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Effect of Rocker Shoe Radius on Oxygen Consumption Rate in Young Able-bodied Persons

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Abstract

We studied oxygen consumption rate of eleven young able-bodied persons walking at self-selected speed with five different pairs of shoes: one regular pair without rocker soles (REG) and four pairs with uniform hardness (35–40 shore A durometer) rocker soles of different radii (25% of leg length (LL) (R25), 40% LL (R40), 55% LL (R55), and infinite radius (FLAT)). Rocker soled shoes in the study were developed to provide similar vertical lift (three inches higher than the REG shoes condition). Oxygen consumption rate was significantly affected by the use of the different shoes ($p<0.001$) and pairwise comparisons indicated that persons consumed significantly less oxygen (per minute per kilogram of body mass) when walking on the R40 shoes compared with both the FLAT ($p<0.001$) and REG ($p=0.021$) shoe conditions. Oxygen consumption was also significantly less for the R25 shoes compared with the FLAT shoes ($p=0.005$) and for the R55 shoes compared with FLAT shoes ($p=0.027$). The three inch lift on the FLAT shoe did not cause a significant change in oxygen consumption compared to the shoe without the lift (REG).

Keywords

rocker shoes; roll-over shape; oxygen consumption; gait

Introduction

Rocker shoes are used frequently in physical medicine and rehabilitation to treat ailments of the lower limb (see review by Hutchins et al. (2009)). Most studies have focused on the effects of rocker shoes on plantar pressures (Nawoczenski et al., 1988; Schaff and Cavanagh, 1990; Mueller et al., 1997; Postema et al., 1998; van Schie et al., 2000; Praet and Louwerens, 2003; Brown et al., 2004), while others have focused on the effects of rocker shoes on kinematics and kinetics of gait (Peterson et al., 1985; Wu et al., 2004; Van Bogart et al., 2005; Myers et al., 2006; Long et al., 2007). Few investigators have examined the effects of rocker shoes on energetic cost during walking.

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Conflict of Interest Statement
The authors have no conflicts of interest to declare.

Perry et al. (1981) studied the effectiveness of a rocker bottom shoe for restoring walking function for several women with multiple sclerosis. The rocker shoes were found to be beneficial to three women in the study with “obstructive spasticity,” helping them improve their self-selected walking speed from 55% to 103% of able-bodied walking speeds. When switching from normal shoes to rocker shoes, energy cost in this subject group was reduced from 717% to 93% of the cost used by able-bodied persons.

Adamczyk et al. (2006) examined the effects of using rigid rocker boots with immobilized ankles on metabolic rate of able-bodied ambulators. They found that the subjects walked with a minimum metabolic rate when the rocker radius was approximately 0.3 times the leg length compared to other rocker radii. Adamczyk et al. (2006) also found that the metabolic rate was higher with rigid rocker boots (and any of the rockers studied) than normal metabolic rates with unconstrained ankles. The research group later attributed this difference in energy cost to the weight of the boots (Vanderpool et al., 2008) and stated that use of an appropriate rocker shape with an immobilized ankle “need not increase energy expenditure for walking.”

A recent study by van Engelen et al (2010) compared the metabolic energy cost of able-bodied persons walking with normal walking shoes and MBT rocker bottom shoes and found a higher metabolic energy cost when walking with the MBT shoes. The group postulated that the increase in metabolic cost may be due to the soft heel region of the MBT shoes, which likely caused instability and increased lower limb muscle activity in early stance and which coincided with higher external mechanical work lost in the “collision” phase. The group also cited the increased weight of the MBT shoes compared with the normal shoes as a potential factor leading to increased metabolic energy cost. It is possible that use of rocker bottom shoes with less compliance in the heel could provide different results. Also, no studies to our knowledge have investigated the effects of different rocker shoe radii (with unconstrained ankles) on oxygen consumption during walking.

The purpose of this study was to examine the oxygen consumption of young able-bodied persons walking using a series of rocker shoes with different rocker radii to determine whether certain radii would provide an energetic benefit. The rocker shoes had soles of uniform hardness and density for the heel and forefoot. We also examined the effects associated with adding the weight and height of the rocker soles by including the same shoe type without the addition of the rocker sole in the study.

Methods

Eleven subjects participated in the study (six males and five females). The subjects had an average (standard deviation) age of 28 (4) years, height of 176 (10) cm, and mass of 71 (14) kg. The sample was primarily graduate students at Northwestern University.

Subjects first went through a consent process approved by the Northwestern University Institutional Review Board and provided written consent at the end of the process. Ankle strength and passive range of motion (non-weight bearing) were tested prior to the study to verify normal function (Boone and Azen, 1979). Subjects indicating a history or fear of ankle injuries were excluded from participation in the study.

