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Development of a new training system for improving the postural control ability of elderly adults †

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Abstract

This study describes a new training system based on an unstable platform and a visual interactive system, that was designed to improve postural control ability. The training system consists of an unstable platform, a safety harness, a monitoring device, and a personal computer. To confirm the effects of the training system, a performance test and a training effect test were conducted. The performance test included calibration and the test-retest experiments. The training effect test was conducted on elderly adults. The results of the calibration demonstrated that the average deviations of COP (center of pressure) in all of the other directions were all less than 0.4cm. The results of the test-retest experiment demonstrated that the ICC (intraclass correlation coefficient) of repeatability was reflective of excellent reliability in both the COP maintenance test and the COP movement test. The training reduced the COP sway path by 5% and the average distance of the COP sway by 32.4%. The RMS (root mean square) of COP after training was reduced by 24% and 33% in the ML (medio-lateral) and AP (anterior-posterior) directions. The training also caused a 25% reduction in the results of the Timed Up and Go test. The PTBW (peak torque/body weight) value was increased by 31% and 17.5% in the knee and ankle joints. The experimental results suggest that this postural control training system using an unstable platform could be applied to training to improve postural control ability in elderly adults.

Keywords: Elderly adults; Postural control; Training system; Unstable platform

1. Introduction

Posture control is a continuous process, and is constantly controlled or adjusted such that the COG (center of gravity) of the body can be stably maintained. Adequate postural control relies on the spatial and temporal integration of vestibular, visual, and somatosensory information regarding the motion of the head and body, coupled with the generation of appropriate responses to that motion. The visual system is a principal contributor to balance, providing information concerning the environment, location, and the direction and speed of the movement. The vestibular system provides information regarding the movement of the head, independent of visual cues. The somatosensory system provides information regarding the position of the body on the basis of sensations transmitted through the skin, including pressure, vibration, tactile sense, and muscle proprioception [1].

Age-related alterations in postural control strategies have also been previously demonstrated to exist. A number of previous studies have reported on the increase in postural sway that occurs with advanced age. The increased incidence of falls in the elderly population indicates that one or more components of the vestibular, visual, and somatosensory systems degenerate with age. Diminished visual, vestibular and somatosensory function and slowing of sensorimotor processing all occur with normal aging, and older people are also at higher risk for a variety of diseases

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that affect the peripheral and central nervous systems. Diminished balance ability is a multifactorial construct. It may be the consequence of degenerations in visual and vestibular sensory systems, degenerations in proprioception, and impairments in central processing, or combinations thereof. In addition to reductions in muscle strength and slower neural processing, a number of sensory changes may also contribute to unsteadiness in elderly adults. These changes include age-related reductions in the numbers of hair cells in both the canals and the otoliths, as well as in the number of nerve fibers in the vestibular nerve, which eventually result in a reduction in vestibular excitability [2-4].

A considerable number of previous studies have addressed training regimens for postural control or strategies to improve standing balance stability in elderly adults and patients. A variety of techniques and instruments have been employed in the effort to improve postural control and balance abilities. The results of several studies have also shown that lower extremity muscular strength is a common factor associated with balance impairment in elderly fallers [5]. Lord [6] previously demonstrated that ankle dorsiflexion strength was one of the three variables that discriminated significantly between older adults who had not fallen or had fallen only once, and those with a history of multiple falls. A study of nursing home residents with a history of falls showed that muscle forces (torque) and isokinetic power were significantly lower in the knee flexors (quadriceps) and extensors (hamstrings), and ankle dorsiflexors (tibialis anterior) and plantar flexors (gastrocnemius and soleus) of those subjects [7]. These studies indicated a strong relationship between lower extremity strength and posture control ability. The association between weak leg muscles and falling has compelled researchers to conduct studies on strength training for the improvement of balance in balance-impaired older adults. These studies have evaluated the effects of strength training, either alone or in combination with other activities, such as tai chi, aerobic exercise, and balance training [8-10]. Hess [11] studied the effects of high-intensity strength-training on functional measures of balance ability in balance-impaired older adults. High-intensity strength training can safely and effectively strengthen lower extremity muscles in balance-impaired older adults, resulting in significant improvements in functional balance ability and decreased risk of falls. Morioka [12] previously evaluated the influence of perceptual learning training for the hardness discrimination of sponge rubber in the soles on postural sway. Seidler [13] determined and contrasted the effects of five weeks of balance training on the postural stability of elderly adults with a history of falls, as compared to those without a history of falls. The effectiveness of short-term balance training for functionally independent elderly adults has been noted previously. Granacher [14] assessed the influence of the postural and muscle responses of heavy resistance training and sensorimotor training in elderly men, and suggested that sensorimotor training might prove to be an excellent technique for fall-preventive programs in elderly people. Page [15] previously described the scientific rationale for the program and the clinical progression of sensorimotor training.

