Original research

Rocker shoe, minimalist shoe, and standard running shoe: A comparison of running economy

Sobhan Sobhani a,*, Steef Bredeweg b, Rienk Dekker a,b, Bas Kluitenbergh, Edwin van den Heuvelc, Juha Hijmansd, Klaas Postema a

a Department of Rehabilitation Medicine, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
b Center for Sports Medicine, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
c Department of Epidemiology, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
d School of Sports Studies, Hanze University of Applied Sciences, Groningen, The Netherlands

ARTICLE INFO

Article history:
Received 2 February 2013
Received in revised form 6 April 2013
Accepted 25 April 2013
Available online 24 May 2013

Keywords:
Energy expenditure
Exercise test
Rocker profile
Barefoot running

ABSTRACT

Objectives: Running with rocker shoes is believed to prevent lower limb injuries. However, it is not clear how running in these shoes affects the energy expenditure. The purpose of this study was, therefore, to assess the effects of rocker shoes on running economy in comparison with standard and minimalist running shoes.

Design: Cross-over design.

Methods: Eighteen endurance female runners (age = 23.6 ± 3 years), who were inexperienced in running with rocker shoes and with minimalist/barefoot running, participated in this study. Oxygen consumption, carbon dioxide production, heart rate and rate of perceived exertion were measured while participants completed a 6-min sub-maximal treadmill running test for each footwear condition. The data of the last 2 min of each shoe condition were averaged for analysis. A linear mixed model was used to compare differences among three footwear conditions.

Results: Oxygen consumption during running with rocker shoes was on average 4.5% higher than with the standard shoes (p < 0.001) and 5.6% higher than with the minimalist shoe (p < 0.001). No significant differences were found in heart rate and rate of perceived exertion across three shoe conditions.

Conclusions: Female runners, who are not experienced in running with the rocker shoes and minimalist shoes, show more energy expenditure during running with the rocker shoes compared with the standard and minimalist shoes. As the studied shoes were of different masses, part of the effect of increased energy expenditure with the rocker shoe is likely to be due to its larger mass as compared with standard running shoes and minimalist shoes.

© 2013 Sports Medicine Australia. Published by Elsevier Ltd. All rights reserved.

1. Introduction

The high amount of load at the forefoot region during the push-off phase in walking and running, makes this region susceptible to different overuse injuries such as metatarsal stress fractures and metatarsalgia. Rocker bottom shoes (hereafter referred to as rocker shoe) have been shown to be able to reduce the excessive plantar pressure in the forefoot region during walking.

Moreover, rocker shoes can reduce the peak plantar flexion moment (related to the force on the Achilles tendon) during propulsion phase of running, and therefore they might be beneficial for runners who are in the recovery phase of Achilles tendinopathy. For these reasons, rocker shoes might play a role in the prevention and treatment of overuse injuries during running.

While the biomechanical effects of rocker shoes in relation to lower limb injuries have been subject to a number of studies, no attention has been made to the possible side-effects such as the energy expenditure during running with these shoes. Some work, however, has been done in walking activities, and conflicting results have been reported. In one study no changes in metabolic cost between rocker bottom shoes and standard shoes were observed. One study reported an increase in energy expenditure during walking with rocker shoes compared with standard shoes, and the opposite was found in another study.

The minimalist shoe is a rather new type of footwear, gaining popularity among runners. Minimalist shoes are presumed to simulate barefoot running and may therefore reduce running injuries. For instance, minimalist shoe running is believed to promote a forefoot strike which reduces the impact force and impact loading
rate during running.\textsuperscript{10,11} Since these factors are related to running injuries, minimalist shoes are used by runners to prevent overuse injuries.\textsuperscript{8,10} Apart from injury prevention, running with minimalist shoes is shown to be more economic than running with standard running shoes.\textsuperscript{1,11,12} However, to date no comparison has been made between minimalist shoes and rocker bottom shoes regarding the running economy (RE).

RE can be an important factor for runners, and might affect the choice of footwear for their regular running activities. Therefore, the purpose of present study was to determine how rocker shoes affect RE, and compare it with minimalist and standard running shoes.

2. Methods

The experimental protocol of this research was approved by the Medical Ethics Committee of the University Medical Center Groningen (METc 2012.014). This study was part of a bigger research project focusing on running overuse injuries and shoe biomechanics with only the female sample population. The selection of females as the sample for the whole project was based on the higher incidence rate of overuse injuries reported for this gender.\textsuperscript{12}

To be included, female runners needed to be between 18 and 55 years old, and be healthy with no history of cardiovascular and musculoskeletal (back and lower limb) problems. Participants had to have experience of running at least twice per week and at least five km per run in the past year. In addition, the runners needed to be familiar with treadmill running, and had the ability (self-reported) to run for approximately 30 min at sub-maximal pace on treadmill.

