Comparison of vertical ground reaction forces between female elderly and young adults during sit-to-stand and gait using the Nintendo Wii Balance Board

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Objective: The purpose of this study was to analyze and compare vertical ground reaction forces during sit to stand (STS) and gait between female elderly and young individuals using the Wii Balance Board (WBB).

Design: Cross-sectional study.

Methods: Fifty-one female elderly people (age: 75.18±4.60 years), and 13 young people (age: 29.85±3.69 years) performed the five times STS test and gait respectively on the WBB. We analyzed time (s), vertical peak (%), integral summation (Int_SUM, %), and counter variables (%) in STS and 1st peak (body weight, BW%), 2nd peak (BW%), peak minimum (BW%), time (second), center of pressure (COP) path length (mm), and Int_SUM (BW%) in gait. The independent t-test was used to assess for differences in STS, gait ability, and general characteristics between the female elderly group and young adults group. With the first and last trials excluded, the mean value was obtained from the middle three of the five trials.

Results: During STS, Int_SUM and time of young adults were significantly less than of the female elderly subjects. There were no significant differences in peak and counter variables. In gait, all variables (1st peak, 2nd peak, min, time, COP_path, and Int_SUM) showed significant differences between groups ($p<0.05$). This study demonstrated that the validity of vertical ground reaction forces occurring during STS and gait was significant in female elderly and young adults.

Conclusions: Based on the measurement of vertical ground reaction forces in STS and gait using the WBB, it is possible to clinically improve the quality of geriatric physical therapy. Further studies are necessary to examine concurrent validity of elderly patients who have undergone total hip or knee replacement.

Key Words: Biomedical technology, Geriatric assessment, Postural balance

Introduction

As aging occurs, the body structure and function is impaired and the movement of an elderly person is reduced. Decreased movement weakens muscle strength, leads to impaired neuromuscular dysfunction and balance control, resulting in a vicious cycle in which mobility is reduced in daily life [1-3].

In clinical practice, sit-to-stand (STS) and walking ability is assessed to determine the strength, balance, and level of movement of the elderly population [4,5]. The STS movement, which is mainly used in everyday life, can be used to evaluate the strength and coordination of the body and lower extremities [6,7]. Walking is also a necessary dynamic balancing ability for independent living, and it is also a key indicator for monitoring intervention effects in the clinical set-

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ting [8-10].

The vertical ground reaction force generated during walking and STS is a factor that can compare physical activity level according to age [11,12]. During walking and STS, the two feet are forced to the ground and the vertical ground reaction force acts in the opposite direction [13]. In the elderly, the moment the hip joint was lifted from the chair during STS, the vertical ground reaction force was significantly lowered at the stage of extending the knee-hip joint [14]. During walking, a high vertical ground reaction force occurred in the early and late stance phase, and the vertical ground reaction force was the lowest in the middle stance. In the elderly, the vertical ground reaction force was less than that of the young adults [11].

In previous studies, the vertical ground reaction force in STS motion has been suggested as a parameter for evaluating dynamic lower extremity strength of the elderly [15,16]. In particular, there was a moderate correlation ($r=0.39-0.43$) between the maximum torque and mean force of isokinetic 60° knee flexion/extension and ankle plantar flexion during STS and with the vertical ground reaction force [17]. In addition, physical activity and risk of falls were significantly correlated ($r=0.26-0.41$) with the vertical ground reaction force generated when lifting the hips from the STS stage and knee-to-hip joint deployment [14]. Similarly, the maximum vertical ground reaction force generated during the stance phase of the gait has been reported to be associated with functional movements, such as walking speed, timed up and go test, and functional stretch in women [18].

The STS movement and gait analysis of the healthy elderly have mainly been performed by motion analyses and force plates [12,19]. The Nintendo Wii Balance Board (WBB) is an easy to use, simple, portable device for clinical use compared to motion analyses and force plates [20].

Studies comparing the concurrent validity of the WBB and force plate showed a high intra-class correlation coefficient (ICC) during STS was between 0.701 and 0.994 and the ICC was 0.869-0.989 during gait. To date, studies using WBB have measured STS, gait and balance for adults and stroke patients [21-23] and demonstrated the feasibility of using the WBB as a quantitative assessment tool.

The purpose of this study was to measure the vertical ground reaction force during walking and STS of healthy elderly women and to extend the application range of the WBB by comparing with healthy adults. The purpose of this study was to assess the STS and walking ground reaction force of healthy elderly women with the WBB and compare

with healthy adults. The research hypothesis is that STS and walking response will differ between female elderly and young adults.

