

Effect of constrained weight shift on the static balance and muscle activation of stroke patients

KYUNG WOO KANG, MS, PT¹⁾, KYOUNG KIM, PhD, PT¹⁾, NA KYUNG LEE, MS, PT¹⁾,
JUNG WON KWON, MS, PT¹⁾, SUNG MIN SON, PhD, PT^{2)*}

¹⁾ Department of Physical Therapy, College of Rehabilitation Science, Daegu University, Republic of Korea

²⁾ Department of Physical Therapy, College of Health Science, Cheongju University: 298 Daeseong-ro, Cheongwon-gu, Cheongju-si, Chungbuk 363-764, Republic of Korea

Abstract. [Purpose] The purpose of this study was to evaluate the effects of constrained weight shift induced by shoe lift beneath the unaffected lower extremity, on balance functions and electromyography of the affected lower extremity of stroke patients. [Subjects and Methods] Twelve patients with unilateral stroke were recruited as volunteers for this study. The subjects were repeatedly measured in a randomized order under three conditions: no-shoe lift, and shoe lifts of 5 mm and 10 mm heights beneath the unaffected lower extremity. [Results] Standing with a 10 mm shoe lift for the unaffected lower extremity decreased the mean velocity of mediolateral sway compared to no-shoe lift. Regarding the velocity of anteroposterior sway, standing with 5 mm and 10 mm shoe lifts decreased the mean velocity of anteroposterior sway. The muscle activation of the affected lower extremity was not significantly different among the no-shoe lift, 5 mm shoe lift and 10 mm shoe lift conditions; however, the muscle activities of the rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius of the affected lower extremity progressively improved with increasing height of the shoe lift. [Conclusion] A constrained weight shift to the affected side elicited by a shoe insole of 10 mm height on the unaffected side can improve the static standing balance of stroke patients, and it resulted in 14–24% increases in the muscle activities of the affected leg.

Key words: Constrained weight shift, Stroke, Balance

(This article was submitted Sep. 26, 2014, and was accepted Oct. 21, 2014)

INTRODUCTION

Post-stroke individuals present an array of changes to the neuromuscular system functions, such as muscle weakness, impaired proprioception, abnormal muscle activation patterns, and impaired postural control^{1,2)}. Balance function of stroke patients is particularly diminished and postural sway can be twice that of their age-matched healthy counterparts^{3,4)}. Impaired balance and increased postural sway are known to be associated with abnormal weight bearing on the lower extremity⁵⁾. Previous studies have reported that stroke patients frequently bear most of their body weight on the unaffected lower extremity. Abnormal weight bearing causes asymmetrical posture, and together with postural asymmetry of stroke patients, poor postural control causes slow and inflexible motor behavior during functional activities of daily living^{6–8)}.

Because weight bearing is a necessary prerequisite to functional movements, such as sit to stand, standing balance

and gait, improvement of weight bearing is the foremost treatment goal of physical therapy for stroke patients^{9,10)}. Therefore, rapid and optimal improvement of symmetrical weight bearing of stroke patients is essential for independence and social participation¹¹⁾. Various therapeutic approaches have been used to help stroke patients to overcome asymmetrical weight bearing^{8,12–14)}. Biofeedback training related to weight distribution has been shown to be effective at restoring symmetrical stance following stroke^{4,13,15,16)}. Another approach, constrained weight shift has been used to facilitate weight bearing on the affected lower extremity by placing a shoe lift under the unaffected lower extremity^{12,17,18)}. The addition of a 10 mm shoe lift results in a 10% increase in weight bearing on the affected lower extremity in stroke patients and improves postural control reactions to external disturbance¹²⁾.

Previous studies of constrained weight shift have investigated postural control reactions to external perturbations and symmetrical standing posture, but there has been little study of balance indexes and EMG differences in the affected lower extremity muscles in relation to the height of the shoe lift of applied to the unaffected lower extremity. Therefore, the purpose of this study was to evaluate the effects of constrained weight shift induced by shoe lift applied to the unaffected lower extremity on the balance function and electromyography of the affected lower extremity of stroke patients.

