A New Training System for Improving Postural Balance Using a Tilting Bed

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Abstract

In this paper, we propose an early rehabilitation training system for the improvement of postural balance with multi-modality on a tilting bed. The integration of the visual, somatosensory and vestibular functions is significant to for maintaining the postural control of the human body. However, conventional rehabilitation systems do not provide multi-modality to trainees. We analyzed the characterization of postural control at different tilt angles of an early rehabilitation training system, which consists of a tilting bed, a visual feedback, a computer interface, a computer, and a force plate. The software that we developed for the system consists of the training programs and the analysis programs. To evaluate the characterization of postural control, we conducted the first evaluation before the beginning of the training. In the following four weeks, 12 healthy young and 5 healthy elderly subjects were trained to improve postural control using the training programs with the tilting bed. After four weeks of training, we conducted the second evaluation. The analysis programs assess (center of pressure) COP moving time, COP maintaining time, and mean absolute deviation of the trace before and after training at different tilt angles on the bed. After 4 weeks, the COP moving time was reduced, the COP maintaining time was lengthened, and the mean absolute deviation of the trace was lowered through the repeated use of vertical, horizontal, dynamic circle movement training programs. These results show that this system improves postural balance and could be applied to clinical use as an effective training system.

Key words : tilting bed, rehabilitation, force plate

I. INTRODUCTION

Postural control and balance are crucial capabilities in performing daily activities without hindrance. Postural control means managing the positions of body segments to reorient the body in a controlled and stable manner [1]. The capability of postural control and balance requires combining the functions of various bodily systems such as the vestibular organs, the cerebellum, motor units, and other sensory organs [2, 3].

As the elderly population increases as a result of extended life spans and as traffic accidents increase due to ever-increasing traffic volume, there is a higher occurrence of patients with balance disorders due to degraded or damaged vestibular systems or somatic sensory organs [4, 5]. Those patients require an appropriate amount of balance rehabilitation training to get back into regular life. Moreover, as people gets older, there is a great need for effective balance rehabilitation training among the elderly [6, 7].

Forceplates have been successfully used by a number of researchers in measuring balance functions and were found to be reliable experimental tools for balance measurements. Drowatzky et al. [8] used force plates to measure the balance performance of normal people. Shumway-Cook et al. [9] and Lehmann et al. [10] did clinical studies using forceplates in patients with brain dysfunctions, and Ruskin et al. [11] studied patients with vestibular dysfunction. Latt et al. [12] measured postural sway using force plates during consecutive Galvanic Vestibular Stimulations (GVS) with diverse frequencies and amplitudes. Henry et al. [13] investigated postural balance control using a forceplate when translational displacement is applied to the base of support.

On the other hand, Seidler et al. [14] studied the effect of short-term balance training on the postural balance capabilities of older persons. An advanced method was reported in the study, applying biofeedback for patients who experience difficulties in balance, as well as measuring displacement of

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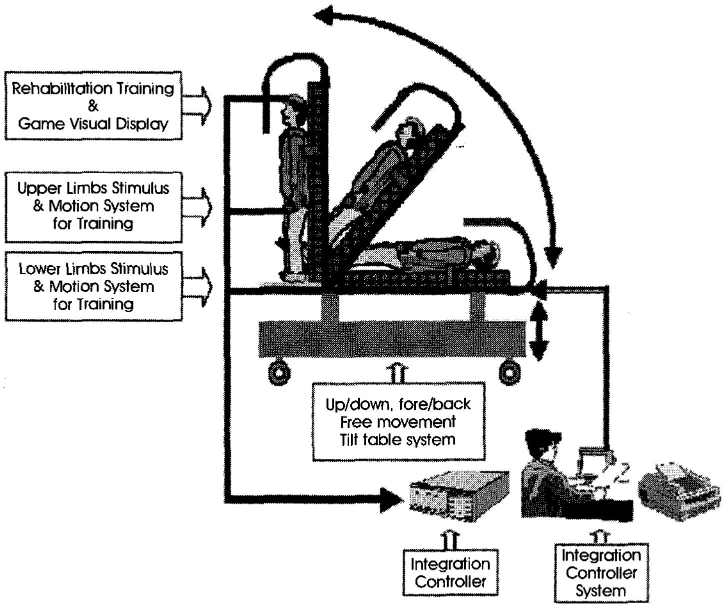


Fig. 1. The developed training system using the tilting bed for improving postural balance

the whole-body, movement in the center of pressure (COP), and the action potential of muscles that react during posture maintenance using force plate, mainly when balance maintenance is interrupted by an external force or limiting input from particular sensory system [7, 15, 16, 17]. Rehabilitation training using forceplates was proved to be effective in postural stability and gait outcome improvement; however, it did not effectively stimulate the visual or somatic senses necessary for postural balance and the subject can become bored. In addition, the biofeedback system is boring because it is a passive form of movement following the direction on the screen or maintaining the balance by the external movement of a forceplate. Moreover, the subject did not go through any long-term training [18, 19, 20].

