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Effects of perceptual learning exercises on standing balance using a hardness discrimination task in hemiplegic patients following stroke: a randomized controlled pilot trial

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Objective: To investigate the effect of perceptual learning exercises for hardness discrimination by the soles on standing balance in stroke patients with hemiplegia.
Subjects: Twenty-eight subjects were randomly assigned to an experimental or a control group and participated in a rehabilitation programme.
Intervention: The experimental group received perceptual learning exercises on hardness discrimination using three different levels of hardness of a rubber sponge for 10 days.
Main measures: Length, enveloped area and rectangular area of the parameter of postural sway were measured by a stabilometer on entry into the study and after 10 days.
Results: Twenty-six subjects completed the study. Data indicate that more parameters indicating postural sway were significantly decreased in the experimental group than in the control group. Also, there was a significant difference between the groups in change scores (pre-exercise minus post-exercise) of length and enveloped area.
Conclusion: The plantar perception exercise used as a method in this study is considered to be effective as a supplemental exercise for standing balance. The possibility of clinical application using the hardness discrimination task with rubber as a balance exercise is therefore suggested.

Introduction

The relearning of postural control through biofeedback in rehabilitation programmes is believed to be an effective therapy for improving balance function. In previous studies on biofeedback therapies for balance function, the stabilometric data obtained by using a forceplate were primarily converted to visual and auditory signals and presented to the subject.[1,2] Stabilometry was used in these studies since the purpose of learning postural control is to acquire postural stability during rest and motion, and swaying around the centre of gravity is the index thought to most directly reflect postural stability. Many investiga-

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tors have recognized the effectiveness of biofeedback therapy using external visual and auditory cues for improvement in postural control in hemiplegics after stroke.[3–7]

On the other hand, it is believed that the perception of the plantar sole is the most influential factor in maintaining posture during standing.[8–11] By requiring trainees to stand on shotgun balls spread all over the floor, Okubo *et al.* found a decrease in postural sway and also noted the importance of foot pressure receptors in the control of standing posture.[12] Also, Rogers *et al.* reported in their recent study that standing balance was improved by increasing sensory input from the passive sole in subjects standing on a rubber mat.[13] Thus, it appears that sensory input from the plantar influences the control of posture, emphasizing the role of the proprioception of the sole. In particular, hypothesia of the tactile and pressure senses due to damage to the sole following stroke in hemiplegics results in sensory disorder. Even when local sensory disorder is present, other sensory modalities make perception possible. Therefore, even hemiplegics with disordered plantar tactile and pressure sensation may be able to acquire perceptive ability through learned experience.

The purpose of the present pilot study was to investigate the possibility that standing balance can be stabilized by exercise that focuses on perceptual learning using feedback from the exploratory actions of the subject's sole during discrimination of the hardness of a sponge rubber.

Methods

All subjects were stroke patients with hemiplegia who were receiving hospital rehabilitation, and standing maintenance was becoming independent. Subjects with a higher brain dysfunction and dementia were excluded from the trial. Twenty-eight cases out of 62 stroke patients meeting the selection criteria were invited to participate and those who agreed gave informed consent. Subjects were randomly assigned to the experimental group (perceptual learning exercise) or to the control group (no perceptual learning exercise) by a physiotherapist who was blinded to the experimental design. A random table was used for the subject assignment to the groups. Fourteen of the 28 subjects were assigned to the control group, while the 14 remaining subjects were assigned to the experimental group.

Subjects in both groups participated in a rehabilitation programme consisting of physiotherapy and occupational therapy, which included ordinary postural control exercises, such as maintenance of standing, shift of the weight loads to the nonparalytic and paralytic side of the foot on the health meter. In addition, the experimental group participated in the perceptual learning exercise described below.

An exercise to discriminate the hardness of sponge rubber placed under the sole of the foot (hardness discrimination exercise) was given to the 14 subjects in the experimental group. This exercise was performed for a total of 10 days over two weeks. Three 30-cm-square sponge rubbers (5, 10 and 15 mm thickness, Sanyu Sangyo Co., Ltd, Nagoya, Japan), of identical shape and material composition were placed under the sole of the foot. The hardnesses of the 5 mm, 10 mm, and 15 mm rubbers were 2425 mN, 1875 mN and 1500 mN, respectively. A hardness tester (Asker JA type, JIS K 6301, Kobunshi Kenki Co., Ltd, Kyoto, Japan) was used for the measurement of rubber hardness.

