



Original Article

Effects of insoles contact on static balance

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Abstract. [Purpose] This study examined the effect of the degree of the contact area between the insoles and soles on static balance. [Subjects and Methods] Thirteen healthy male and female adults voluntarily participated. All of the subjects wore three different types of insoles (no orthotic insole, partial contact, full contact) in the present experiment. The subjects were instructed to place both feet parallel to each other and maintain static balance for 30 seconds. Center of pressure parameters (range, total distance, and mean velocity) were analyzed. [Results] The results show that the anteroposterior range and mediolateral (ML) total distance and velocity decreased when orthotic insoles with partial contact or full contact were used in comparison to when a flat insole (no orthotic insole) was used. Also, the ML range and total distance were lower with full contact than in the other two conditions. These results indicate that static balance improves as the degree of contact between the soles and insoles increases. [Conclusion] The results of this study suggests that using insoles with increased sole contact area would improve static balance ability.

Key words: Insoles, Somatosensory, Balance control

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INTRODUCTION

Balance is the process in which the human body constantly works to maintain its center of gravity¹⁾. Balance is achieved through the integration of afferent information from the visual system, the vestibular system, and the somatosensory system by the central nervous system⁴⁾. Out of this afferent information, the cutaneous sensation from the soles of the feet is known to play a very important role in controlling balance²⁾. People with sensory impairment of the sole show large postural sway and have difficulties maintaining their balance³⁾. When the sensation of the sole has been degraded by ice or anesthesia, even healthy persons have poorer postural control abilities than those with normal sensation^{4, 5)}.

Many therapeutic approaches for improving balance control have been studied⁶⁻⁸⁾. Among the approaches, stimulating the sole using an insole has been found to be capable of affecting balance⁶⁾. For instance, according to Qiu F et al.⁶⁾ and Hatto et al.⁹⁾, the texture and intervals of the stimulation of the insoles affects static postural control. While many studies have shown that stimulation of the sole affects balance control, additional inserts for the insoles cannot be easily added to treatment, because doing so can contribute to instability⁹⁾.

Many studies that have examined orthotic insoles have compared prefabricated insoles with customized insoles. The largest difference between these two types of insoles is in the degree to which they accurately fit the wearer's feet. Most studies indicate that the difference in the degree between prefabricated insoles and customized insoles is not large^{10, 11)}. However, customized insoles can enhance the tactile information of the sole more than prefabricated insoles¹²⁾. That is, customized insoles are thought to increase the degree of contact between the soles and the insoles so that richer tactile information can

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be obtained.

The present study examined the effect that the degree of the contact between insoles and soles has on static balance. Toward this end, different degrees of the contact between insoles and soles were used. Based on the results of previous studies, the hypothesis of this study was that higher degrees of contact between insoles and soles would enhance static balance ability.

SUBJECTS AND METHODS

The study was conducted with 13 adult males and females who had no orthopedic or neurosurgical pathological condition in the feet and no past history of surgery on the feet or the ankle joint. The mean age of the study subjects was 23.2 ± 2.39 years, their mean height was 170.4 ± 8.10 cm, and their mean weight was 62.33 ± 14.47 kg. All of the subjects were provided with sufficient explanation about the experiment, and each voluntarily agreed to participate in this study. The present study was approved by the Research Ethics Committee of the Catholic University of Daegu.

The following three types of insoles were used in the experiment: 1) a flat insole not thermally formed (no orthotic insole condition, NC), 2) a customized orthotic insole with the area of contact removed by about half (partial condition, PC), and 3) a customized orthotic insole with whole contact with the sole (full condition, FC) (Fig 1).

The contact area under soles was the greatest in FC, and the least in NC. Individual insoles were made through a thermal forming machine and the surfaces were removed, except for the heel cup since it might have affected the alignment of the skeleton. Three insoles had a completely flat surfaces. The NC insole was made from EVA (Ethylene-Vinyl Acetate Copolymer) with the contact surface raised by 20 mm. The PC and FC insoles are made from EVA with the contact surface raised by 20 mm (Fig 1). All of the subjects wore each of the three different types of insoles for this experiment.

