



Running Economy While Running in Shoes Categorized as Maximal Cushioning

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ABSTRACT

International Journal of Exercise Science 11(2): 1031-1040, 2018. The purpose of the study was to determine if running economy was influenced by wearing maximal cushioning shoes vs. control (neutral cushioning) shoes. Participants (n=10, age=28.2±6.1yrs; mass=68.1±10.2 kg; height=170±6.1 cm) completed two experiments. Each experiment included running conditions wearing control and maximal cushioning shoes. In Experiment 1, participants ran on a treadmill at three speeds in each shoe condition (6 total conditions). The speeds were: 1) preferred speed, 2) preferred speed + 0.447 m·s⁻¹, and 3) preferred speed - 0.447 m·s⁻¹. In Experiment 2, participants ran on a treadmill at two inclines (0%, 6%) in each shoe condition (4 total conditions) at preferred speed. Experiments were conducted on separate days with Experiment 1 first. For all conditions, participants ran for 8-10 minutes while rate of oxygen consumption (VO₂) was recorded. Average VO₂ during steady state for each running condition was calculated. For Experiment 1, a 2 (shoe) × 3 (speed) repeated measures ANOVA (α=0.05) was used. For Experiment 2, a 2 (shoe) × 2 (incline) repeated measures ANOVA (α=0.05) was used. Rate of oxygen consumption was not influenced by the interaction of speed and shoe (p=0.108); VO₂ was different between speeds (p<0.001), but not between shoes (p=0.071). Rate of oxygen consumption was not influenced by the interaction of incline and shoe (p=0.191); VO₂ was greater for incline vs. level (p<0.001), but not different between shoes (p=0.095). It is concluded that a maximal cushioning running shoe did not influence running economy when compared to a control shoe (neutral cushioning running shoe).

KEY WORDS: Footwear, rate of oxygen consumption, running shoe design

INTRODUCTION

Nearly 17 million people in the United States ran in some form of road race or marathon in 2016 (16). Though running is popular and a good form of cardiovascular exercise, it is associated with a high risk of developing overuse injuries. It has been reported that between 25% and 70% of runners sustain an overuse injury that required medical attention (6, 18). Although the mechanism of running injuries is not fully understood (6, 17), running shoes are often considered a way to minimize the risk of overuse injury (7). However, despite changes in shoe technology over the past 30-40 years, running injuries continue to persist.

Over the past 10 years, barefoot running or running in minimalist shoes gained in popularity in part as a way to minimize the risk of overuse injuries, but also as a way to potentially improve running economy (2). However, overall injury rates during running continue to be high (18). Furthermore, the effect of shoe type (e.g., minimalist, trainer, racing flat, etc.) on running economy has been small (2). More recently, shoes with more cushioning have become available to consumers (e.g., HOKA, Altra, etc.). In retail terminology, this new category of shoe is commonly described as a 'maximal' or 'extreme' cushioning type shoe. Phrasing to describe a traditional trainer shoe would be something like 'neutral cushioning'. Shoes with little cushioning are typically referred to as 'minimalist' shoes. In this new category of shoe, the shoe is designed with a higher amount of cushioning material than a traditional trainer shoe. However, it is important to note that there are no specific shoe characteristics that define this category of shoe. For example, there is no minimal thickness of cushioning, heel-toe drop height, or type of cushioning material used. Instead, this shoe category is more generally described as being on the opposite end of a cushioning spectrum than a minimalist shoe.

