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ORIGINAL

Development of Core Strength Training Equipment and Its Effect on the Performance and Stability of the Elderly in Activities of Daily Living

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Objective: This study aimed, first, to develop core strength training equipment with elderly-friendly, easy-to-use features and, second, to investigate the effect of core strength training using the equipment on the performance and stability of the elderly in activities of daily living.

Method: In this study, we developed training equipment with a stability ball that can be used for performing core strength exercises in the elderly. Twenty-three elderly subjects (age: 77.87 ± 6.95 years, height: 149.78 ± 6.95 cm, and weight: 60.57 ± 7.21 kg) participated in this study. The subjects performed the core strength training exercise with 16 repetitions for 8 weeks (2 repetitions per week). Performance in activities of daily living was assessed by using the Short Physical Performance Battery (SPPB), a test of going up and down 4 stairs, and one-leg static balance test. Stability was quantified as changes in the center of pressure (COP) and C90 area.

Results: With the core strength equipment, trunk core strength exercise could be performed by pulling or pushing a rope with 2 hands on the stability ball. During the task, the tension in the rope was manipulated by a motor connected to the rope and the COP of the subject was measured by 4 load cells mounted in the equipment. Our results showed that the SPPB score was significantly higher ($p < .05$), the time to complete the "going up and down 4 stairs" test was significantly shorter ($p < .05$), and one-leg static balance statistically improved under an eyes-open condition ($p < .05$) after as compared with before the core strength training. The changes in the COP in the anteroposterior and mediolateral directions, and C90 area were significantly lower in the posttest ($p <. 05$) than in the pretest.

Conclusion: The core strength training exercise using the equipment developed in the present study improved the performance and stability of the elderly in activities of daily living.

Keywords: Core strength exercise equipment, Development, Older adult, COP, Activities of daily living

INTRODUCTION

The increasing elderly population heightened the prevalence of chronic diseases in the elderly and the incidences of fall-related injuries, which gradually increased the per capita healthcare expenditures (Reinhardt, 2003; Rubenstein, 2006). Aging-associated physical changes alter and aggravate the central nervous system (e.g., loss of sensory and motor neurons), neuromuscular system (e.g., type 2 muscle fiber atrophy), and skeletal system. These in turn are associated with severe kyphosis, which ultimately cripples postural control and diminishes strength and resistance, in the elderly (Callisaya, Blizzard, Schmidt, McGinley, & Srikanth, 2010; Kasukawa et al., 2010; Katzman, Vittinghoff, & Kado, 2011). In this regard, several studies have made efforts from various perspectives to enhance the physical functions related to posture in the elderly, such as increasing muscle strength, resistance, and balance. In addition, many preceding studies reported that increased lower limb muscle strength reduced older adults' risk of fall-related injuries and increased the stability of dynamic postures (Granacher, Muehlbaue, Zahner, Gollhofer, & Kressig, 2011; Granacher, Zahner, & Gollhofer, 2008; Park, Kim, Kim, Lee, & Lim, 2010).

However, the recent research trend emphasizes the importance of enhancing core strength for successful movements in activities of daily living and sports-related activities (Akuthota & Nadler, 2004; Granacher, Lacroix, Muehlbauer, Roettger, & Gollhofer, 2012). Core muscle refers

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to the muscles of the spine, abdomen, and hips, which support the muscles of the extremities in completing functional activities without stressing the spine (Kisner & Colby, 2002). Core muscles are a kinematical link that facilitates the delivery of momentum and torque between the upper and lower limbs while performing a sports technique (Behm, Drinkwater, Willardson, & Cowley, 2010). Furthermore, they are especially deemed important for performing activities of daily living because they provide proximal stability for distal motility (Kibler, Press, & Sciascia, 2006).