After wearing the insoles, each of the subjects stood on a force plate. The subjects were instructed to place both feet parallel to each other, position their arms comfortably, and look straight ahead. The subjects maintained static balance for 30 seconds. Measurements of each insole condition were repeated three times, and a 5-minute rest was provided between the tasks. Order effects were prevented by applying counterbalancing to the insole conditions for the subjects.

Postural sway data generated during quiet standing were collected using the AccuGait[®] force plate (AMTI, Newton, MA, USA). Force sensors under the force plate convert the physical force exerted by an individual into ground reaction forces and moments in the X (mediolateral), Y (anteroposterior), and Z (vertical) axes. The signals from the force plate were recorded by a computer with sampling frequency of 200 Hz, and prepared for offline analysis using MATLAB[®] (Mathworks, MA, USA). The raw data of the signals consisted of the ground reaction forces and moments in each axis (F_x , F_y , F_z , M_x , M_y , and M_z). The raw data were filtered using a low-pass Butterworth filter with a cut-off frequency of 15 Hz, and then used to calculate time-varying center of pressure (COP) in the anteroposterior (AP) and mediolateral (ML) displacements. COP displacements represent postural sway and were derived using the following equations:

$$\text{COP}_{\text{AP}} = \frac{M_x - (F_y \cdot dz)}{F_z} \quad \text{and} \quad \text{COP}_{\text{ML}} = \frac{M_y - (F_x \cdot dz)}{F_z}$$

where d_z is the distance from the surface to the plate.

The COP displacements were used to calculate the postural sway parameters: COP displacement range, total distance of COP displacement, and mean COP velocity. All parameters were calculated separately in the anteroposterior (AP) and mediolateral (ML) directions. The following equations were used to calculate the parameters.

$$\text{Range} = |\max(\text{cop}) - \min(\text{cop})|$$

$$\text{Total distance} = \sum_{n=1}^N |\text{COP}[n]|$$

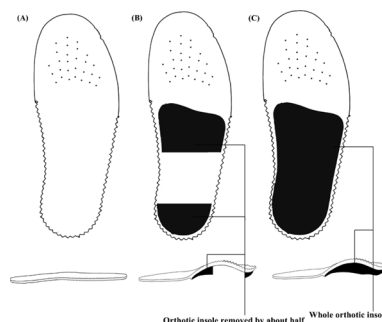


Fig. 1. Three orthotic insole contact conditions were used: (A) no orthotic insole (NC), (B) orthotic insole removed by about half (PC), and (C) complete orthotic insole (FC)

$$\text{Mean velocity} = \frac{\sum_{n=1}^{N-1} |\text{COP}[n+1] - \text{COP}[n]|}{T}$$

where N is the total number of data points (60,000) and T is the total duration (30 s). Range represents the linear distance between the most positive and negative COP trajectory positions and indicates the extent of postural sway. Total distance of COP displacement represents the length traveled by the COP in 30 seconds and indicates the total amount of postural sway. Mean velocity refers to postural sway length per unit time (1 s). A larger value in this variable indicates a corresponding longer postural sway length per unit time. Mean velocity may represent the instability of postural sway.

Dependent variables in the current study were the COP parameters: COP displacement range, total distance of COP displacement, and mean COP velocity. All dependent variables were analyzed in the AP and the ML directions. One-way repeated ANOVAs were used to examine the significance of differences among the conditions (NC, PC, FC). The statistical significance level used was $\alpha=0.05$.