Methods

Study subjects

This study was conducted on 51 elderly women aged 65 years or older and 13 young adults living in Daejeon. The elderly and young adult selection criteria were as follows: those without neurological or musculoskeletal disorders and those who were able to sit up and walk independently without assistance. The exclusion criterion was any presence of orthopedic disorders or inability to communicate or understand instructions of the research process.

The process of this study was approved by the Research Ethics Committee of Konyang University (approval No. KYU-2018-121-01), and the participants agreed with the purpose and method of this study.

Assessment tools

The WBB (Nintendo, Redmond, WA, USA) collects information continuously over four load cells at the corners and wirelessly connects to the computer using Bluetooth. Data were collected using Balancia software ver. 2.0 (Mintosys Inc., Seoul, Korea) and data sampling was performed at 100 Hz [21].

Measurement variable

The center of pressure (COP) and body weight (BW) % values were extracted from STS and walking, and the following variables were obtained. The variables used for the analysis in STS were integral summation (Int_SUM, BW%), time (s), counter (BW%), and peak (BW%). The 1st peak (BW%), 2nd peak (BW%), peak minimum (BW%), time (s), COP path length (mm) and Int_SUM (BW%) was assessed during gait.

Two values of counter force and vertical peak force were extracted during STS. Counter refers to the ground reaction force observed as a decrease in vertical force after starting the counter activity. That is, the pressure on the foot is reduced before the weight is applied to perform the action that takes place while sitting.

Peak value refers to the maximum value of the vertical ground reaction force generated when the knee and torso begin to extend at the same time. In walking, only the ground reaction force of the stance phase is extracted and the values

of heel contact and toe-off times are extracted.

The heel contact is the first part of the stance phase. When the heel touches the ground, the repulsive force is the first peak in the stance phase (1st peak). Toe-off is the step of releasing the tip of the toe in order to move the body forward. This is the second peak of the ground reaction force (2nd peak).

Measurement process

STS measurements were made in a sitting position in a chair 45 cm in height with no armrests. Both feet were placed at equal distance from the center of the WBB (Figure 1A). Starting from a sitting position, after pressing the data save button and 3 seconds had passed, the 'start' signal had been given for the subject to stand up at a comfortable and safe speed. The subject was asked to maintain the standing position for 3 seconds.

For gait measurements, subjects walked approximately 6 m on a wooden board that was the same height as the WBB, and the WBB was in the center (Figure 1B). The starting position was set at the position of WBB for the stance phase to occur. Each subject was allowed to walk at a comfortable and safe speed at the start signal. The subjects were instructed to step over the WBB with the dominant foot, and a sticker was attached at the height of the subject's eye to allow for the subject to gaze at the front and walk. The evaluator was located within 1 meter from the subject in case there was a risk of falls.

All subjects were instructed to practice STS and walking sufficiently, and were measured 5 times each. After the assessment of STS, a 5-minute rest-interval was provided, fol-

lowed by gait assessment. All assessments were completed within 30 minutes per subject, including break time and practice time.

Statistical analysis

The statistical processing was performed with PASW Statistics ver. 18.0 software (IBM Co., Armonk, NY, USA) and the mean and standard deviation (mean $\pm$ standard deviation) of each group were calculated. Independent sample t-test was conducted to determine the differences in general characteristics, STS and gait ability of the elderly and young adults, and statistical significance was set at $\alpha=0.05$. With the exception of the first and 5th trial, the average of the middle three trials were obtained.

Results

General characteristics of subjects

Table 1 shows the general characteristics of the subjects. There was a significant difference between the two groups in the Int_SUM and time during STS. There was no significant difference between the two groups in peak and counter values during STS (Table 2).

There was a significant difference between the two groups in all variables (1st peak, 2nd peak, min, time, COP_path, Int_SUM) during walking (Table 3). The first peak (BW%) and the second peak (BW%) of the elderly women during walking were $100.18\pm3.75\%$ and $100.93\pm2.90\%$, respectively, lower than those of young adults ($106.49\pm7.18\%$ and $108.59\pm3.56\%$ ($p<0.05$)).

During STS, the maximum vertical ground reaction force

Figure 1. Experimental process of (A) sit-to-stand and (B) gait.