We constructed a series of rocker shoes (Figure 1) starting with canvas high-top shoes (Converse All-Stars) and three inch lifts of crepe material (35–40 shore A durometer) on the shoes. We also asked the subjects to walk with a pair of unaltered canvas high-top shoes, i.e. without the three inch lift, to see potential effects of the lift on oxygen consumption. We labeled this regular shoe condition REG. For one pair of shoes, the three inch lift was left alone creating a FLAT (infinite radius) condition. For the other pairs of shoes, we cut radii into the three inch lift equating to approximately 25%, 40%, and 55% of the leg length of persons who would normally wear each particular shoe size (foot size to leg length scaling determined from data of Dreyfuss (1960)). These shoe conditions were labeled R25, R40, and R55, respectively. Canvas high-top shoes were chosen for the study because they prevent the heel from slipping out of the shoe in late stance phase of walking without restricting ankle motion. More details on the shoe construction can be found in Wang and Hansen (2010).

Subjects came to the laboratory twice, once for gait analysis (see results in Wang and Hansen (2010)) and a second time for measurement of oxygen consumption rate with the different shoe conditions. The unaltered shoe (REG) was used first in both experiments. The rocker shoe conditions (FLAT, R55, R40, and R25) were tested after the REG condition in random order, although the same order was used for both gait and oxygen testing visits.

Oxygen consumption rate (ml O_2/min/kg) was measured using a Cosmed K4b^2 portable spirometer while subjects walked on a Cosmed T170 treadmill (Cosmed, Rome, Italy) at the speed they self-selected during gait analysis sessions. In four cases, the subjects requested to walk at a slightly slower speed (ranging between 0.1 and 0.3 m/s slower) on the treadmill than their speeds for the gait analyses. However, during treadmill walking the speed was held constant for all shoe conditions for a given individual because of the known effects of walking speed on oxygen consumption rate. After initial setup and calibration of the system, subjects were instructed to sit quietly for five minutes to establish an initial rest state. Then, for each pair of shoes, they walked on the treadmill for seven minutes while their oxygen consumption rate was measured. Between shoe conditions, subjects sat quietly for five minutes to reestablish a resting baseline and to minimize carry-over effects of the rocker sole conditions. There were a total of five walking trials and six resting periods.

Oxygen consumption rate results (normalized by body mass) were exported directly from the Cosmed data acquisition software. The last three minutes of each seven minute walking period was averaged and a resting consumption rate was found by averaging the averages of the last three minutes of the six resting periods. Average oxygen consumption rate values for the different shoe conditions were compared using repeated measures ANOVA. A separate repeated measures ANOVA was used to investigate possible effects of the order of use of the shoes in the study. Pairwise comparisons were conducted using a Bonferroni adjustment for multiple comparisons. The statistical software (SPSS, Chicago, Illinois) automatically readjusts the significance level of the pairwise comparisons to 0.05 after the Bonferroni adjustment.

Results

The shoes significantly affected oxygen consumption rate ($p<0.001$; see Figure 2). Pairwise comparisons indicated that less oxygen (per minute per kg of body mass) was consumed when walking with the R40 shoes compared with the FLAT shoes ($p<0.001$) and also compared with the REG shoes ($p=0.021$). Oxygen consumption was also reduced when walking with the R25 shoes compared with the FLAT shoes ($p=0.005$) and when walking with the R55 shoes compared with the FLAT shoes ($p=0.027$). No other conditions were found to be significantly different (see Table 1). Also, the order in which the rocker shoes were tested did not significantly affect oxygen consumption ($p=0.064$). The subjects walked on the treadmill at an average speed of 1.12 (0.12) m/s.

Discussion

Users who walked with rocker shoes with a radius of 40% of leg length (R40) had reduced oxygen consumption rates compared with using flat rocker shoes, regardless of lift (REG and FLAT). Users also had reductions in oxygen consumption rate when using either of the other rocker shoes (R25 or R55) compared with the FLAT shoes, but not compared with the REG shoes. The R40 shoes were not found to significantly reduce oxygen consumption compared with the R25 or R55 shoes. A trend is seen in the data that suggests an optimal rocker radius between R25 and R55, although a larger sample size would be needed to see if there are small but significant differences in oxygen consumption rate between these rocker radius conditions.

The magnitudes of the differences seen in the study are small, with the largest difference being 1.2 ml O2/min/kg (between the R40 and FLAT shoe conditions). This difference in O2 consumption is equivalent to that which would be expected in an adult who increases their walking speed by about 9 meters per minute from their comfortable walking speed (Waters and Mulroy, 1999). This change may only be relevant for able-bodied persons who walk long distances. Effects of rocker shoes have been seen to have much larger effects on some persons with multiple sclerosis (e.g. Perry et al. 1981).

The findings of this study are in conflict with those of van Engelen et al (2010), who found an increase in metabolic energy cost when using the MBT rocker shoes compared with normal shoes. The primary difference between the MBT rocker shoes and the rocker shoes used in this study is heel compliance. MBT rocker shoes have highly compliant heel sections and less compliant forefoot sections. The rocker shoes in this study utilized a uniform hardness throughout the soles, a hardness we believe to be closer to the forefoot sections of the MBT rocker shoes. The soft heel of the MBT is thought to cause instability and subsequent increase in muscular activity in the shank (a point noted by van Engelen et al, 2010), which may have caused an increase in metabolic energy cost in their study. Persons walking with the MBT shoes also displayed larger losses during the “collision” phase (van Engelen et al, 2010), a result that may also be attributed to the highly compliant heel. A future study should compare rocker shoes of different heel compliance to see if this compliance affects losses in the “collision” phase.

