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**The Impact of Running with Minimal Shoes on Physiological Responses and Endurance Performance**

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##### ABSTRACT

**Chatzakis P, Paradisis G, Maridaki M, Zanni E, Zacharogiannis E.** The Impact of Running with Minimal Shoes on Physiological Responses and Endurance Performance. **JEPonline**2016;19(6):40-51. The purpose of this study was to examine the differences between running with minimal running shoes (MRS) and running shod on physiological responses and on endurance performance. Twelve subjects (10 men and 2 women) performed two incremental tests on a treadmill with MRS and shod. A 3,000 m familiarization race using MRS followed. The subjects also performed two 5,000 m race trials on the treadmill running either with MRS or shod. Physiological responses between running shod or with MRS and the 5000 m performance did not differ. It was also found that 5,000 m performance time positively correlated with the time course to attain maximum heart rate during the race trial and negatively correlated with vVO2 max and VT in both footwear conditions (P<0.01). VO2 peak (relative value) and 5,000 m performance time were negatively correlated only when running with MRS (P<0.05). The present study shows that habitually shod runners running with MRS have no profound endurance performance advantages. Future studies with extended MRS familiarization period may be needed for noticeable running endurance performance benefits or changes in physiological responses.

**Key Words**: Barefoot, Running, Performance, Physiology

**INTRODUCTION**

Barefoot running is running either without shoes or in minimalist running shoes (MRS). While running in MRS simulates barefoot running, the primary purpose of MRS is to avoid foot injuries from sharp objects or burns. Biomechanically, it is well known that MRS and barefoot running differ from shod running. Thompson et al. (26) found that barefoot running leads to shorter stride length, which may result in lower ground reaction forces and decreased knee and ankle moments in the sagittal plane. Also, the shorter stride length is followed by a reduced contact time and a higher stride frequency in barefoot running (25). Sinclair (23) found that barefoot and MRS running could result in improved patellofemoral kinetics, but significantly increase the load on the Achilles tendon. Moreover, when running barefoot, where the initial contact is made with the midfoot or the forefoot, there is an increase in proprioceptive feedback due to the direct contact with the ground and internal foot control by the foot muscles (22).

Existing data regarding the physiological responses to MRS or barefoot running compared to shod running are quite inconclusive. Paulson and Braun (16) found that barefoot running is more economical than running with MRS or shod, while other studies (17,25) found that running with MRS is more economical than shod running. Hanson et al. (10) found improved running economy, as well as lower heart rate and Rate of Perceived Exertion (RPE), when running with MRS at 70% vVO2 max (i.e., velocity at VO2 max). Running with MRS may also result in higher vVO2 max and peak treadmill velocity, due to the improved running economy (21). The improvements in running economy may be the result of the reduced mass carried by the runner (3,7). Moore et al. (15) claimed that increased somatosensory feedback during barefoot running may lead to lower oxygen consumption. Habituation may also be an important factor, as a 4-wk familiarization period with MRS results in improved running economy, lower RPE between pre- and post-tests for the MRS condition, and lower heart rate between the MRS and shod conditions at the post-test (27).

In fact, data from a recent meta-analysis supports the notion that MRS and barefoot running have the tendency to be more economical than shod running (4). Other studies (5,8,11,24) indicate that MRS and barefoot running do not have any benefit, either in running economy (RE) or on selected physiological responses. This point is further supported by the work of Pilianidis et al. (18) who reported that in pre-pubertal children there was no difference in 1 km performance between barefoot and shod running. Yet, Leuchanka et al. (14) reported significant improvement in a 5 km race trial with MRS, following a 10-wk familiarization period. Fuller et al. (9) also reported significant performance improvement in 5 km with MRS, as a result of improved RE.

It is clear that more studies are needed to find out whether MRS or barefoot running has significant physiological and/or endurance performance benefits when compared to shod running. The purpose of the study was to examine differences between running with MRS and running shod on physiological responses and on endurance performance. We hypothesized that the 5 km performance will be improved with MRS due to an improved running economy.

###### METHODS

**Subjects**

Twelve (10 men and 2 women) moderately trained subjects (physical education students and recreational runners), 22 to 49 yrs old, participated in this study. The subjects’ mean ± SD for height, body mass, and % body fat were: 1.74 ± 0.09 m, 74.13 ± 8.66 kg, and 18.29 ± 4.19% respectively. The subjects were experienced runners who had participated in at least 5 endurance races of 3 to 20 km during the previous year. They were injury free and were not consuming any medication. All subjects were informed of the purpose of the study and the experimental protocol, and they signed a consent form.

