Changes of Postural Steadiness Following Use of Prefabricated Orthotic Insoles

Hamid Bateni
Northern Illinois University

Orthoses are designed to assist a malaligned foot in adapting to the environment and reduce the frequency of injury. Literature is divided on the benefits of orthotics for postural stability. The current study was conducted to determine the effect of prefabricated orthotic arch supports on postural stabilization. Twelve healthy young adults participated in this study and were tested with and without prefabricated orthotics. Different variables were computed from movement of center of pressure (COP) during orthotic use as suggested in the literature. The mean position of COP was significantly shifted forward and toward the dominant side. Neither the COP movement nor the velocity changes following the use of orthotics revealed significant differences. Mediolateral range of COP movement and the 95% confidence circle area of sway was significantly reduced (\(P = .022\) and 0.048 respectively), but changes in 95% confidence circle and ellipse areas of fractal dimension were not significant (\(P = .053\) and \(P = .057\) respectively). In conclusion, orthotic insoles significantly improved postural sway initially by reducing mediolateral range of postural sway and 95% confidence circle area of sway at the cost of increased fractal dimension area variables and power.

Keywords: orthotic devices, postural balance, rehabilitation

This study aims to compare postural sway of young adult individuals with and without orthotic insoles in the time domain distances and area measures, fractal dimension, and frequency domain variables. Postural control often has been used as a measure of lower extremity function and is defined as the process of maintaining the center of gravity with the body's base of support. Postural stabilization is often quantified by measurement of postural sway, which is the movement of the center of pressure (COP) while participants are standing on a force platform. Postural sway provides an indication of postural control during quiet stance. Normal limitations of postural sway are about 12 degrees in the sagittal plane and 16 degrees in the frontal plane. Numerous studies have shown that poor postural stabilization can be identified by an increase in time-domain distance and area variables of sway. It also has been shown that postural control can be characterized by frequency domain variables such as power of the sway. More recent studies have suggested that fractal dimensional variables of sway signal are valid and reliable measures of postural steadiness.

The purpose of this study was to examine the effects of prefabricated orthotics on postural stability in young healthy subjects with a neutral hind foot. It was hypothesized that prefabricated orthotics would shift the mean antero-posterior (AP) position of COP and decrease postural sway as reflected by total excursion and mean distance and root mean square distance from the mean COP. Furthermore, it was hypothesized that
use of orthotic insoles would cause a reduction in the 95% confidence circle, which consists of 95% of COP positions. We expected no significant changes on fractal dimension or total power of sway following the use of orthotics.

Methods

Following approval from the Institutional Review Board of Northern Illinois University, twelve healthy young adults (5 males, 7 females) between the ages of 22 and 27 (mean = 23, SD = 1.4) were recruited to participate in the study. Participants were included if they (a) had neutral rear-foot alignment with less than 5 degrees of calcaneal varus or valgus as measured by the angles formed between the midline of the posterior aspect of the distal third of the leg and the midline of the posterior aspect of the calcaneus, (b) had no physical or mental disability which could potentially affect their balance and could stand on a single limb for 30 seconds. Individuals with any visual or vestibular deficits and those with a history of injury or surgery on the lower extremities in the past 6 months were excluded from the study. All recruited participants were right handed and right legged. To determine whether participants were right handed and right legged, they were asked two questions: (a) which hand do you use to write? (b) if you were to kick a ball which leg would you use? Participants were asked to sign a consent form before participation in the study.

ProFoot Super Sport Arch supports (Profoot, Inc., Brooklyn, NY) that were used in this study are differently sized for men and women. All participants were using gender-appropriate ProFoot Super Sport Arch supports for orthotics trials. ProFoot Super Sport Arch support is a typical orthotic insole that supports both longitudinal arches as well as the transversal arch of the foot. The insole covers the plantar surface of the foot under the heel up to the head of metatarsals. The reason for selection of this model of orthotics was availability and low cost. Previous studies have shown that there are no significant differences between different brands of prefabricated orthotic insoles.20,21 The Kistler-9287BA force platform (Winterthur, Switzerland) was used to collect position data of the COP at 100 Hz. The Matlab program was used to compute several variables of postural sway.

