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Original Article

Impact of alternative footwear on human energy expenditure

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ABSTRACT

Purpose: Use of alternative footwear options such as flip-flop style sandals and minimalist athletic shoes are becoming increasingly popular footwear choices. The purpose of the investigation was to analyze the energy expenditure and oxygen consumption requirements of walking at preferred pace while wearing flip-flops, slip-on style shoes, and minimalist athletic shoes. Methods: Eighteen healthy male adults participated in this study. In addition to an initial familiarization session, participants were tested in three different footwear conditions [thong-style flip-flops (FF), Croc® slip on shoes (CROC), and Vibram Fivefingers® minimalist shoes (MIN)]. Then after a brief warm-up, participants walked a one-mile distance at their preferred pace. Immediately following completion of the one-mile walk, participants stood quietly on the treadmill for an additional period to assess excess post-exercise oxygen consumption (EPOC). Results: A repeated-measures ANOVA that the following variables did not show evidence of a significant differently value between conditions: preferred pace ($p = 0.392$), average oxygen consumption ($p = 0.804$), energy expenditure per mile ($p = 0.306$), or EPOC ($p = 0.088$). There was shown to be a significantly higher RER during exercise in CROC compared to MIN ($p = 0.031$) with no significant differences observed when comparing CROC to FF ($p = 0.106$) or FF to MIN ($p = 0.827$). Conclusion: Based on the results of the current study, it appears that the alternative footwear selected for evaluation do not lead to a substantial alteration of walking pace or

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overall EE. However, the significant difference in RER suggesting a slightly elevated exercise intensity while wearing the CROC could perhaps be related to the softer sole, influencing overall mechanical efficiency. **Key words:** MINIMALIST FOOTWEAR, SLIP-ON SHOES, PHYSICAL ACTIVITY, WALKING.

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INTRODUCTION

Footwear is the interface between the human body and the terrain traversed. This interface plays an important role in influencing energy expenditure (EE) necessary for locomotion. As the popularity of running and walking for exercise has increased, greater focus has been placed on the important role that footwear plays in biomechanical and physiological aspects. Barefoot running has emerged as a popular strategy to improve overall performance ability (Robbins & Hanna, 1987; Squadrone & Gallozzi, 2009). There are a number of factors that play into this decision to try barefoot running, but research has displayed that barefoot runners often employ more of a mid-foot strike pattern over a heel strike strategy (Stacoff, Nigg, Reinschmidt, van den Bogert, & Lundberg 2000). This strategy better distributes the impact forces throughout the foot rather than just the heel and in addition lessens the impact and related pain experienced by a heel strike strategy (De Wit, De Clerq, & Aerts, 2000; Hanson, Berg, Deka, Meendering, & Ryan, 2011; Kurz & Stergiou, 2004). The plantar fascia act as a shock absorber for the foot and also supply a significant amount of elastic energy during walking or running to contribute to overall locomotion (Bramble & Lieberman, 2004). It has been suggested that the longer a person spends barefoot, the stronger the arch becomes and the potentially more efficient their movement becomes (Hanson et al., 2011).

People who are able to apply more metabolically efficient running or walking strategies should necessitate less oxygen utilization (Hanson et al., 2011). It is well known that one of the most important factors in distance running is running economy (Bassett & Howley, 2000; Hanson et al., 2011; Lucia et al., 2006; Noakes, 1988). Greater running economy should potentially lead to a decrease in overall EE at a more efficient self-selected pace. This principle can be applied to walking as well. More efficient walking patterns could also potentially delay the onset of fatigue as physical activity time progresses. Hanson et al. (2011) suggested that through their assessment of barefoot runners and shod runners, barefoot running was more metabolically efficient in that at the same relative workload, the runners exhibited higher oxygen consumption and perceived exertion when wearing shoes than when barefoot. It has also been suggested that wearing flip-flop style sandals instead of athletic shoes decreases a person's movement ability (Robinson, Rudisill, Weimar, Breslin, Shroyer, & Morera, 2011). This could lead to a greater amount of energy expended by a person wearing flip-flops to perform the same relative workload as when they are in athletic shoes or possibly barefoot.

