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Influence of Plantar Hardness Discrimination Training on Center-of-Gravity Sway while Standing on One Leg: a Randomized Controlled Trial

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Abstract. [Purpose] We investigated the influence of plantar hardness discrimination training on center-of-gravity sway while standing on one-leg. [Subjects] Twenty healthy adult volunteers were randomly divided into intervention (n = 10) and control groups (n = 10). [Methods] The intervention group subjects carried out 10-day plantar hardness discrimination studies on sponges with 5 different levels of hardness. The control group underwent the same training except that they were not instructed to discriminate sponge hardness. Center-of-gravity (COG) sway while standing on one-leg with the eyes open or closed was measured before and after the training. Statistical analyses were performed the COG path length, enveloped area and rectangular area values. [Results] The number of correct answers for hardness discrimination significantly increased with the number of training days. There were significant reductions in the COG path length, enveloped area and rectangular area values after training in the intervention group compared to their respective values prior to training. In contrast, the control group showed no significant changes in these 3 parameters. [Conclusion] Our results suggest that the ability of healthy individuals to regulate center-of-gravity sway while standing on one-leg improved with enhancement of plantar perceptual ability through hardness discrimination training.

Key words: Discrimination training, One-leg standing, Center-of-gravity sway

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INTRODUCTION

Centripetal information from the visual, somatosensory, and vestibular labyrinth pathways plays a crucial role in posture control, and individuals integrate this information to maintain an upright posture[1]. It was reported that only the somatosensory labyrinth pathway of the plantar surface that comes into sustained contact with the floor participates in posture control[2–6]. Okubo et al. reported that center-of-gravity sway decreased significantly after subjects stood on shotgun pellets spread on the floor[7]. In addition, Rogers et al. found that center-of-gravity sway decreased significantly after subjects stood on a rubber mat[8]. These studies indicate that posture control is improved by an increase in sensory input to the plantar surface. In contrast, it has been reported that posture control improves through intervention not only at the sensory level but also at the perception level[9–11]. Morioka et al. reported that the center-of-gravity sway and the functional reach test of healthy adults improved significantly with plantar hardness discrimination training[9]. In addition, it was reported that the same training improves posture control in the elderly and hemiplegic patients following stroke[10,11]. These finding indicate that an improvement in the ability to perceive sensory information input from the plantar surface plays a crucial role in the improvement of posture control.

The above-mentioned studies demonstrate that improvement in the plantar surface's perceptual ability plays a crucial role in posture control while standing on two-legs. However, they did not demonstrate the influence of improved plantar perceptual ability on center-of-gravity sway while standing on one-leg. Standing on one-leg is a test that is simple and easy to carry out, does not require special equipment, and is frequently used in physical rehabilitation as an equilibrium function test for patients and the elderly[12]. It is also reported that center-of-gravity sway while standing on one-leg is related to the risk of falls among the elderly[13]. Therefore, it is necessary to demonstrate that the influence of plantar hardness discrimination training on center-of-gravity sway while standing on one-leg can be applied to physical rehabilitation.

Thus, this study aimed to investigate the influence of plantar perceptual ability improvement through hardness discrimination training on center-of-gravity sway while standing on one-leg.

Table 1. Characteristics of the intervention and control groups

	Intervention group (n = 10)	Control group (n = 10)
Age (years)	25.4 ± 2.7	25.0 ± 2.3
Gender (M/F)	5/5	7/3
Height (cm)	167.5 ± 5.5	168.2 ± 5.5
Weight (kg)	60.2 ± 9.3	61.5 ± 8.0

Mean ± SD.

SUBJECTS AND METHODS

Twenty healthy adult volunteers aged 22–29 years, participated in this study. Subjects were excluded if they had a chronic (orthopedic, neurological, or psychiatric) disease that might influence the results. The study protocol was explained to each subject who subsequently provided their informed consent. The research ethics committee of Kio University approved this study.

The subjects were randomly divided into intervention (n=10) and control groups (n= 10) by a random number generation program (RAND function; Microsoft Office Excel 2007). The information is detailed in Table 1.