Based on the results of these studies, training targeted at the improvement of balance ability in elderly adults needs to involve an enhancement of the strength of the muscles in the lower extremities, particularly the ankle plantar and dorsiflexor muscles, and also must involve improvements in the somatosensory system via sensorimotor training. In this study, a postural control training system for elderly adults that could improve the effects of postural balance training is recommended. In order to confirm the accuracy, repeatability, and efficacy of the training system using the unstable platform, several different types of experiments have been conducted.

2. Training system for postural control

2.1 Construction of the system

The training system consisted of an unstable platform, a safety frame, a safety harness, a monitoring device, a computer interface, and a computer, as shown in Fig. 1. The unstable platform provided 360 degrees of movement, allowing for postural training in various directions. The dimensions of the unstable platform were as follows: length 500mm; width 400mm; and height 90mm. The curvature radius of the unstable platform was 400mm. The maximum tilt angles were 18 and 28 degrees in the L-R (left-right) and A-P (anterior-posterior) directions. Two tilt sensors (SA1, DAS Technology) were installed within the unstable platform. Using the tilt sensors, we could compute the COP of the subject on the unstable platform. The signals from the tilt sensors were input into a computer by using a PCI-6024E card and an SCB-

68S connector (National Instruments).

2.2 Training and evaluation software

To train or evaluate postural control ability in elderly adults, a software package composed of an option module, a training module, an evaluation module, and a data analysis module was developed. Fig. 2 shows the developed training programs actually performing in the different movement patterns. Each movement pattern had five selectable levels (4, 5, 6, 7 and 8cm) and five selectable speeds (0.3, 0.45, 0.6, 0.75 and 0.9cm/s). Fig. 3 provides samples of the evaluation programs. Some samples of the analysis programs are provided in Fig. 4. All software was developed by using LabVIEW 8.0 (National Instruments).

3. Methods

To verify the effects of the training system, we conducted evaluation experimentation during the different kinds of experiments. This included the calibration of the unstable platform, the test-retest experiments, and the evaluation of the effects of training.

3.1 Calibration experiment

The calibration experiment was conducted to verify the reliability of the unstable platform. Five healthy volunteers (3 males and 2 females, age: 26.8±3.28 years;

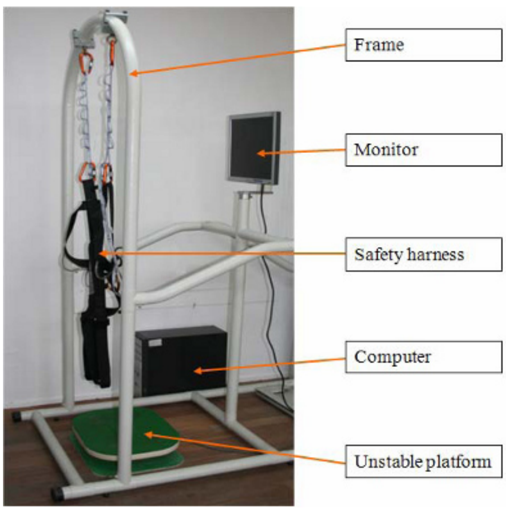


Fig. 1. Training system for postural control using an unstable platform.