*Corresponding author. Sung Min Son (E-mail: ssm0417@hanmail.net)

SUBJECTS AND METHODS

Subjects were selected from patients referred by a physical therapist participating in the stroke program of a rehabilitation hospital. Twelve subjects (7 men, 5 women) with hemiparesis associated with unilateral stroke participated in this study. The average age of subjects was 62.07 ± 10.57 years, and their average height was 166.27 ± 8.81 cm. The period since stroke onset was 8.20 ± 3.48 months. Seven subjects had right-sided hemiparesis and 5 had left-sided hemiparesis. The inclusion criteria were the following: hemiparesis due to cerebrovascular accident, and the ability to stand independently without an assistive device or an ankle-foot orthosis (AFO) for up to 5 minutes without rest. Exclusion criteria were: visual or vestibular deficits (such as hemianopia, neglect and pusher syndrome), inability to understand the informed consent form because of impaired cognitive function (a score less than 24 on the MMSE), a history of lower extremity orthopedic problem, or a neurological condition other than stroke. Each subject gave written consent to the experimental procedure which was approved by the institutional review board of the local ethics committee.

In this study, we used the Good Balance System (Metitur Ltd., Jyväskylä, Finland) which measures the moving trajectory of COP, a variable that quantifies balance ability. Static balance was assessed using the movement of the center of pressure during standing. During measurements of balance, surface EMG was measured to collect information on muscle performance using a FlexComp Infinity system from Thought Technology.

The balance ability of all subjects was measured for each condition on the Good Balance System. The subjects stood on the Good Balance System, and wore a harness to prevent falls. The subjects were repeatedly measured in a randomized order under three conditions: shoe lift of 5 mm height placed beneath the unaffected lower extremity, shoe lift of 10 mm height, and no-shoe lift.

The average velocity of COP in the x- and y-axes was calculated in mm/s from the mediolateral and anteroposterior sway distances over 30 seconds with the eyes open. While balance was being measured by the Good Balance System, we collected EMG data of the affected leg. We placed surface electrodes on the affected lower limbs to record surface electromyography (Flex com Infinity TM, Thought Technology Ltd., Canada) of four muscles: the rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius. Pairs of Ag/AgCl electrodes (3M, RedDot) with a surface diameter of 2 cm were arranged parallel to the muscle belly. The electrode sites were prepared by shaving and rubbing the skin with alcohol to ensure good contact. The EMG data was acquired at a sampling rate of 1,000 Hz. After acquisition, the data was filtered with a dual pass fourth order digital low pass Butterworth filter with a cut-off frequency of 15 Hz. The input impedance of the electrode units was 1,000,000 M Ω and the Common Mode Rejection Ratio in the range of 20–500 Hz was greater than 130 dB.

All data were analyzed with SPSS for Windows version 18.0. One-way repeated measures ANOVA was used

Table 1. A comparison of balance parameters with the eyes open under the three shoe lift conditions

	NSI (M \pm SD)	5 mm-SI (M \pm SD)	10 mm-SI (M \pm SD)
M-L Sway	7.51 \pm 2.02	6.08 \pm 2.67	5.14 \pm 1.84*
A-P Sway	7.63 \pm 2.03	6.00 \pm 1.53*	5.63 \pm 1.50*

* $p < 0.05$

M-L: mediolateral, A-P: anteroposterior, NSI: no-shoe insole beneath the unaffected lower extremity, 5 mm-SI: 5 mm shoe insole beneath the unaffected lower extremity, 10 mm-SI: 10 mm shoe insole beneath the unaffected lower extremity

Table 2. Post hoc tests of M-L balance for the three shoe lift conditions

Parameters	(I) Sway-Velocity	(J) Sway-Velocity	MD (I-J)
M-L Sway	NSI	5 mm-SI	1.44
		10 mm-SI*	2.37
	5 mm-SI	10 mm-SI	0.93
A-P Sway	NSI	5 mm-SI*	1.63
		10 mm-SI*	1.992
	5 mm-SI	10 mm-SI	0.37

* $p < 0.05$, MD: mean difference

M-L: Mediolateral, A-P: Anteroposterior, NSI: no-shoe insole beneath the unaffected lower extremity, 5 mm-SI: 5 mm shoe insole beneath the unaffected lower extremity, 10 mm-SI: 10 mm shoe insole beneath the unaffected lower extremity

to compare the balance values and muscle activities of the affected lower extremity (rectus femoris, biceps femoris, tibialis anterior, medial gastrocnemius). The post-hoc LSD method was used. A significance level of 0.05 was chosen for all analyses.