It has previously been shown that barefoot running decreases the metabolic cost through oxygen consumption compared to running shod (Burkett, Kohrt, & Buchbinder, 1985; Divert, Mornieux, Baur, Mayer, & Belli, 2005). However, it wasn't clear whether this was related purely to biomechanical factors or whether the mass of the shoe played a significant role (Burkett et al., 1985). By design, minimalist shoes are supposed to provide the same benefits as barefoot running while also providing a small amount of protection to the foot. Squadrone and Gallozzi (2009) reported that when participants ran while wearing a minimalist shoe (Vibram Fivefingers®), oxygen consumption and peak impact forces significantly declined compared to a shod condition and that the values reported were similar to those seen with barefoot running. Shoe softness (or hardness) could also be a potential factor as it relates to mechanical efficiency. Kurz and Stergiou (2004) suggested that shoe hardness may lead to an alteration in ankle coordination strategy during locomotion. Divert, Mornieux, Freychat, Baly, Mayer, and Belli (2008) reported that stride frequency was significantly greater when barefoot compared to when in a shod condition. In addition, it was also reported that mechanical efficiency declined when in a shod condition and was explained to occur as a result of the decrease in storage and restitution of elastic energy (Divert et al., 2008).

Athletic performance ability has been shown to be impaired when wearing flip-flop thong-style sandals (Robinson et al., 2011). However, it has currently not been shown whether a low to moderate intensity mode of activity such as walking leads to a significant difference in pace between shod, flip-flop, or minimalist shoe conditions. The popularity of wearing flip-flops in the American culture has led to an increased choice of many to wear them exclusively during warm months. Shroyer & Weimar (2010) have suggested that people often wear flip-flop style shoes beyond their structural limit and have an altered gait biomechanics when compared to a normal, shod condition. It has been reported that when comparing a shod condition versus wearing flip-flops, a shortened stride and stance phase of normal gait results when wearing flip-flops (Shroyer & Weimar, 2010; Zhang, Paquette, & Zhang, 2013). However, it has also been suggested that when speed is kept constant, a slightly altered stride length may have minimal effect on running economy (Moore, Jones, & Dixon, 2015; Perl, Daoud, & Lieberman, 2012). It has not yet been shown whether minimalist shoes or flip-flops definitively cause a significant change in walking pace or overall EE and whether they are significantly different from barefoot walking. It will be important to assess whether wearing flip-flops, minimalist shoes, or the barefoot condition leads to a significantly different choice of self-selected walking pace.

Although there is an increasing amount of literature assessing the differences in barefoot and shod walking/running, there appears to currently be a lack of research as it pertains to metabolic efficiency and fatigue when walking barefoot, in flip-flops, or in minimalist shoes for an extended period of time. The aim of the present study was to measure and assess EE when walking for an extended period of time in different footwear and the potential differences that may be seen in fatigue and preferred pace. This study also included an assessment of metabolic effects of fatigue following walking through measurement of excess post-exercise oxygen consumption.

MATERIALS AND METHODOLOGY

Participants

The study was approved by the University's Institutional Review Board and informed consent was obtained from the participants prior to participation in the protocol. The study was able to recruit 18 healthy, recreationally trained males aged 18 – 44. Males were chosen in order to limit hormonal influences on EE. Sample size estimation was conducted a priori and when conducting an a priori analysis using G*Power 3.1.7 (Dusseldorf, Germany) using RM-ANOVA within-between interaction, with a desired power of 0.8, using an alpha level of 0.05.

The Physical Activity Readiness Questionnaire (PAR-Q) (Thomas, Reading, & Shephard, 1992) was used to screen for any potential contraindications to exercise. Participants completed a 7-day physical activity questionnaire to determine physical activity status (Sallis, Haskell, & Wood, 1985). Height and weight were measured by standard scales.

Procedures

The testing procedure was conducted on the premises of The Applied Biomechanics Laboratory (ABL) and Kevser Ermin Applied Physiology Laboratory. In addition to an initial familiarization session, participants were tested in three different footwear conditions [Croc® slip on shoes (CROC), thong-style flip-flops (FF), and Vibram Fivefingers® minimalist shoes (MIN)] that were counter balanced, on three separate days separated by a minimum of 48 hours. Each of the testing days began with a brief 10-minute warm-up protocol (consisting of jogs, high knees, lunge walking, and jumping) while wearing the assigned footwear. Figures 1 – 4 provide visual images and information pertaining to the selected footwear.