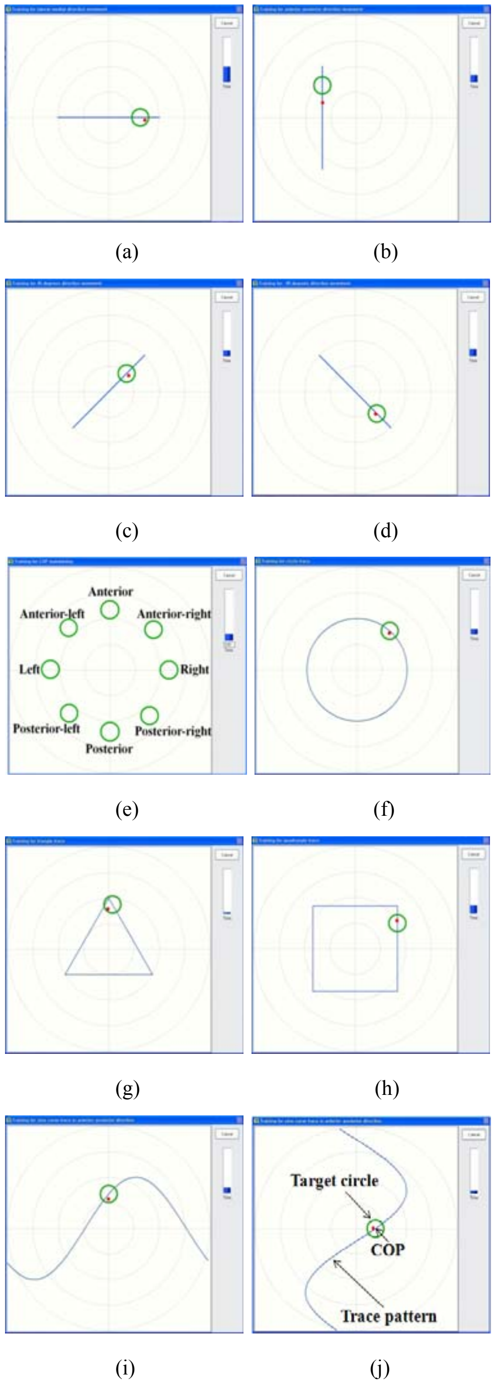
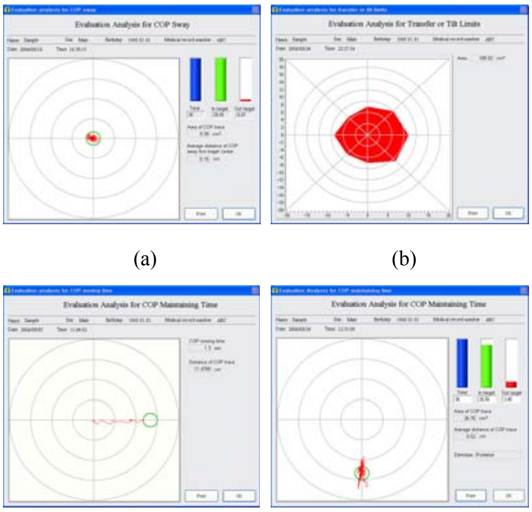


Fig. 2. Training programs: (a) COP movement training in left-right direction (b) COP movement training in anterior-posterior direction (c) COP movement training in 45° direction (d) COP movement training -45° direction (e) COP maintenance training (f) The circle trace (g) The triangle trace (h) The quadrangle trace (i) The sine curve trace in anterior-posterior direction (j) The sine curve trace in left-right direction.



(a) (b)

(c) (d)

Fig. 3. Evaluation programs: (a) Evaluation of COP sway (b) Evaluation of transfer or tilt limits (c) Evaluation of COP moving time (d) Evaluation of COP maintenance time.

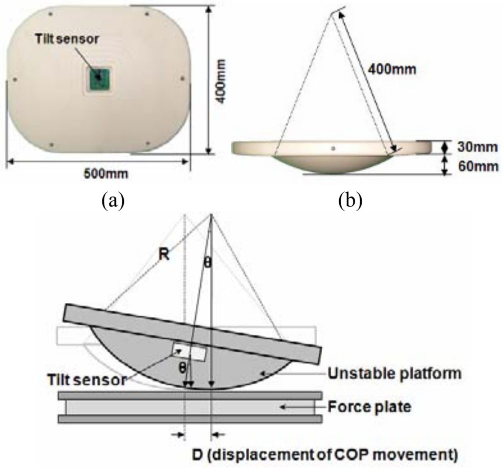
(a) (b)

Fig. 4. Analysis programs: (a) Analysis of circle trace training (b) Evaluation of COP sway.

weight: 59.12±9.3kg; height: 171±7.6cm) participated in this study. Prior to the beginning of the examination, the volunteers were all informed fully about the experiment, and all provided written consent.

This experiment was conducted on a force plate (Model: 4060-08, Bertec Corporation) and the unstable platform. The force plate was placed on the floor, and the unstable platform was positioned on the center of the force plate. The subject stood on the unstable platform and gazed at a monitor that was fixed at eye-level at a distance of approximately 80cm. The monitor displayed the subject's COP.

The subject was instructed to move the COP to the appointed target circle displayed on the monitor. The subject then maintained the COP in the target circle for 30sec. The location of the target circle included nine directions--center, anterior, posterior, left, right, anterior-left, anterior-right, posterior-left, and posterior-right (Fig. 2(e)). The distance from the center to the target circle was 10cm. The experiment was repeated five times in each direction. The data obtained from 30 sec on the unstable platform and the force plate was synchronously input to the computer using a data acquisition card (PCI-6024E, National Instruments) and a connector (SCB-68S, National Instruments).