Participants were randomly assigned to 4 trials (2 conditions: with and without orthotics, 2 repetitions), each lasting 30 seconds. Participants were instructed to stand on the platform as quietly as possible, looking straight ahead, toward a black circle (1 inch in diameter) located on the wall 6 feet distant in the anterior view. Landmark lines were drawn on the force platform to ensure participants would stand at the same location on the force platform during all tests. During the tests, participants stood in a standard position determined, from literature, to represent a typical self-selected stance (14 degrees between medial foot margins, heel-center spacing = 11% of body height.22 For the orthotics trial, prefabricated orthotics were placed under each foot.

Force platform data were collected for a period of 30 seconds. Anteroposterior and mediolateral time series data were filtered through a fourth-order zero-phase Butterworth low-pass filter with cut-off frequency of 5 Hz as suggested in the literature.23 The first 10 seconds of data were cut off following the method of Prieto and colleagues23 to remove potential lead-in effect on the postural sway. The last 2 seconds also were cut off to avoid any sway effect due to anticipation of the end of the trial. The middle 18 seconds was used in the analysis. An in-house-developed Matlab program was used to compute several variables of postural sway in both time and frequency domains as reflected by the movements of the COP. A detailed explanation of time and frequency domain variables computed in this study is provided in the literature.23–27 To compute the fractal dimension, the algorithm of Myklebust and Myklebust was adopted.23

\[
\text{Fractal Dimension} = \log(N) / \log\left(\frac{N_d}{\sum_{n=1}^{N-1} \sqrt{[\text{AP}(n+1) - \text{AP}(n)]^2 + [\text{ML}(n+1) - \text{ML}(n)]^2}}\right)
\]

where N is the number of data points included in the analysis, d represents the maximum distance between any two points, and AP and ML are coordinates of COP position in mediolateral (ML) and anteroposterior (AP) directions. Matlab and SAS statistical analysis programs were used for data processing and analysis. Resultant and direction characteristics of postural sway in time and frequency domains were compared. Repeated measures analyses of variance with a single random effect of orthotic vs no orthotic with replicates within subjects were performed to identify significant differences (P < .05). Analysis of normality assumption was conducted for each response variable and results showed normality.

Results

The mean position of the COP was significantly shifted forward and toward the dominant side when the orthotics were used (P_{ML} = 0.001, P_{AP} = 0.036) (Figure 1). Some time domain variables changed significantly following the use of orthotics (Table 1). Movement of the COP, resultant and directional (ML and AP) mean distance from the mean COP and velocity of sway following the use of orthotics did not change significantly (P > .05). The resultant root mean square (RMS) of the distance substantially changes, but did not reach statistical significance (P = .07). Changes in the mediolateral sway range were statistically significant (P = .02). Neither the resultant nor the AP and ML directional total excursions of the COP were significantly changed (P > .05). From
Figure 1 — Box plots of mean position of COP in both AP and ML directions. Two conditions of no orthotics (NO) and with orthotics (WO) were compared. The line at the middle of the boxes represents medians and diamond shape represents mean value. Notches on each box indicate 95% confidence intervals of median values. Plus signs on the graph represent outliers. Overlap of notches between two boxes shows that no significant difference at 95% confidence exist between medians. *Shows significant difference ($P < .05$) between mean values.

Table 1  Descriptive statistics of the COP-based measures of postural sway, comparison of with orthotics, without orthotics, and overall