Herein, we made an improvement of the effect of rehabilitation by simultaneously stimulating postural balance control-related sight, the somatic and balance senses of the vestibular organ, and by developing an early rehabilitation training system. The system uses a tilting bed capable of starting rehabilitation as early as when the patient is lying on the hospital bed. For most rehabilitation institutions, any rehabilitation activity has been only possible when the patient was well enough to stand.

This study quantitatively evaluated the controlling power of postural balance and the effect of rehabilitation training with twenty subjects. The evaluation and training was done in various tilting angles of the automatic tilting bed with an attached forceplate. The visual feedback to the subject was given by an LCD monitor attached to the system. This study analyzed the effect of training at diverse tilting angles of the bed toward postural balance capability, and examines usability as a future device for rehabilitation training.

II. SYSTEM CONFIGURATION

A. Hardware

To improve vestibular organ functions and to break away from boring training routines, we have developed an original tilting bed system controlled by a computer. The tilting bed can rotate at a regular speed in anteroposterior direction or in mediolateral direction. To improve the function of somatic senses, a forceplate having a rough surface was attached to the foothold of the tilting bed. The intensity and the speed of excises were controlled by computer and presented to the subject through an LCD monitor with wide visual field of view. The LCD monitor provides a realistic sense of balance to the patient and is used to control the power of postural balance. Fig 1 shows the diagram of the training system developed in this study.

Fig 2 is a picture of the new postural balance improving system with the tilting bed during an experiment when the tilt angle of the bed was changed. To apply early rehabilitation training, the system can provide various patterns of visual stimulation and training activities for somatic senses and balance senses essential for postural balance control in accordance with the patient's response and capability. Based on the recordings of the movement of the center of pressure

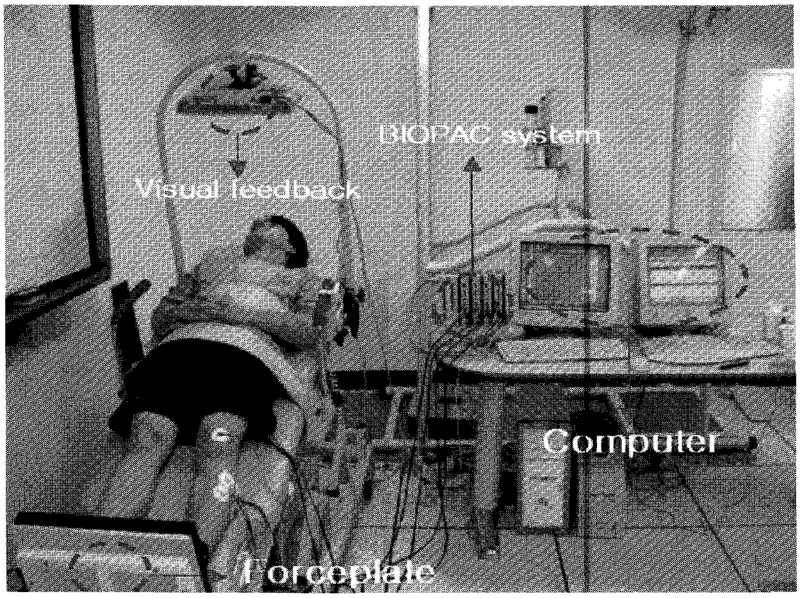
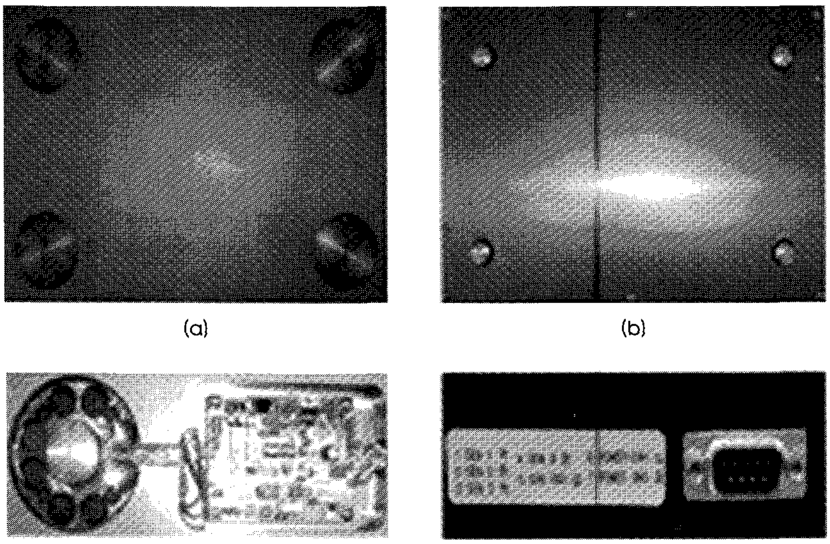


