INSTANTANEOUS AND PROLONGED EFFECTS OF A TRIPLE DENSITY MIDSOLE DURING STANDING AND WALKING TASKS

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The purpose of this study was to determine if there were any biomechanical differences between an unstable triple density midsole (TRIPLE) and a stable single density midsole (CONTROL). Twelve females completed 10 walking trials and three static trials followed by a two hour prolonged activity assessment during which participants alternated between standing and walking on a treadmill. Muscle activity, center of pressure, plantar forces and tissue oxygenation were measured for each footwear condition on two separate days. Standing in the TRIPLE condition resulted in better pressure distribution and lower peak forces, while walking in the TRIPLE condition resulted in greater tissue oxygenation. This midsole could be incorporated into other footwear where prolonged exposure to standing and walking tasks are the norm, such as work boots.

KEY WORDS: multiple density footwear, plantar pressure, tissue oxygenation, EMG, comfort

INTRODUCTION: Unstable shoes are intended to be used as a training device by providing an unstable support surface in order to elicit changes in the neuromuscular or locomotor systems (Nigg et al., 2012). These changes are thought to be beneficial over time, as unstable shoes have been shown to improve balance, and increase the strength of the muscles surrounding the ankle joint (Landry, Nigg, & Tecante, 2010). In addition to strength and balance benefits, previous literature has also shown that unstable footwear interventions can reduce pain in individuals with moderate knee osteoarthritis (Nigg, Emery, & Hiemstra, 2006), and can reduce perceived low back pain in a population of golfers (Nigg et al., 2009). Typically the instability is created through the footwear geometry, which includes a rounded, unstable, outer sole. There are however alternative approaches to introducing instability to a piece of footwear, such as varying the density of different regions of the midsole. Currently, there is a sandal on the market that aims to take advantage of this approach. Anecdotal evidence suggests that users of this footwear feel more energetic and their feet feel less sore, in comparison to standard sandals, after spending prolonged periods of time on their feet. However, it is unknown if any of these subjective claims can be attributed to actual biomechanical effects. Additionally, it is unclear whether varying the density of the midsole actually creates an unstable surface. Therefore, the goal of this study was to (1) determine if there is any biomechanical evidence to support users' subjective claims regarding comfort and energy, and to (2) determine if this footwear is less stable than a control sandal.

METHODS: Two sandals were compared; one with a thick, triple density midsole (TRIPLE), and the other with a thin single density midsole (CONTROL). The TRIPLE sandal had the highest density at the heel, and lowest density at the midfoot, whereas the single density sandal was uniform throughout. Twelve females (Age = 43.9 yrs ± 10.3, Mass = 72.1 kg ± 10.5) participated in this study, with each completing two testing sessions on separate days. Each testing session consisted of an initial assessment followed by a prolonged activity assessment. During the initial assessment, subjects competed 10 walking trials (1.3 m/s ± 10%) and three 30s bipedal standing trials, in each of the two footwear conditions. During the prolonged activity assessment, subjects alternated in ten minute increments between standing on a treadmill, and walking on a treadmill (self selected speed) for a total duration of two hours. Due to the duration of the collection, only one footwear condition was tested per day during the prolonged activity asessment. During the initial assessment walking trials, muscle activity (EMG) of the right leg was measured from the muscle bellies of the tibialis anterior (TA), peroneus longus (PL), vastus medialis (VM), gastrocnemius medialis (GM), soleus (SOL), and biceps femoris (BF), using bipolar surface electrodes (Biovision, Werheim, Germany). A wavelet analysis technique (von Tscharner, 2000) with 13 non-linearly scaled wavelets was used to resolve the EMG signals into time-frequency space. The total EMG intensity across wavelets 2-11 during the window of greatest activity for each individual muscle was analyzed. During the initial assessment static trials, plantar pressure (Novel, Minniapolis, USA) and ground reaction forces (Kistler, Winterthur, Switzerland) were collected. Plantar pressure was recorded using two instrumented pressure insoles, which were placed on top of the sandals. Due to the nature of the footwear, the straps of each sandal had to be manually removed in order to allow for proper positioning of the insoles. The distribution of force (coefficient of variation), contact area (% of active cells), and peak force (highest individual force) was calculated for the heel, midfoot, and forefoot region of each insole for each condition. Ground reaction force data was collected simultaneously from which global center of pressure (CoP) variables were derived. These included both maximum displacement and average velocity in the medio-lateral and antero-posterior directions, as well as the total path length. During the prolonged activity assessment, tissue oxygenation (TOI) was measured from the muscle bellies of the tibialis anterior and gastrocnemius medialis of the left leg using Near Infrared Spectroscopy (NIRS). NIRS is a non-invasive technique that measures the changes in oxygenated and deoxygenated hemoglobin concentrations in tissue (Jobsis, 1977). Prior to the prolonged activity assessment, subjects were seated (90 degrees knee flexion) in bare feet and instructed to remain still and not to speak for five minutes, in order to get a stable baseline reading. Data was averaged over eight-minute windows within each of the 10 minute walking and standing portions of the prolonged activity assessment. Subjective measures of comfort and stability were taken after the prolonged activity assessment.