<table>
<thead>
<tr>
<th>Measure</th>
<th>No Orthotics, mean (SD)</th>
<th>Orthotics, mean (SD)</th>
<th>Overall, mean (SD)</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ML position (mm)</td>
<td>–15.33 (7.62)</td>
<td>–13.81 (9.05)</td>
<td>–14.57 (8.31)</td>
<td>.0011</td>
</tr>
<tr>
<td>Mean AP position (mm)</td>
<td>–1.92 (2.85)</td>
<td>–2.96 (2.27)</td>
<td>–2.44 (2.6)</td>
<td>.0364</td>
</tr>
<tr>
<td>Mean distance (mm)</td>
<td>2.94 (0.85)</td>
<td>2.71 (0.472)</td>
<td>2.83 (0.69)</td>
<td>.2242</td>
</tr>
<tr>
<td>RMS distance (mm)</td>
<td>3.43 (0.91)</td>
<td>3.14 (0.52)</td>
<td>3.29 (0.75)</td>
<td>.0745</td>
</tr>
<tr>
<td>ML range (mm)</td>
<td>21.99 (7.12)</td>
<td>20.68 (7.33)</td>
<td>21.34 (7.18)</td>
<td>.0228</td>
</tr>
<tr>
<td>Total excursion</td>
<td>182.72 (54.66)</td>
<td>186.84 (33.84)</td>
<td>184.78 (44.97)</td>
<td>.634</td>
</tr>
<tr>
<td>Mean velocity</td>
<td>10.14 (3.03)</td>
<td>10.37 (1.87)</td>
<td>10.26 (2.49)</td>
<td>.634</td>
</tr>
<tr>
<td>95% confidence circle area (mm²)</td>
<td>112.67 (58.99)</td>
<td>90.68 (32.31)</td>
<td>101.68 (48.34)</td>
<td>.0484</td>
</tr>
<tr>
<td>Mean AP frequency (Hz)</td>
<td>0.90 (0.28)</td>
<td>0.98 (0.21)</td>
<td>0.94 (0.25)</td>
<td>.0495</td>
</tr>
<tr>
<td>Mean ML frequency (Hz)</td>
<td>0.82 (0.20)</td>
<td>0.82 (0.23)</td>
<td>0.83 (0.31)</td>
<td>.7297</td>
</tr>
<tr>
<td>Fractal dimension-CC</td>
<td>1.58 (0.08)</td>
<td>1.62 (0.06)</td>
<td>1.61 (0.08)</td>
<td>.0530</td>
</tr>
<tr>
<td>Fractal dimension-CE</td>
<td>1.67 (0.12)</td>
<td>1.71 (0.09)</td>
<td>1.69 (0.11)</td>
<td>.0574</td>
</tr>
<tr>
<td>Total AP power</td>
<td>82.63 (35.95)</td>
<td>102.13 (43.39)</td>
<td>92.38 (40.63)</td>
<td>.0248</td>
</tr>
</tbody>
</table>

Note. Mean ML and AP positions are the position of COP from the center of the force platform. For all other measures, ML and AP positions are normalized based on the mean ML/AP positions of COP. Table also indicates $P$ values resulting from comparison of two conditions: with or without orthotics.
the time domain area measures, the 95% confidence circle area of sway was significantly reduced following the use of insoles \( (P = .048) \).

The mean anteroposterior frequency of the COP movement and total anteroposterior power also were significantly changed \( (P = .049 \) and \( 0.025 \) respectively). Total power calculated as the integrated area of the power spectrum in both directions showed a significant increase in AP direction \( (P = .025) \) following the use of insoles (Figure 2). Fractal dimension circle area and fractal dimension ellipse area did not show statistically significant differences in their mean \( (P = .053 \) and \( 0.057 \) respectively). The median value of fractal dimension ellipse area, however, changed significantly at the 5% significance level.

**Discussion**

Most studies in the literature have reported the effects of the use of foot orthotics in athletes\(^\text{5}\) or in the presence of a pathological condition (eg, References 2–4 and 6). It is difficult to conclude from the literature, however, whether the observed changes reported were attributed to the orthotics or to the special conditions of participants. The focus of the current study was on the effect of foot orthotics on postural steadiness of young adults without the presence of any pathologies or conditions that differentiated participants from the healthy young adult population.

A limitation arises from the quasi-experimental nature of this study. Participants of this study were not randomly selected, although all were from the target population of healthy, young adults, and none had been prescribed or were using orthotic insoles at the time of the study. Participants were not wearing shoes during the tests, as footwear in general can contribute to changes in postural sway as can differences in footwear.\(^\text{26}\) Lack of footwear, however, could potentially deform the insole and alter the proper functioning of the insole. Such limitations must be given consideration when interpreting the results.