The radius of the MBT shoe’s rocker is not known directly by our group. However, to estimate the undeformed rocker radius of the MBT shoe, we found a side view photo of a MBT shoe from the internet and drew a circle in Powerpoint (Microsoft, Redmond, Washington) that most closely matched the rocker shape. We then estimated the length of a foot that would fit the shoe and compared the foot length to the radius of the circle (rocker). The radius of the circle was about 1.15 times the foot length, which equates to approximately 33% of the leg length (using foot length to height and leg length to height ratios from Dreyfuss, 1960). This rough estimate suggests that the range of rocker shoe radii in this study included the radius of the MBT shoe, further suggesting that the soft heel of the MBT shoes is the feature that leads to increases in metabolic energy cost. Shoes with more uniform hardness soles such as those used in this study may actually provide an energetic benefit to able-bodied persons during walking.

Wang and Hansen (2010) described gait analysis results of able-bodied persons walking with the various shoes in this study and suggested that rocker shoes could be created and used clinically to “naturally immobilize” the ankle during single limb support using the person’s tendency to maintain a consistent roll-over pattern. This approach may be useful in certain clinical cases where immobilization is being considered as a way to reduce pain in the foot and ankle. The results of this study suggest that these types of shoes may also reduce oxygen cost slightly for these patients during walking, which could potentially allow them to walk longer distances without fatigue. More work is needed to determine if similar effects can be found in patient populations.

While use of certain rocker shoes was found to reduce oxygen consumption rate in our study, it should be expected that these shoes will be unstable for standing tasks and will likely require increased ankle activity to maintain balance. Hansen and Wang (2010) showed that able-bodied persons create an effective shape with their ankle-foot systems during standing and swaying that is quite flat, although the effective shape taken during walking is curved. Rocker bottom shoes with flat regions have also been shown to alter postural responses to standing surface perturbations in young able-bodied persons (Albright and Woodhull-Smith, 2009). Although this study suggests a possible advantage of rocker shoes for energetic reasons during walking, these advantages may be countered by increased metabolic activity to maintain balance for standing and swaying tasks performed throughout a given day.

There are limitations in comparison of the REG shoes to the other shoe conditions in the study. The REG shoes were lighter in weight (Men’s size 8 REG ~ 375g; Men’s size 8 FLAT: ~650g) and had more flexible soles compared to the other shoes because no crepe material was added to their soles. Persons walking with the REG shoes would also have had shorter effective leg lengths during walking (by about 3 inches). Despite these differences, the oxygen consumption rate was similar between the REG and FLAT shoes, indicating that the effects of these factors were small or in balance. The fact that the REG shoes were not tested in a random order with the other rocker shoes is another limitation of the study. The finding that order of use was not significant, however, suggests that the lack of randomization of this shoe type may not be a critical issue. Another limitation of the study is that we did not measure stride frequency during the $O2$ consumption trials and the stride frequency could affect efficiency. However, our post-hoc analysis of gait analysis results of the study (over ground walking) showed no significant differences between cadence levels when walking with any of the rocker shoes at the same walking speed. Persons walked with a slightly yet significantly higher cadence when using the REG shoes compared with the FLAT shoes and when using the REG shoes compared with the R40 shoes. It is possible that stride frequencies were different during treadmill walking for the oxygen consumption trials compared with the over ground walking for the gait analysis trials.

The range of rocker radii tested in this study is unbalanced when considering that former work has suggested an optimal radius of 30% of leg length (McGeer, 1990; Hansen, 2002; Hansen and Childress, 2004; Hansen et al., 2004; Hansen and Childress, 2005; Adamczyk et al, 2006). The smallest radius chosen for the study was equal to 25% of the leg length. We found in pilot work that creating rocker shoes with smaller radii than the R25 shoes would necessitate lifts higher than three inches (7.6 cm) and we did not want to go above this height for safety reasons.

In conclusion, we found that rocker shoes with a radius of curvature around 40% of the leg length provided an energetic benefit during walking compared with shoes that had flat soles, with or without a lift. Rocker shoes with slightly smaller and slightly larger radii (25% and 55%, respectively) also provided an energetic benefit during walking compared with flat shoes with a lift, but did not provide an energetic benefit compared with flat soled shoes without a lift.

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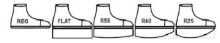

Figure 1.
Shoe conditions and abbreviations used in this study.

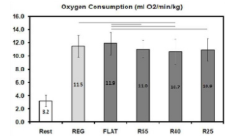

Figure 2.

Mean oxygen consumption rates for walking with the different shoe conditions and for the resting phases. Error bars indicate one standard deviation above and below the mean. Horizontal lines (above the bar graph) are drawn between conditions that were found to be significantly different.

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Table 1

Significance (p) Values for Pairwise Comparisons

Shoe Conditions	**FLAT**	**R55**	**R40**	**R25**
REG	0.499	0.172	**0.021**	0.366
FLAT		**0.027**	**<0.001**	**0.005**
R55			1.000	1.000
R40				0.957