The hardness discrimination task for these sponge rubbers was performed daily; the subjects were in the standing posture and were blindfolded. The test administrator, who was blinded to the experimental protocol, verbally explained the ascending arrangement of the sponge rubbers with different hardnesses, from 5 mm to 15 mm and the descending one from 15 to 5 mm. Next, the subjects participated in three trials, during which they were instructed to estimate the hardness of the sponges. Immediately after the subject's response, verbal feedback regarding the correct hardness of the sponge was given. The same verbal direction as to the correct hardness of sponge was given to the subject after every explanation of the ascending and descending arrangements, aiming at further memory formation of the hardness. Thirty seconds later, 10 trials were administered according to a random sampling table during which subjects estimated the hardness of sponges. The random table was designed such that each thickness constructed with sponge rubbers was chosen three times in the 10 trials. The number of incorrect answers during the exercise according to the table was used as the score of the hardness discrimination task. During the 10 trials, feedback to the subject regarding whether the estimated hardness was correct was not given.

This protocol was the hardness discrimination exercise given in a single day. This exercise was then repeated each day for 10 days over two weeks. Furthermore, subjects were blinded to the fact that the hardness discrimination exercise was a trial for standing balance improvement. At the end of the study subjects were informed that these exercises were for sensory training of the foot sole.

A stabilometer (GS2000; Anima Co., Ltd, Tokyo, Japan) was used to assess postural sway as outcome data on entry into the study and after 10 days under two conditions: (1) standing with eyes open, (2) standing with eyes closed. Measurements were performed by a physiotherapist who was blinded as to the experimental design of the study. The sampling time was set to 50 ms and the measurement was carried out three times over a 20-second interval for each condition. The mean value of the three measurements was used for data analysis. Measurement was carried out in an ordinary standing position with legs 12 cm apart. For measurement with eyes open, the subjects were directed to fix the eyes on an object 2 m ahead. The measurement was started with a delay of 5 seconds after the start sign to exclude early sway. Total locus length (LNG), enveloped area (ENV-AREA) and rectangular area (REC-AREA) were used as the parameters for postural sway. LNG, ENV-AREA and REC-AREA were calculated by the following formulain which x and y are the coordinates of the centre of gravity:

$$\text{LNG: } \sum_{i=1}^{n} \sqrt{\Delta x_i^2 + \Delta y_i^2} \qquad (1)$$

where n is the sampling number,

$$\text{ENV-AREA: } \sum_{i=1}^{120} (r_i \cdot r_{i+1} \cdot \sin \theta/2) \qquad (2)$$

$$r_i = \sqrt{x_i^2 + y_i^2},\ \theta = 3$$

$$\text{REC-AREA: } (x_{max} - x_{min}) \bullet (y_{max} - y_{min}) \qquad (3)$$

The mean number of incorrect answers during the 10 trials in the hardness discrimination exercise over 10 days was analysed by one-way ANOVA with repeated measures. The repeated measure ANOVA was followed by a Tukey post-hoc test for comparison of significant differences between each day. This analysis was used to investigate the perceptual learning effect. Student's t-tests were used to test for differences in the selected parameters pre- and post-hardness discrimination exercises. Also, change scores in each parameter were calculated by subtracting the post-exercise measure from pre-exercise measure. These change scores were compared between the experimental and control group using two-tailed t-tests. All statistical tests were completed at the 0.05 alpha level.

Results

Two subjects from the experimental group were lost from the study due to discharge prior to completion of the study. The final sample consisted of 14 subjects in the control group and 12 in the experimental group (Figure 1). The groups were similar in age, time since stroke and maintenance of standing and gait. Two-point discrimination distance on the planter sole was measured toward the forefoot from the centre of heel. Results indicate that there was no statistically significant difference between groups (Table 1). Also, there were no significant improvements in two-point discrimination distance after hardness discrimination exercise in both groups. Furthermore, there were no significant differences in the value of all parameters with eyes open and closed before exercise between the groups.

The mean number of incorrect answers given by the 12 subjects significantly decreased as the number of trials increased, suggesting that hardness discrimination was improved through exercise. Tukey post-hoc comparisons revealed statistical significance between 1st day and 4th–10th days, and between 3rd day and 4th–10th days ($p < 0.01$). Data indicate that the number of incorrect answers were decreased when days were repeated (Table 2).

