Original Paper DOI: 10.5604/20831862.1144417 Biol. Sport 2015;32:149-154

Effect of training in minimalist footwear on oxygen consumption during walking and running

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ABSTRACT: The present study sought to examine the effect of 5 weeks of training with minimalist footwear on oxygen consumption during walking and running. Thirteen college-aged students (male n=7, female n=6, age: 21.7±1.4 years , height: 168.9±8.8 cm, weight: 70.4±15.8 kg, VO_2max: 46.6±6.6 ml·kg^{-1}·min^{-1}) participated in the present investigation. The participants did not have experience with minimalist footwear. Participants underwent metabolic testing during walking (5.6 km·hr^{-1}), light running (7.2 km·hr^{-1}), and moderate running (9.6 km·hr^{-1}). The participants completed this assessment barefoot, in running shoes, and in minimalist footwear in a randomized order. The participants underwent 5 weeks of training with the minimalist footwear. Afterwards, participants repeated the metabolic testing. Data was analyzed via repeated measures ANOVA. The analysis revealed a significant ($F_{4,32}$= 7.576, η_p^2=0.408, p≤0.001) interaction effect (time×treatment×speed). During the initial assessment, the minimalist footwear condition resulted in greater oxygen consumption at 9.6 km·hr^{-1} (p≤0.05) compared to the barefoot condition, while the running shoe condition resulted in greater oxygen consumption than both the barefoot and minimalist condition at 7.2 and 9.6 km·hr^{-1}. At post-testing the minimalist footwear was not different at any speed compared to the barefoot condition (p> 0.12). This study suggests that initially minimalist footwear results in greater oxygen consumption than running barefoot, however; with utilization the oxygen consumption becomes similar.

CITATION: Bellar D, Judge LW. Effect of training in minimalist footwear on oxygen consumption during walking and running. Biol Sport. 2015;32(2):149–154.

Received: 2014-08-12; Reviewed: 2014-11-28; Accepted: 2014-11-28; Published: 2015-03-15.

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Key words:
barefoot
shod
minimalist
aerobic exercise

INTRODUCTION

Aerobic exercise is important for the population of the United States as the nation is now facing an unprecedented increase in diseases linked to metabolic syndrome [1]. Aerobic exercises such as running and jogging are methods to increase aerobic exercise and can help a person meet the recommended amount of daily physical activity [2]. Jogging and running have gained popularity in the United States since the jogging craze of the 1970s [3,4].

The modern running shoe has a wedge shape with cushioning under the heel of the foot. It has been suggested that the wedge was introduced under the heel in order to have gravity assist the runner's forward progress [5]. More recently running shoes have undergone numerous changes in material and design in order to increase comfort and decrease injury. However, a recent meta-analysis [6] concluded that the prescription of modern running shoes was not an evidence based practice. It has also been reported that the cost of a pair of modern running shoes may not correlated to the cushioning ability of the shoes [7].

An alternative to running shod has always been to simply run barefoot. A recent survey of a large number of runners (n=785) indicated that 75.7% were interested in running barefoot or in minimalist footwear and that 30.4% had tried running in minimalist footwear [8]. While there is obviously interest in minimalist footwear in the running community, the use of minimalist footwear has been observed has been associated with injury. Salzler et al. [9] observed stress fractures and plantar fascia injuries in a group of runners within 1 year of transitioning from traditional to minimalist footwear. A recent review by Jenkins and Cauthon [10] in the Journal of the American Podiatric Medical Association concluded that scientific evidence had not yet provided conclusive evidence to support or refute the advantages of barefoot running over traditional shod running, however; the review noted that barefoot running may be an acceptable method of training.