Several prior studies on enhancing core strength in the elderly have been conducted. In particular, Suri, Kiely, Leveille, Frontera, & Bean (2009) verified that an association among increased trunk muscle strength, balance, and daily functions. Hicks et al. (2005) reported that trunk muscle composition is a predictor of functional stability of the elderly. In addition, many scholars believe that core strength training has the potential of strengthening trunk muscles, controlling posture, and improving balance, and functional stability in the elderly (Hicks et al., 2005; Katzman, Vittinghoff, & Kado, 2011; Suri et al., 2009).

Despite that, several preceding studies revealed that the benefits of core strength training promoted the improvement of performance in activities of daily living and postural stability in the elderly, core strength training has not been widely disseminated because of the difficulty associated with performing the exercise. In general, the sit-ups is a classical exercise that increases trunk muscle strength but is not safe for the elderly because of the potential of causing excessive pressure on the lumbar spine (Bogduk, 2005; Juker, McGill, Kropf, & Steffen, 1998). Furthermore, patients are frequently exposed to the risk of posterior injuries during resistance exercise in core strength training. In particular, heavy resistance training of the spinal extensors may excessively strain the body (Akuthota & Nadler, 2004). The common and effective core strengthening exercises for core instability strength training include yoga (Ni, Mooney, Harriell, Balachandran, & Signorile, 2014; Schmid, Van Puymbroeck, & Koceja, 2010) and Pilates (Newell, Shead, & Sloane, 2012; Smith & Smith, 2005). However, these exercise programs are usually performed as group exercises, which poses problems in generating effective outcome in the elderly, as the elderly have difficulty maintaining appropriate posture by themselves.

We recognized that older adults need to create an environment for performing effective core-strengthening exercises on their own. Thus, a core-strengthening exercise system that does not overly strain the elderly and could be performed without assistance should be devised. Hence, the present study developed a core strength training device for the elderly that is elderly-friendly and easy to maneuver. The objective of this study was to analyze physical performance and changes in the center of pressure (COP) during exercise to verify the effects of exercise using our core strength training equipment on older adults' performance of activities of daily living and core muscle strength.

METHODS

1. Subjects

This study was conducted with 23 female healthy adults aged ≥65 years who were from Seoul and had no musculoskeletal impairments. The mean age of the subjects was 77.87 ± 6.95 years, their mean height was 149.78 ± 6.95 cm, and their mean weight was 60.5 7 ± 7.21 kg. The investigator provided adequate explanation regarding the study procedure and obtained informed consent from all the participants. This study was approved by the institutional review board at Hanyang University (IRB: HYI-12-044-Comp2).

2. Design of the core strength training equipment for the elderly

1) External design of the exercise equipment

We designed a physical fitness device that is useful for strengthening the core trunk muscles by inducing instability on the surface of the subject's seat (gym ball shaped) while performing upper limb exercise only (pulling on the arms), without involving the lower limbs. The equipment was easy to maneuver by the elderly. The equipment was designed to provide information related to the movement of the center of gravity as exercise feedback to help the users focus on using the core-related muscles during exercise.

2) Software design

To stimulate the interest of the elderly while exercising and to make exercising fun, several Korean folk and trot songs were embedded in the software to be synchronized with the exercise. In addition, we provided further motivation to exercise by designing the equipment to present a score after the training session.

3. Exercise program composition

The 23 female subjects used the core strength training equipment that we designed to exercise twice per week for 8 weeks (16 sessions). The composition of the program is shown in (Table 1).

4. Measurement items and methods

1) Body Composition

Height and weight were measured by using an automatic scale (SH-9600A, Sewoo system). Body composition was measured with a body composition analyzer (Inbody 4.0, Biospace) that utilizes bioelectrical impedance. Body mass index (BMI) was calculated by using the equation suggested by the American College of Sports Medicine as follows: body weight (kg) divided by height squared (m^2).