The participants were evaluated by walking on a treadmill at their preferred pace while wearing the selected footwear on each visit. This speed was determined by evaluating their pace from 6 timed 70 feet trials on an indoor track. Participants were timed over the middle 50 feet during each trial and preferred pace was determined as the mean pace traveled over those 6 trials in a manner previously described (Browning & Kram, 2005; Chander, Morris, Wilson, Garner, & Wade, 2016; Loftin et al., 2010; Morris et al., 2014; Morris, Garner, Owens, Valliant, & Loftin, 2016). Indirect calorimetry was employed to measure oxygen consumption and related variables during treadmill walking or running using the ParvoMedics TrueOne 2400 (Sandy, Utah) measurement system. Once on the treadmill, participants stood for 5 minutes to assess standing ambulatory rest. Then after a brief warm-up, participants walked a one-mile distance at their preferred pace. Immediately following completion of the one-mile walk, participants stood quietly on the treadmill for an additional period to assess excess post-exercise oxygen consumption (EPOC). This EPOC period lasted for five minutes which for every participant was long enough for the participant to return to resting VO_2 as measured during standing ambulatory rest. The entire procedure was repeated for the three footwear conditions presented in a randomized order. The participants were given at least 48 hours of rest in between their testing sessions.

Figure 1. Croc® slip on shoes (CROC)

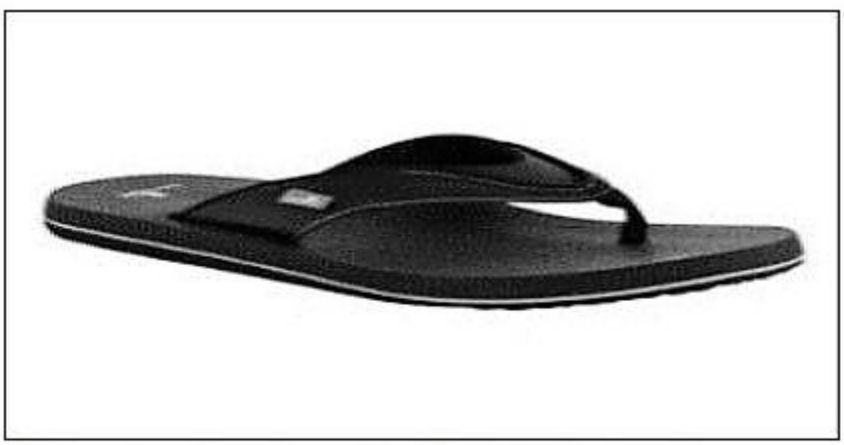

Figure 2. Thong-style flip-flops (FF)

Figure 3. Vibram Fivefingers® minimalist shoes (MIN)

Figure 4. Participant walking at preferred pace while wearing selected footwear

Statistical Analyses
A one-way ANOVA was used to compare body mass values across test days. A mixed-factor repeated-measures ANOVA (RM-ANOVA) was used to compare all other dependent variables for each test day (preferred pace, oxygen consumption, EE) for within-subjects and between-subjects. If interactions occurred, they were followed up with a Sidak adjustment for multiple pairwise comparisons. All analyses were conducted using SPSS software (Version 20, SPSS, Inc., Chicago, IL). Statistical significance was defined as a *p*-level less than 0.05 and partial eta squared was calculated to determine effect size.

RESULTS

Participant Characteristics
The mean age of the participants (in years) was 22.9 years [standard deviation (SD) = 2.88]. The mean height of the participants was 1.89 m (SD = 0.06). The mean unshod body mass of the participants for the CROC condition was 80.86 kg (SD = 8.61). The mean unshod body mass of the participants for the FF condition was 81.46 kg (SD = 8.99). The mean unshod body mass of the participants for the MIN condition was 81.47 kg (SD = 9.04).

Walking Pace and Metabolic Data

Table 1 displays descriptives for preferred walk pace, average VO_2 across completion of condition, average respiratory exchange ratio (RER) across completion of condition, EE (kcal/mile), average excess post-exercise oxygen consumption (EPOC) across completion of condition. RM-ANOVA showed that the following dependent variables did not show evidence of a significant differently value between conditions: preferred pace (p = 0.392), average VO_2 (p = 0.804), EE/mile (p = 0.306), or EPOC (p = 0.088). RM-ANOVA showed that there was a significant difference in average RER (p = 0.016). Post hoc pairwise comparisons revealed a significantly higher average RER in CROC compared to MIN (p = 0.031) with no significant differences observed when comparing CROC to FF (p = 0.106) or FF to MIN (p = 0.827).