Recent research into minimalist running has revealed that foot strike patterns often differ between traditionally shod runners, who tend to rear foot strike, and habitually barefoot runners who tend to forefoot strike [10]. Squadrone and Gallozzi [11] studied the biomechanical and physiological difference between two shod conditions and barefoot in a group of experienced barefoot runners. They reported that running in a traditional running shoe resulted in lesser plantar flexion at the ankle and higher impact forces compared to

the barefoot condition. These authors also reported that a type of minimalist footwear designed to mimic the natural shape of the foot resulted in similar kinematic and physiological data compared to the barefoot condition. The finding that minimalist footwear mimicked the physiological responses of barefoot running was supported by a recent study by Perl, Daoud and Lieberman [12]. This study suggested that at a speed of 3 meters per second minimalist footwear was between 2.41 and 3.32% more economical that running in traditional running shoes regardless of a forefoot or rear foot strike. Habituation to minimalist footwear has also been demonstrated to be associated with improvements in running economy and alteration in foot strike pattern with instruction [13,14]. These studies began to address the effects of minimalist footwear on running economy, the next logical step is to question will this effect persist with training and will it be present at more than one speed of movement. Based upon kinematic data is appears plausible that there are advantages to running barefoot [15,16] as a forefoot strike might allow for the increased energy absorption by the elastic structures in the foot.

With the interest in minimalist footwear among the running community it is important to understand the implications for the transition to use of minimalist footwear. The present investigation sought to determine the physiological responses to the progressive use of minimalist footwear among runners with no previous experience with this type of footwear. In particular the response to training that satisfied aerobic exercise for adults recommended by the American College of Sport Medicine and the American Heart Association.

MATERIALS AND METHODS

In order to determine the effect of progressive use of minimalist footwear on unaccustomed individuals a five-week training study was designed. The Institutional Review Board at the University of Louisiana at Lafayette approved the present investigation. Prior to beginning the study, participants gave written informed consent. Participants were pretested for metabolic responses to three different speeds of movement (5.6, 7.2, 9.6 $km \cdot h^{-1}$) with a counterbalanced order of footwear conditions (barefoot, traditional running shoes, minimalist footwear). Following five weeks of progressive training the participants were retested in all conditions and changes in physiological responses among different footwear conditions pre to post were examined.

Participants

The participants in the present investigation were 13 apparently health college aged students, all of whom gave written informed consent prior to participating. Inclusion criteria were the ability to run continuously for 30 minutes and being completely naive to the use of minimalist footwear or barefoot running for training, and having a pair of traditional running shoes that the individual as accustom to training in and were in sufficiently good condition to be used during the course of the study. The participants were active runners who ran more than once per week, and in many cases competed recreationally is local 5k road races. The resultant participants (age: 21.7±1.4 years , height: 168.9±8.8 cm, weight: 70.4±15.8 kg) were 7 males and 6 females who had slightly better than average cardiovascular fitness (VO_2max: 46.6±6.6 $ml \cdot kg^{-1} \cdot min^{-1}$).

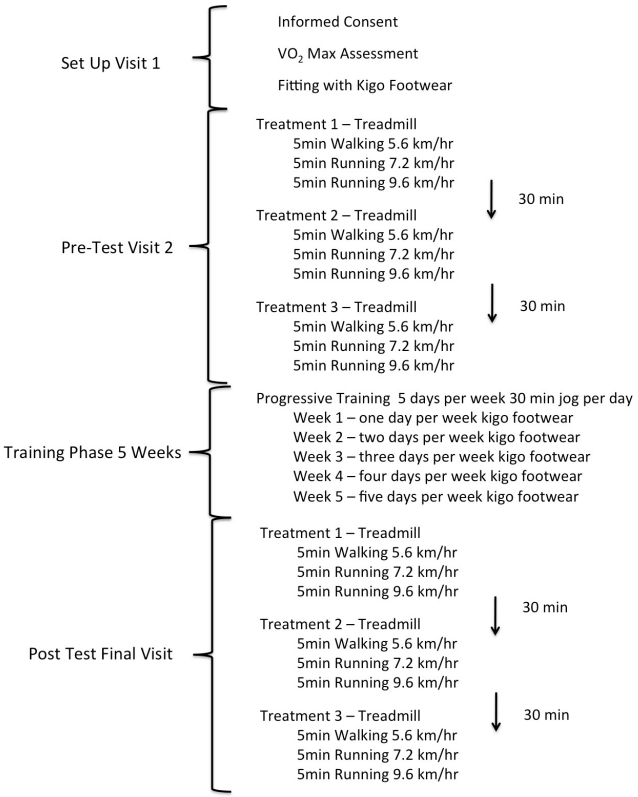

FIG. 1. Schematic of experimental protocol.