(a) (b)

(c)

Fig. 5. Measurement of COP movement distance of the unstable platform: (a) Top view of the unstable platform (b) Side view of the unstable platform (c) Measurement of COP movement distance.

Fig. 5 shows the method by which the COP on the unstable platform (UP) was calculated as follows:

$$COP(UP)_X = \frac{2\pi \times R}{360} \times \frac{V_X - V_{offset}}{S} \quad (1)$$

$$COP(UP)_Y = \frac{2\pi \times R}{360} \times \frac{V_X - V_{offset}}{S} \quad (2)$$

where V_X and V_Y represent the voltage of the sensors, R represents the radius of the unstable platform, and S is the sensitivity of the tilt sensor, V_{offset} represents the voltage of the tilt sensors at 0° inclination position.

The COP of the force plate (FP) was calculated as follows:

$$COP(FP)_X = \frac{-h \times F_x - M_y}{F_z} \quad (3)$$

$$COP(FP)_Y = \frac{-h \times F_y - M_x}{F_z} \quad (4)$$

where h is the thickness above the top surface of any material covering the force plate, F_x, F_y and F_z are the force components in the force transducer coordinate system, and M_x and M_y are the moment components in the force transducer coordinate system.

In our study, the average deviation of the COP between the force plate and the unstable platform was calculated in order to assess the reliability of the unstable platform. The average deviation was calculated as follows:

$$Average\ deviation_X = \frac{1}{n}\sum_{i=1}^{n}\left|COP(UP)_{Xi} - COP(FP)_{Xi}\right| \quad (5)$$

$$Average\ deviation_Y = \frac{1}{n}\sum_{i=1}^{n}\left|COP(UP)_{Yi} - COP(FP)_{Yi}\right| \quad (6)$$

where n is the total number of samples, and i is the sample number.

3.2 Test-retest experiment

To assess the repeatability of the new training system for postural control, the test-retest experiment was conducted. Fifteen healthy volunteers (9 males and 6 females; age: 27.88±4.09 years; weight: 64.13±9.39kg; height: 173±5.26cm) participated in this study.

This experiment was conducted on the unstable platform in a fashion similar to the calibration test. The repeatability examination included the COP maintenance examination and the COP trace examination. In the COP maintenance examination, the subject was instructed to maintain his or her COP in the appointed target circle for 30 sec. The location of the target circle included eight directions--anterior, posterior, left, right, anterior-left, anterior-right, posterior-left, and posterior-right (Fig. 2(e)). The distance from the center to the target circle was 8cm. In the COP trace examination, the subject was instructed to move his or her COP in order to follow a target circle which moved in accordance with the specified trace pattern. The trace patterns were the COP movement in the anterior-posterior direction, the COP movement in the left-right direction, the COP movement in the 45-degree direction, and the COP movement in the -45-degree direction (Fig. 2(a), (b), (c) and (d)). The rest time between each examination session was 20 sec. All of the experiments were repeated three times. Average values were used in the data analysis. After a week, the same trial was conducted again. The repeatability was analyzed via the experimental results prior to and after the week.

The average distance of the COP sway path was used for the repeatability examination. It was calculated by

$$Sway\ path = \sum_{i=1}^{n-1}\sqrt{(X_{i+1} - X_i)^2 + (Y_{i+1} - Y_i)^2} \quad (7)$$

where n is the total number of samples, i is the sample number, X is the displacement of COP in the ML direction, and Y is the displacement of COP in the AP direction.

Statistical data analysis was completed by SPSS software. The intraclass correlation coefficient (ICC) was used in order to evaluate the reliability of the unstable platform. ICC values in excess of 0.8 were considered statistically significant.

3.3 Evaluation of training effects

To evaluate the training effects, 15 healthy elderly adults (7 males and 8 females; age 68.43±2.44 years; weight: 64.64±9.3 kg; height 164.36±8.97 cm) were enrolled in the study on a volunteer basis.

After an initial evaluation, the trainees participated in training sessions three times a week for eight weeks, in one hour sessions. After the training session, the second evaluation was repeated.

The training sessions included a COP maintenance training session and a trace training session. The COP maintenance training was conducted in eight directions. The subject was instructed to move the COP in the appointed direction and to maintain the COP in the appointed target circle for 30sec, then repeated twice. The target circle was a distance of 6 cm from the center. The rest time was 30 sec. The directions were anterior, posterior, left, right, anterior-left, anterior-right, posterior-left, and posterior-right. The direction was selected in random order, and then the trace training was conducted. In the trace training, the subject was required to move his or her COP in accordance with the movement of a target circle, which traced along the appropriate trace pattern. The trace patterns used were the circle trace, the quadrangle trace, the triangle trace, and the sine curve trace. In this study, the moving speed of the target circle was 0.6cm/s; levels of 5cm and 7cm were selected. All of the trace patterns were selected in random order and repeated twice. The rest time was 30sec.

