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Rocker bottom soles alter the postural response to backward translation during stance

Bruce C. Albright [a,*], Whitney M. Woodhull-Smith [b]

[a] Department of Physical Therapy, College of Allied Health Sciences, Health Sciences Building, East Carolina University, Greenville, NC 27858, United States
[b] Department of Physical Therapy, College of Allied Health Sciences, East Carolina University, Greenville, NC 27858, United States

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ABSTRACT

Shoes with rocker bottom soles are utilized by persons with diabetic peripheral neuropathy to reduce plantar pressures during gait. This population also has a high risk for falls. This study analyzed the effects of shoes with rocker bottom soles on the postural response during perturbed stance. Participants were 20 healthy subjects (16 women, 4 men) ages 22–25 years. Canvas shoes were modified by the addition of crepe sole material to represent two forms of rocker bottom shoes and a control shoe. Subjects stood on a dynamic force plate programmed to move backward at a velocity that produced an automatic postural response without stepping. Force plate data were collected for five trials per shoe type. Sway variables for center of pressure (COP) and center of mass (COM) included: mean sway amplitude, sway variance, time to peak, anterior and posterior peak velocities, functional stability margin, and peak duration time. Compared to control, both the experimental shoes had significantly larger COP and COM values for mean sway amplitude, sway variance and peak duration. The functional stability margins were significantly smaller for the experimental shoes while their anterior and posterior peak velocities were slower and time to peaks were significantly longer. In young healthy adults, shoes with rocker bottom soles had a destabilizing effect to perturbed stance, thereby increasing the potential for imbalance. These results raise concerns that footwear with rocker bottom sole modifications to accommodate an insensate foot may increase the risk of falls.

1. Introduction

A concern for patients with diabetic peripheral neuropathy (DPN) is the formation of foot pressure ulcers and the increased risk and incidence of lower extremity amputation [1,2]. Therapeutic footwear has addressed this concern by the incorporation of a variety of soft liners, insole and outsole components, and designs to reduce localized pressure [3–8]. Characteristically, the rocker bottom sole has a forefoot rocker pattern that functionally relocates the apex of the forefoot rocker posterior to the metatarsal heads [8]. As such, it reduces pressure on the metatarsal heads and promotes the transition from mid-stance to toe-off during gait [3,6,9]. The forefoot rocker is often combined with either a reduced heel height (negative heel) to further off-load the metatarsal heads or a mild rounded heel edge to aid the transition from initial contact to mid-stance. Sole thickness and the location of the apex alter the amplitude and distribution of plantar pressures and gait kinematics [8,10].

Persons with DPN are also prone to balance problems and falls [11–18]. Compared to normal subjects, those with DPN demonstrate increased body sway and impaired postural control [12–14]. Sway amplitude, frequency, range, velocity and the center of pressure–center of mass (COP–COM) variable have been reported to be significantly increased in subjects with DPN [12,15,19,20].

Though postural instability in persons with DPN is well documented, there is limited information on how off-loading footwear devices and shoes with rocker bottom soles affect standing postural control [21]. As an initial investigation into the effects of rocker bottom shoes on balance, the purpose of the present study was to determine the effect of shoes with rocker bottom soles on the postural response to perturbed stance in a group of young healthy adults. It was hypothesized that shoes with rocker bottom soles would have a destabilizing effect on postural control during perturbed stance compared to normal shoes.

2. Methods

2.1. Subjects

A total of 20 young adults (16 women and 4 men) ages 22–25 were recruited from the general university population. Subjects were excluded if they had a neurological impairment, an orthopedic deformity of the lower extremity or an injury that required medical intervention within 6 months of their participation.

* Corresponding author. Tel.: +1 252 744 6231; fax: +1 252 744 6240.
E-mail address: albrightb@ecu.edu (B.C. Albright).

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Fig. 1. Photographs of shoes showing control and experimental sole patterns: (A) control shoe (CNTR); (B) rocker bottom shoe (RB); (C) negative heel shoe (NH).

Subjects had to fit comfortably in either a women's size 8 or a men's size 10 canvas tennis shoe. This project was approved by and was in compliance with the University and Medical Center Institutional Review Board for the utilization of human subjects in research (UMCIRB # 05-0594).

2.2. Equipment

Subjects wore three types of shoes for testing (Fig. 1). Shoes were canvas with rubber soles and of the same style and brand in sizes women's 8 and men's 10. All shoes were modified by the addition of a 5/8th-in. thick crepe sole material to the outsole, shaped to conform to the shoes' perimeter. Shoe soles were modified to represent either a control shoe (CNTR), a mild rocker bottom shoe (RB) or negative heel shoe (NH). In the control shoe the crepe material was full thickness throughout the length of the shoe. In the RB shoe the crepe sole was full thickness from the heel to apex and gently rounded to zero thickness at the toe. The rocker apex was positioned posterior to the ball of the shoe and within 60–65% of shoe length [8]. The heel edge was also slightly rounded. In the NH shoe the location of the rocker apex and the contour of the forefoot sole material were the same as the RB shoe. From the rocker apex to the heel, the sole material remained flat and was reduced to zero thickness at the heel. A certified orthotist designed and fabricated all shoe modifications.

A dynamic dual force plate (NeuroCom International, Oregon, USA) was programmed to present a horizontal backward translation perturbation for a distance of 12.5 cm for 0.550 s at a velocity of 0.23 m/s. Platform velocity was determined prior to the study to provoke a visible postural response without stepping.