Procedures

The initial visit to the Human Performance Laboratory consisted of measurement of the feet to determine proper sizing of the minimalist footwear (Model: Edge or Drive, Kigo Footwear Corporation, Atlanta, GA) as well as the collection of height and weight data. Following the collection of this basic information, a graded exercise test was performed to determine the baseline cardiovascular fitness of each participant. During the next laboratory visit (no less than one week later) the participants physiological responses (VO_2 and heart rate) were examined in each of the foot wear conditions (barefoot, traditional running shoes 0.54±0.23 kg per shoe, minimalist footwear 0.33±0.06 kg per shoe) at one walking (5.6 km·h^{-1}) and two running (7.2 and 9.6 km·h^{-1}) speeds. The order of footwear testing was randomized. The participants then began a five-week period of progressive training with the minimalist footwear. Following the training the physiological testing for all three footwear conditions at the walking and two running speeds was repeated for comparison. A schematic of the protocol can be seen in Figure 1.

Graded Exercise Testing

Participants in the study all received the same graded exercise test format on the same equipment in the Human Performance Lab. The subjects ran on a Track Master TMX 425 treadmill (Full Vision Inc., Newton, KS.) during the assessment. Participants expired air was sampled and analyzed with a ParvoMedic TrueOne 2400 metabolic measurement system (ParvoMedics, Sandy, UT.) The system utilizes a mixing chamber and was set to sample expired air every 15 seconds. The system was calibrated prior to each test according to the manufacturers specifications. Listed accuracy for the gas sensors in the unit are: paramagnetic O2 analyzer ±0.1%, infrared CO2 analyzer ±0.1%. pneumotach ± 2%. After each assessment drift within the sensors was checked for, but determined to be negligible.

For the assessment a custom ramp protocol was used that had been developed after pilot testing on a similar group of athletes. This protocol included a 30 second initial familiarization stage at 1.6 kilometers per hour, and then a two-minute first stage at 1.6 km·h^{-1} and a 2.0% grade. After the initial stage the speed and grade were increased every 2 minutes by 1.6 km·h^{-1} and 1.5% respectively until the conclusion of the test. The test was concluded when the oxygen consumption was determined to have reached a plateau or the participant volitionally quit exercise. Heart rate during the test was determined through a Polar Wear Link heart rate sensor (Polar Electro Inc., Lake Success, NY.) that was linked to a receptor on the metabolic measurement system.

Training Protocol

Participants were required to complete five thirty minutes runs per week for a total of five weeks of training. This pattern results in 150 minutes of aerobic exercise per week, and given that average fitness individuals were used in the present study the volume of training was based upon the American College of Sports Medicine (ACSM) 2011 Position Stand dealing with necessary quantities and qualities of exercise [17]. The participants were instructed to train at their normal intensities. The first week of the training protocol one of the five runs was completed in the minimalist footwear, the remaining in the participants self selected traditional running shoes. For the next four weeks an additional run was completed with the minimalist footwear until during the fifth week all five runs were completed in the minimalist footwear condition.

Participants were required to keep a weekly online log of their training and email the log to the investigator. Out of the 13 subjects only 7 missed training sessions were reported, resulting in 97% compliance with the protocol. Soreness in the plantar flexors of the lower leg was listed as the reason for 3 out of the 7 missed trainings (other reasons included URTI and academic pursuits).

Testing for Differences Among Footwear

The same metabolic cart and treadmill that were used for the graded exercise test were used for this assessment. The participants' respiratory gas exchange and heart rate were monitored continuously during the assessment for each of the three footwear conditions (barefoot, traditional running shoe, minimalist footwear). The order the participants used the footwear was counterbalanced. Participants were asked to walk at 5.6 km·h^{-1}, and run at 7.2 and 9.6 km·h^{-1} for 5 minutes each (total of 15 minutes of continuous exercise) on the treadmill in each footwear condition. Given the moderate nature of the beginning of the protocol, as warm-up was not deemed necessary prior to the start of the protocol. A minimum of 30 minutes rest was undertaken between footwear conditions. This protocol was duplicated exactly at the pre and post training time points for each participant.