Fig. 2. The new postural balance improving system using a tilting bed

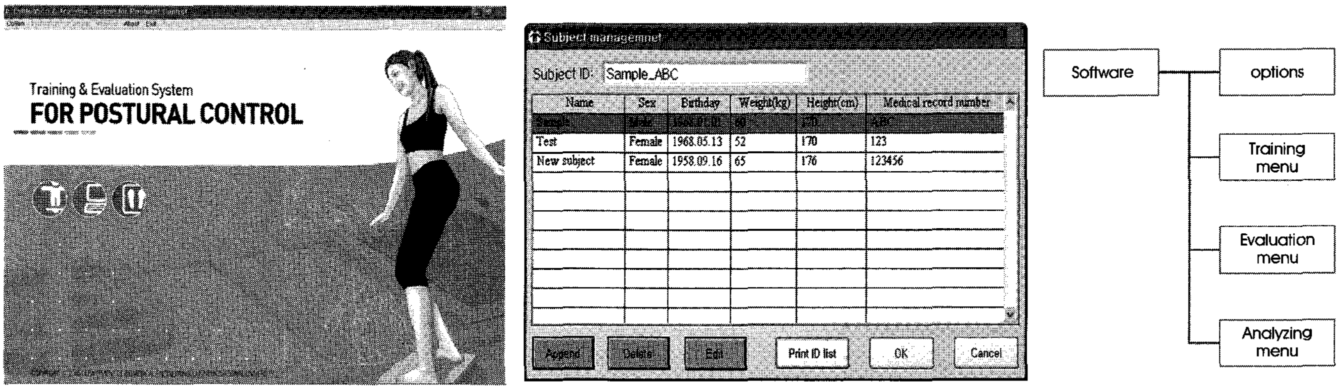
applied to the forceplate by the patient, the computer could analyze, synthesize, and control the velocity of the visual image, the angles of the tilting bed, and the forceplate.

The forceplate shown in Fig 3 is rectangular in shape with a width of 400 mm and a depth of 300mm. There are four circular shaped load cells (50kg weight limits) installed in the plate with a vertical spacing of 180 mm and a horizontal spacing of 280mm. The four load cells gives out the measurements of normal forces applied to the load cells at the four edges of the plate. The signals from the load cells were amplified because the actual voltages from each load cell are only a few millivolts (mV). The amplifier gain was set at 250 to make the amplified output to be 10V for the weight of 50kg. The amplified signal was fed to an A/D converter to be used in the computer analysis. In addition, a low-pass filter was installed between the amplifier and the A/D board so that only the signals below 300Hz could pass to the A/D converter. Based on these four electronic signals from the four load cells, we can compute the location of the center of pressure (COP) applied to the forceplate by the subject. The signals from the



(a) (b) (c) (d)

Fig. 3. Force plate: (a) Top view (b) Bottom view (c) One load cell (d) 9 pin analogue output port



(a) (c) (c)

Fig. 4. Training & evaluation software for postural balance : (a)Main screen (b) Subject management module (c) Software configuration

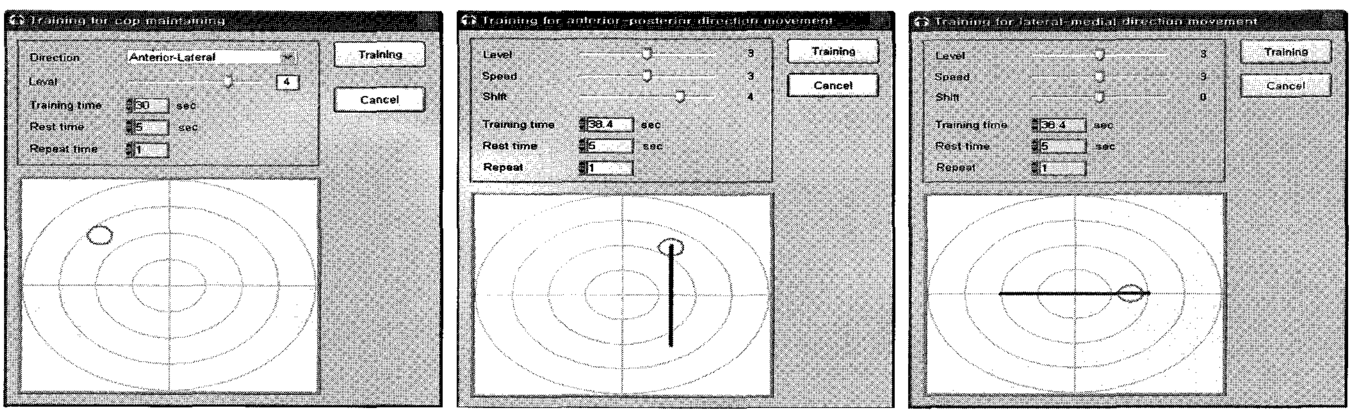
load cells in the force plate are collected using a PCI-6024E A/D converter card (National Instruments Inc., USA) through an SCB-68S I/O connector block.

B. Software

The software of this training instrument was developed with LabVIEW 6.1 of National Instrument Inc., USA. Figure 4 shows the postural balance training and evaluation software: Fig 4 (a) is the main screen of the postural balance sense improvement training software; Fig 4 (b) shows an window for the registering of basic information of the subject and training information which can be searched; Fig 4 (c) shows the evaluation program that was developed to confirm the training effect by analyzing the performance of the subject. The training system can also be used with various computer games which can run on a PC.