2.3. Procedures

Subjects stood on the force plate with each foot in a predetermined position [22]. Subjects were asked to stand relaxed with arms by side, to look forward at an eye level target and to maintain balance without stepping. Data were collected 5 s before and after the onset of the perturbation that created an anterior body sway. The 5 s prior to the perturbation was to ensure a quiet stance and to make the onset of the perturbation less predictable. There were five perturbations for each shoe type. Shoe selection was random and the perturbations occurred at unexpected intervals.

2.4. Sway variables

The NeuroCom software computed the center of mass (COM) and center of pressure (COP) based upon the subject's height and weight. The body sway variables for anterior–posterior (A–P) COM and COP included: mean sway amplitude (SA); sway variance (SV); time to peak (T2P); anterior and posterior peak velocities; functional stability margin (FSM); and peak duration time (PDT) (Figs. 2 and 4). The sway amplitude is the mean anterior–posterior (AP) displacement of the COP or COM as a function of time. The sway variance is the standard deviation of the sway amplitude. Time to peak is the time period between perturbation onset and the maximum peak displacement. Sway range is the distance between the anterior and posterior peak displacements. Anterior and posterior peak velocities are the maximum rate of movement (meters/second) of the COP and COM toward and away from their respective maximum displacements. The functional stability margin is the numerical difference between the peak COP and peak COM. A comparatively small FSM indicates that the peak COM displacement is closer to the peak COP and may be indicative of an increased potential for postural instability [23,24]. The peak duration time is a measure of the time period involved in the stopping and reversing of the direction of movement. It was calculated as the time period when the anterior displacement of either the COP or COM was within ±25% of their respective peak amplitudes. A comparatively longer PDT indicates a longer time involved to reverse the direction of body sway.

2.5. Statistical analysis

Data were analyzed for 2.5 s post-perturbation. The independent variable was shoe type. The dependent body sway variables were calculated by MatLab and analyzed by MANOVA with planned post hoc comparisons using Boniferroni corrections (SPSSv 13) with a $P < 0.05$ level of significance. Omnibus *F*-test was set at $P < 0.05$ for all variables. Degrees of freedom (d.f.) were 2, 38 and planned post hoc comparisons were determined a priori.

3. Results

3.1. Center of pressure

The means and standard deviations of all variables are shown in Table 1. Backward platform translation resulted in a forward sway as evident by an initial anterior displacement of both COP and COM followed by a posterior directed recovery response (Fig. 2). The RB and NH experimental shoes responded similarly and there were no significant differences between these shoes for any of COP sway variables. Compared to the control shoe, the experimental shoes had significantly larger COP sway amplitudes and sway variances (Table 1, Figs. 2 and 3). Though the mean displacement of COP for the control shoe was greater than the experimental shoes (Fig. 2), the duration of the displacement was longer for the experimental shoes as evident by larger sway amplitudes (Figs. 2 and 3). Compared to the control shoes, the experimental shoes had a significantly longer peak duration times (Table 1 and Fig. 2). In contrast to the control shoe, plots of the COP displacement for the experimental shoes showed a distinct plateau period. Not only was the PDT significantly longer for the experimental shoes but the COP remained relatively stationary at its anterior displacement prior to initiation of a posterior recovery response (Fig. 2). There was, however, no significant difference between control and experimental shoes for sway range (Table 1).

Table 1
Sway variable means and standard deviations for rocker bottom shoe (RB), negative heel shoe (NH) and control shoe (CNTR).

	RB	NH	CNTR
Sway amplitude			
COM	1.068 ± 0.041	1.098 ± 0.044	$0.854 \pm 0.030^*$
COP	1.313 ± 0.045	1.350 ± 0.066	$1.142 \pm 0.035^*$
Sway variance			
COM	1.236 ± 0.038	1.264 ± 0.047	$1.036 \pm 0.031^*$
COP	1.535 ± 0.047	1.565 ± 0.067	$1.441 \pm 0.039^*$
Sway range			
COM	3.832 ± 0.071	3.865 ± 0.112	$3.497 \pm 0.072^*$
COP	5.217 ± 0.109	5.214 ± 0.155	5.213 ± 0.123
Functional stability margin	0.852 ± 0.219	0.848 ± 0.279	$1.117 \pm 0.267^*$
Peak duration time			
COM	0.458 ± 0.103	0.474 ± 0.070	$0.341 \pm 0.034^*$
COP	0.356 ± 0.068	0.383 ± 0.060	$0.323 \pm 0.071^*$
Time to peak			
COM	0.920 ± 0.026	0.939 ± 0.025	$0.788 \pm 0.763^*$
COP	0.920 ± 0.026	0.605 ± 0.025	$0.470 \pm 0.013^*$
Ant peak velocity			
COM	5.892 ± 0.126	5.701 ± 0.134	$7.153 \pm 0.129^*$
COP	26.346 ± 1.139	27.350 ± 1.095	$30.586 \pm 1.028^*$
Post-peak velocity			
COM	10.866 ± 0.559	10.062 ± 0.755	$12.334 \pm 0.773^\dagger$
COP	26.124 ± 1.156	26.976 ± 1.122	$30.564 \pm 1.032^*$

* Denotes significant difference ($P < 0.05$) between control (CNTR) and experimental shoes (RB and NH).
† Denotes significance difference only between CNTR and NH shoes.