Statistical Analysis

Data were analyzed via repeated measures ANOVAs for VO_2, Respiratory Exchange Ratio (RER) and Heart Rate (time × footwear condition × speed) with sex (male,female) included as a between subjects factor to examine gender differences. Though no statistical difference in body mass were noted between pre and post testing, subjects mass was not identical from pre testing and thus absolute oxygen consumption was used to examine pre to post changes in oxygen consumption. Post hoc analysis was conducted on any significant interaction effect with a Bonferroni correction for multiple comparisons. A modern statistical software package was utilized for all analysis (SPSS ver 20.0). Statistical significance was set a priori at $p<0.05$.

RESULTS

Oxygen Consumption. Overall, all participants' oxygen consumption decreased (Pre-Training 1.678 L·min^{-1} 95% CI = 1.479 to 1.877, Post-Training 1.627 L·min^{-1} 95% CI 1.434 to 1.820, $p=0.033$) across all walking and running speeds for both the running shoe and minimalist footwear conditions (Table 1, approx. 3% improvement

TABLE I. Results of oxygen consumption pre and post training.

Treatment	Absolute Oxygen Consumption ($L \cdot min^{-1}$)		95% Confidence Intervals of Difference		Alpha
	Pre Training	Post Training	Lower Bound	Upper Bound	
Minimalist	1.74	1.68	0.01	0.12	p=0.031
Running Shoe	1.71	1.64	0.02	0.13	p=0.014
Barefoot	1.68	1.65	-0.01	0.12	p=0.367

in running economy pre to post) validating the compliance reported in the online log.

The analysis revealed significant main effects for time (pre, post $F_{4,32}$= 4.841, η_p^2=0.306, p=0.05) and treatment ($F_{4,32}$= 10.311, η_p^2=0.484, p=0.001). The analysis also revealed a significant (F4,32= 7.576, η_p^2=0.408, p≤0.001) interaction effect (time×treatment×speed) for oxygen consumption. During pre-testing the minimalist footwear resulted in significantly greater oxygen consumption compared to the barefoot condition at 9.6 $km \cdot h^{-1}$ (p=0.04, 95% CI of Diff .079 to .21 $L \cdot min^{-1}$), but not during walking at 5.6 $km \cdot h^{-1}$ (p=0.619, 95% CI of Diff -0.05 to 0.008 $L \cdot min^{-1}$) or running at 7.2 $km \cdot h^{-1}$ (p=.484, 95% CI Diff -.028 to .10 $L \cdot min^{-1}$)(see Figure 2). At pre testing the traditional running shoe condition resulted in greater oxygen consumption at 7.2 $km \cdot h^{-1}$ (p=0.001, 95% CI Diff 0.059 to 0.15 $L \cdot min^{-1}$) and 9.6$km \cdot h^{-1}$ (p=0.001, 95% CI Diff 13 to .25 $L \cdot min^{-1}$) compared to the barefoot condition, but was not significantly different at the walking speed (p=0.493, 95% CI Diff -0.26 to .051 $L \cdot min^{-1}$). When compared to the minimalist footwear condition during pre testing the running shoe resulted in greater oxygen consumption at 7.2 $km \cdot h^{-1}$ (p=0.013, 95% CI Diff 0.02 to 0.12 $L \cdot min^{-1}$) and 9.6 $km \cdot h^{-1}$ (p=0.039, 95% CI Diff 0.00 to 0.12 $L \cdot min^{-1}$), but was not significantly different at the walking speed (p=0.619, 95% CI Diff -0.02 to .04 $L \cdot min^{-1}$).

No differences (p>0.06; barefoot 1.60 $L \cdot min^{-1}$ 95% CI 1.45 to 1.83, minimalist shoe 1.63 $L \cdot min^{-1}$ 95% CI 1.46 to 1.89, running shoe 1.64 $L \cdot min^{-1}$ 95% CI 1.45 to 1.85) were revealed between the traditional running shoe, the minimalist footwear and the barefoot condition during post testing times at the walking or running speeds (Figure 3). Gender was not revealed to be a significant effect within the analysis of oxygen consumption (p>0.05).