RESULTS

According to the statistical results, the effects of the insole conditions were statistically significant for all CoP parameters except for the CoP AP velocity ($p>0.05$). Post-hoc analyses showed that the FC condition was the most stable condition for ML CoP, total AP distance, and ML velocity. In post-hoc tests, the CoP AP range and total ML distance, balance was most unstable under the NC condition. These results indicate that higher degrees of contact between insoles and soles reduce postural sway and further stabilize posture (Table 1).

DISCUSSION

The present study examined changes in balance control ability based on the degree of contact between the soles and the insoles. The results showed that the AP range, and total ML distance and velocity decreased when PC and FC insoles were used in comparison to when the NC insole was used. Also, the ML range and total distance in the FC condition than in the NC and PC conditions. These results indicate that static balance improved as the degree of contact between the soles and insoles increased.

What are the reasons for these results? First, these findings are attributable to the fact that the degree of contact between the soles and the insoles were associated with facilitation of an ankle neutral position. That is, correction of the ankle position by the functional insoles is thought to have balanced the muscles and the structures around the ankle facilitating more effective postural responses¹³. Previous studies have revealed that changes in the coronal and sagittal planes of the feet affect the surrounding structures causing abnormal motion of the feet^{13, 14}. In addition, balancing of surrounding structures is an important element in total ankle¹⁵.

Second, enhancement of somatic sense by increased sole contact area is considered to have contributed to improved postural control. According to the results of previous studies, although balance control ability decreases when sole sensation is inhibited by applying ice to the sole, it improves when stimulation to the sole is increased by the use of textured insoles^{4, 16-18}. These results indicate that somatic sense is enhanced by tactile stimulation of the sole, resulting in an improvement in postural control^{6, 9, 10, 19}.

The results of the present study provide several suggestions for the use of functional insoles in clinics. First, using insoles with high sole contact for persons with greatly impaired balance ability (e.g., elderly persons) is recommended, since the insoles would improve their static balance ability. Second, using prefabricated insoles that can support the sole to some extent would also be capable of improving balance ability. In the present study, no significant differences were found in the

Table 1. Comparison of CoP variations based on the contact ratio

CoP parameters		Range (cm)		Total Distance (cm)		Velocity (cm/s)	
		AP	ML	AP	ML	AP	ML
Flat (A)	Mn (stdev)	2.04 (0.56)	0.93 (0.42)	21.22 (5.49)	13.40 (4.43)	0.71 (0.18)	0.45 (0.15)
	Range (min-max)	1.40-3.22	0.48-2.02	14.18-35.86	8.00-22.90	0.47-1.20	0.27-0.76
50% (B)	Mn (stdev)	1.80 (0.32)	0.85 (0.29)	21.31 (5.38)	12.23 (3.90)	0.71 (0.18)	0.41 (0.13)
	Range (min- max)	0.99-2.29	0.48-2.02	13.91-32.72	7.74-23.30	0.46-1.09	0.26-0.78
100% (C)	Mn (stdev)	1.70 (0.45)	0.82 (0.33)	20.43 (3.59)	12.20 (3.74)	0.68 (0.12)	0.41 (0.13)
	Range (min- max)	0.84-2.64	0.41-1.37	13.34-26.06	7.13-21.88	0.44-0.87	0.27-0.73
p-value		0.005	0.023	0.037	0.041	0.121	0.024
Level		A>(B=C)	(A=B)>C	(A=B)>C	A>(B=C)	A=B=C	A>(B=C)

* $p<0.05$; AP: anteroposterior; ML: mediolateral

CoP parameters between the PC and FC conditions, and this may indicate that prefabricated insoles can sufficiently improve balance stability as well as customized insoles.

This present study had several limitations. It included only a small number of subjects and the subjects were adults in their 20s. In addition, the feet characteristics of the subjects were not considered. The degree of contact with the insoles might change with the shape of a subject's sole (e.g., flat feet, pes cavus). In future studies, more accurate examinations will be necessary in order to sufficiently consider the feet characteristics of the subjects and the time it takes the subjects to adapt to wearing of insoles.

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