2) Activities of daily living

Performance in activities of daily living was measured by using the Short Physical Performance Battery (SPPB) protocol, "going up and down 4 stairs" test, and one-leg static balance test. Measurement methods are detailed as follows:

Table 1. The 8-week core training program

Training week	Composition
1	Stretching (5 min)/Low level of the core program (10 min)/Stretching (5 min)
2	Stretching (5 min)/Low level of the core program (10 min)/Stretching (5 min)
3	Stretching (5 min)/Low (5 min) and middle levels (10 min) of the core program/Stretching (5 min)
4	Stretching (5 min)/Low (5 min) and middle levels (10 min) of the core program/Stretching (5 min)
5	Stretching (5 min)/Middle level of the core program (15 min)/Stretching (5 min)
6	Stretching (5 min)/Middle (5 min) and high levels (10 min) of the core program/Stretching (5 min)
7	Stretching (5 min)/Middle (10 min) and high levels (10 min) of the core program/Stretching (5 min)
8	Stretching (5 min)/Middle (10 min) and high levels (10 min) of the core program/Stretching (5 min)

(1) Short physical performance battery

The SPPB comprises a balance test, repeated chair stands, and walking. The 3 scores were summed (total of 12 points) to measure performance in activities of daily living. All time measurements were obtained from the point closest to 0.1 second after beginning the stopwatch. Each measurement was graded 0~4 points based on the subject's performance, with a total score of up to 12 points (Guralnik et al., 2000).

① Balance test

The balance test involved side-by-side, semi-tandem, and tandem stance. In the side-by-side stance, the subject stands with the feet spread in shoulder length and arms comfortably dropped along the sides of the body. In the semi-tandem stance, the subject stands with the 2 feet together but with one foot touching only half of the other foot. In the tandem stance, the subject stands with the heel of one foot touching the toes of the other foot. Grading was based on whether the subject could maintain each stance for >10 seconds, so we did not measure time of >60 seconds. One point was given if the subject could maintain the side-by-side and semi-tandem stance for >10 seconds. For tandem stance, 1 point was given for maintaining the stance for >3 seconds; and 2 points, for maintaining the stance for >10 seconds. The total score in the balance test was up to 3 points.

② Gait speed

During the gait test, the subjects were instructed to walk 4 m in their regular gait speed and graded as follows according to the time it took to perform the test: 0 point, if the subject could not perform the walking test; 1 point, >8.7 seconds; 2 points, 6.21~8.7 seconds; 3 points, 4.82~6.20 seconds; and ≥4 points, 4.82 seconds. Gait speed was measured 2 times, and the faster time was used for the analysis.

③ Repeated chair stands (5 times)

In repeated chair stands, the subject was timed for performing 5 sets of standing up from a chair and sitting back down with arms folded across the chest, as quickly as possible. The subjects were graded as follows according to the time it took to complete the test: 0 points, if the subject could not perform the task or took >60 seconds; 1 point, >16.7 seconds; 2 points, 13.7~16.69 seconds; 3 points, 11.2~13.69 seconds; and 4 points, ≥11.19 seconds.

(2) Going up and down 4 stairs

The subjects began the exercise upon receiving a cue from the investigator, and the investigator timed the subjects from the moment the subjects began going down 4 stairs until they came back up 4 stairs and rested both feet on the starting point.

(3) One-leg static balance

For one-leg static balance, the subjects were instructed to balance on one leg with their hands crossed over their chest. The investigator timed them from the point they lifted one leg until they landed the leg back on the ground. Two types of static balance were assessed, one with open eyes and the other with closed eyes.

3) COP measurement

To provide feedback on the core exercises based on the change in the center of gravity while training with the core strength training equipment, we installed 4 load cells beneath the surface of the seat, based on which we calculated the COP. We accumulated COP data for a total of 16 exercise sessions (twice a week for 8 weeks).

5. Data analyses

1) Body composition and daily activity performance test

All the variables in this study are presented as means and standard deviations. Paired *t* tests were performed to examine changes in body composition, SPPB, "going up and down stairs", and one-leg static balance test scores from before to after the 8-week training.