The investigated shoes in this research (European sizes 37–42) were as follows: rocker shoe (average mass per pair: 858 ± 96 g, Fig. 1A), standard running shoe (Dutchy\textsuperscript{TM}, average mass per pair: 541 ± 44 g, Fig. 1B), and minimalist shoes (Merrell\textsuperscript{TM} Pace Glove, average mass per pair 321 ± 25 g, Fig. 1C). Rocker shoes were modified from standard shoes with a stiffened rocker sole by a certified orthopedic shoe technician. The apex (rolling-point) of the rocker shoes and baseline shoes were respectively positioned at 53\% (proximal to metatarsal region), and 65\% of the shoe length from the heel. The rocker profile thickness for different sizes was 2.2 ± 0.1 cm at the apex and under the heel.

Oxygen consumption (VO\textsubscript{2}) and carbon dioxide production (VCO\textsubscript{2}) were recorded and monitored continuously via face mask using an open circuit breath-by-breath gas analysis system (Cortex Metalyzer 3B, Leipzig Germany) and its dedicated software (MetaSoft 3.9.5, Germany). Prior to data collection, the gas analysis system was calibrated according to manufacturer’s instructions using ambient air and known gas concentrations. The volume calibration was performed using a 3-l syringe. Heart rate (HR) was measured using a wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland).

Rating of Perceived Exertion (RPE) of running was determined using 15 points (6–20) Borg scale\textsuperscript{14} for each shoe condition. This scale was used to subjectively measure the overall effort when running with three different shoes for the first time. The Borg scale has been shown to be a reliable method for rating perceived exertion in treadmill running.\textsuperscript{15}

The experimental procedure was as follows: each participant visited the exercise laboratory once, and all testing procedures were conducted under similar conditions. Prior to data collection, the procedures were described in detail for participants and each participant read and signed a consent form. Then, body weight and height were recorded without shoes. After preparation, each participant ran on a treadmill (Valiant; Lode, B.V., Groningen, The Netherlands) with all three shoe conditions. Participants were randomly assigned to the six different orders in running with the shoes, but with the restriction that the design would be balanced. The treadmill grade was set at 1\% incline to compensate for lack of air resistance.\textsuperscript{16} The sub-maximal running tests for each shoe condition included two running bouts: (1) running for 3 min at the speed of 7 km h\textsuperscript{-1} to help the participants to get familiar with experimental condition (e.g. face mask and shoes), (2) running for 6 min at the speed of 9 km h\textsuperscript{-1} to allow the runners to reach the steady state. The running pace for the economy test (9 km h\textsuperscript{-1} for 6 min) was assumed to be moderate enough as a sub-maximal test for our sample group who were experienced endurance runners. There was a 2 min rest between each measurement, which allowed participants to rate the perceived exertion, and change the shoes. In total a RE test for each participant took 31 min.

Descriptive statistics were used to describe the characteristics of the population. The data of the last 2 min of each shoe condition were averaged to calculate the mean VO\textsubscript{2} (ml kg\textsuperscript{-1} min\textsuperscript{-1}), respiratory exchange ratio (RER), and HR (bpm) for analysis. VO\textsubscript{2} and VCO\textsubscript{2} values were normalized to the participant’s body mass (kg) while...
not wearing shoes. For two persons, HR could not be measured for technical reasons, and thus for this parameter data analysis was performed using the data of 16 participants.

The data were analyzed using a linear mixed model. Participants were treated as random effect nested within the order of wearing shoes, and the effect of shoes was estimated when corrected for the order of wearing shoes and for period effects. Type III tests were used to determine the effects of shoe, order of shoe and period. An α level <0.05 was taken as significant. All analyses were conducted using SPSS software (version 20). Two plots were created by MatLab™ software (R2012a) to visualize the individual values of RE when wearing the rocker shoe and the percentage difference to the other two shoe types (Fig. 2).

3. Results

Characteristics of the sixteen participants were as follows (mean ± SD): age = 23.6 ± 3 years, height = 171.5 ± 6 cm, weight = 61.7 ± 7 kg and self-reported 10-km race time = 49.6 ± 5.8 min. Type III tests revealed no shoe order for any of the response variables (VO2, p = 0.91; RER, p = 0.38; HR, p = 0.96; RPE, p = 0.11). Compared with rocker shoes, VO2 was significantly lower during running with standard (p < 0.001) and minimalist shoes (p < 0.001). There was no significant difference between VO2 of minimalist shoe compared with the standard shoe (p = 0.186). No significant differences were found concerning in RER, HR, and rate of perceived exertion across three shoe conditions. The mean values with their 95% confidence intervals for the outcome measures were determined with the linear model and they are provided in Table 1. This table also contains the p-values for the comparisons between shoes. The individual differences in VO2 between the rocker shoes and the other two shoes, expressed in percentages, are provided in Fig. 2.

4. Discussion

The current study is the first that has evaluated RE for a rocker shoe design in comparison with other running shoes. Running with rocker shoes caused a significant increase in VO2 compared with the standard shoe (on average 4.5%). In this study the rocker shoe was modified by adding a stiffened rocker profile to the forefoot region of the standard shoe. The added rocker profile not only changed the structure of the rocker shoe, which could potentially have affected the running mechanics, but also led to a shoe mass difference of 317 g (on average) compared with the standard shoe.