Respiratory Exchange Ratio

The analysis did not reveal a significant main effect for treatment ($F_{4,32}$= 1.457, η_p^2=0.117, p=0.255) or time (pre,post $F_{4,32}$= 0.024, η_p^2=0.002, p=0.880). There were also no significant interaction effects for treatment×time (F4,32= 1.026, η_p^2=0.085, p=0.375). The overall mean RER at during pre-testing was 0.852 (95% CI 0.825 to 0.878) and at post-testing was 0.855 (95% CI 0.833 to 0.876). The mean for the minimalist footwear condition was 0.877 (95% CI 0.827 to 0.928) at pre-testing and 0.866 (95% CI 0.823 to 0.910) at post-testing. This was similar to the means for the running shoe (pre: 0.873 95% CI 0.812 to 0.933, post: 0.875 95% CI 0.822 to 0.929) and barefoot (pre: 0.851 95% CI 0.798 to 0.903, post: 0.883 95% CI 0.824 to 0.943).

Heart Rate

The analysis did not reveal any significant main or interaction effects between pre and post time points and the footwear conditions

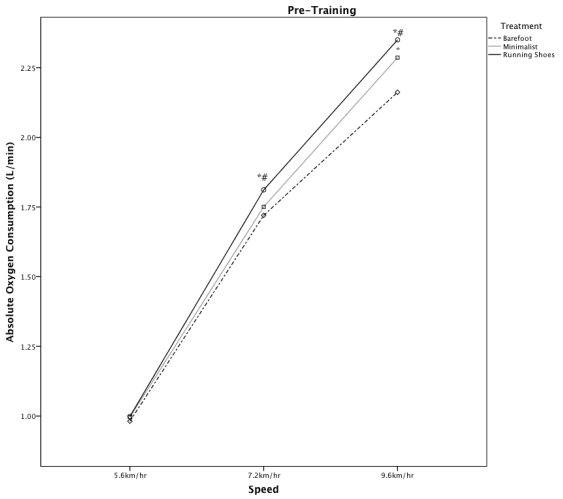

FIG. 2. Mean oxygen consumption ($L \cdot min^{-1}$) during the pre-training testing at 5.6, 7.2 and 9.6 kilometers per hour per by treatment.
Note: (*) represents significantly different from barefoot condition at similar speed (p<0.05), (#) represents significantly different than minimalist shoe condition at similar speed (p<0.05).

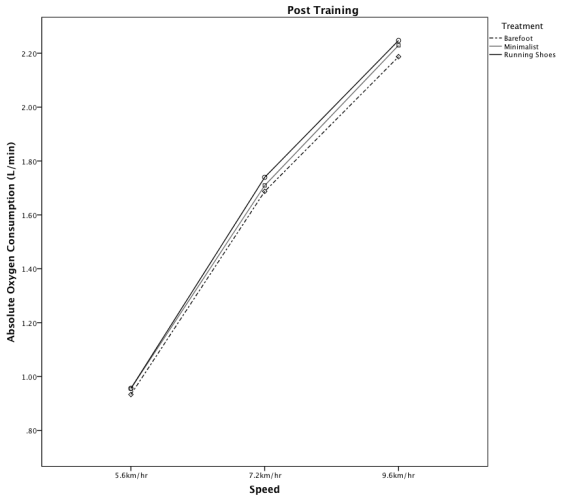

FIG. 3. Mean oxygen consumption ($L \cdot min^{-1}$) during the post-training testing at 5.6, 7.2 and 9.6 kilometers per hour by treatment.
Note: (*) represents significantly different from barefoot condition at similar speed (p<0.05), (#) represents significantly different than minimalist shoe condition at similar speed (p<0.05).

($p>0.05$). During the pre-testing period the heart rate across all speeds for the barefoot condition was 138 bpm (95% CI 122 to 154), for the minimalist footwear was 138 bpm (95% CI 126 to 151) and for the running shoe was 138 bpm (95% CI 120 to 156). At post-testing the barefoot condition resulted in a heart rate of 138 pm (95% CI 121.6 to 155.3), the minimalist shoes 138 bpm (95% CI 121 to 155) and the running shoes 142 bpm (128 to 157).