The intervention group carried out plantar discrimination training with sponges of different hardness that were set up on the floor[9–11]. The sponges had 5 different levels of hardness although their surface material and shape were identical (INOAC Co.). During the discrimination training subjects had their eyes closed and were in a sitting position. The training was carried out in pairs comprising an assistant and a subject. The assistant set up the sponge on the floor, and the subject's foot was placed on the sponge. Then, the subject moved the ankle joint in plantarflexion and dorsiflexion so that the plantar surface remained on the sponge, and was asked to discriminate sponge hardness. Initially, the subjects were asked to memorize hardness in sets of 5 by discriminating the hardness in ascending (from sponge 1 to 5) and descending (from sponge 5 to 1) orders (verbal feedback was provided to enable memorization of sponge hardness by the assistant). After memorization, the subject performed 10 sets of hardness discriminations based on a random table created by a random number generation program (RAND function; Microsoft Office Excel 2007) and was thereafter instructed to determine levels of hardness (without verbal feedback in this instance). The number of correct answers in the random table was designated as the assessment of perceptual ability. The table was formulated so that each of the 5 hardness-graded sponges was included twice in the 10 sets that comprised the hardness discrimination training. The control group underwent the same training except that they were not instructed to perform hardness discrimination. This training was carried out over a 2-week period for 10 days.

The center-of-gravity (COG) sway while standing on one-leg with eyes open or closed was measured before and after the 10-day training period. Statistical analyses were performed for COG path length (LNG, cm), enveloped area (ENV-AREA, cm^2) and rectangular area (REC-AREA, cm^2). Center-of-gravity sway was measured by G-6100 (ANIMA CO.). The measurement cycle was 50 ms. The measurements of each parameter were performed for 30 s, 3 times, and the mean value of the 3 measurements was calculated. The subject was directed to gaze forward at a point 2 m away and at eye level during measurement.

The number of correct answers for the discrimination training was analyzed by one-way ANOVA with repeated measures. The repeated measures ANOVA was followed by Scheffe post-hoc comparisons to test for significant differences between each day. The paired t-test was used to analyze the difference between center-of-gravity sway values before and after the discrimination training. All statistical tests used a significance level of $\alpha = 0.05$. In addition, we calculated intraclass correlation coefficients to determine the reproducibility of center-of-gravity sway measurements.

RESULTS

Table 2 shows the result of changes to the number of correct answers for the hardness discrimination training performed over 10 days. The number of correct answers for the hardness discrimination training increased significantly with the number of days ($F = 12.3$, $p<0.01$). Scheffe post-hoc comparisons revealed a statistical significance between day 1 and days 7–10 ($p<0.01$), day 2 and days 7–10 ($p<0.01$, $p<0.05$), day 3 and days 8–10 ($p<0.01$, $p<0.05$), and day 4 and day 10 ($p<0.05$).

Table 3 shows the result of comparison of center-of-gravity sway while standing on one-leg before and after the 10-day training. There were significant reductions in the length, enveloped area and rectangular area values of center-of-gravity sway with eyes open and closed after the 10-day training period compared to that before training in the intervention group ($p<0.01$, $p<0.05$, respectively). In contrast, there were no significant changes in these 3 parameters in the control group. The intraclass correlation coefficient showed "substantial" and "moderate"[14].

DISCUSSION

When changes to the number of correct answers for the hardness discrimination training were evaluated, the number of correct answers was found to have increased significantly with the number of days. This results demonstrates that plantar perceptual ability improved with hardness discrimination training.

There were significant reductions in the length, enveloped area and rectangular area values of center-of-gravity sway while standing on one-leg with eyes open and closed after training compared to the measurements obtained before

Table 2. Changes to the number of correct answers given in hardness discrimination training performed over 10 days

	Day									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Mean	5.20	5.30	5.80	6.30	6.80	7.20	7.70	8.10	8.40	8.60**
SD	1.48	1.34	1.23	1.16	1.14	1.03	1.06	0.99	0.97	0.84

Max: 10, Min: 0, **: p<0.01

Table 3. Comparison of center-of-gravity sway while standing on one-leg before and after 10 days of hardness discrimination training.