Previous studies have shown that adding 100 g mass to the shoes/feet would result in approximately 1% increase in VO2.17–19 Thus, based on the extra shoe mass, an average increase of 3.1% in VO2 was expected while running with the rocker shoe in comparison with the standard shoe. Our findings, however, showed an average increase of 4.5% in VO2. This result supports the hypothesis that factors other than the shoe mass might play a role in RE.11 The participants in the current study were not experienced in running with rocker bottom shoes. This factor might have led to higher energy expenditure during running with the rocker shoe. Moreover, rocker shoes have different biomechanical characteristics than the standard shoes. In the only biomechanical study on rocker shoes in running,4 Boyer and Andriacchi reported that the MBTM rocker shoe could substantially change the lower extremity kinetics and kinematics especially in the ankle region. Considering the common features between our rocker shoe design and the MBTM shoe in above mentioned study (e.g. the rocker component in the forefoot region), similar changes in running biomechanics could be expected and might have negatively affected the running energetic with the rocker shoe. In addition, the correlation between RE and some spatiotemporal variables such as stride length and stride frequency has been previously reported.20,21 These variables could have been influenced by the rocker shoe, leading to more energy consumption while running with this shoe. The present study was not aimed however, to assess the mechanisms underlying these differences, but rather to provide initial insight into physiological characteristics when running with a rocker shoe design. Further studies are warranted to systematically assess the effects of aforementioned factors on RE when using rocker shoes. In brief, running with the rocker shoes caused higher energy expenditure compared with standard running shoes. While this effect is not desirable for the competitive runners, it might have values in physical fitness and body weight management programs.

The other shoe condition which was compared with our rocker shoe was the minimalist shoe which is gaining popularity in runners. By simulating barefoot running, lightweight minimalist shoes are presumed to prevent running injuries and also reduce energy expenditure during running.9,11,12 However, little information is still available on RE with this type of shoe. In this study running with the minimalist shoe was more economic, and required on average 5.6% less VO2 compared with the rocker shoe. As mentioned before, every 100 g extra shoe mass results in 1% increase in energy cost. Considering the fact that rocker shoes were on average 537 g heavier than minimalist shoe, an increase of 5.6% in VO2 can be explained by the difference in shoe mass. However, the rocker shoe was considerably different in design from minimalist shoes...
Significant The In Squadron our while standard in HR, study were observed with foot/minimalist. It was interesting in future studies to compare RE while two shoe conditions are matched for weight as it was done in walking. In addition, some biomechanical comparison studies can provide more information about differences or similarities when running with these shoes. Our experiment gave us the opportunity to compare RE when running with minimalist and standard shoes. The results showed that although not significant, running with minimalist shoes was 1.1% more economic than running with standard shoes. Squadrone and Gallozi reported 2.8% improvement in RE for minimalist shoes compared with standard shoes in a group of barefoot runners. In a recent study after controlling the shoe mass, strike type, and strike frequency, running with minimalist shoes reported to be on average 2.4–3.2% more economic than running with standard shoes. The observed difference in our study was smaller than what was previously reported. One explanation can be the difference in the population examined. In our study we recruited runners who were not experienced in barefoot/minimalist running, while in previous studies participants were habitually barefoot/minimally runners. Additionally, RE in our study were assessed in female runners at speed of 9 km h⁻¹, while in previous works RE were evaluated mainly in male runners at higher speeds of 10.8 km h⁻¹ and 12 km h⁻¹. Another explanation might rely on different models of minimalist shoe used in study (Merrell™ Pace Glove) and the model previously used (Vibram™ Fivefingers).

In the present study, the mean RER was less than 1 and validated the sub-maximal intensity which is necessary in RE evaluation. Further, the mean rate of perceived exertion was about 11 for all three footwear conditions, which corresponds to “light” intensity on the Borg scale.

It is a limitation of this study that the shoe weight was not controlled for as a potential confounder. Unlike previous research, we were unable to find significant differences between minimalist and standard shoes concerning RE. This study was under-powered to detect small differences between these two shoe conditions.

Our sample included female runners who were inexperienced in running with minimalist and rocker shoes, and therefore, the generalizability of the findings to other populations is limited. Additionally, the findings might only be valid for the shoe designs experimented in this research.

5. Conclusion

In conclusion, the findings showed that running with the studied rocker shoe design is less energy efficient than running with minimalist and standard shoes. Although not totally clear from the findings of this study, it seems that the mass of the rocker shoe is the main contributor to the increased energy consumption during running with this type of shoe. Therefore, to be used by runners, this factor should be considered when fabricating rocker shoes.

Practical implications

- In this study the energy expenditure while running with the rocker shoe was compared with minimalist and standard running shoes.
- More energy expenditure should be expected when running with the rocker shoe (studied in the present research) compared with standard running shoes.
- Running with the studied rocker shoe is less efficient than running with minimalist shoe.

Acknowledgements

No sources of funding were used to assist in the preparation of this article. The authors wish to thank all runners who participated in this study. The authors also would like to thank the staff and graduate students at the Exercise Laboratory in School of Sports Studies, Hanze University of Applied Sciences for their collaboration.

References