RESULTS

One-way repeated measures ANOVA revealed significant differences in the velocities of mediolateral sway and anteroposterior sway ($p < 0.05$) (Table 1). In the post hoc test of the velocity of mediolateral sway, standing with 10 mm shoe lift beneath the unaffected lower extremity decreased the mean velocity of mediolateral sway, compared to no-shoe lift ($p < 0.05$) (Table 2). In the post hoc test of the velocity of anteroposterior sway, standing with 5 mm and 10 mm shoe lifts decreased the mean velocity of anteroposterior sway ($p < 0.05$) (Table 2).

The average values of muscle activities in the affected lower extremity was not significantly different among the shoe lift conditions ($p > 0.05$); however, the muscle activation of the rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius of the affected lower extremity progressively improved with increasing height of the shoe lift (Table 3).

Table 3. A comparison of muscle activities of the affected leg during standing under the three shoe lift conditions

	NSI (M±SD)	5 mm-SI (M±SD)	10 mm-SI (M±SD)
RF	14.57±9.37	15.86±9.73	16.74±9.66
BF	13.93±7.04	15.06±7.07	16.07±7.31
TA	11.08±5.50	12.31±5.86	13.83±6.16
GA	13.65±6.73	14.97±7.02	16.55±7.26

NSI: no-shoe insole beneath the unaffected lower extremity, 5 mm-SI: 5 mm shoe insole beneath the unaffected lower extremity, 10 mm-SI: 10 mm shoe insole beneath the unaffected lower extremity, RF: Rectus Femoris, BF: Biceps Femoris, TA: Tibialis Anterior, GA: Gastrocnemius

DISCUSSION

The results of the current study showed that the balance dysfunction of stroke patients can be improved by applying a lift to the shoe of the unaffected lower extremity. The balance parameters of mediolateral sway and anteroposterior sway in static standing proportionately improved when 5 mm and 10 mm shoe lifts were placed under the shoe of the unaffected lower extremity of the stroke patients. Shoe lift induced constrained weight shift to the affected lower extremity. In addition, the muscle activities of the affected lower-extremity gradually increased with increasing shoe lift from 0 to 10 mm. Our findings demonstrate that shoe lift beneath the unaffected lower extremity reduces standing sway and induces weight shift toward the affected-lower extremity of stroke patients.

The results of our study show there was a reduction in mediolateral sway and anteroposterior sway during static standing with shoe lift. These results show that the static balance function of stroke patients can be improved by placing a lift under the shoe of the unaffected lower extremity. Our results are in agreement with several previous studies that have reported that the symmetry of stance of stroke patients can be improved by shifting the weight to the affected side by adding a lift to the shoe beneath the unaffected lower extremity^{12, 17, 18}. Chaudhuri et al.¹⁷ reported that weight shift induced by lifts applied to the shoe of the non-affected lower extremity improved weight symmetry, shortened latencies, and increased the magnitude of the response strength. Moreover, the muscle activation of the rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius of the affected lower extremity progressively improved with increasing height of the shoe lift. Our results indicate that muscle activities of the affected lower extremity with 5 mm shoe lift of the unaffected side increased by 8–11% over those of no-shoe lift, and that 10 mm shoe lift increased them by 14–24%. A previous study also reported that the proportion of body weight supported by the affected side increase with shoe lift, reaching almost 50–50 weight distribution with an increase of load of 11% body weight when a 10 mm shoe lift was used¹².

We consider that weight shift to the weaker side induced by a shoe lift placed beneath the unaffected lower extremity provides a more equal distribution of forces on both the lower extremities through shift the center of gravity from

the unaffected side to the midline. Thus, increased weight bearing by the affected side due to shoe lift on the unaffected side facilitates load receptor feedback to the central nervous system.

Our results suggest that constrained weight shift to the affected side elicited by a shoe insole of 10 mm height beneath the unaffected leg can improve the static standing balance of stroke patients, and it increases by 14–24% the muscle activation of the affected leg. Several limitations should be taken into account when interpreting the data. Because our study was only conducted with stroke patients who were able to independently stand, the results may not be generalized to those with more severe forms of stroke who use assistive walking devices or are incapable of independently standing. We did not investigate the balance function and muscle activation of the affected lower extremity of shoe lift heights other than 5 mm and 10 mm. Therefore, future studies may be needed in order to address these issues.