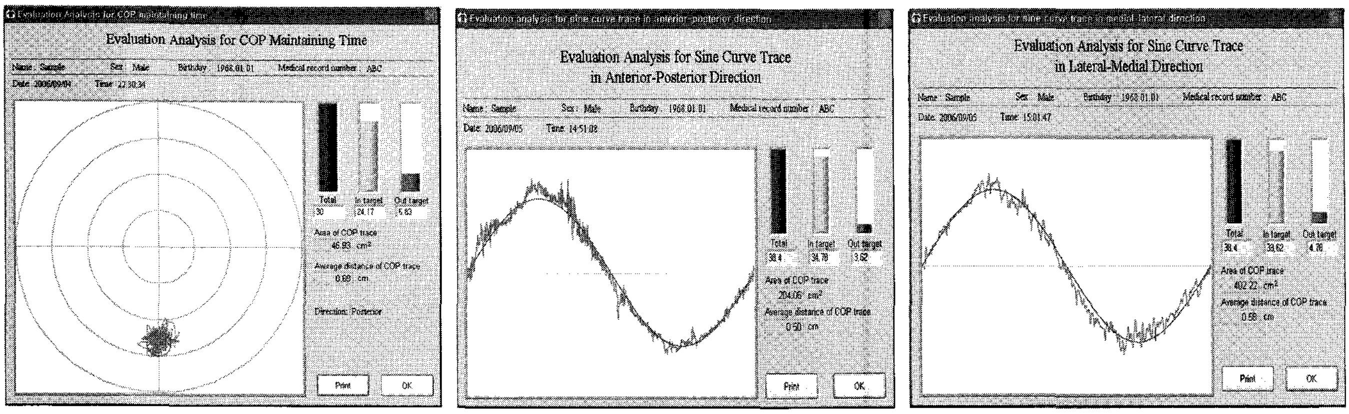
Fig 5 shows the dynamic circle training program that can provide the COP maintaining practice, the vertical movement training and the horizontal movement training, and the tracing of various shapes. Fig 6 shows the training evaluation program. In the visual display, the location of the COP of the subject is represented as a dot on a 2D coordinate in the screen. In the training and evaluation program, the subject is asked to move the location of COP on the screen to certain aimed location, which is displayed by a small circle, by varying the force applied to the force plate or by changing the posture. In the sine curve trace evaluation, the aimed location for the COP is moved following a sine wave curve. The since curve trace evaluation can be done either in anteroposterior direction or in mediolateral direction. The dynamic circle evaluation program requires the subject to move the COP toward a circle at certain locations on the screen and to keep the COP inside the circle until the experiment ends. The location of the circle can be presented in 8 directions: the anterior, posterior, left, right, anterior-left, anterior-right, posterior-left, and posterior-right.

The analysis program shown in Fig 7 made it possible to



(a) (b) (c)

Fig. 5. Training programs: (a) Dynamic circle training (b) Horizontal movement training (c) Vertical movement training



(a) (b) (c)

Fig. 6. Evaluation programs : (a) Dynamic circle evaluation (b) Sine curve trace evaluation (Anterior-posterior direction) (c) Sine curve trace evaluation (Lateral-medial direction)

compare and analyze data right after training. The mean absolute deviation of the trace means the distance between the location of the COP and the desired location on the aimed path. The duration of the time for the subject to maintain the location of the COP inside the dynamic circle can also be calculated. The COP moving time means the time it took for the subject to move the COP from a central location to a target at certain locations. The COP maintaining time indicates the total time that the COP was maintained inside a circle.

III. METHODS

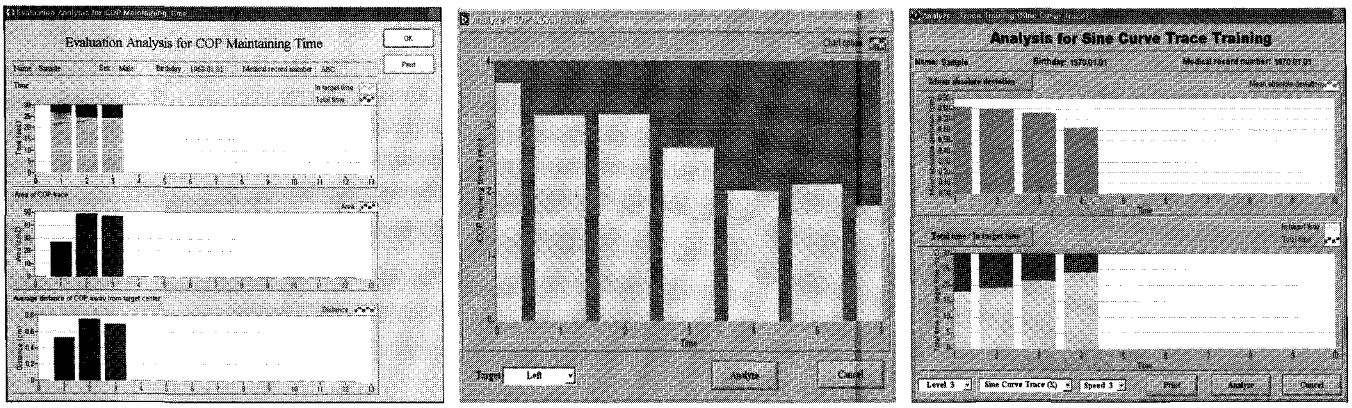
A. Subject

The subjects for the experiment were twelve healthy young students (six females and six males) volunteered from the department of biomedical engineering in Chonbuk National University. Their ages ranged from 23 to 28 years. The experimental elderly subjects were 5 healthy adults (two female and three males). Their ages ranged from 70 to 74 years old. Before the experiments, each subject was informed of all the test procedures and signed a consent form.