**Procedures**

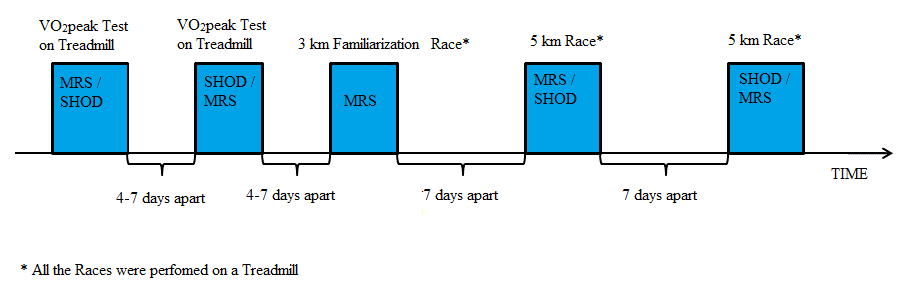
During the first two trials, all subjects performed two incremental tests to exhaustion on a treadmill (with MRS and shod) to evaluate their physiological responses in both footwear conditions. After a brief warm-up, the subjects began the trial from an initial velocity of 8 to 10 km·h-1, depending on their performance level. For RER values<1, the treadmill velocity was increased by 1 km·h-1 every 3 min, and when the RER value exceeded 1, the velocity was increased by 1 km·h-1 every 2 min until exhaustion. Four minutes after the completion of the trial, a blood sample was taken to evaluate the blood lactate concentration. The respiratory data were collected using an automatic gas analyzer connected to a computer (Quark CPET, Cosmed, Italy). Blood lactate concentration was calculated using the Lactate Plus Analyzer (USA). Peak oxygen consumption (VO2 peak), maximum ventilation (VE max), respiratory quotient (RQ), maximum heart rate (HR max), running economy (RE) at 12 km·h-1, oxygen consumption increase per stage (VO2 incr), the blood lactate concentration (La), velocity at peak oxygen consumption (vVO2 max) and velocity at ventilatory threshold (vVT) were recorded for analysis. The exhaustive trials were performed in random order 4 to 7 days apart (Figure 2), depending on the footwear condition.

On Day 3, they completed a 3 km race trial on the treadmill running with MRS to familiarize themselves with the 5 km race performance trial. Always preceding the 3 km race trial was a standard 7 min warm-up followed by stretching exercises. The subjects started the 3 km race trial with a velocity corresponding to their individual 95% vVO2 max (1). During the race effort they were free to increase or decrease the treadmill velocity at will and none of the attendees could influence the subject’s decisions concerning race pace. The subjects were not aware of the elapsed time. They could, however, see their velocity and the distance covered.

During the last two laboratory visits (Figure 2), the subjects completed two 5 km race trials on a treadmill. Standard warm-up and stretching exercises preceded each 5 km race trial. Their initial velocity was defined as the average value of the velocities at 90% vVO2 max of the previous exhaustive tests (1). Each subject was free to increase or decrease the treadmill velocity at will and none of the attendees could influence the subject’s decisions concerning his or her race strategy. The subjects were also unaware of the elapsed time, but they could see the velocity and the distance on the treadmill monitor. RPE was measured immediately after the completion of the trial and blood lactate concentration was measured 4 min post-race. The 5 km races were performed either with MRS or the shod condition, in a random order 7 days apart (refer to Figure 2). During the 5 km race trials, the performance time, the maximum heart rate (HR max), the time course to reach HR max (tHR max), the race strategy, the RPE, and the blood lactate concentration (La) were evaluated. The MRS used in this study are presented in Figure 1.



**Figure 1. Minimalist Running Shoes Freet Tarsa 4+1 Barefoot Running Shoes, UK.**



**Figure 2. Schematic Representation of the Experimental Protocol.**

**Statistical Analyses**

The paired *t*-test was used for the comparison of the physiological responses and the race performance parameters between the two footwear conditions. One-way ANOVA for repeated measures was used to compare the maximum heart rate and the blood lactate concentration in both trials between the two footwear conditions, as well as the average velocity for every kilometer between MRS and shod running. To examine the interaction of tactics and footwear condition, a two-way ANOVA was used. The Pearson’s product moment correlation coefficient was also used. Significance level was determined at P≤0.05 and the analyses were performed by IBM SPSS Statistics 20.

RESULTS

The results, as evaluated during the incremental test to exhaustion on the treadmill (Table 1, Mean ± SD, Figure 3), indicate that there was no significant difference in the subjects’ physiological responses running with MRS or shod.

