5710m, Takei Scientific Instruments, Co., Ltd, Niigata, Japan) just above the medial and lateral malleoli. Strength measurements were performed twice for both legs and the maximum value was recorded. For the range of motion evaluation, the ankle plantarflexion and dorsiflexion angles were measured using a standard goniometer (GS-100, OG Wellness Co., Ltd, Okayama, Japan) once for both ankles.

Participants were divided into two groups (independent variable) based on age i.e. adults and elderly. The dependent variables for Wii Fit were the time scores for ski slalom and snowboard slalom, and distance scores for balance bubble; and the sway area for the six conditions for CTSIB. Normality of the dependent variables were checked using the Shapiro-Wilk test. Following this, outlier scores were identified and removed. For assessment of the concurrent validity, Pearson's or Spearman's rank correlation coefficient was used. For assessment of discriminant validity between the two groups, independent sample t-test or Mann-Whitney U test was used. Statistical significance was set at 0.05 and all analysis was performed using the SPSS software version 25.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Table 1 summarizes the characteristics for the adults (n=50, 19 females) and the elderly (n=20, 15 females). The height and body weight of the adults were significantly greater than those of the elderly (p<0.001). The isometric knee extension muscle strength of the adults was also significantly greater than the elderly for both legs (p<0.001). All other comparisons were not significant. No outliers were found for the Wii Fit scores. For the CTSIB, 10 outliers from 6 participants (1 adult, 1 score; 5 elderly, 9 scores) were identified and removed.

Table 2 summarizes the correlation coefficients between Wii Fit and CTSIB parameters (concurrent validity). For the adults, ski slalom was significantly correlated with condition 6 (r=0.32, p<0.05). In addition, balance bubble was significantly negatively correlated with condition 4 (r=−0.30, p<0.05). For the elderly, only snowboard slalom was significantly negatively correlated with conditions 2 (r=−0.48, p<0.05), and 3 (r=−0.52, p<0.05). All other correlations were not significant.

The results for discriminant validity are summarized in Table 3. For Wii Fit parameters, the independent t-test demonstrated that the adults performed significantly better in all three activities compared with the elderly. For the CTSIB parameters, the Mann-Whitney U tests demonstrated that the adults performed significantly better than the elderly for conditions 4 (p<0.05), and 5 (p<0.001). All other parameters were not significantly different.

DISCUSSION

The isometric knee extension muscle strength of the adults was significantly greater than the elderly for both left and right legs. This is consistent with the evidence that muscle strength decreases with age[27] and negatively correlated with balance ability[28]. Therefore, this could be the reason why the adults performed better than the elderly in both the Wii Fit and CTSIB parameters (Tables 2 and 3).

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Table 1. Participant characteristics, isometric knee extension strength, and ankle range of motion

	Adults (18 to 64 years) (n=50)		Elderly (above 65 years) (n=20)		p-value
	Mean	SD	Mean	SD	
Age (years)	30.6	12.4	73.6	5.6	<0.001
Body Weight (kg)	63.5	10.2	53.5	7.3	<0.001
Height (cm)	165.7	8.2	154.9	6.5	<0.001
Body Mass Index (kg/m^2)	23.1	3.1	22.3	2.3	0.375
Isometric Knee Extension Strength (kgf)					
Right	46.0	12.4	25.5	8.6	<0.001
Left	45.9	12.1	26.8	9.7	<0.001
Ankle angle (plantar flexion) (degrees)					
Right	51.6	11.6	50.3	7.7	0.649
Left	51.0	11.7	51.0	7.9	0.962
Ankle angle (dorsiflexion) (degrees)					
Right	19.0	5.9	19.4	3.9	0.922
Left	18.7	5.8	18.8	4.5	0.887

Table 2. Correlation coefficients for Wii Fit and CTSIB parameters for adults and elderly

		Adults (18 to 64 years)			Elderly (above 65 years)		
		Snowboard slalom	Ski slalom	Balance bubble	Snowboard slalom	Ski slalom	Balance bubble
CTSIB, rectangle area							
Condition 1	eyes open, firm surface	0.10	0.25	−0.05	−0.02	0.41	−0.30
Condition 2	eyes closed, firm surface	0.04	0.16	−0.08	−0.48*	0.06	−0.26
Condition 3	eyes conflicted, firm surface	0.07	0.12	0.11	−0.52*	−0.04	0.20
Condition 4	eyes open, foam surface	−0.02	0.09	−0.30*	−0.28	−0.15	−0.24
Condition 5	eyes closed, foam surface	0.13	0.22	−0.17	−0.08	0.27	0.02
Condition 6	eyes conflicted, foam surface	0.14	0.32*	−0.15	−0.31	−0.18	−0.33

*$p<0.05$.
CTSIB: Clinical Test of Sensory Integration for Balance.