B. Experimental Procedure

Fig 8 indicates the systemic evaluation and training protocol in this experiment. The dynamic circle training (COP maintaining practice) and COP movement tracing practice (horizontal and vertical movement training) were performed a total of 20 times, 5 times per a week for 4 weeks, and it took about 60 minutes per a day. Between different training routines, there was a 5 minutes break. The evaluations were done before the start of the first training and were done again after 4 weeks of training.

The COP moving time and the COP maintaining time were measured using dynamic circle evaluations for the evaluation



(a) (b) (c)

Fig. 7. Anlysis module : (a) COP maintaining time (b) COP moving time (c) Mean absolute deviation of traces

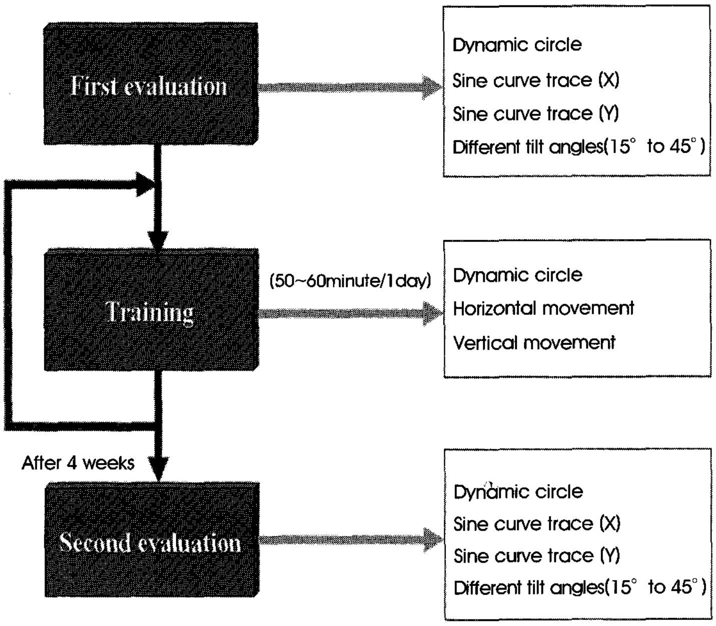


Fig. 8. Training & Evaluation protocol

of dynamic postural balance. For the dynamic evaluation, the cursor was rapidly moved into target circles presented from each direction and maintained for as long as possible. The COP moving time is the time needed for the COP to reach the location to the circle, and the COP maintaining time indicates the total time that a COP is maintained within the circle during evaluation. The path's mean absolute error was measured in the Sine curve trace evaluation program, and the effectiveness of postural balance training was analyzed through the evaluation results before and after the training. Since the measurement time and the sampling rates are constant, the shorter COP moving time means the subject moved the COP more quickly and the longer COP maintaining time means that the subject maintained postural balance at certain posture without too much movement for a long time. Therefore, the shorter the COP moving time and the longer the COP maintaining time are, the superior the controlling power of the postural balance of the subject is.

Ⅳ. RESULTS AND DISCUSSION

A. COP Moving Time

Here, the COP moving time indicates the time it takes for a subject to move his or her COP to reach a desired target location away from the central location. The COP moving time is an important parameter in evaluating the ability to