The implied intent of additional cushioning material for maximal cushioning shoes is that impact forces would be reduced during running. However, a potential downside to using maximal cushioning is that running economy may be negatively influenced due to the shoe being too soft and/or a potential increase in shoe weight due to more cushioning material (4, 11, 13, 15). Running economy is defined as the steady-state rate of oxygen consumption (VO_2) when running at a specific speed (16). There is evidence that running economy is worse when running on surfaces that are soft (11). For example, Lejeune, Willems, and Heglund (11) reported that running economy was worse when running on sand than on a hard surface. Likewise, there is evidence that running economy can be worse with weight added to the shoes (4, 13, 15). However, it also seems reasonable that a maximal cushioning shoe would not influence running economy if the cushioning provided elastic recoil (vs. energy absorption only), shoe weight was not dramatically different than a neutral cushioning shoe, and/or running style changed in a way to accommodate to the maximal cushioning shoe. Nevertheless, to the authors' knowledge there is presently no published research on running economy while wearing maximal cushioning shoes. This work is important to provide runners with information regarding how running economy may or may not be influenced by shoe selection. Furthermore, this type of information might be helpful to runners when selecting a shoe for training or for racing. Therefore, the purpose of this study was to compare running economy while wearing maximal cushioning or control (neutral cushioning model) shoes. To provide a more in-depth examination of potential influence of shoe cushioning on running economy, two experiments were designed. The purpose of the first experiment was to determine if running economy was influenced by shoes worn (i.e., maximal and control shoes) during different running speeds. The purpose of the second experiment was to determine if running economy was influenced by shoes worn (i.e., maximal and control shoes) while running on a level grade or uphill. This second experiment was designed in part based upon shoe design. The maximal cushioning shoe tends to have more cushioning concentrated in the rear foot section. Therefore, by running up an incline, it was thought that subjects would likely strike the ground less directly on the rear foot (8, 11).

METHODS

Participants

Participants (n=10, age=28.2±6.1yrs; mass=68.1±10.2 kg; height=170±6.1 cm) were free from injury at the time of testing and completed all experimental running conditions. All participants had to be currently running at least 10 miles per week and all were comfortable running on the treadmill for the planned duration of the study. All participants gave written informed consent prior to testing. The study was approved by the University Institutional Review Board.

Protocol

All participants completed two experiments, each experiment on a separate day. For each experiment, participants ran in two shoe models: Maximal Cushioning (HOKA Bondi4) and Control Shoe (neutral cushioning; Adidas Response Cushion). As per retail industry shoe-guide report (<http://www.runnersworld.com>), the HOKA shoes have a heel-to-toe-drop of 7.3 mm, 289 g weight (for pair), and heel height of 42.3 mm (men's size 9, women's size 7). The Adidas shoes have a heel-to-toe-drop of 11.0 mm, 326 g weight (pair), and heel height of 35.1 mm.

For Experiment 1, participants ran at three different speeds. For Experiment 2, participants ran at two different incline settings ([0%]0% and 6% incline) at a single speed. Participants always completed Experiment 1 first and all participants completed both experiments with the exception that one subject could only sustain 3% incline during Experiment 2. The data for that subject were subsequently dropped from analysis resulting in an n=9.

For each experiment, preferred speed (PS) was determined while running on a treadmill in the Control Shoe. Participants ran on the treadmill with the speed display hidden from view and were asked to self-select a speed that could be sustained for a 30-min run. The speed was recorded upon selection and the process was repeated twice more for a total of three times. The average of the three speeds was used as the PS. The procedure to determine PS was conducted for each experiment.

For each experiment, VO_2 was measured continuously using an open circuit, breath-by-breath, metabolic measurement system (MOXUS, Applied Electrochemistry, Pittsburg, PA). The gas analysis system was calibrated each day prior to testing according to manufacturer's instructions using ambient air and known gas concentrations. Rating of Perceived Exertion (RPE) was measured using Borg's 6-20 point scale each minute (1).

Experiment 1 consisted of having participants run in the two shoe models at three speeds: PS, PS+0.447 m s⁻¹ (PS+), and PS-0.447 m s⁻¹ (PS-) (total of six conditions). The order of speeds was always slow to fast and shoes were counterbalanced. Each condition lasted 5-10 min, depending on the length of time to reach steady state.

For Experiment, 2 each participant ran at PS in both shoe models while running on a level treadmill and at a 6% incline (total of four conditions). Order of conditions was level followed

by 6% with shoe order counterbalanced. Each condition lasted 5-10 min, the time varying based upon how quickly participants reached steady state.

Statistical Analysis

Dependent variables VO_2 and RPE were each averaged over 3-5 minutes of steady state exercise for each condition. Steady state was operationally defined as little or no change in VO_2 . The section of data that was averaged across was then fit with a linear line of best fit to confirm the slope was near zero (i.e., steady state). Furthermore, the slopes were compared between conditions with there being no difference ($p>0.05$). We also inspected RER during each averaging window and determined 98% of the trials had an RER of less than 1.0. We inspected the 2% of trials that had an RER >1.0 and confirmed that the slope was near zero.