2) COP calculation

The weekly mean COP was calculated. Then, we analyzed the 8-week data to verify the weekly changes during the 8-week training. We visualized the phase plane portrait of the anterioposterior (AP) and mediolateral (ML) signals, which is a method known to provide static and dynamic plane information in consideration of both position and speed in the COP (Riley, Benda, Gill-Body, & Krebs, 1995). The AP COP, ML COP, total COP, and C90 area were calculated by using the equations shown in (Table 2) (Moghadam et al., 2011).

We performed repeated-measures analysis of variance to analyze the 8-week AP COP, ML COP, total COP, and COP 90 area data (mean of the 2 rounds of training per week) and conducted a simple post hoc test on the weekly data. All the statistical analyses were performed by

Table 2. The formulae for calculating the COP parameters

Parameter	Formula
	Phase plane portrait (arbitrary unit)
AP	$\sigma_{r_x} = \sqrt{\sigma_x^2 + \sigma_{v_x}^2}$ where $\sigma_x = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{N-1}}$, $\sigma_{v_x} = \sqrt{\frac{\Sigma(v_{x_i} - \bar{v})^2}{N-1}}$, $v_{x_i} = \frac{x_i + 1 - x_i}{t_i + 1 - t_i}$
ML	$\sigma_{r_y} = \sqrt{\sigma_x^2 + \sigma_{v_y}^2}$ where $\sigma_y = \sqrt{\frac{\Sigma(y_i - \bar{y})^2}{N-1}}$, $\sigma_{v_y} = \sqrt{\frac{\Sigma(v_{y_i} - \bar{v})^2}{N-1}}$, $v_{y_i} = \frac{y_i + 1 - y_i}{t_i + 1 - t_i}$
Total	$\sigma_{r_t} = \sqrt{\sigma_{r_x}^2 + \sigma_{r_y}^2}$
Area (mm^2)	$A = 2\pi F_{0.05[2,N-2]} \sqrt{\sigma_x^2 \sigma_y^2 + \sigma_{xy}^2}$ where $\sigma_{xy} = \frac{(x_i - x)(y_i - y)}{N-1}$

COP: center of pressure; AP: anteroposterior; ML: mediolateral.

using PASW Statistics 18.0 with a significance level of $p < .05$.

RESULTS

1. Development of the core strength training equipment for the elderly

In the present study, we developed core strength training equipment for the elderly (patent application No. 10-2015-0067635). The equipment enabled the elderly to sit on a gym ball-type BOSU ball and pull the rope connected to a motor load to the direction instructed by the program (e.g., upper and lower diagonal), or to maintain their posture while pulling the rope with their arms. The subjects were instructed to maintain the center of their body at the center of the BOSU ball and not to lean toward the pulling direction of the rope in order to induce contraction of their abdominal, external oblique abdominal, back, lumbar, and gluteus medius muscles, thereby strengthening their core muscles.

As shown in (Figure 1), the newly developed training equipment could be explained in terms of its hardware and software. The hardware comprises a BOSU ball with an adjustable height (with load cells beneath the ball to track the shifting of the COP), a rope that can also be adjusted to fit the height of the user's elbows (2 motions are available: pulling using a motor and holding out), a safety bar for safety during the exercise, and a monitor that runs the training program