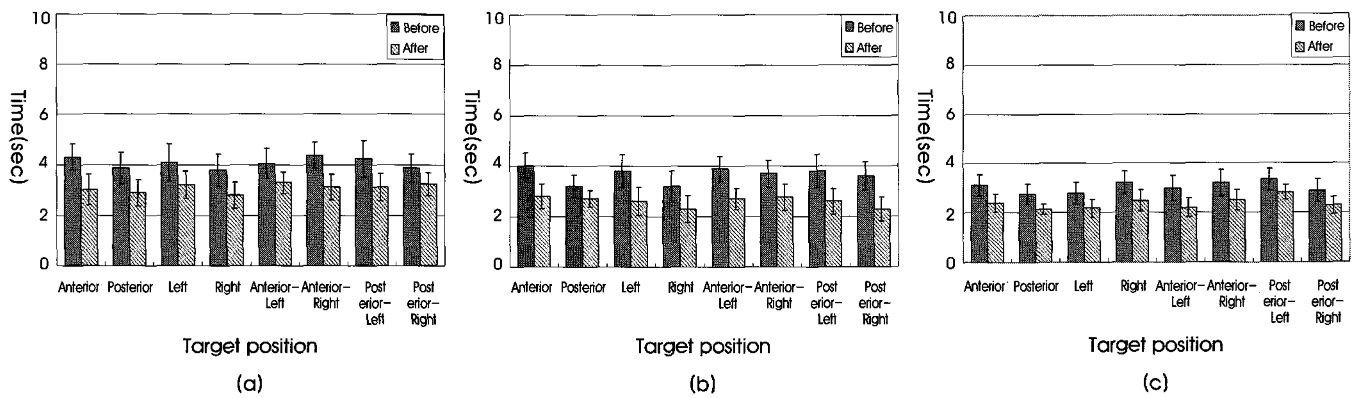


Fig. 9. COP moving time before and after the training at different tilt angles of the bed (15° to 45°) in their twenties : (a) Tilting angle; 15° (b) Tilting angle; 30° (c) Tilting angle; 45°

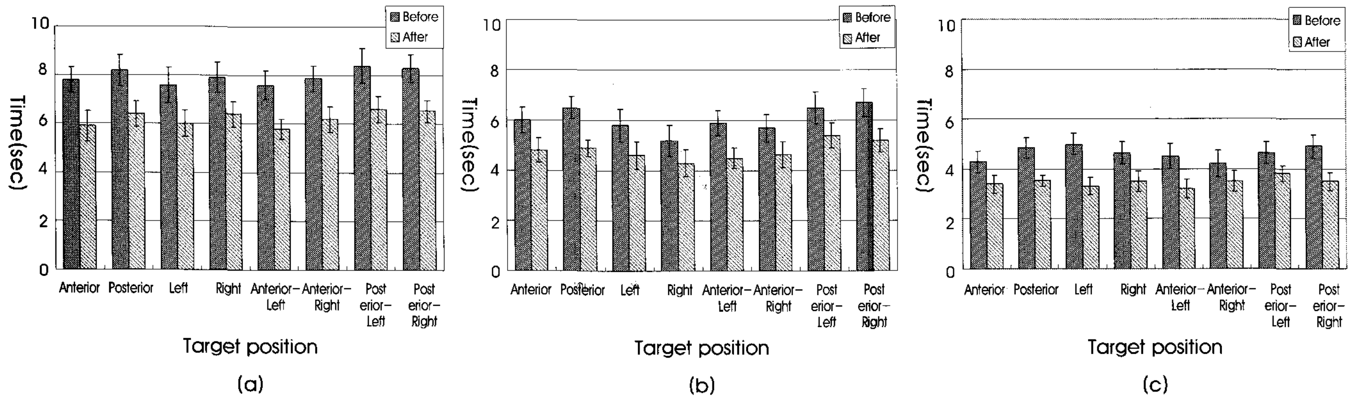


Fig. 10. COP moving time before and after the training at different tilt angles of the bed (15° to 45°) in their seventies: (a) Tilting angle; 15° (b) Tilting angle; 30° (c) Tilting angle; 45°

control the movement of the COP. In the experiment, we measured the COP moving time in eight directions. The eight directions were anterior, posterior, left, right, anterior-left, anterior-right, posterior-left, and posterior-right directions. We analyzed the parameters obtained before the training with those obtained after the training using a 3-way ANOVA in SPSS 12.0. Fig 9 and10 show the COP moving time before and after the training for different tilt angles varied from 15° to 45°. As shown in the figure, the COP moving times measured after training was shorter than those before training by 23.6% at the tilting angle of 15°, 27.2% at the tilting angle of 30°, and 18.6% at the tilting angle of 45° in their twenties. The COP moving times measured after training was shorter than those before training by 24.6% at the tilting angle of 15°, 29.2% at the tilting angle of 30°, and 17.6% at the tilting angle of 45° in their seventies. The 3-way ANOVA results showed that p is lower than 0.001. The comparison of COP moving time before the training with those after training shows distinctive improvement and shows that the new training system can have a positive effect toward the improvement of postural balance..

B. COP Maintaining Time

We analyzed the COP maintaining time obtained before and after training using a 3-way ANOVA in SPSS 12.0. Fig 11 and 12 show the COP maintaining time before and after training for different tilt angles varied from 15° to 45°. As shown in the results, the COP maintaining times measured after training are longer than those before training by 24% for the tilting angle of 15°, 12.7% for the tilting angle of 30°, 9.7% for the tilting angle of 45° in their twenties. the COP maintaining times measured after training are longer than those before training by 23% for the tilting angle of 15°, 21.5% for the tilting angle of 30°, 19.1% for the tilting angle of 45° in their seventies. The 3-way ANOVA results showed that p is lower than 0.001. These results prove that the training system can improve the ability of postural control in the trainee. The comparison of