DISCUSSION

The pre training data from the present investigation are in agreement with two current studies of the physiological responses of runners to minimalist footwear [12,13]. The present study demonstrated that over the course of five week of progressive use the minimalist footwear condition, which caused significantly different oxygen consumption during the pre-training phase, became similar to the oxygen consumption caused by barefoot running post-training. The pre training assessment performed in the present investigation is in agreement with findings of Perl, Daoud and Lieberman [13] in that at the two running speed the minimalist footwear condition was slightly more economical (reduced oxygen consumption at similar workload) than the running shoe condition. However, the present investigation expands this comparison to include a barefoot condition at the pre training time point, which resulted in greater economy across all running speeds. What is also different about the present investigation as compared to the Perl, Daoud and Lieberman [13] study is the use of individuals naive to both barefoot running and minimalist footwear use. The results are also consistent with a meta-analysis by Fuller et al. [18] which suggest minimal to trivial gains in running economy with several types of minimalist footwear.

While the study failed to find differences in heart rate or substrate utilization (RER) in conjunction with the changes in running economy these variables were important to assess as they have applicability to training. Based upon these findings, HR is not adequate to determine the impact of footwear condition on training, and the small changes in running economy that occur with acute uses of different footwear are not enough to shift substrate utilization. The most interesting results from the present investigation are found in the post-training period, where economy increased across both the running shoe and minimalist conditions and no significant differences were revealed between any footwear conditions at any speed. This is likely due to increased economy after training in both the running shoes and minimalist footwear. As far as the author is aware this is the first training study to examine the physiological responses to minimalist footwear with training. Given the nature of the injuries reported in conjunction with minimalist footwear use [9,19], it was concluded that a progressive fashion of increased use of minimalist footwear was the appropriate course of training. However, in this manner the participants did engage in 10 training sessions with their traditional running shoes and 15 with the minimalist footwear. This may account for the increases in running economy seen with both the traditional running shoes as well as the minimalist footwear. The overall increases in running economy noted from pre to post across all treatments are likely due to increases in economy within the novel treatments, and not likely a result of increases in fitness. As the barefoot condition was not used for training this might explain why no change in running economy was observed in this condition (which would have been noted if fitness had increased), and may further suggest that minimalist footwear is not similar enough to barefoot training to promote changes in barefoot economy.

While the present investigation is not without limitations, the intention was to simulate the fashion that a naive individual would choose to incorporate minimalist footwear into their training (i.e. in combination with traditional shoes). One limitation to the study was the difference in mass that resulted from the different running conditions. As noted earlier the running shoes were heavier than the minimalist shoes, and this could have contributed to the results of the paper.

The present investigation was limited by the necessity of allowing the participants to engage in the testing and training involved in the study in their self-selected traditional running shoes. This was decided upon so as to limit the adaptation to a novel pair of shoes to only the minimalist footwear that was introduced. However, it did introduce a larger variety in shoe weight and construction in the traditional running shoe condition. This again does mimic the likely scenario in real-life as runners would be switching to a minimalist shoe from a variety of different makes and models of traditional trainers. The study was also limited by the length of time incorporated in the training. Results might be affected if longer training periods were employed.

CONCLUSIONS

Those professionals involved in the prescription of running as a form of aerobic exercise should be aware that at the onset of use minimalist footwear will result in greater economy in running compared to traditional running shoes and less economy when compared to barefoot running. Practitioners need to be aware of this impact, and similarly aware that simple measures such as heart rate will not demonstrate the changes that accompany the use of different footwear during training. However, with training and experience the naive runner will adapt and demonstrate similar running economy is all three footwear types. Finally, the minimalist footwear while similar in many regards to barefoot running, does not appear to be similar enough promote changes in barefoot economy.

Acknowledgements

Partial support for this study was provided by the Kigo Footwear Company. The author does not have an professional relationships with the Kigo Corporation and did not have any conflict of interest in conducting this investigation.

Conflict of interests: the authors declared no conflict of interests regarding the publication of this manuscript.

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