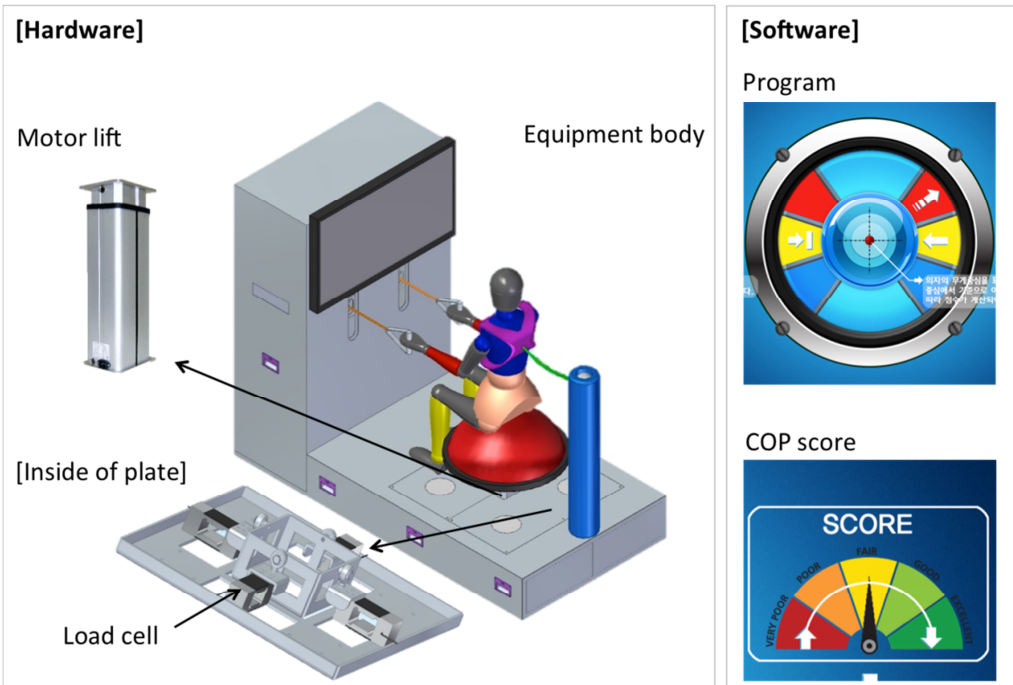

Figure 1. Development of the core exercise equipment for older adults.

software (with a touchscreen feature).

The software comprises of 10 trot songs and 8 Korean folk songs, which can be selected by the user, and arrows are shown on the screen (pull: upper diagonal, lower diagonal; hold out: inner arrow) while the music is playing. The monitor also presents a mark that shows the position of the center of gravity in real time; thus, the mark moves according to the trajectory of the shift of the user's center of gravity. When one training session (one song) is completed, the movement range of the COP (sum of AP and ML movements) is presented as the final feedback score. The training program consists of 3 levels of difficulty (beginning, intermediate, and advanced), where the instructed motions become increasingly complex with higher levels of difficulty.

2. Body composition test

(Table 3) presents the significant differences in weight, skeletal muscle mass, fat mass, BMI, percent body fat, and basal metabolic rate between the pre- and post-8-week training (p < .05).

Table 3. Body composition of the subjects

Variable \ Test	Pre	Post	t value
Weight (kg)	60.57 ± 7.24	59.48 ± 7.47	3.272*
Skeletal muscle mass (kg)	19.00 ± 2.15	19.61 ± 2.02	3.480*
Fat mass (kg)	24.30 ± 5.68	22.52 ± 5.82	5.096*
BMI (kg/m^2)	27.09 ± 3.37	26.35 ± 3.13	3.364*
Percent body fat (%)	40.04 ± 5.66	37.39 ± 5.63	4.985*
Basal metabolic rate (kcal)	115.39 ± 80.13	1169.00 ± 73.73	3.257*

Data are expressed as mean ± SD and significant at *p < .05.

3. Daily activity performance test

(Table 4) shows the subjects' SPPB, "going up and down the stairs", and one-leg static balance test scores before and after the 8-week training using the core strength training equipment. The total SPPB score was significantly higher after the training (p < .05), and the time required for going up and down 4 stairs was significantly shorter after the training (p < .05). In the one-leg static balance test, a significant difference was observed between pre- and post-training with open eyes only (p < .05).