The differences in the postural sway in subjects in the experimental group pre- and post-exercise with eyes open were all significant, while the LNG during eyes closed was significantly decreased. The differences in postural sway in control group subjects pre- and post-exercise with eyes open was significant in REC-AREA only (Table 3). Change scores between the groups were statistically significant in LNG and

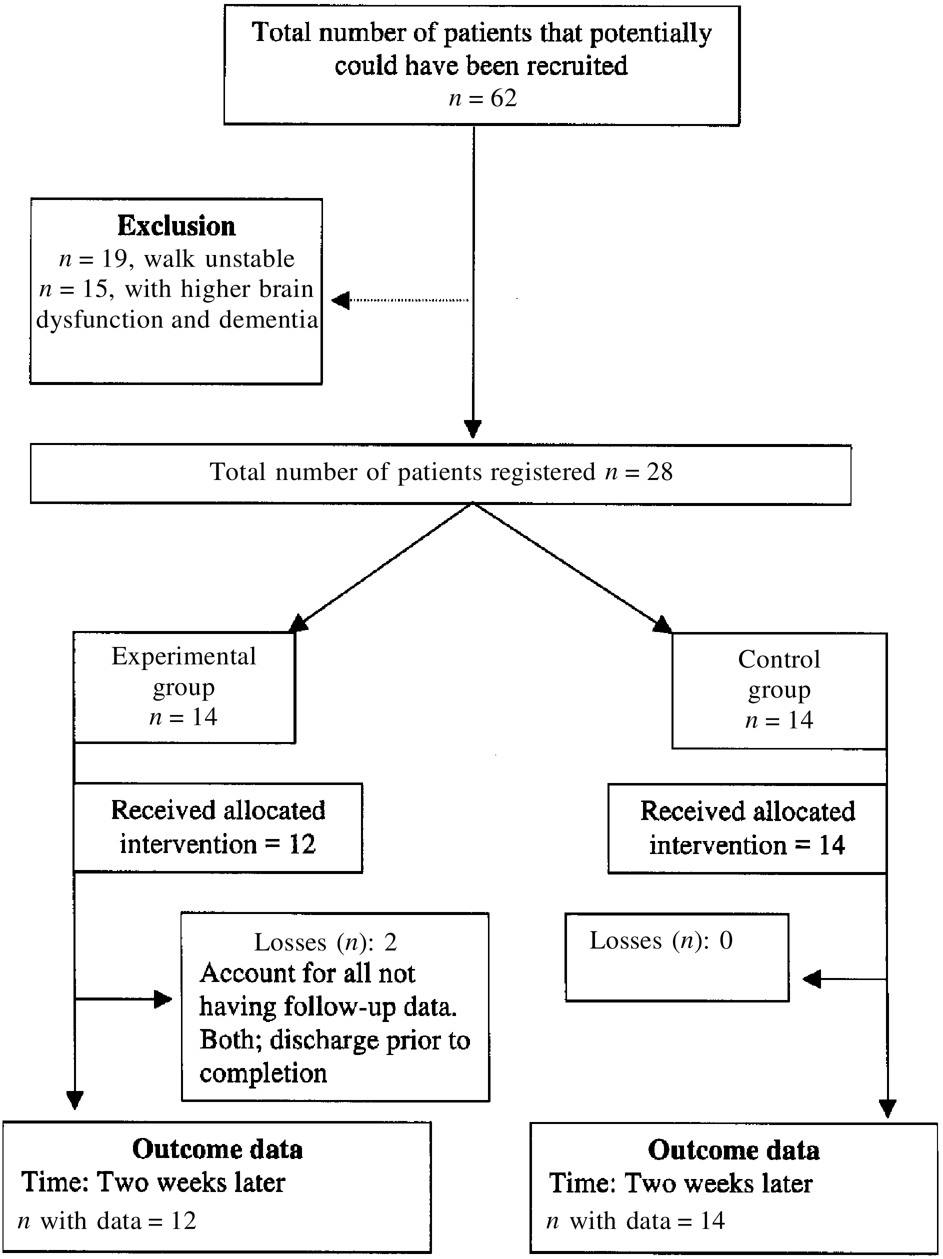

Figure 1 Flow diagram for randomized subject assignment in this study.

Table 1 Subject characteristics

Characteristic	Group	
	Control	Experimental
N	14	12
Age (years)		
Mean ± SD	61.3 ± 11.0	62.6 ± 13.3
Range	56–73	51–79
Time since stroke (days)		
Mean ± SD	61.9 ± 20.8	65.4 ± 18.6
Range	31–111	36–106
Side of hemiparesis		
Left : Right	5 : 9	6 : 6
Gender		
Male : Female	8 : 6	9 : 3
Two-point discrimination distance In the foot sole		
Paralytic side (mean ± SD)	7.2 ± 3.6	6.6 ± 4.6
Nonparalytic side (mean ± SD)	3.6 ± 2.4	3.5 ± 2.4

Table 2 Number of incorrect answers regarding hardness discrimination according to day ($N = 12$)

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	*F*	*p*-value
Mean	5.50	6.00	5.58	3.50	3.42	3.50	2.83	3.08	2.67	2.92	6.34	0.001
SD	2.10	2.65	2.10	1.32	1.61	1.26	1.46	1.19	0.75	1.61		

Max: 10, Min: 0.