**Table 1. Physiological Responses during the Incremental Test to Exhaustion.**

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | SHOD | MRS | Sig (2-tailed) |
| VO2 peak (mL·kg-1·min-1) | 54.04 ± 4.44 | 54.68 ± 3.74 | 0.532 |
| RE (mL·kg-1·min-1 @ 12 km·h-1) | 47.87 ± 3.26 | 47.63 ± 2.49 | 0.786 |
| VO2 incr (mL·kg-1·min-1) | 3.45 ± 0.53 | 3.48 ± 0.51 | 0.886 |
| VE max (L·min-1) | 122.99 ± 22.61 | 122.56 ± 19.58 | 0.870 |
| RQ | 1.11 ± 0.05 | 1.09 ± 0.06 | 0.236 |
| HR max (beats·min-1) | 184 ± 7 | 183 ± 9 | 0.699 |
| La (mmol·L-1) | 11.3 ± 5.5 | 9.4 ± 1.8 | 0.282 |
| vVO2 max (km·h-1) | 14.18 ± 1.23 | 14.38 ± 1.37 | 0.273 |
| vVT (km·h-1) | 10.46 ± 1.08 | 10.54 ± 0.99 | 0.438 |

**B**

**A**

**Figure 3. Comparison between MRS and Shod Running for VT: (A) RE at 12 km·h-1; (B) vVO2 max; (C) and VO2 peak (D)** (P>0.05).

**D**

**C**

The race performance parameters were not different between the two footwear conditions (Table 2, Mean ± SD). The time needed to cover the 5 km distance (Figure 4), the race strategy (Table 3, Mean ± SD) and the 1-km splits (Figure 5) were not different between running with MRS and shod.

**Table 2. 5 km Race Performance Parameters When Running with MRS or Shod**.

|  |  |  |  |
| --- | --- | --- | --- |
| PARAMETER | SHOD | MRS | Sig (2-tailed) |
| 5 km Time (sec) | 1458 ± 141 | 1446 ± 139 | 0.225 |
| HRmax (beats·min-1) | 182 ± 9 | 182 ± 11 | 0.408 |
| tHRmax (min) | 22.17 ± 2.26 | 22.58 ± 2.04 | 0.418 |
| La (mmol·L-1) | 8.4 ± 2.9 | 8.4 ± 4.2 | 0.994 |
| RPE | 17.17 ± 1.59 | 17 ± 1.76 | 0.674 |

**Figure 4. 5 km Performance When Running with MRS or Shod** (P>0.05).

**Table 3. 5 km Race Tactics.**

|  |  |  |  |
| --- | --- | --- | --- |
| PARAMETER | SHOD | MRS | Sig (2-tailed) |
| % Overall time for the 1st Half of the 5 km race | 49.98 ± 1.1 | 50.12 ± 1.43 | 0.694 |
| % Overall time for the 2nd Half of the 5 km race | 50.02 ± 1.1 | 49.88 ± 1.43 | 0.694 |
| Sig (2-tailed) | 0.959 | 0.783 |  |

Figure 5. Schematic Illustration of 1 km Splits during the 5 km Race with MRS and Shod Running.

Furthermore, during the 5 km trials the subject attained similar HR max values compared to the corresponding HR max values during the incremental test to exhaustion. Post-exercise blood lactate concentration was also similar to incremental exhaustive tests and 5 km race trials.

The time needed (Table 4) to cover the 5 km distance is positively correlated (r = 0.79 - 0.87, P<0.01) with the time course to reach maximum heart rate during the race trials and negatively correlated (r = -0.89) with vVO2 max and vVT (r = -0.87, P<0.01). VO2 peak was correlated with 5 km performance time (P<0.05) only when running with MRS (Table 4).

**Table 4. Correlation Matrix of Cardiorespiratory and Race Parameters and 5,000 m Performance Time.**

|  |  |  |
| --- | --- | --- |
| PARAMETER | 5,000 m TIME (SHOD) | 5,000 m TIME (MRS) |
| VO2 peak (mL·kg-1·min-1) | -0.504 | -0.692\* |
| RE (mL·kg-1·min-1 @ 12 km·h-1) | 0.393 | 0.536 |
| VO2 incr (mL·kg-1·min-1) | 0.190 | 0.551 |
| VE max (L·min-1) | -0.172 | -0.496 |
| RQ | 0.077 | -0.103 |
| HR max (beats·min-1) | -0.048 | -0.145 |
| La (mmol·L-1) | -0.538 | 0.258 |
| vVO2 max (km·h-1) | -0.888\*\* | -0.896\*\* |
| vVT (km·h-1) | -0.863\*\* | -0.874\*\* |
| HR max in 5,000 m race (beats·min-1) | 0.116 | -0.175 |
| tHR max in 5,000 m race (min) | 0.791\*\* | 0.873\*\* |
| La in 5,000 m race (mmol.L-1) | -0.094 | -0.211 |
| RPE in 5,000 m race | -0.193 | 0.170 |

\*P<0.05 \*\*P<0.01

DISCUSSION

The purpose of this study was to examine the impact of MRS on the physiological responses and performance parameters and compare it to shod running.