4. Center of pressure

In the present study, COP was calculated by using the following 4 parameters to examine the effects of training with the core strength training equipment in the elderly: AP COP, ML COP, total COP, and COP 90 area (Figure 2). A significant difference in AP COP was observed after 8 weeks of training (F = 4.345 and p = .000). The simple post hoc test of weekly data showed an F value of 10.244 and p value of .008 on week 4. The difference in ML COP after 8 weeks of training was significant (F = 4.425 and p = .000). The simple test result showed an F value of 11.119 and a p value of .006 on week 4. The difference in total COP after 8 weeks of training was significant (F = 4.425 and p = .000). The simple test results showed an F value of 11.119 and p value of .006 on week 4. Finally, a significant difference in COP 90 area after 8 weeks of training was observed (F = 3.417 and p = .003), and the simple test revealed an F value of 7.298 and a p value of .019 on week 4 and an F value of 5.371 and a p value of .039 on week 7.

Table 4. Results of the SPPB, "going up and down of 4 stairs", and one-leg static balance tests

(unit: sec)

Variable \ Test			Pre	Post	t value
SPPB	Balance	Side-by-side stance	55.65 ± 14.41	60.00 ± 0.00	1.447
		Semi-tandem stance	53.39 ± 15.83	60.00 ± 0.00	2.003
		Tandem stance	36.22 ± 19.98	34.00 ± 20.73	0.401
	Gait speed		4.00 ± 1.28	3.43 ± 0.73	2.418*
	Rising from a chair 5 times		10.44 ± 6.07	8.51 ± 2.54	2.127*
	Total SPPB score		11.30 ± 1.40	11.70 ± 0.77	2.598*
Going up and down 4 stairs			8.55 ± 4.39	5.24 ± 2.47	3.449*
One-leg static balance test	Open eyes		4.70 ± 3.93	7.15 ± 5.01	2.124*
	Closed eyes		2.00 ± 1.85	1.93 ± 1.12	0.182

Data are expressed as mean ± SD and significant at *p < .05.

DISCUSSION

The core strength training equipment developed in the present study enabled the elderly to exercise according to a program that incorporates music (trot and Korean folk songs) with exercise. Users start from a starting position at elbow height and either pulls the rope upward or downward diagonal or hold out their starting position while pulling the rope pulls with their arms, during which their rectus abdominus and external oblique abdominal muscles are contracted and their back and psoas muscles are extended.

After 8 weeks of training using the newly developed equipment, the subjects' body compositions improved, including increased skeletal muscle mass and reduced BMI. SPPB score, which is closely related to bodily functions, also increased. According to a preceding study, trunk