Table 1. Descriptives of Metabolic Data

	Preferred Pace (mph)				Average VO_2 During Walk (mL/kg/min)				Average RER				Total EE (kcal/mile)				EPOC (L)			
	$\bar{X}$	SD	Min	Max	$\bar{X}$	SD	Min	Max	$\bar{X}$	SD	Min	Max	$\bar{X}$	SD	Min	Max	$\bar{X}$	SD	Min	Max
Croc	3.16	0.34	2.30	3.80	14.2	2.2	8.3	18.0	0.88[b]	0.04	0.82	0.97	105.1	13.1	83.0	144.0	0.70	0.34	0.11	1.49
Flip-flop	3.07	0.31	2.30	3.50	14.1	1.5	10.7	16.2	0.86[a]	0.04	0.79	0.93	108.5	12.2	88.0	136.0	0.89	0.37	0.40	1.57
Minimalist	3.12	0.37	2.30	3.60	13.9	1.6	10.3	16.0	0.85[a]	0.04	0.76	0.93	106.8	15.1	84.0	148.0	0.77	0.31	0.31	1.29

**Different letters indicate significant difference present (p < 0.05) for between-groups comparison.*

DISCUSSION

The results of the current study aimed to address the potential differences in diverse footwear conditions to a specific anthropometric blocked population. Hence, this study attempted to analyze metabolic measures of gait and provide a comprehensive summary of potential differences with respect to different footwear and the fatigue they elicit. In regards to the lack of significant difference in pace between the three footwear conditions, this takes the data that has been reported previously by Shroyer and Weimar (2010) and Zhang et al. (2013) one step further and suggests that despite the potential shorter stride length seen when wearing flip-flops, it doesn't lead to a substantial change in overall pace. This lack of a difference in walking pace is also perhaps what drives the similarities seen in VO_2 during the walk and total EE. This mirrors and supports what has been previously suggested by Moore et al. (2015) and Perl et al. (2012) that if speed and stride length are similar, energy expenditure shouldn't vary substantially when wearing flip-flops or minimalist shoes.

Studies have shown that when participants, regardless of training status, perform the same relative amount of work, there is not a significant difference in EPOC (Brehm & Gutin, 1986; Frey, Byrnes, & Mazzeo, 1993; Sedlock, 1994; Short & Sedlock, 1997). Findings of previous research have suggested that variations in EPOC are more likely related to the level of exercise intensity performed relative to an individual's exercise capacity than by an absolute level of exercise intensity (Sedlock, Lee, Flynn, Park, & Kamimori, 2010). EPOC is a measure of recovery and can be used as a measure of the amount of fatigue that a particular activity caused. The measurement of EPOC can help to show the potential increased metabolic recovery that is ongoing following a bout of walking for different shod conditions. While not a significant difference, the slight increase in EPOC when wearing flip-flops could suggest that if the walk were conducted for a longer period of time or at a higher than preferred pace (such as would be required if a person were in a hurry) could be a potential sign of earlier onset of physiological fatigue. While merely a speculation based on the available data, it is possible that the length of time required of the walk was not substantial enough to elicit observable fatiguing effects.

The difference exhibited in RER could perhaps be related to shoe hardness. RER can be used as a measure of exercise intensity, and despite the lack of a difference in overall EE, pace, or oxygen consumption, a significant difference appears to be present between the footwear conditions. Based on this data, the CROC elicited a slightly higher, but significant, difference in RER, suggesting that the participants could be operating at a slightly higher exercise intensity when wearing these shoes over the same absolute workload as the other conditions. There are two potential explanations for this difference. It could be related to the weight of the shoe, though the very slight differences in weight (approximately 3 oz. for FF, 7 oz. for CROC, and 6 oz. for MIN) are not likely enough to elicit that observed difference. The other explanation could be related to the reporting of both Divert et al. (2008) and Kurz and Stergiou (2008) that shoe hardness could influence overall mechanical efficiency. It's possible that the much softer sole of the CROC could result in the decrease in storage and restitution of elastic energy, leading to the expenditure of extra force during the push-off phase of each step. This would be in line with the previous findings of Divert et al. (2008). While these values were not measured in the present study, it is a plausible explanation that requires further study to confirm.

CONCLUSION

Based on the results of the current study, it appears that the alternative footwear selected for evaluation do not lead to a substantial alteration of walking pace or overall EE. It is possible that the level of exercise performed was not enough to elicit a sizeable modification in pacing strategy by the participants. However, the significant difference in RER suggesting a slightly elevated exercise intensity while wearing the CROC could perhaps be related to the softer sole, influencing overall mechanical efficiency. This assertion requires further study to confirm.

DISCLOSURE STATEMENT

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