REFERENCES

- Geurts AC, de Haart M, van Nes IJ, et al.: A review of standing balance recovery from stroke. *Gait Posture*, 2005, 22: 267–281. [Medline] [CrossRef]
- Kleindorfer D, Lindsell CJ, Moomaw CJ, et al.: Which stroke symptoms prompt a 911 call? A population-based study. *Am J Emerg Med*, 2010, 28: 607–612. [Medline] [CrossRef]
- Bonan IV, Colle FM, Guichard JP, et al.: Reliance on visual information after stroke. Part I: Balance on dynamic posturography. *Arch Phys Med Rehabil*, 2004, 85: 268–273. [Medline] [CrossRef]
- de Haart M, Geurts AC, Huidekoper SC, et al.: Recovery of standing balance in postacute stroke patients: a rehabilitation cohort study. *Arch Phys Med Rehabil*, 2004, 85: 886–895. [Medline] [CrossRef]
- Laufer Y, Dickstein R, Resnik S, et al.: Weight-bearing shifts of hemiparetic and healthy adults upon stepping on stairs of various heights. *Clin Rehabil*, 2000, 14: 125–129. [Medline] [CrossRef]
- Cameron DM, Bohannon RW, Garrett GE, et al.: Physical impairments related to kinetic energy during sit-to-stand and curb-climbing following stroke. *Clin Biomech (Bristol, Avon)*, 2003, 18: 332–340. [Medline] [CrossRef]
- Marigold DS, Eng JJ: The relationship of asymmetric weight-bearing with postural sway and visual reliance in stroke. *Gait Posture*, 2006, 23: 249–255. [Medline] [CrossRef]
- Messier S, Bourbonnais D, Desrosiers J, et al.: Weight-bearing on the lower limbs in a sitting position during bilateral movement of the upper limbs in post-stroke hemiparetic subjects. *J Rehabil Med*, 2005, 37: 242–246. [Medline] [CrossRef]
- Desrosiers J, Noreau L, Rochette A, et al.: Predictors of handicap situations following post-stroke rehabilitation. *Disabil Rehabil*, 2002, 24: 774–785. [Medline] [CrossRef]
- Lin JH, Hsieh CL, Hsiao SF, et al.: Predicting long-term care institution utilization among post-rehabilitation stroke patients in Taiwan: a medical centre-based study. *Disabil Rehabil*, 2001, 23: 722–730. [Medline] [CrossRef]
- Pollock A, Baer G, Pomeroy V, et al.: Physiotherapy treatment approaches for the recovery of postural control and lower limb function following stroke. *Cochrane Database Syst Rev*, 2003, (2): CD001920. [Medline]
- Aruin AS, Hanke T, Chaudhuri G, et al.: Compelled weightbearing in persons with hemiparesis following stroke: the effect of a lift insert and goal-directed balance exercise. *J Rehabil Res Dev*, 2000, 37: 65–72. [Medline]
- Laufer Y, Sivan D, Schwarzmann R, et al.: Standing balance and functional recovery of patients with right and left hemiparesis in the early stages of rehabilitation. *Neurorehabil Neural Repair*, 2003, 17: 207–213. [Medline] [CrossRef]
- Lee NK, Son SM, Nam SH, et al.: Effects of progressive resistance training integrated with foot and ankle compression on spatiotemporal gait parameters of individuals with stroke. *J Phys Ther Sci*, 2013, 25: 1235–1237. [Medline] [CrossRef]
- Dickstein R, Abulaffio N: Postural sway of the affected and nonaffected pelvis and leg in stance of hemiparetic patients. *Arch Phys Med Rehabil*,

- 2000, 81: 364–367. [[Medline](#)] [[CrossRef](#)]
- 16) Chae JB, Lee MH, Lee SY: Post-stroke rehabilitation intervention: effect of spinal stabilization with visual feedback on the mobility of stroke Survivors. *J Phys Ther Sci*, 2011, 23: 225–228. [[CrossRef](#)]
- 17) Chaudhuri S, Aruin AS: The effect of shoe lifts on static and dynamic postural control in individuals with hemiparesis. *Arch Phys Med Rehabil*, 2000, 81: 1498–1503. [[Medline](#)] [[CrossRef](#)]
- 18) Rodriguez GM, Aruin AS: The effect of shoe wedges and lifts on symmetry of stance and weight bearing in hemiparetic individuals. *Arch Phys Med Rehabil*, 2002, 83: 478–482. [[Medline](#)] [[CrossRef](#)]