Experiment 1 used a 2 (shoe type) \times 3 (speed) repeated measures ANOVA. It was decided *a priori* to use simple effects testing if there was a speed main effect to compare VO_2 during PS to PS+ and PS to PS- ($\alpha=0.05$). Experiment 2 used a 2 (shoe type) \times 2 (incline) repeated measures ANOVA. There were no comparisons of dependent variables between experiments. Statistical analyses were performed using SPSS (IBM SPSS Statistics, version 22.0.0.0).

RESULTS

The preferred speed for Experiment 1 was 2.3 ± 0.4 m \cdot s $^{-1}$. Rate of oxygen consumption was not influenced by the interaction of shoe type and speed (Control Shoe PS- 34.8 ± 6.4 ml \cdot kg $^{-1}$ \cdot min $^{-1}$, PS 40.7 ± 5.3 ml \cdot kg $^{-1}$ \cdot min $^{-1}$, PS+ 46.0 ± 5.9 ml \cdot kg $^{-1}$ \cdot min $^{-1}$, Maximal Cushioning Shoe: PS- 33.8 ± 6.9 ml \cdot kg $^{-1}$ \cdot min $^{-1}$, PS 39.1 ± 6.1 ml \cdot kg $^{-1}$ \cdot min $^{-1}$, PS+ 45.7 ± 6.0 ml \cdot kg $^{-1}$ \cdot min $^{-1}$; $p=0.108$; Figure 1) and there was no main effect for shoe type ($p=0.071$). Rate of oxygen consumption was influenced by speed such that it was greater as speed increased ($p<0.001$). This effect was independent of shoe type. Rating of perceived exertion (6-20 point scale) was not influenced by the interaction of speed and shoe (Control Shoe: PS- 7.4 ± 2.0 , PS 10.8 ± 1.9 , PS+ 14.0 ± 3.0 ; Maximal Cushioning Shoe: PS- 7.4 ± 1.7 , PS 10.2 ± 2.0 , PS+ 13.7 ± 2.9 ; $p=0.746$; Figure 2) and was not different between shoe type ($p=0.383$) but increased with speed ($p<0.001$).

The preferred speed for Experiment 2 was 2.4 ± 0.3 m \cdot s $^{-1}$. Rate of oxygen consumption was not influenced by the interaction of shoe type and incline (Control Shoe: 0% 32.1 ± 5.4 ml \cdot kg $^{-1}$ \cdot min $^{-1}$, 6% 48.3 ± 5.0 ml \cdot kg $^{-1}$ \cdot min $^{-1}$; Maximal Cushioning Shoe: 0% 34.2 ± 3.2 ml \cdot kg $^{-1}$ \cdot min $^{-1}$, 6% 48.9 ± 4.8 ml \cdot kg $^{-1}$ \cdot min $^{-1}$; $p=0.191$; Figure 3), and there was no main effect for shoe type ($p=0.095$). Rate of oxygen consumption was influenced by incline ($p<0.001$) such that VO_2 was greater while running at 6% vs. 0% incline regardless of shoe type worn. Rating of perceived exertion was not influenced by the interaction of incline and shoe type (Control Shoe: 0% 7.7 ± 2.0 , 6% 12.9 ± 2.4 ; Maximal Cushioning Shoe: 0% 8.5 ± 2.1 , 6% 13.6 ± 2.5 , $p=0.958$; Figure 4). There was a significant main effect of incline ($p=0.027$) and shoe type ($p<0.001$) on RPE.