RESULTS: During the initial assessment, significant differences were found for multiple variables associated with plantar force. The TRIPLE condition displayed a smaller coefficient of variation, $F(3) = 14.68$, $p < 0.00$, greater surface area contact, $F(3) = 7.08$, $p = 0.01$, and smaller peak forces, $F(3) = 35.18$, $p < 0.00$. These differences were found at the heel and mid foot in all three variables, but not at the forefoot. No significant differences in muscle activity were found between the TRIPLE and the CONTROL condition, nor were there any significant differences in the global center of pressure variables. During the prolonged activity assessment, TOI in the gastrocnemius medialis was significantly higher, $F(1) = 6.16$, $p = 0.03$, in the TRIPLE condition compared to the CONTROL condition during walking, however no differences were found during the standing, $F(1) = 1.85$, $p = 0.12$. Additionally, no differences were found in the TOI of the tibialis anterior during standing or walking. Subjectively, questionnaires indicated that participants felt more comfortable, $Z = -3.14$, $p < 0.00$, and more stable, $Z = -2.97$, $p < 0.00$ in the TRIPLE condition compared to the CONTROL condition.

Table 1
Summary of significant findings. Values displayed as mean (standard error).

	TRIPLE	CONTROL
Plantar Force		
Coefficient of Variation - Heel [N]	2.02 (0.2)	2.54 (0.3)
Coefficient of Variation - Midfoot [N]	1.56 (0.2)	2.14 (0.3)
Area - Heel [%]	94.0 (2.1)	88.4 (2.7)
Area - Midfoot [%]	66.1 (4.5)	56.5 (2.7)
Peak - Heel [N]	12.9 (2.5)	14.7 (3.0)
Peak - Midfoot [N]	7.4 (1.3)	8.0 (1.6)
Tissue Oxygenation Index		
Gastrocnemius Medialis [a.u.]	71.2 (4.9)	67.05 (3.1)
Subjective Ratings		
Comfort [5 point scale]	4.3 (0.2)	1.5 (0.2)
Stability [5 point scale]	4.4 (0.2)	2.3 (0.3)

DISCUSSION: The purpose of this study was to determine if there was any biomechanical evidence to support users' perceived benefits of wearing a triple density sandal, as well as to determine if this footwear induced postural instability. Previous anecdotal evidence suggested that users felt more energetic and less sore after spending a prolonged period of time in this footwear. In the current study, muscle activity and tissue oxygenation was analyzed in order to understand the energetic effects, plantar forces provided information regarding pressure distributions and foot comfort, and the global centre of pressure variables yielded results related to instability.

A significant increase in both the contact area and force distribution, as well as a decrease in the peak force, was found during standing in the TRIPLE condition. Price, Graham-Smith and Jones (2013) found similar results when they examined pressure patterns during over ground walking in the TRIPLE sandal. These findings are believed to be directly related to the subjective measures of comfort, in which the TRIPLE condition was rated as significantly more comfortable compared to the CONTROL condition. It is speculated that this improved comfort stems from a more even plantar pressure distribution, which may explain why previous users' had reported feeling less foot soreness after wearing this footwear (Chen, Nigg, & de Koning, 1994).

When examining the muscle activity during walking, no significant differences in total intensity were found, however there was a general trend of less activity in the TRIPLE condition compared to the CONTROL condition. The most interesting aspect of this result is that the trend was in the opposite direction of what would be expected if this were in fact an unstable piece of footwear. Additionally, during the two hour prolonged activity assessment, the TRIPLE condition yielded significantly greater levels of tissue oxygenation during walking compared to the CONTROL condition. It is speculated that there was more available oxygen at the site of the gastrocnemius muscle, an indication that participants didn't have to work as hard, or were more efficient, while walking in the TRIPLE condition. These two findings may explain why previous users' had reported feeling more energetic after spending extended periods of time in this footwear.

No significant differences were found between the two footwear conditions in any of the COP variables (range, velocity, path length), similar to what was found by Plom and colleagues during both double and single leg standing tasks (Plom, Strike, & Taylor, 2014) . CoP is often used as a measure of stability and/or balance, with larger excursions arguably indicating less control and a more unstable base of support. Based on the findings of this study, the TRIPLE condition was not any less stable than the CONTROL condition, and therefore should not be considered unstable. Interestingly, when examining subjective measures of stability, it was found that participants actually felt *more* stable while in the TRIPLE condition compared to the CONTROL condition. Considering that the TRIPLE sandal does not appear to be unstable, other unique features, such as the contoured design of the sole, may have been contributing to the current findings.

CONCLUSION: Regardless of whether or not the TRIPLE condition falls under the umbrella of unstable shoes, there still appears to be benefits to the end user, which have been measured both subjectively and biomechanically. Individuals who experience plantar pain wearing traditional flip flops or sandals, whether it be pathological or due to an injury, should consider this footwear as a viable option. Additionally, this insole technology could also be incorporated into other types footwear in order to benefit specific occupations (i.e. construction workers), or specific populations (i.e. obese).

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