The evaluation of training effects included the timed up and go test (TUG), the static postural stability examination, and the examination of the concentric isokinetic strength of the ankle, knee, and hip joints.

To evaluate the functional mobility of the training, the timed up and go test was also applied, and the time required for a seated subject to stand, walk 3m, pass around an object, walk back to the chair, and sit down again was measured and recorded in seconds [16].

Static postural stability was measured while the subject stood on the force plate (Model: 4060-08, Bertec Corporation) for periods of 30 sec each. The platform allowed for the measurement of COP displacement. The signals were amplified. The sampling rate was 100Hz. Posturography was conducted first with the eyes open (EO) and then with the eyes closed (EC). During the EO test, the subject gazed at a monitor that was fixed at eye-level at a distance of approximately 80 cm. The monitor displayed the subject's COP on the force plate. The subject stood barefoot, with the feet positioned side-by-side with no space between them, and with the arms hanging freely at either side, and was instructed to minimize postural sway. All of the sessions were repeated three times.

The Biodex System 3 (Biodex Medical Systems Inc., Shirley, NY, USA) was employed to determine the concentric isokinetic strength of the ankle, knee, and hip joints. Extension and flexion isokinetic concentric strength were measured in both ankles at speeds of 30°/s and 60°/s. Extension and flexion isokinetic concentric strength were measured in both knees at speeds of 60°/s and 120°/s. Extension and flexion isokinetic concentric strength were measured in both hips at speeds of 45°/s and 90°/s. To normalize the data obtained from the studied individuals, the peak torque/body weight (PTBW) was used to evaluate the training effects.

The data from the static postural stability examinations were then analyzed. RMS (root mean square) in the AP and ML directions, the COP sway path, and the average distance of the COP away from the target center were used to evaluate the training effects. RMS was calculated by

$$RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{n} S_i^2} \qquad (8)$$

where, n is the total number of samples, i is the sample number, and S is the displacement of COP in the ML direction or AP direction.

The average distance of the COP away from the target center was calculated by

$$Average\ distance = \frac{1}{n}\sum_{i=1}^{n}\sqrt{X_i^2 + Y_i^2} \qquad (9)$$

where, n is the total number of samples, i is the sample number, X is the displacement of COP in the ML direction, and Y is the displacement of COP in the AP direction.

Data analysis was completed by using SPSS software. The paired sample T-test was used to evaluate training differences in the experimental and control groups for changes in the measured parameters. A P value of less than 0.05 was considered statistically significant.

4. Results

4.1 Calibration of the unstable platform

Fig. 6 shows the average deviation of COP between the force plate and the unstable platform in the ML and AP directions. The average deviation of the center was 0.069cm in the ML direction and 0.07cm in the AP direction. This was the lowest value among the selected directions. The average deviations in all of the other directions were all less than 0.4 cm in the ML and AP directions.

4.2 Test-retest

Fig. 7 provides the results of the test-retest of COP maintenance in different directions. Fig. 8 provides the results of the test-retest of the different COP movement patterns. We noted no significant differences between the second test and the first test. Via reliability analysis, the value of ICC was determined

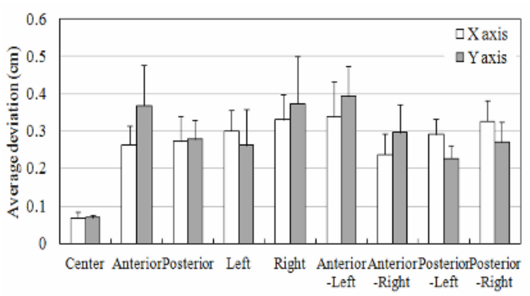


Fig. 6. Average deviation of COP between the force plate and the unstable platform in the X axis and Y axis.

to be higher than 0.8 in both the COP maintenance test and the COP movement test.

4.3 Training effects

The training induced a significant improvement in the results of the TUG test. The TUG value of pre-training and post-training is provided in Fig. 9. The TUG value of pre-training was 9.73 sec and post-training was 7.79 sec. The TUG value was reduced by 20% post-training as compared with pre-training.

Fig. 10 shows the COP sway path under different visual conditions for pre-training and post-training. COP sway paths in both the EO and EC conditions were reduced significantly post-training. Sway path under the EO condition was reduced by 5% post-training as compared with pre-training. Sway path in the EC condition was reduced by 5.2% post-training. Sway path increased by 12% in the EC condition.