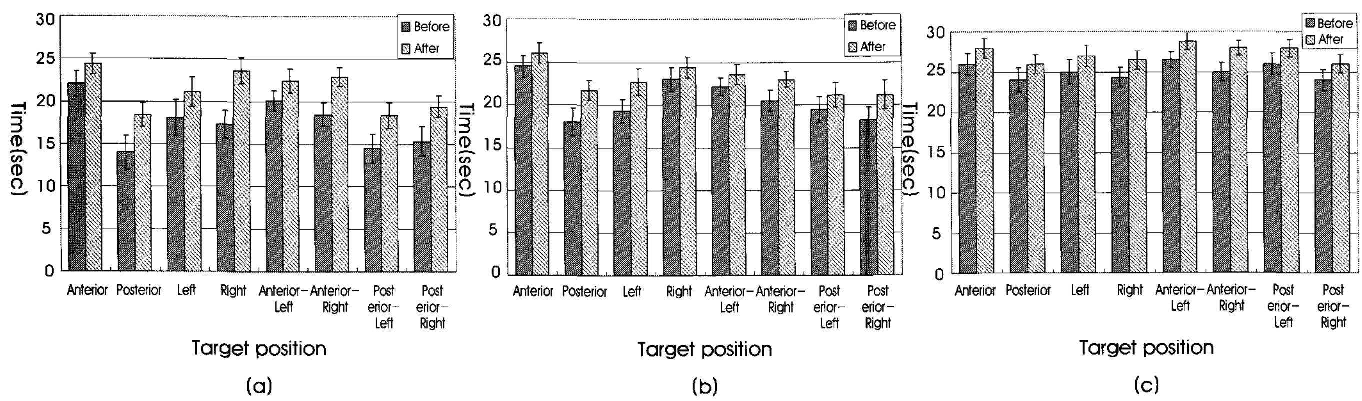


Fig. 11. COP maintaining time before and after the training at different tilt angles of the bed (15° to 45°) in their twenties: (a) Tilting angle; 15° (b) Tilting angle; 30° (c) Tilting angle; 45°

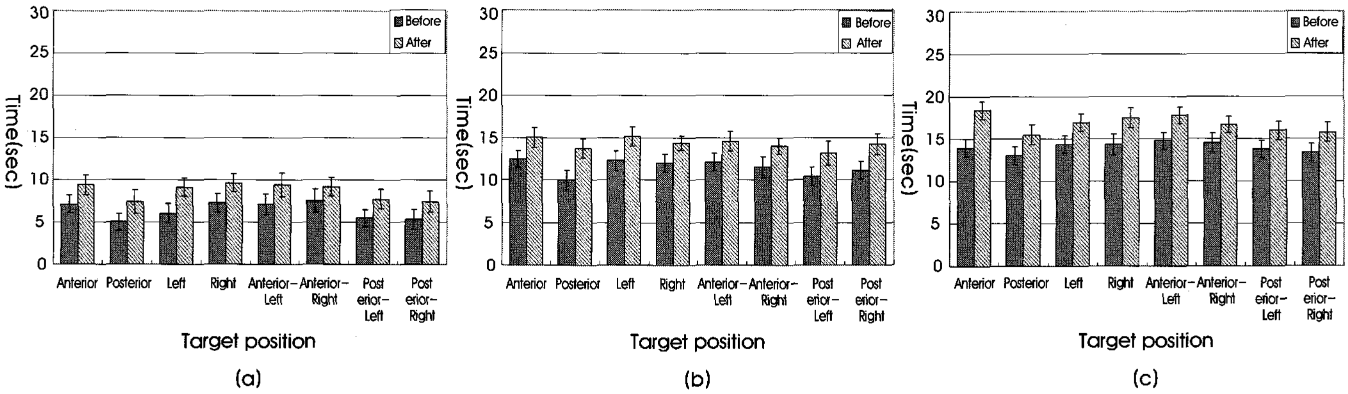


Fig. 12. COP maintaining time before and after the training at different tilt angles of the bed (15° to 45°) in their seventies:
(a) Tilting angle; 15° (b) Tilting angle; 30° (c) Tilting angle; 45°

COP maintaining time before and after the training also shows distinctive improvements. These results also confirm the effectiveness of the training system in improving the ability of postural control of the trainee.

C. Mean Absolute Deviation of the Trace

Mean absolute deviation of the trace represents the mean absolute deviation of the following trace from the target in the monitoring device. In this experiment, we measured the mean absolute deviation in the Sine curve trace (Lateral-medial direction), and the Sine curve trace (Anterior-posterior direction). Eq. [1] shows the method to calculate the mean absolute deviation of the trace.

$$Mean\ absolute\ deviation = \frac{\sum(X-\bar{X})}{n} \quad (1)$$

Where X represents the location of the COP in the monitoring device, $\bar{X}$ represents the location of the target in the monitoring device, and n is the number of times being measured.

We analyzed mean absolute deviation of the trace before and after training using a 3-way ANOVA in SPSS 12.0 at different tilt angles (15° to 45°). Fig 13 and 14 show the mean absolute deviation before training and after training. As shown in the results, the mean absolute deviation of the path after training is lower than that before training for different tilting angles (15° to 45°) in all subjects. The 3-way ANOVA results showed that p is lower than 0.001. These results prove that the training system can have a positive effect toward the improvement of the ability of postural control in the trainee. Using different trace shapes, the subjects trained their COP moving ability at different speeds, angles, and directions. The decrease in the mean absolute deviation also means that the training of postural control using this system is feasible.

