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CLINICAL REPORT

The Development and Clinical Evaluation of a Standing Biofeedback Trainer

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Abstract—A new standing biofeedback training device, which includes a height-adjustable work table, weight-bearing sensors, and a real-time visual and auditory feedback system, has been developed for postural training. Sixty persons with hemiplegia after acute stroke or traumatic brain injury were randomly divided into Group A (experimental) and Group B (control). After a training period of 4 weeks, the percentage of postural asymmetry in Group A and Group B was reduced from 17.2±10.8% and 17.0±10.0% to 3.5±2.2% and 10.1±6.4 percent, respectively ($p=0.003$). There was no significant difference between subjects with right or left hemiplegia. The results indicated that this device had a positive training effect on stance symmetry in hemiplegic subjects.

Key words: *biofeedback, postural symmetry, rehabilitation, standing training.*

INTRODUCTION

Postural control is related to righting and equilibrium reactions. The ability to stand erect and maintain posture against gravity is acquired through maturation and learning, and needs repetition for a period of time. The learned patterns of postural control are programmed centrally and specify statokinetic postural reactions of motor neuron activity to all involved muscles and inputs. Pathological influence after brain damage can generate an irrelevant motor program leading to abnormal posture (1,2).

Postural disorders of hemiplegic persons in an antigravity position are considered to be related to asymmetric weight bearing. Most subjects with hemiplegia exhibit an asymmetrical standing posture, supporting most of their weight by using the non-paretic leg (3,4). Moreover, fear of falling further limits their functional activities. Several researchers have found a strong correlation between various measurements of static standing and locomotor function (5–7). Therefore, static standing balance is crucial for ambulation performance.

Loading exercises over the affected lower limb of the person with hemiplegia can be performed by means of manual techniques and balance control through platform balance training by the physical therapist, and postural adjustment during activities of dynamic stabilized standing by the occupational therapist (8–13).

Kottke et al. found that whatever pattern of activity was practiced, that pattern would be developed (14). According to Ferier, every form of active muscular exertion necessitates the simultaneous cooperation of an immense assemblage of synergic movements through the body to secure steadiness and maintain general equilibrium. Resistive movements of upper limbs may establish postural stabilization. In view of these findings, a task-oriented program for the relearning of postural control

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has been developed in the Department of Occupational Therapy of the Chang Gung Memorial Hospital and has been demonstrated to have a therapeutic effect in helping persons with hemiplegia to regain postural symmetry and stability. The device used consists of a height-adjustable worktable, a pelvic belt, and a suspension system to help the client maintain symmetry in an upright stance, while performing a task of pushing and pulling a load by means of resistive movements of the upper limbs (15). This device is called a standing training table (STT). The subject or therapist, however, does not know how much weight is actually transferred to the affected leg during the training program with the conventional STT. The therapist asks the subject to put more weight over the affected leg based mainly on a subjective impression or experience.

The purpose of this study is to develop an economical biofeedback system with visual and auditory signals for the conventional STT. This new system is called a standing biofeedback trainer (SBT), and its effect was evaluated by comparing the percentage of weight bearing on the affected side achieved with the SBT and with the STT, respectively.

METHODOLOGY

Subjects

Forty-three male and 17 female persons with unilateral hemiparesis or hemiplegia from a first acute stroke (CVA) or traumatic brain injury (TBI) were recruited for this study. The average age was 51.3±13.9 years (**Table 1**). All were alert and oriented, medically stable with no prevailing complications, and were evaluated by an experienced physiatrist to have the potential for functional ambulation with rehabilitation. The subjects were randomly divided into Group A and Group B. Both groups were equal in number and motor status as evaluated by Brunnstrom's staging. Group A received SBT, and Group B received STT training, respectively (**Table 2**).

Table 1.
Subject data.

Group	A	B	Total
Age (y/o)	52.5±14.8	52.8±12.4	51.3±13.9
Age range (y/o)	30-74	33-72	
Sex Male	21	22	43
Female	9	8	17
Etiology			
CVA	27	28	55
Head injury	3	2	5
Hemiplegia			
Left	12	17	29
Right	18	13	31

Group A: trained by the new standing biofeedback trainer (n=30).
Group B: trained by the conventional standing table (n=30).