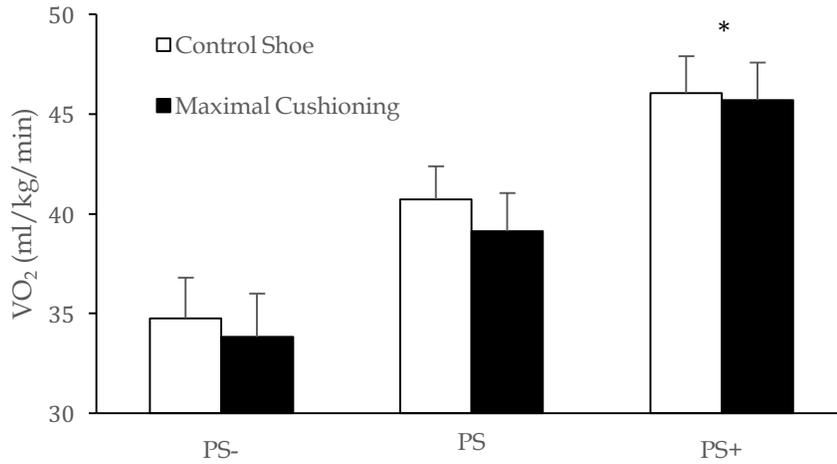


Figure 1. Illustration of mean and standard error of rate of oxygen consumption (VO₂) while running at Preferred Speed (PS), slower than PS (PS-), and faster than PS (PS+). Speeds were 0.447 m s⁻¹ slower or faster than PS. At each speed, participants wore a Control and Maximal Cushioning shoe. Note: * VO₂ increased across speeds (p<0.001) but was not different between shoes (p=0.071).

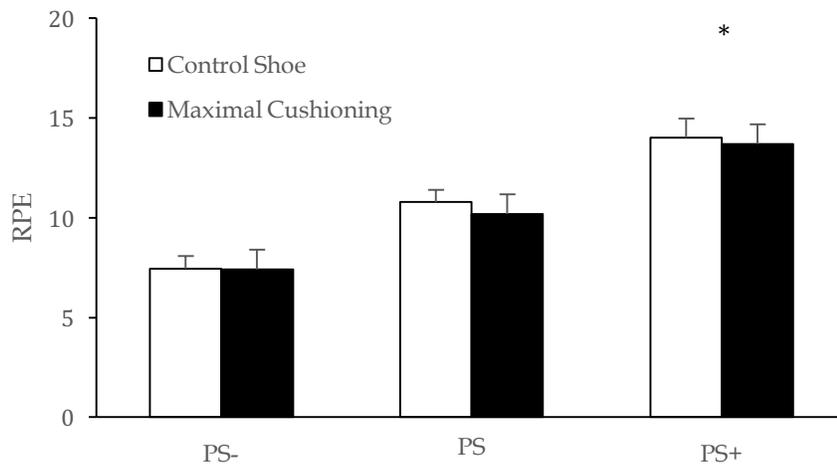


Figure 2. Illustration of mean and standard error of Rating of Perceived Exertion (RPE) while running at Preferred Speed (PS), slower than PS (PS-), and faster than PS (PS+). Speeds were 0.447 m s⁻¹ slower or faster than PS. At each speed, participants wore a Control and Maximal Cushioning shoe. Note: * RPE increased across speeds (p<0.001) but was not different between shoes (p=0.383).

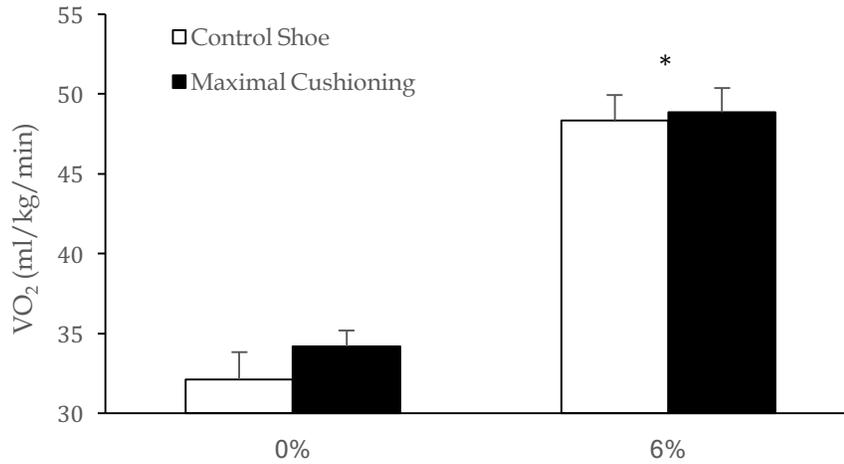


Figure 3. Illustration of mean and standard error of rate of oxygen consumption (VO₂) while running at Preferred Speed (PS) on level (0%) and incline (6%) while wearing a Control and Maximal Cushioning shoe. Note: * VO₂ increased across inclines (p<0.001) but was not different between shoes (p=0.095).