Table 1. General characteristics of participants

(N=64)

Variable	Elderly women (n=51)	Young adults (n=13)	t(p)
Sex (male/female)	0/51	6/7	
Age (y)	75.18 (4.60)	29.85 (3.69)	0.591 (<0.001)
Height (cm)	151.79 (6.46)	168.38 (10.36)	5.615 (<0.001)
Weight (kg)	56.52 (7.16)	66.35 (17.19)	18.050 (0.065)

Values are presented as number only or mean (SD).

Table 2. Comparison of sit to stand between groups

(N=64)

Variable	Elderly women (n=51)	Young adults (n=13)	Mean difference	t(p)
Int_SUM (BW%)	148.65 (34.76)	119.22 (15.22)	29.44	6.549 (<0.001)
Time (s)	2.03 (0.49)	1.83 (0.16)	0.20	10.370 (0.015)
Peak (BW%)	116.13 (5.62)	115.42 (4.08)	0.72	1.316 (0.648)
Counter (BW%)	6.09 (3.68)	6.54 (3.14)	0.44	1.103 (0.691)

Values are presented as mean (SD).

Int_SUM: integral summation, BW: body weight.

Table 3. Comparison of gait ability between groups

(N=64)

Variable	Elderly women (n=51)	Young adults (n=13)	Mean difference	t(p)
1st peak (BW%)	100.18 (3.75)	106.49 (7.18)	6.31	6.946 (0.009)
2nd peak (BW%)	100.93 (2.90)	108.59 (3.56)	7.65	0.177 (<0.001)
Min (BW%)	90.06 (2.66)	81.72 (4.00)	8.34	2.847 (<0.001)
Time (s)	0.72 (0.09)	0.54 (0.06)	0.18	1.317 (<0.001)
COP_path (mm)	24.74 (4.08)	27.43 (3.46)	2.69	0.114 (0.033)
Int_SUM (BW%)	5.79 (0.68)	4.52 (0.46)	1.27	1.696 (<0.001)

Values are presented as mean (SD).

BW: body weight, min: peak minimum, COP_path: central of pressure path length, Int_SUM: integral summation.

of female elderly and young adults was $116.13\% \pm 5.62\%$ and $115.42\% \pm 4.08\%$, respectively, and the peak value of female elderly was higher than that of female elderly. A 0.49 (s), younger adults were 1.83 ± 0.16 (s) and older women were older ($p < 0.05$). The walking time of the elderly women was 0.72 ± 0.09 (s), which was longer than that of young adults (0.54 ± 0.06 s) ($p < 0.05$).

Discussion

As the degenerative changes in the elderly body are found, lower extremity strength is weakened and balance is decreased compared to healthy adults [24]. The older the elderly become, the more likely they are to fall and become physically injured. The possibility of falls is twice as high in female than that of male elderly persons and so it is necessary to evaluate the physical changes of elderly women in

particular [25]. STS and gait are simple and useful clinical evaluation methods to confirm lower extremity strength and balance ability of the elderly. Therefore, the purpose of this study was to evaluate the characteristics of the vertical ground reaction force during STS and walking in female elderly subjects using the WBB, which is suitable for clinical use, and to compare with the vertical ground reaction force of healthy young adults.

In contrast to this study hypothesis, the maximal vertical ground reaction force during STS was not significantly different between female and young adults. However, the maximum vertical ground reaction force of the female elderly subjects was lower than that of young adults in gait, and there was a significant difference between the two groups.

Fifty healthy elderly women with an average age of 69.8 years underwent two STS sessions, confirming the reliability of measuring the repulsive force of the ground plate

[16]. The results were $118\% \pm 11.0\%$ and $117\% \pm 13.0\%$, respectively, which was very similar to the maximum vertical ground reaction force of $116\% \pm 5.6\%$ in 51 healthy elderly women. In a study by Yamada and Demura [16], STS was applied in a similar way except that the height of the chair was adjusted to the knee height of the subject, and the results obtained by the WBB appeared to be similar to those obtained by the force plate.

Vander Linden *et al.* [26] also showed similar results. Both studies allowed the subjects to perform STS at a comfortable rate. The peak value of the previous studies on 7 elderly women and 1 male elderly people was $115\% \pm 8.1\%$. The mean peak value of this study was $116\% \pm 5.7\%$. Considering that there was a higher proportion of elderly women in the previous studies, this was considered to be a meaningful comparison. According to Linden's study, the peak value increased when STS was performed at a faster rate compared to a comfortable rate. The higher the velocity of STS, the greater the momentum of the center of gravity, which is thought to have had an effect on the vertical ground reaction force [27,28].