Table 2.
Motor status of hemiplegia according to Brunnstrom's stage.

Stage	Group A	Group B	Total
II	10	9	19
III	5	8	13
IV	8	8	16
V	7	5	12
Total	30	30	60

Design of the Standing Biofeedback Trainer

The SBT is a modification of the STT, consisting of a height-adjustable worktable, postural correction mirror, forearm suspension system, and hip fixation system. The forearm suspension system is applied to keep the upper trunk and bilateral shoulders in a symmetrical posture. The hip fixation system is used to keep the pelvis and lower trunk in a neutral position. For measuring and monitoring weight distribution, foot pressure sensors were installed under a dual force platform. A real-time visual weight bearing biofeedback display with two numerical light-emitting diodes (LEDS) and a light illuminating balance scale were mounted on the center of the postural correction mirror. Also, an auditory alarm system in Taiwan's three most commonly spoken languages (Mandarin, Taiwanese, Hakanese) provided a warning signal to the subjects (**Figures 1** and **2**).

Training Protocols

The training protocols for the physical and occupational therapeutic programs were the same in both groups.

The standing training took 60 min per session. For each person, the SNT was adjusted to keep the subject standing in a symmetrical upright posture under the assistance of the forearm suspension and pelvic fixation systems. The subject performed a weight-loaded task of

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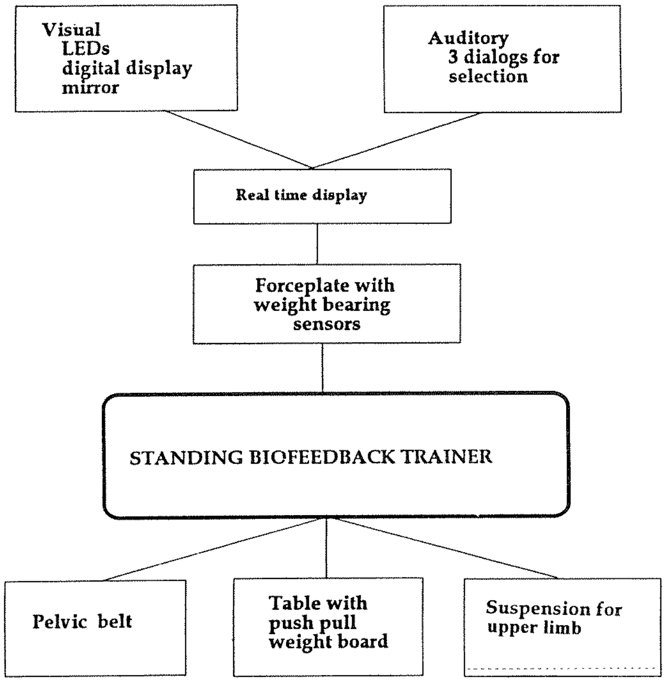

Figure 1.
Functional design of the standing biofeedback trainer (SBT).