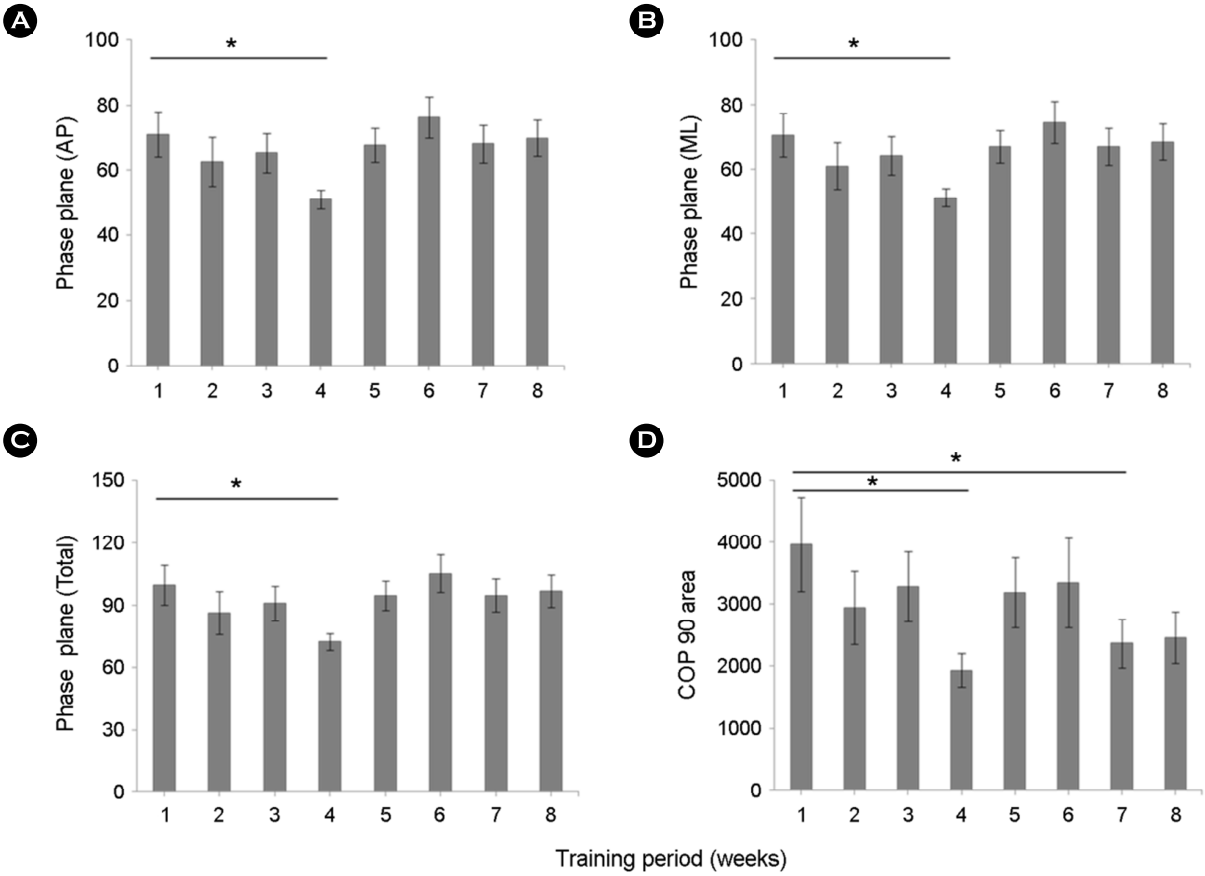

Figure 2. COP data during the training period. COP: center of pressure, AP: anterioposterior, ML: mediolateral, Total: sum of AP and ML. The units of the COP parameters are as follows: mm^2 (COP 90 area) and an arbitrary unit for the phase plane. *p < .05, **p < .01, significance levels.

extension exercise increased the SPPB scores of the elderly (Granacher et al., 2012), and core stabilizing exercise based on a Pilates program significantly increased the elderly's gait speed (Newell, Shead, & Sloane, 2012). The findings of this study, where SPPB scores significantly increased after training using the core strength training equipment and where the elderly's gait speed (subfactor of SPPB) significantly increased after training, support the result of preceding studies. In particular, our study seems especially associated with the study by Newell, Shead, and Sloane (2012), suggesting that 8 weeks of core stabilizing exercise affected the older adults' gait, as both studies have examined equal exercise durations.

Meanwhile, from the perspective that trunk muscles are essential for maximizing the functions of various activities such as walking, running, going up the stairs, and minimizing weight load on joints (Ryerson, Byl, Brown, Wong, & Hidler, 2008), the significantly increased speed for going up and down the stairs in the present study implies that exercise using the developed core strength training equipment may affect the dynamic balance of the elderly. Several studies have confirmed that trunk exercise affected not only older adults' performance in activities of daily living but also their dynamic and static balance (Lee et al., 2013; O'Sullivan, 2000; Stevens et al., 2007). Similarly, the present study also confirmed that core-strengthening exercise enhanced the elderly's performance in going up and down the stairs and in maintaining one-leg static balance with eyes open. Hence, the training equipment developed in the present study is believed to fulfill our intended purpose of strengthening older adults' core muscles, as it increased their physical functions, dynamic balance, and static balance, all of which are intimately related to performance in activities of daily living.