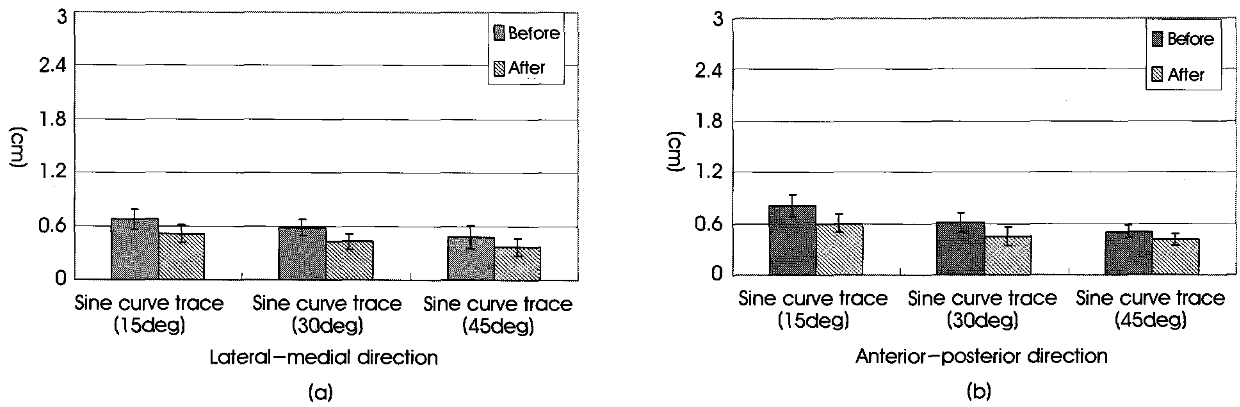


Fig. 13. Mean absolute deviation of sine curve traces before and after the training at different tilt angles of the bed (15° to 45°) in their twenties:
(a) Sine curve trace (Lateral-medial direction) (b) Sine curve trace (Anterior-posterior direction)

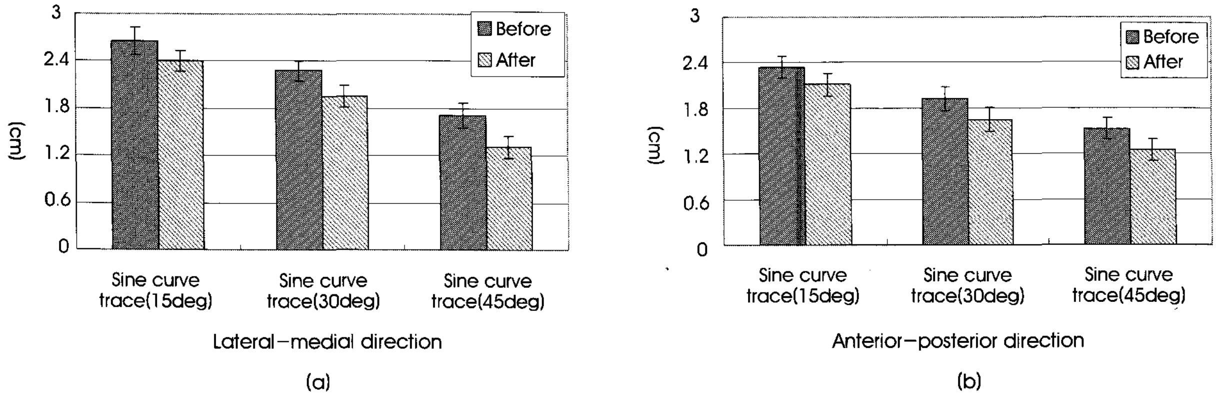


Fig. 14. Mean absolute deviation of sine curve traces before and after the training at different tilt angles of the bed (15° to 45°) in their seventies: (a) Sine curve trace (Lateral-medial direction) (b) Sine curve trace (Anterior-posterior direction)

V. CONCLUSION

A new postural balance improving system using a tilting bed was developed to overcome the weak points of traditional long-term rehabilitation practices by engaging patients and reducing boredom. The new training instrument is capable of improving balance control through training on the tilting bed enabling the start of rehabilitation at the early stage of recovery. Various characteristics in the training for different angles of the bed have been studied. The effectiveness of the dynamic balance training for younger adults has been measured and analyzed. As a result, the COP maintaining time, which is the time a subject maintains the COP within a targeted area, increased after training. The COP moving time, which is the time moving to the target, was greatly improved. The mean absolute path deviation, which is the absolute deviation of the mean distance between the designated location on an aimed path and the location of the COP, also significantly increased after training. Therefore, the results suggest that the new postural balance improving system using the tilting bed may improve the ability of postural balance through rehabilitation on the bed with repetition of training. It is expected that the effectiveness of postural balance training may be increased by active practice through the training programs involving visual feedbacks. However, it has to be carefully interpreted: experiments with large population of elderly volunteers and patients are necessary to show how much effect the new device can have toward the improvement of their postural balance ability. Further studies are also necessary to test the long term effect of the training.

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