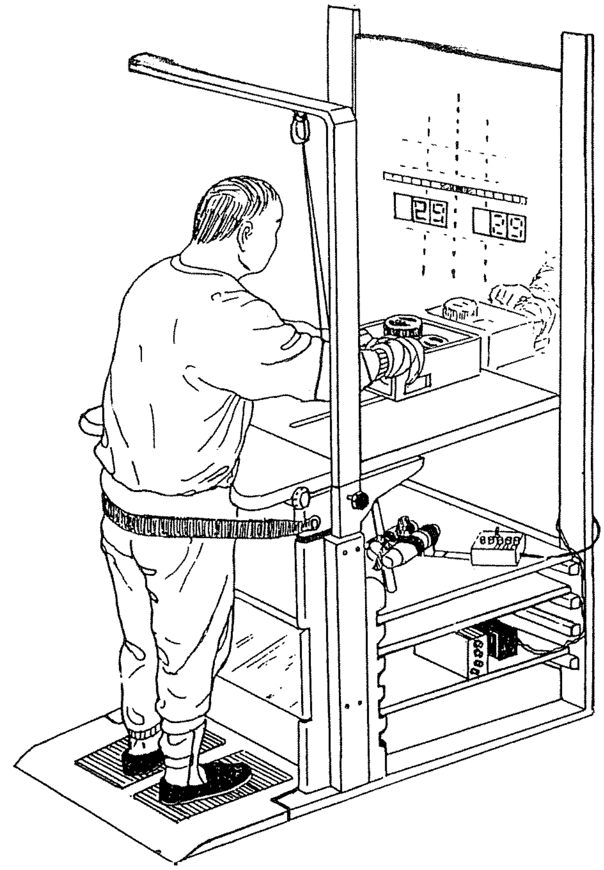

Figure 2.
The standing biofeedback trainer with visual and auditory display for recording stance symmetry.

pushing and pulling a box by its handhold on the table. An elastic bandage was used to fix the paretic hand to the handle of the box. The weight was started at 2 kg and gradually increased by 1 kg/day, according to the person's tolerance, until a maximum of 12 kg was reached. Many rest breaks were allowed during each training session if the client complained of fatigue. One training session was administered per day, 5 days per week, for 3 to 4 weeks.

When the subject was able to maintain upright stance steadily, the fixation system would be removed. All 60 persons completed the study.

Evaluation Method and Data Analysis

Both groups received identical tests before and after each training session. During the test, no forearm suspension system was used, and the subject was unable to see the mirror. The overall experimental design consisted of a mixed two-factor model with treatment condition (STT or SBT) as the between-subject factor and test (before or after training) as the within-subject (repeated measures) factor.

Postural symmetry was calculated using the following equation:

$$\text{Postural symmetry} = \left| \frac{\text{weight on affected side}}{\text{body weight}} - 0.5 \right| \times 100\%$$

With this definition, a percentage of 0 indicated equal symmetry and best postural control in quiet standing, while a higher percentage indicated asymmetry and poor postural control. The effect of standing balance training of both groups was compared by paired t-test and analysis of variance (ANOVA). A 0.05 significance level was used for all analyses.

RESULTS

The improvement of stance ability was found in all individual subjects throughout the experiment. As shown in **Table 3,** the ability to maintain stance by percentage of postural symmetry in the group trained with the SBT was

Table 3.
Effect of standing training by percentage of postural symmetry.

	Group A		Group B		
	No.	**Mean±SD (%)**	**No.**	**Mean±SD (%)**	**p**
Pre-training	30	17.2±10.8	30	17.0±10.0	0.971
Posttraining					
Day 1	30	12.4±10.0	30	15.2±9.7	0.276
Week 1	30	9.1±6.0	30	12.6±7.6	0.049*
Week 2	30	6.6±5.1	30	10.1±6.1	0.019*
Week 3	22	6.2±6.2	20	9.5±5.7	0.083
Week 4	14	3.9±3.0	11	10.1±6.4	0.003*

*p<0.005.

better than that of the group trained with the STT. The subjects demonstrated improvement in the first 2 weeks. About one third of them had good standing ability through successful training and shifted to ambulation training. The persons who received the standing training program decreased in number at the third and fourth weeks in both groups. After 4 weeks, the percentage of postural symmetry in Group A and Group B was reduced from 17.2±10.8 percent and 17.0±10.0 percent to 3.5±2.2 percent and 10.1±6.4 percent, respectively (p=0.003). The gradual change in the percentage of postural symmetry in both groups by paired t-test is shown in **Table 4.** The immediate learning effect after the first day of training in Group A (p=0.013) was obviously better than Group B (p=0.166). There was no significant difference in the subjects with right or left hemiplegia (**Table 5**). Clinically, the SBT demonstrated a better training effect for hemiplegic persons than the STT (**Figure 3**).