In terms of the relationship between the core muscles and the stability of the body, the latter is maintained by channeling the core muscles and the stiffness they provide (Bergmark, 1989; Crisco & Panjabi, 1991). When stability is maintained, the increased activation of the trunk antagonist muscles strengthens the spinal system and enables it to be less affected by external disturbances (Gardner-Morse & Stokes, 2001; Granata, Slota, & Bennett, 2004). Biodynamic assessment of a sitting posture is thought to provide a deeper insight than a clinical assessment (Genthon, Vuillerme, Monnet, Petit, & Rougier, 2007). Hence, the present study hypothesized that the smaller the change in the COP, which was calculated by tracking the movements of the center of gravity, during exercise in a seated position, the smaller the influence of external disturbances (i.e., induced arm movement in the present study) on the core. The fact that the center of gravity was less disturbed over the 8 weeks of training can be interpreted as a result of the exercise indeed strengthening the core muscles. COP, which represents the center of gravity, provides varied information that explains the mechanism of postural control based on data collected from various signals (Palmieri,

Ingersoll, Stone, & Krause, 2002). Many studies have predicted the elderly's risk of falling by analyzing COP parameters (Piirtola & Era, 2006; Pajala et al., 2008), and validated the effectiveness of balance training programs (Crilly, Willems, Trenholm, Hayes, & Delaquerriere-Richardson, 1989; Judge, Lindsey, Underwood, & Winsemius, 1993). In the present study, we found significant differences in AP COP, ML COP, total COP, and COP 90 area between before and after the 8-week training ($p < .05$), which means that the movement trajectories of the older adults' center of gravity significantly declined. As shown in the post hoc tests, the movement of the elderly's center of gravity in all directions (AP COP, ML COP, total COP, and COP 90 area) was significantly lower on week 4 than on week 1 of using the core strength training equipment ($p < .01$), indicating that the effect of minimizing the movement of the center of gravity through core strengthening emerged after 4 weeks of exercise. A few studies promoted older adults' functional improvement through 4 weeks of exercise. Choi et al. (2012) conducted a 4-week core-stabilizing exercise with a Swiss ball in the elderly and reported that the core-stabilizing exercise significantly affected their balance and gait. In addition, Lee et al. (2013) studied the effects of a 4-week exercise program that incorporated core-stabilizing exercises in the elderly and found that such program was more effective in improving their balance. These studies support that 4 weeks is a significantly effective period of exercise for the elderly. Furthermore, Tsang and Hui-Chan (2004) suggested that a core-strengthening tai chi exercise significantly improved the elderly's vestibular capacity and static equilibrium from week 4 of exercise until week 8 of exercise. Such findings imply that the reduced COP area in the present study is an indication that the movement of the COP of the subjects was minimized from week 4 to week 8 of core-strengthening training.

The core strength training equipment developed in this study was designed to strengthen the core muscles and their coordination through external disturbance (i.e., inducing arm movement while subjects try to maintain their trunk balance). As we verified our hypothesis that the use of the training equipment had a positive effect on the core-related muscles based on the COP movement data shown as feedback after exercise, future studies should also validate the effectiveness of the equipment in strengthening core muscles by directly analyzing the activation of muscles that affect the core.

CONCLUSION

The objective of this study was to develop an elderly-friendly core-strengthening training equipment that enables older adults to perform exercise on their own and to verify the effectiveness of the equipment. To verify whether body functions were enhanced, we conducted SPPB, "going up and down 4 stairs", and static balance tests. Movements of the COP during exercise were tracked by using a system installed on the equipment. We then analyzed the changes in the COP in accordance with the period of exercise and thereby obtained the following conclusions:

1. Eight weeks of exercise using the core strength training equipment for the elderly increased the elderly's physical performance, "going up and down stairs" test scores, and static balance, all of which are related with performance in activities of daily living.
2. Eight weeks of exercise using the core strength training equipment for the elderly significantly reduced AP COP, ML COP, total COP, and COP 90 area, indicating that the equipment is effective in strengthening the trunk core muscles.

The core strength training equipment for the elderly that we developed in this study strengthened the elderly's trunk core and enhanced their performance in activities of daily living. This equipment is expected to be effectively used by older adults with weak legs, as the users' core muscles are strengthened through exercise that involves only the upper body and is performed while sitting on a ball.

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