The peak value of this study was higher than that of a study by Millington *et al.* [29], which confirmed the peak value during STS in 10 elderly people. The mean peak value of the subjects in Millington's study [29] was $111\% \pm 4.0\%$. Previous studies did not control the speed of STS, and although arms were allowed to be used, they were not allowed to create a pushing force. On the other hand, in this study, upper limb movements were relatively restricted by having the subjects cross their arms across their chests. In addition, although the subjects' movement patterns (pelvis, knee, and torso) were similar, there was a difference between the subjects in the upper limb movements (elbow and shoulder) and most of the subjects used shoulder flexion and elbow flexion during half of the STS movement [29].

Considering these results, we suspect that the limitation of upper limb movements may have affected the peak value. It is also difficult to compare the results of our study that included only female elderly people and with existing studies that included 5 male elderly and 5 female elderly participants.

There was no difference in the vertical ground reaction force between STS of elderly women and young adults. We did not measure the physical abilities of female elderly and young adults, but they appeared to have vertical ground resilience similar to that of young adults because they were healthy elderly women living in the community. Although the elderly women took more time to perform STS than the

healthy adults and were slower at a comfortable speed condition, it did not seem to affect the reaction force difference considering that previous results showed that there was no difference in the maximum joint torque between healthy elderly and young adults.

In this study, there was a significant difference in vertical ground reaction forces between the elderly female and young adults during walking. Toda *et al.* [11] also found that elderly women had lower vertical ground reaction forces compared to younger adults at both 1st peak and 2nd peak, respectively. This study partially agrees with the results of Toda *et al.* [11] on the vertical ground reaction force of the elderly women during gait. In the previous study, the second peak of female elderly was lower than that of younger adults and was statistically significant. The second peak is the push-off phase at the end of the stance phase. In particular, the plantar moment of the elderly was much lower than those of the male elderly and young adults. This study suggests that when female elderly persons control the vertical ground reaction force during walking, the plantar moment is smaller and the second peak value is lower than that of young adults.

The results of the study by Stergiou *et al.* [12] were different from those presented in this study. The results showed that there was no difference in the vertical ground reaction force between the two groups during walking. On the other hand, the results of this study showed that 1st peak and 2nd peak of young adults were much higher and were different than the female elderly people. Walking at a fast pace causes a larger vertical ground reaction force, and the walking speed of the elderly women is slower than that of the younger persons, and the length of one step is shorter [30,31]. It is considered that the results of this study shows a more accurate difference compared to previous studies because it consisted of young male and female subjects.

There are some limitations in interpreting the results of this study. First, the number of young adults was small compared to the number of elderly women, rendering the results to be somewhat difficult for generalization. However, in previous studies [21], WBB was used in healthy young adults and proved the validity of ground reaction force in walking with STS. The healthy young adults were composed of 9 males and 8 females, which was close to 1 to 1.

Thirteen young adults participated in this study, which consisted a similar ratio males and females with six males and seven females. The data were normally distributed, and the gait characteristics of young adults were not found to be highly variable.

Second, since the results cannot be applied to the elderly male population, future studies should use the WBB to confirm the vertical ground reaction force during STS and walking of the elderly male population.

Third, the COP_path length (mm) value during walking was not standardized to the subject's foot size, which made it difficult to interpret.

This study was conducted with healthy elderly women. In a follow-up study, we recommend that the WBB be used to study the vertical ground reaction force of the elderly with a history of knee and hip arthroplasty. Data from this study will serve as the basis for future clinical decisions and may improve the qualitative aspects of geriatric physical therapy. The results of this study can provide a basis for vertical ground reaction force during STS and walking of female elderly and young adults.

The purpose of this study was to evaluate the usefulness of the WBB as a quantitative evaluation device for assessing the vertical ground reaction force to compare the extracted data of the vertical ground reaction force during STS and walking for geriatric physical therapy. According to the results of the study, the elderly women in STS showed higher vertical ground reaction force than young adults, but showed no significant difference. On the other hand, during walking, female elderly showed lower vertical ground reaction force than young adults, and the difference was significant. Therefore, the WBB can quantitatively evaluate STS and walking ability of the female elderly population. Future research will need to investigate the validity of the vertical ground reaction force of the elderly with a history of knee and hip arthroplasty using the WBB.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

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