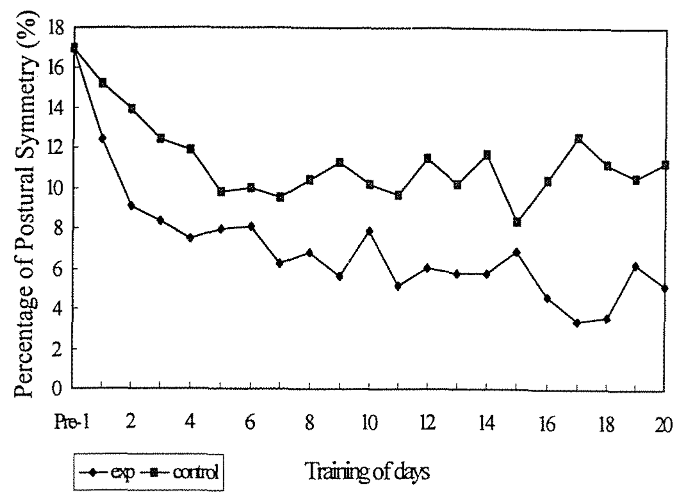

Figure 3.
The effect of standing training for both groups by percentage of postural symmetry over time.

DISCUSSION

Symmetry, steadiness, and dynamic stability are three elements of postural control (16). Symmetry is the ability to distribute weight evenly between the two feet in an upright stance. Steadiness is the ability to keep the body as motionless as possible. Dynamic stability is the ability to transfer the vertical projection of the center of gravity around the supporting base.

The use of a moving platform in the study of balance training improved distribution of body weight on

Table 4.
Comparison from pre-training to posttraining by paired t-test.

	1st day	**1st week**	**2nd wk**	**3rd wk**	**4th wk**
Group A	0.013*	0.002*	0.0002*	0.088	0.037*
Group B	0.166	0.010*	0.004*	0.084	0.508

*p<0.05.

Table 5.
Effect of standing training according to right- and left-sided hemiplegia.

	Group A			Group B		
	Lt. Hemi	Rt. Hemi	p	Lt. Hemi	Rt. Hemi	p
Pre-training	14.5±7.4	16.4±12.3	0.638	15.1±9.9	19.0±10.0	0.31
Posttraining						
Week 1	7.2±5.3	8.5±6.4	0.553	12.3±7.3	13.2±8.3	0.74
Week 2	4.3±3.1	6.5±5.7	0.233	10.3±6.6	10.1±5.2	0.91
Week 3	4.0±4.5	6.0±5.0	0.393	8.5±6.0	10.1±5.3	0.54
Week 4	2.7±1.4	4.3±2.5	0.178	8.3±4.7	12.4±7.8	0.31

the two feet during unperturbed stance. This was demonstrated by recording the EMG activity of the inactive foot dorsiflexor of the impaired leg (7). Winstein showed that hemiparetic subjects trained with the visual feedback system had better standing symmetry than those without the system (17).

However, one difficulty in identifying the specific determinants of balance deficits is that balance behavior can be influenced by the somatosensory (proprioceptive, cutaneous, and joint), visual, and vestibular systems. Persons may incur deficits in balance control during expected and unexpected perturbations, voluntary postural adjustments, or postural adjustments preceding voluntary limb movements. In this study, a standing biofeedback training system was developed, with the main advantage of keeping the subjects in an upright standing posture (through forearm suspension system) while the upper limbs performed a push-pull task of maximum weight load, while the lower limbs self-adjusted themselves to weight bearing using the visual and auditory feedback system in a static condition. Further research is needed concerning dynamic posture and movement.

Most of the subjects would like to have an auditory alarm in addition to the visual digital display to make them more alert to adjustments for the symmetricality of upright posture, especially in the first 2 weeks. Some asked to turn off the auditory feedback after 2 weeks, because they felt the visual feedback was enough.

The comparison of training effect through this biofeedback trainer and AMTI force plate was done for testing in six subjects with hemiplegia. There were no significant differences in these two kinds of evaluation modalities ($P>0.05$).

The possible confounders, including type of insult (CVA vs. TBI), age, gender, or duration between onset and test, will be examined after more cases are collected in further study. With the successful experience of this new training device for symmetry, more research is needed to assess balance control by forceplate measurements and locomotion performance by instrumented gait analysis.

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