ENV-AREA with eyes open. Furthermore, the standard deviation was high in both groups for decrease value with eyes closed (Table 4).

Discussion

The task of the present experiment was to train hemiplegics following stroke with plantar sense disorder to discriminate the hardness of sponge rubber under the sole via cutaneous pressure sensation for 10 days. Results from this exercise were used to evaluate whether standing balance was improved. Data indicate that the experimental group had more parameters in which postural sway significantly decreased than the control group. Also, significant differences in LNG and ENV-AREA with eyes open between the experimental group and the control group were found in a comparison of change scores. In addition, parameters from the experimental group with eyes closed increased following exercise, as indicated by change scores. Results indicate that there were no improvements on two-point discrimination of the planter sole on the paralytic side in both groups. The reason for the improvement in motor performance, such as standing balance, due to improved perceptive ability may be inferred from the following. Because damage to somatic sensation has been sustained in hemiplegics after stroke, perceptual and motor learning through the conscious control stage is mediated via the cerebral cortex and pyramidal tract. Thus the hardness discrimination exercise was transferred to the achievement stage of reflective control. The effect of transfer of learning is conceivable as well. Using a computer display synchronized to a platform, hemiplegics after stroke performed dynamic exercise to match the centre of gravity with a target on the display. In this study McRae *et al.* observed a decrease in postural sway in a static standing posture.[14] They cited the positive transfer of learning as the reason for this decreased swaying.

Table 3 Comparison of the value for each parameter of the centre of gravity sway at pre- and post-exercise (mean ± SD)

	Experimental group (N = 12)				Control group (N = 14)			
	Eyes open		Eyes closed		Eyes open		Eyes closed	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
LNG (cm)	52.9 ± 17.8	40.4 ± 11.9	82.5 ± 46.9	72.6 ± 37.5	54.0 ± 20.6	52.4 ± 21.2	88.3 ± 44.3	83.7 ± 38.0
	** (Pre vs Post)		* (Pre vs Post)					
ENV-AREA (cm^2)	9.8 ± 4.7	7.1 ± 3.7	14.5 ± 5.7	12.2 ± 4.9	9.8 ± 3.4	8.9 ± 2.4	15.1 ± 8.4	14.8 ± 9.5
	* (Pre vs Post)							
REC-AREA (cm^2)	86.3 ± 42.3	72.3 ± 32.8	147.0 ± 101.2	126.9 ± 78.1	90.9 ± 32.3	84.9 ± 37.3	156.6 ± 91.9	148.1 ± 85.9
	* (Pre vs Post)				* (Pre vs Post)			

*$p < 0.05$; **$p < 0.01$. LNG, total locus length; ENV-AREA, enveloped area; REC-AREA, rectangular area.

Table 4 The comparison of change scores for each parameter in the experimental and control group (mean ± SD)

	Eyes open		Eyes closed	
	Experimental	Control	Experimental	Control
LNG (cm)	11.6 ± 8.8 *	1.7 ± 3.8 *	9.9 ± 10.1	4.6 ± 8.0
ENV-AREA (cm^2)	2.7 ± 2.4 *	0.8 ± 2.0 *	2.3 ± 5.1	0.3 ± 4.6
REC-AREA (cm^2)	14.0 ± 12.7	7.3 ± 6.9	20.1 ± 26.6	8.5 ± 20.3

*$p < 0.05$.

Since the present exercise of perceptual learning was conducted similarly in a standing position, motor responses to task stimuli at the measurement of the sway of the centre of gravity resemble those in McRae's study. Therefore, it may be said that the improved ability to achieve the task of hardness discrimination decreased the swaying in a standing position.

These results indicate that supplementation of perception by vision and hearing does not compensate for the loss of plantar sensation during postural control by somatosensory perception. Furthermore, the use of sponge rubber for the task of hardness discrimination is convenient and easy in clinical applications to balance dysfunction in hemiplegics after stroke. In addition, it is suggested that there was an immediate effect on the exercise. Therefore, this relatively inexpensive form of sensory feedback may be of clinical value.

However, it is difficult to provide conclusive evidence from this pilot study due to subject selection bias regarding performance status and rehabilitation response. Also, it was not determined whether performance, such as standing balance, was improved directly by the perceptual learning. In addition, we are unable to ascertain at present whether this learning continues. The selection of the degree of difficulty of the task depending upon the subject's ability and the effects of varying training period and frequency are to be investigated in the future. In addition it is our goal to generalize the present methods to a wide range of daily living activities.

In conclusion, our results indicate that perceptual learning of the planter sole may change postural sway. We suggest that the hardness discrimination task by the planter sole may be an effective, simple standing balance exercise, if the limitations imposed by the conditions of the current study are removed.

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