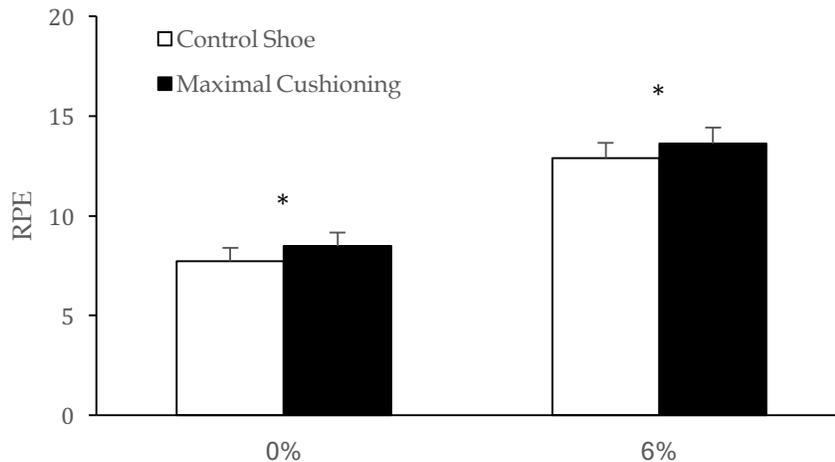


Figure 4. Illustration of mean and standard error of Rating of Perceived Exertion (RPE) while running at Preferred Speed (PS) on level (0%) and incline (6%) while wearing a Control and Maximal Cushioning shoe. Note: * RPE was influenced by incline (p=0.027) and shoe (p<0.001).

DISCUSSION

The overall aim of this study was to determine if running economy was influenced by wearing maximal cushioning shoes as compared to a neutral cushioning shoe. The most important observation of this study was that VO₂ was not influenced by the type of shoe that was worn during running. That is, there was no difference in running economy when participants wore

the maximal cushioning or control shoe (neutral cushioning). As expected, VO_2 increased with speed and incline.

These results are similar to those reported by Mercer, Branks, Wasserman, and Ross (14) who compared VO_2 while running in traditional running shoes and 'spring-boots'. The spring-boots were designed such that the shoe sole was a large leaf-spring. This spring compressed during the initial phase of running stance and recoiled during the later portion of stance to aid in propulsion. Although the spring-boot was much heavier than the running shoe utilized, VO_2 was not different while wearing the spring-boot or shoe. The main design difference between the maximal cushioning shoe and the spring-boot used by Mercer et al. (14) is that the maximal cushioning shoe does not provide the same energy return mechanism as the spring-boot.

When running on surfaces that are compliant but do not provide energy return, running economy can be worse (11). Lejeune et al. (11) reported a twofold increase in VO_2 while running on sand compared to running on a hard surface while wearing shoes. Sand is a softer surface compared to running on a treadmill. However, when running on sand, there is no energy returned during the stance phase of gait whereas while running on a treadmill, the cushioning of a shoe does rebound and can potentially provide some energy return during running. The energy return of a shoe may likely explain the contrasting results of the present study with Lejeune et al. (11). Interestingly, Kryztopher, Franz, and Kram (10) indicated the amount of shoe cushioning typically used in shoes may have a beneficial effect on running economy by offsetting the weight of the cushioning. Furthermore, Kryztopher et al. (10) hypothesized that there may be an optimal shoe cushioning thickness for each runner that could lead to improved running economy. Likewise, it may be that individual runners will benefit from shoes with different amounts of cushioning.