**Physiological Responses**

The results of the present study, which showed that VO2 peak values between MRS and shod running are comparable, agree with the existing literature (14,21). As expected, VE max and RQ values were not different between the footwear conditions. Jones (11) reported that MRS and shod running have similar VE when running at the same gradient and Leuchanka et al. (14) did not find any alterations in VE max after a 10-wk familiarization period. Also, Paulson and Braun (16) observed similar values for VE max and RQ between shod and barefoot running. Sobhani et al. (24) and Franz et al. (8) reported the same findings with the present study, concerning the RQ.

The footwear type had no impact on RE at 12 km·h-1, although the hypothesis was that MRS may be more economical than shod running. This is in agreement with a number of studies (5,8,11,16,24) even though other studies have reported the opposite (4,10,17,21,25). It is possible that the lack of significance in RE is caused by the fact that the subjects were habitually shod runners. As Warne and Warrington (27) state, a familiarization period can have a great impact on RE. Furthermore, since there was no difference in RE, it was expected that a difference in the mean oxygen consumption increase per stage between the two footwear conditions would not be found.

Regarding the vVO2 max, unlike the study of Reeves et al. (21), there was no difference between MRS and shod running. Reeves and colleagues (21) claim that the improved vVO2 max in their study is a result of improved RE, which is not applicable in the present study, as no difference in RE was found. To our knowledge, this study is the first that examined the effect of MRS running on VT. We did not find any difference between the two conditions, which was expected since there were no differences between the respiratory parameters used to determine the ventilatory threshold.

There was no difference between the HR max and La. Most of the studies are in agreement with this finding (11,14,16,24,25), except for the study by Hanson et al. (10). They reported that MRS resulted in a lower HR response compared to shod running at the same intensity, which is in agreement with Warne and Warrington (27). They, too, indicate that HR is lower when running with MRS, that is, after a 4-wk familiarization. There are no data found concerning the blood lactate concentration in the literature. The fact that there was no difference in La between the two conditions can be explained by the fact that there was also no difference in vVT and the subjects made the same maximum effort in both trials.

**Endurance Performance**

The major finding of this study was that MRS and shod footwear had no significant impact on the subjects’ performance time of the 5 km race trial. Pilianidis et al. (18) reported similar findings after a 1 km field race trial in pre-pubertal children. More recently Leuchanka et al. (14), as well as Fuller et al. (9), reported improved performance in a 5 km race trial. Leuchanka et al. (14) used a 10-wk familiarization period, which possibly leads to improved running performance with MRS. On the other hand, Fuller et al. (9) reported that improved performance was also followed by improved RE, through reduced shoe mass and a change in running pattern with MRS, which was not found in the present study. Despite the lack of significance in the present study, there was a tendency for better performance when running with MRS, given that the average 5 km time was faster by 12 secs in comparison with shod running. As the literature shows, familiarization is a very important factor and the fact is a longer familiarization period may result in significant running performance benefits.

It is also shown that the subjects followed the same pacing strategies during the two 5 km races. The % of overall time needed to cover the 1st half of the race was similar with the % of overall time needed to cover the 2nd half of the race. The 1 km splits were also comparable between the two conditions. The study of Leuchanka and colleagues (14), however, reported significantly faster times during the last mile of the 5 km race trial following the familiarization period with MRS.

The lack of significant difference in RPE between the two conditions is in agreement with most of the studies (11,16,21,24). The HR max values were also similar between the 5 km races trials, with Leuchanka et al. (14) arriving at a similar conclusion. The similarity of the race strategy that was adopted during both race trials may explain the identical HR response, RPE, and lactate concentration.

**Correlations**

Another major finding of the present study was that the 5 km performance time was positively correlated with the time course to reach maximum heart rate during the race trial. According to the literature, subjects with higher VO2 peak values (higher training level) also attain faster kinetics of the HR response (2). This can lead to an improved endurance performance, since faster HR kinetics at the beginning of an exercise bout are related to improved O2 kinetics and, thus the O2 steady state is more rapidly achieved (12). The 5 km performance time was negatively correlated with vVO2 max and VT in both footwear conditions. The VO2 peak value in this study seems to have significantly lower predictive ability on 5 km performance time compared to vVO2 max, VT, and tHR max. These results are in accordance with the results of other studies (6,13,19) that claim VT and vVO2 max have a strong correlation with endurance running performance.

### **CONCLUSIONS**

The major findings of this study are that there are no significant differences both in the physiological responses of habitually shod runners whether running shod or with MRS, and in the 5 km performance time of shod or with MRS runners. However, despite the lack of significance, there was a tendency for better performance in the MRS condition. Future studies with extended familiarization period with MRS may be needed to show significant endurance running performance benefits.

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