Use of prefabricated orthotics shifted the mean position of the COP anteriorly and laterally. This shift in the COP has not been reported in previous studies on foot orthotics. Small changes in the position of the COP, however, have been found to result in large alterations of forces and moments on knee joints.\(^\text{29}\) Changes in the position of the COP per se, without being accompanied by changes in the distance or velocity of the COP movement, do not necessarily indicate changes in postural steadiness. Such changes may be considered an issue of concern that warrants further studies on more at-risk groups such as older adults or pregnant women.

This study does not support significant changes in postural sway velocities in either AP or ML directions and is in agreement with the finding of a previous study on 15 college athletes with ankle sprain.\(^\text{6}\) In addition, Percy and Menz (2001) reported that use of orthotics does not significantly affect postural sway, as measured through optoelectronic devices that were recording movement of the waist. They did note a trend, however, in participants to sway less in the unipedal position when prefabricated orthotics were used.\(^\text{5}\) The current study also confirmed that participants tended to sway less when the mean distance from mean COP position was measured. Furthermore, the measurement of 95% confidence circle

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**Figure 2** — The results of 95% confidence fractal dimension circle and ellipse area in addition to total power computed based on the power spectrum. Two conditions of no orthotics (NO) and with orthotics (WO) are compared. *Indicates statistically significant difference \( (P < .05) \). Note that nonoverlapping intervals in the fractal dimension ellipse indicate significant differences between the two medians at 5% significance level.
area of sway confirmed that individuals will sway in a significantly smaller area while wearing orthotics than while not wearing orthotics.

Mediolateral range of postural sway substantially decreased when orthotics were used ($P = .023$). Range of postural sway is known to represent the most reliable traditional variable of postural performance. $^{30}$ Significant reduction in mediolateral sway of the COP is particularly important to determine, since associations between aging, lateral instability and the risk of falling is well established. $^{31–34}$ Studies of risk factors for hip fracture have suggested that the ability to avoid lateral falls may be equal if not more important than factors such as bone quality or body mass index. $^{35–37}$

The 95% confidence circle and ellipse areas of fractal dimension were computed as suggested in the literature. $^{23,26,27}$ It appears that these variables have not been measured in any other studies investigating the effect of foot orthotics on postural steadiness. Fractal dimension is a unitless measure indicating the potential of the COP movement curve to fill out a metric space that it encompasses. Fractal dimension measures are reported to be more reliable than traditional measures of postural sway $^{30}$ since they provide additional information about the underlying dynamics of the sway.

The 95% confidence circle and ellipse areas of fractal dimension were both measured in this study. Both values showed a nonsignificant increase in the mean value following the use of orthotics ($P = .053$ and $P = .057$ respectively). Fractal dimension ellipse area, however, showed a significant increase in median value (at the 5% significance level). Fractal dimension values technically are derived from both velocity and movements of COP; therefore, fractal dimension quantifies the relationship between the effort made by the central postural control system and achieved postural steadiness. $^{23}$ Substantial increase in 95% confidence circle and ellipse areas of fractal dimension may indicate that when participants were using orthotics, they may have put forth more effort to reach the same level of postural steadiness as without orthotics. Substantial increase in the mean frequency of postural sway in AP direction ($P = .0495$) and total AP power ($P = .0248$) also support the possibility of change in mechanism of control when orthotics were used. This may be due to the immediate change that participants experienced under their feet and change of the mean position of the COP as discussed earlier. One could speculate that if the participants use orthotics long enough to get used to changes in the mean position of the COP, fractal dimension differences will be reduced to near original values. So, after a given time, the presumed benefits and side effects of orthotic insoles may diminish due to adaptation phenomenon.

In conclusion, the results showed that use of orthotic insoles significantly reduced mediolateral range of postural sway and 95% confidence circle area of sway and therefore improved postural steadiness initially. The substantial increases in the 95% confidence ellipse areas of fractal dimension, however, suggest the possibility of an increase in muscle activity to control posture. Future studies should focus on the long-term effects of orthotic insoles on postural control to determine whether initial changes last over time.

Acknowledgments

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References

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