Fig. 11 shows the average distance of COP away from the center under the different visual conditions for pre-training and post-training. Average distance in both the EO and EC conditions was reduced significantly post-training. The average distance was reduced by 38.8% under the EO condition, and by 26% under the EC condition.

Fig. 12 shows the RMS in the ML and AP directions of the different visual conditions for pre-training and post-training. The RMS was significantly reduced in both directions and under both visual conditions. RMS in the ML direction of post-training was reduced by 32% under the EO condition, and by 16.3% under the EC condition. RMS in the AP direction of post-training was reduced by 35.9% under the EO condition, and by 30.3% under the EC condition. RMS in both directions was significantly higher under the EC condition than under the EO condition. RMS under both visual conditions was higher in the AP direction than in the ML direction.

Fig. 13 shows the pre-training and post-training PTBW values of the ankle, knee, and hip joints. The PTBW value of the ankle joints in both legs at both the 30°/s and 60°/s speeds was increased significantly post-training. The PTBW value in the plantar flexion motion of the right ankle joint was increased by 14.9% at 30°/s, and by 13% at 60°/s. The PTBW value in the dorsiflexion motion of the right ankle joint was increased by 28.3% at 30°/s, and 22% at 60°/s. The PTBW value in the plantar flexion motion of the left ankle joint was increased by 8.5% at 30°/s, and by 14.7% at 60°/s. The PTBW value in the dorsiflexion motion of the left ankle joint was increased by 25.1% at 30°/s, and by 10.5% at 60°/s. The knee joints' PTBW value for two legs at 60°/s was increased significantly post-training. We noted no significant differences at 120°/s between pre-training and post-training. The PTBW value in the extension motion of the right knee joint was increased by 26% at 60°/s. The PTBW value in the flexion motion of the right knee joint was increased by 28.8% at 60°/s. The PTBW value in the plantar flexion motion of the left knee joint was increased by 30.9% at 60°/s. The PTBW value in the extension motion of the left knee joint was increased by 41.1% at 60°/s. With regard to the hip joint, we noted no significant difference between the post-training and pre-training results.

5. Discussion

Through several different types of experiments, this study confirmed the accuracy, repeatability, and efficacy of a training system employing an unstable platform.

5.1 Accuracy

The calibration examination completely confirmed the accuracy of the unstable platform. Our experiments verified the validity of the COP measurements on the unstable platform. With regard to the measurement of the coordinates of COP, the experimental results were consistent with the design of this training system. This training system required that the deviation in COP be less than 0.5cm. Considering the reason for the deviation, including the resolution of the tilt sensors, the production of the unstable platform, and the subjects, our experimental results showed that the COP movement on the unstable platform was very consistent with that of the force plate. The COP measurement technique was also validated, as was the accuracy of the unstable platform.

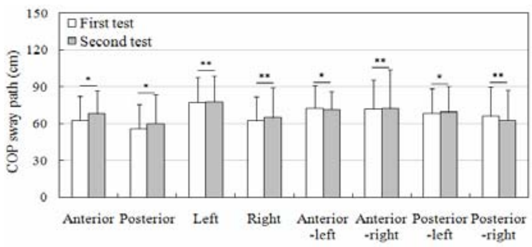


Fig. 7. Test-retest of COP maintenance in different directions (* ICC>0.8, ** ICC>0.9).

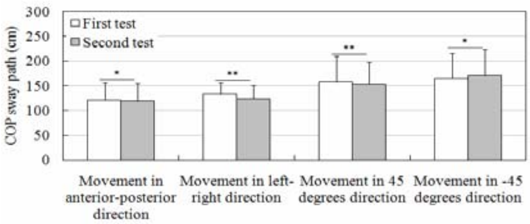


Fig. 8. Test-retest of COP movement in different patterns (* ICC>0.8, ** ICC>0.9).

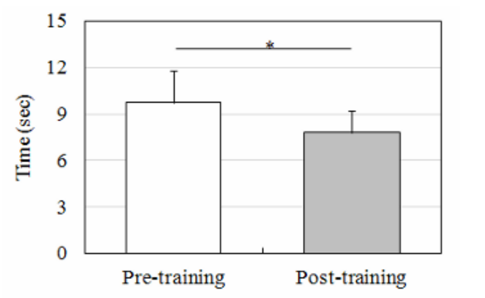


Fig. 9. TUG value of pre-training and post-training (* P<0.05).