Table 3. Differences between adults and elderly for Wii Fit and CTSIB parameters

		Adults (18 to 64 years) (n=50)		Elderly (above 65 years) (n=20)		p-value
		Mean	SD	Mean	SD	
Wii Fit						
Snowboard Slalom (sec)		93.8	20.4	105.6	16.1	0.024[†]
Ski Slalom (sec)		74.7	23.9	108.6	22.8	<0.001[†]
Balance Bubble (m)		505.9	312.6	339.1	210.4	0.013[†]
CTSIB, rectangle area (mm^2)						
Condition 1	eyes open, firm surface	437.6	198.9	566.7	259.7	0.060
Condition 2	eyes closed, firm surface	767.7	418.2	833.0	338.9	0.499
Condition 3	eyes conflicted, firm surface	671.5	364.5	753.0	379.7	0.354
Condition 4	eyes open, foam surface	951.2	402.8	1246.2	332.3	0.003[‡]
Condition 5	eyes closed, foam surface	2131.7	1057.4	3119.6	769.8	<0.001[‡]
Condition 6	eyes conflicted, foam surface	2032.2	837.8	2419.4	1062.9	0.271

[†]t-test, [‡]Mann-Whitney U test.
CTSIB: Clinical Test of Sensory Integration for Balance.

With regards to concurrent validity for the adults (Table 2), ski slalom and balance bubble demonstrated concurrent validity with condition 6, and condition 4 respectively (i.e. somatosensory conflicted conditions). Therefore, in the absence of a force platform, it may be possible to conduct assessments of postural sway using the same Wii Fit activities for adults. These findings also have implications for improving balance function in adults by selecting the balance tasks that uniquely challenges their somatosensory strategies, i.e. standing on foam surface.

With regards to concurrent validity for the elderly (Table 2), only snowboard slalom demonstrated significant negative correlations with conditions 2 and 3. In other words, the better their snowboard slalom score, the worse their CTSIB sway area for conditions 2 and 3 became. Since CTSIB is the "gold standard" for COP assessment of postural sway, this can only mean that Wii Fit has no concurrent validity for COP assessment in the elderly. A similar trend (albeit statistically not significant) was also seen in ski slalom, indicating no concurrent validity for this activity as well.

With regards to discriminant validity using the Wii Fit assessments (Table 3), all of the three balance activities selected for this study demonstrated the ability to discriminate between the adults and the elderly, i.e. the adults performed significantly better in all three activities compared with the elderly. While it may be possible that the adults were more familiar with *exergames*, we minimized this effect by selecting participants who had no prior experience with Wii Fit. The learning effect was minimized further by conducting the familiarization session through verbal explanations and demonstrations only, with no physical practice prior to testing. Therefore, the differences in the Wii Fit results could not be attributed to prior experience with *exergames* and could be due to actual differences in their balance ability because of their age disparities.

With regards to discriminant validity using the CTSIB assessments (Table 3), the discriminant validity for the CTSIB parameters were demonstrated only in conditions 4 and 5. This suggests that both adults and elderly participants performed differently only when their somatosensory input was challenged. When both their visual and somatosensory input were challenged (condition 6), or when only their visual input was challenged (conditions 2 and 3) the two groups demonstrated similar results.

Therefore, our results suggest that the deterioration in postural control in the healthy elderly may be due more to somatosensory rather than visual input. This contrasts with a report that "with age there is an increased dependence on visual information to maintain balance"[29]. This finding also has important implications for treatment of postural control in the elderly, i.e. balance exercises that challenge the somatosensory input for the elderly may be more effective.

A limitation of this study is that only three out of the eight balance activities in standing for the Wii Fit were evaluated. It may be necessary to evaluate the concurrent validity of the other five activities in future studies. Another limitation in our study was that the youngest age of our participants was 18 years. Results from previous studies suggest that children may also be different from adults in their preference for sensory input for control of postural sway[30]. It may be necessary to investigate three groups (children, adult and elderly) in future studies to determine the discriminant validity of Wii Fit and CTSIB as balance function matures and deteriorates with aging.

In conclusion, for adults, our results demonstrated that there was concurrent validity for the assessment of COP using Wii Fit ski slalom for CTSIB condition 6, and Wii Fit balance bubble for CTSIB condition 4. For the elderly, however, Wii Fit has no concurrent validity for the assessment of COP. Our results also demonstrated that the three Wii Fit balance activities selected in this study could be used to discriminate between adults and the elderly in their balance ability. Therefore, within the limitations of this study, we believe that Wii Fit is a viable and affordable alternative to CTSIB performed on a conventional force platform for the assessment of postural sway.

Funding and Conflict of interest

None.

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