In the present study, the lack of significant change in VO_2 between shoe types may be an indication that the maximal cushioning shoes were not dramatically more cushioned than the control shoes in terms of energy absorption (i.e., cushioning). A sample of shoes used in the present experiment were impact tested. It was determined that the maximal cushioning shoes had about 14.7% less impact acceleration than the control shoe, indicating the maximal cushioning shoes had greater energy absorption capabilities than the control shoe. This is in line with the design feature of the maximal cushioning shoe. Since VO_2 was not different between shoe types, it may be that the difference in cushioning (i.e., 14.7%) between shoes was not functionally meaningful. Alternatively, it may be that the cushioning materials provided enough energy return to offset any potential negative influence the cushioning would have on running economy. Another possible explanation for the lack of difference in VO_2 between shoes is that runners adjusted their running style for shoe types in a way that offset any negative effect the maximal cushioning might have had on VO_2 . Additional research is needed on the shock attenuating capacity of maximal cushioning vs. control (neutral cushioning) shoes and the biomechanics of running in maximal cushioning shoes.

It is known that adding weight to a shoe can increase VO_2 (5, 12). In the present study, the maximal cushioning shoe mass (pair: 599 ± 68.0 g) was similar to the control shoe (pair: $630 \pm$

62.3 g). Fuller et al. (5) conducted a meta-analysis of research investigating the influence of shoe on running economy. Based upon the data presented, running economy was only influenced when the difference in shoe mass between conditions was quite large (greater than 15%). In the present study, difference in mass between shoes was < 6%. Based on the results of Fuller et al. (5), the two shoe types used may have been too similar in mass and impact energy absorption performance to influence VO_2 .

In an attempt to compare shoe types independent of the cushioning in the rear foot section of the shoe, we included running at 6% grade. During uphill running, foot strike tends to be less on the rear foot and more towards mid foot or forefoot as grade increases (8, 12). By using this experimental approach, it was observed that VO_2 was not influenced by shoe type when running on the incline. This may be an indication that the shoe cushioning characteristics were not that dramatically different and/or the runners adjusted running style for both shoe types worn to reduce metabolic cost. However, we did not measure running gait characteristics like foot strike or stride length. Future work is needed to determine if runners maintain the same running style when running in maximal cushioning vs. control shoes while running at different speeds and/or inclines.

It is also important to recognize that individual runner responses can often be masked by analyzing group data. Since the p-values for a shoe main effect for VO_2 were less than 0.10 for each experiment, we inspected individual data and observed that the difference in VO_2 between shoes for similar run conditions was positive in about half the subjects and negative in the other half. Furthermore, the absolute difference in VO_2 between similar conditions was within 3% between shoe conditions in about 64% of the conditions. Finally, the effect size (using pooled standard deviation) for Experiment 1 was 0.09 and -0.16 for Experiment 2. Based upon this, it seems that the responses were overall similar across subjects. However, given that the direction of VO_2 response was not the same for all subjects (i.e., some subjects had greater VO_2 in one shoe vs. another) there are likely some runners that would benefit from one type of shoe vs. another based upon their run experience, running style, and anthropometrics, for example. Likewise, there are likely runners who may have a negative response to using maximal cushioning shoes for the same reason (i.e., run experience, running style, anthropometrics, etc.).

A limitation of this study was that we tested only one model of maximal cushioning and control (neutral cushioning) shoes. Although these shoes fit into different shoe categories (e.g., 'Maximal Cushioning', 'Neutral Cushioning'), it may be that the structural and/or mechanical design were not that dramatically different between the two shoes. There may be benefit of testing different models or brands of maximal cushioning shoes as well as other control models. Also, we conducted Experiment 1 (i.e., shoe, speed manipulation) first and Experiment 2 (i.e., shoe, incline manipulation) second. It is possible that the results from Experiment 2 were influenced by Experiment 1. However, the results are consistent between studies regarding the lack of influence of shoe influence on the dependent variables. Along with this, the study is limited by the subjects tested. It may be helpful to test runners of different ages, fitness levels, and running experiences, for example.

In conclusion, running economy was not different while running in shoes that were categorized as 'Maximal Cushioning' vs. a control shoe (i.e., neutral cushioning shoe). It seems wearing a running shoe with maximal cushioning will not negatively influence running economy from a physiological perspective as compared to a control shoe of similar mass. Future research is needed to determine if this type of shoe influences parameters related to running overuse injuries such as impact force characteristics and pronation/supination kinematics.

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