	Intervention group (n = 10)							
	Eyes open				Eyes closed			
	Before	ICC	After	ICC	Before	ICC	After	ICC
LNG (cm)	109.7 ± 20.7	0.635	103.9 ± 16.9	0.675*	259.1 ± 33.4	0.631	237.9 ± 32.9	0.619**
ENV-AREA (cm2)	4.0 ± 0.6	0.483	3.6 ± 0.4	0.419*	18.3 ± 4.1	0.488	16.7 ± 4.3	0.413**
REC-AREA (cm2)	11.0 ± 3.4	0.452	9.3 ± 2.4	0.519**	54.9 ± 23.0	0.459	41.5 ± 15.4	0.492**
	Control group (n = 10)							
	Eyes open				Eyes closed			
	Before	ICC	After	ICC	Before	ICC	After	ICC
LNG (cm)	103.7 ± 18.0	0.615	102.9 ± 18.3	0.660	248.5 ± 33.5	0.615	247.9 ± 33.0	0.628
ENV-AREA (cm2)	3.6 ± 0.6	0.425	3.5 ± 0.5	0.529	16.6 ± 4.8	0.510	16.5 ± 5.0	0.493
REC-AREA (cm2)	10.1 ± 2.9	0.426	10.0 ± 3.0	0.467	47.1 ± 18.0	0.450	46.6 ± 17.9	0.517

Mean ± SD, *: p < 0.05, **: p < 0.01. ICC: Intraclass Correlation Coefficient.

training in the intervention group. In contrast, there were no significant changes to these 3 parameters in the control group.

Both groups received the same sensory information through the plantar surface during the 10-day discrimination training. However, training for the intervention group included a perceptual process, in which sensory information at the plantar surface was memorized and discriminated. It was reported that motor skill ability improved along with perceptual ability in motor learning theory[15,16]. This means that the internal reference[17] for motion is established by improvement of perceptual ability, and requires execution of a certain motion before it becomes able to correct detailed motion by comparative matching of the internal reference with actual motion and improving motor skill ability. It was reported that center-of-gravity sway while standing on one leg increased significantly compared to the sway experienced while standing on two legs; centripetal information from the visual, somatosensory, and vestibular labyrinth pathways plays a crucial role in posture control while standing on one leg[18]. Moreover, we have reported that motor-related areas such as the premotor and supplementary motor areas are involved in comparitive matching of somatosensory information and the production of motor program activation during plantar hardness discrimination training like that carried out in the present study[19]. The results of the present study suggest that the subject eventually becomes able to appropriately perceive the plantar somatosensory information required for posture control while standing on one leg by improving somatosensory perception through hardness discrimination training, and becomes able to correct, and therefore, decrease center-of-gravity sway while standing on one-leg.

A limitation of the present study was that we could not examine the maintenance of the improvement of center-of-gravity sway while standing on one leg by hardness discrimination training. In addition, difficulty, term, and frequency of training corresponding to subjects' abilities were not evaluated. Moreover, we should not expect to obtain a result similar to that of healthy adults if the elderly, who experience failures of cognitive and somatosensory functions, or hemiplegic patients following stroke, who present sensory abnormality, are enrolled as subjects. However, it was reported that the center-of-gravity sway and functional reach test results of elderly and hemiplegic patients were improved by enhancement of plantar perceptual ability through hardness discrimination training[10,11]. However, it will be necessary to show the influence of plantar hardness discrimination training on center-of-gravity sway while standing on one leg for the elderly and hemiplegic patients before applying this technique to physical rehabilitation. In the future, we would like to develop this technique further to cater for the rehabilitation of patients presenting with disequilibrium as well as the elderly with experience of falls, and to examine the cross-sectional and longitudinal effectiveness of such intervention.

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