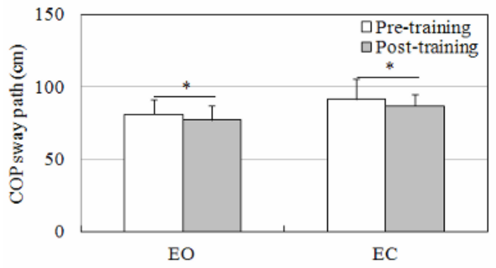


Fig. 10. COP sway path under the different visual conditions, pre-training and post-training (* P<0.05).

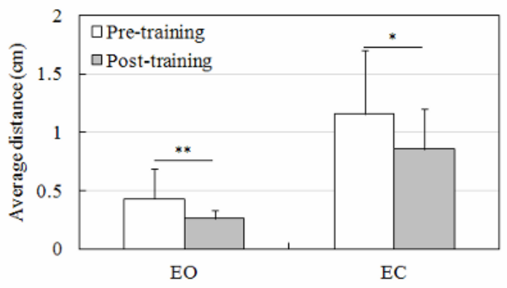


Fig. 11. Average distance of COP away from the center in the different visual conditions of pre-training and post-training (* P<0.05, ** P<0.001).

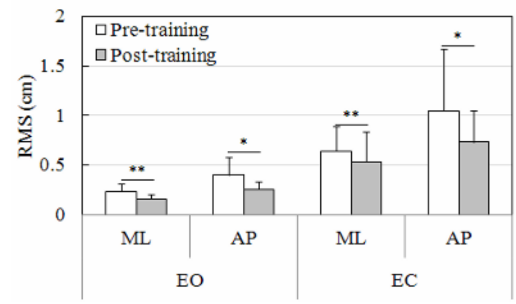
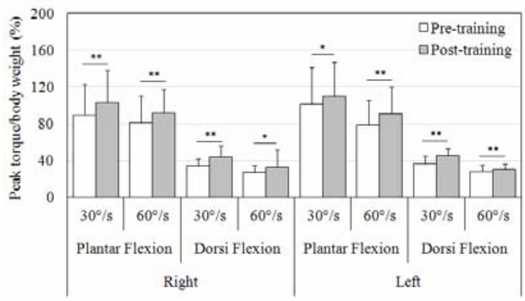
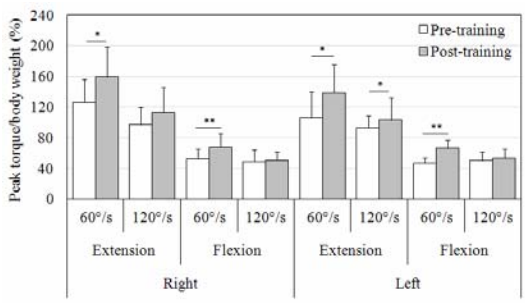


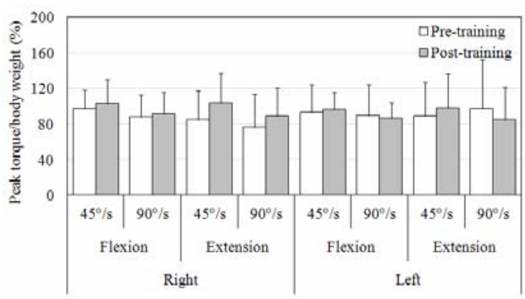
Fig. 12. RMS of ML and AP direction under the different visual conditions, pre-training and post-training (* P<0.05, ** P<0.001).



(a)



(b)



(c)

Fig. 13. PTBW value in the joints pre-training and post-training (* P<0.05, ** P<0.001): (a) Ankle joint (b) Knee joint (c) Hip joint.

5.2 Repeatability

The test-retest examination validated the repeatability of the unstable platform. Bartko [17] reported previously that ICC values in a range of 0.80-1.00 were reflective of high reliability, ICC values in a range of 0.60-0.79 indicated medium reliability, and ICC values of less than 0.60 were reflective of no reliability. Our test-retest results showed that the COP sway path did not differ significantly in the first test as compared with the second test after a week. The ICC of repeatability was reflective of excellent reliability in both the COP maintenance test and the COP movement test (ICC>0.8).

5.3 Efficacy

Our assessments of the training effect validated the efficacy of the training system using the unstable platform. The primary findings of the present study were that elderly adults who participated in the training course evidenced significant improvements in all of the evaluation parameters. The training significantly reduced the sway path and average distance under both the EO and EC conditions. RMS in both directions was reduced significantly under both visual conditions after training. The training also induced significant improvements in the results of the TUG test. The PTBW value was significantly increased in the knee and ankle joints, and this was particularly true in the ankle joints.

First, the TUG test was both sensitive and specific with regard to the identification of individuals with balance impairment who were likely to fall [16]. Shumway-Cook [18] demonstrated that elderly adults with scores of greater than 13.5 seconds have a 90% probability of being fallers. A TUG score of 11.5 seconds corresponds to a fall risk of approximately 50%. A TUG score of 9.7 seconds corresponds to approximately a 30% fall risk. The TUG value was reduced from 9.73 sec to 7.79 sec after training. Therefore, as a result of training, using the TUG as a measure of fall risk, those after the training evidenced a reduction in fall risk in excess of 20%.

Second, the data from our experiments showed that postural sway decreased as somatosensory input increased from the soles, and from the ankle and knee joints. Jeka [19] determined that postural sway was reduced when the subject touched some object with one hand during tandem standing on a small base for effective support. Additionally, the tactual input was suggested to reduce postural sway not only for tandem standing on a small support base, but also for ordinary upright posture on the feet [20]. Furthermore, Lackner [21] reported that even touching with a forefinger could reduce postural sway during tandem standing with the eyes closed. These effects of tactile sensation are comparatively large for posture controlled by somatic sensation, such as with the eyes closed. These findings indicate the role of foot pressure receptor input on the control of standing posture during somatosensory input from the foot sole directory. According to the results of these previous studies, we concluded that the tactile and pressure sensation of the foot sole performs a crucial function in standing balance. Our experimental results showed that the training system for postural control developed and described herein could effectively improve postural control ability. In particular, the somatosensory inputs from the foot sole, the ankle and knee joints were all effectively improved. Under the EO condition, visual, vestibular, and somatosensory systems performed a dominant function in standing balance. Under the EC condition, vestibular and somatosensory systems played the dominant role. Under both the EO and EC conditions, the decreased COP sway path, average distance, and RMS in the ML and AP direction demonstrated that the somatosensory input was increased post-training. The unstable platform allows for 360 degrees of movement, permitting postural training in various directions. Using these training programs, trainees could train for COP movement in different directions, and at different angles and speeds. This is quite different from the possibilities provided by a stable support base. To maintain balance on the unstable platform, more information from the visual field, vestibular organ, and somatosensory aspects was required. The foot position, the tilt angles of the unstable platform, the angle of the ankle joint, and visual information were all of great relevance to the ability to maintain balance on an unstable platform. To move the COP on the unstable platform, the movement direction, movement speed, and the control of the body's COG proved to be extremely important factors. However, maintaining the balance of the body on the unstable platform also was extremely important to the subject. This process requires a greater integration of the information obtained from the visual field, vestibular system, and somatosensory aspects, in addition to the selection of motor responses. The training programs included a variety of movement patterns. Each pattern provided different movement directions, movement speeds, and movement levels. Therefore, the elderly subjects derived greater benefit from training with this system to improve their postural control ability, as confirmed by our finding of significant changes in static postural stability.

Third, the experimental PTBW values demonstrated that the training system could effectively improve the strength of the lower extremities, particularly the ankle joints. It definitively induced improvements in static postural stability. Woollacott [11] previously reported that high-intensity strength training could safely and effectively strengthen lower extremity muscles in balance-impaired older adults, thus significantly improving functional balance ability and decreasing fall risk. The training regimen resulted in statistically significant increases in the strength of the ankle and knee flexors and extensors in this population of balance-impaired individuals. Our findings regarding the significant changes in the static postural stability evaluation were consistent with this notion. The training caused statistically significant increases in the peak torque of the ankle and knee joints of the elderly adults. The training patterns included in this system could effectively train ankle and knee joint strength using an unstable platform. Different movement patterns, directions, speeds, and tilt angles induced different movements of the ankle and knee joints. Therefore, the strength of the ankle and knee joints could be effectively improved. Simultaneously, the ability to maintain body balance on the unstable platform could also be effectively improved. It directly improved the static postural stability of the trainees. With regard to the hip joints, we noted no significant difference between the post-training and pre-training results. This showed that this training system indicated no significant improvement of the concentric isokinetic strength of the hip joints.

6. Conclusions

We evaluated the accuracy, repeatability, and efficacy of a training system for postural control that employed an unstable platform. The experimental results demonstrated that the training system accurately measured the COP and evidenced a high degree of reliability in postural control training. Additionally, the results of the training effect test showed that this training system could successfully enhance the postural control ability of the trainees. Our findings indicated that this postural control training system using an unstable platform could be applied to training targeted toward improvements in postural control ability in elderly adults.

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