



## EVALUATION OF BAREFOOT RUNNING IN PREADOLESCENT ATHLETES

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## ABSTRACT

**Purpose.** The literature shows few studies on shod and unshod running performance in athletes, with most limited to laboratory settings. The aim of this study was to evaluate preadolescent 1000 m running performance when barefoot and in running spikes or training shoes. **Methods.** A sample of 22 boys and 21 girls aged  $10.6 \pm 1.1$  years was recruited. Anthropometric data and  $VO_{2max}$  were recorded when completing the three study protocols in a counter balanced design. Student's t tests were applied to compare mean 1000 m finish times while ANOVA was used to evaluate sex differences between the protocols. Pearson's correlation analysis measured interactions between the finish times, anthropometric variables, and  $VO_{2max}$ . **Results.** Running performance with spikes (4.58 min) was significantly better than with training shoes (5.21 min) and barefoot (5.18 min). Male 1000 m times were overall better than the females. A substantial effect of  $VO_{2max}$  and body fat on performance was found in all protocols. **Conclusions.** Preadolescent endurance performance was not significantly different between training shoes and barefoot; this may serve as an incentive for future research on the training of developmental age runners.

**Key words:** efficiency, running events, adolescence, performance

## Introduction

Although humans have been running for millions of years, the concept of the modern running shoe did not take form until the 1970s. During the largest part of human evolutionary history, runners were either barefoot or wore minimal footwear such as sandals or moccasins with low heels and little cushioning [1]. In the last 40 years, sports scientists have focused on evaluating the running stride characteristics of athletes wearing training or competition shoes and barefoot [2]. Laboratory studies have shown that the energy cost of running is reduced by approximately 4% when the feet are not shod. In spite of these apparent benefits, barefoot running is rare in competition and there are no published controlled trials concerning the effects of running barefoot on simulated or real competitive performance.

Some authors have stressed that the interaction between the shoe and surface is important, with this aspect now well accepted [3]. In running events, it was reported that training foot wear should be considered more as a protective device (from dangerous objects or painful impacts) than a corrective device, as their capacity for shock absorption and control of over-pronation is limited [4]. Modern running footwear is credited with generally reducing sensory feedback without diminishing injury-induced impact, leading to what has been described as a “perceptual illusion” of athletic footwear safety [5]. Other studies on oxygen consumption found that running at 12 km/h in shoes weighing

700 g showed 4.7% higher values than in bare feet. While an increase in oxygen consumption of ~4% is of little importance to the recreational runner, the competitive athlete would notice a major effect on running speed [6].

In the majority of endurance athletes who train with shoes, foot strike occurs with the heel whereas during barefoot running the foot first makes contact with the ball of the foot and ends with the heel [7]. Barefoot running may induce an adaptation that transfers impacts to the yielding musculature, thus sparing the fascia and accounting for the low incidence of plantar fasciitis in barefoot runners [8]. When running barefoot on hard surfaces, one study found runners compensate for the lack of cushioning underfoot by plantar flexing the foot at contact, thus providing a softer landing [9]. Barefoot runners may also land midfoot, increasing the work of the foot's soft tissue support structures and thereby increasing their strength and possibly reducing the risk of injury [10].

A great part of foot wear manufacturers' technology is devoted to designing preadolescent and adolescent training and competitive shoes [11]. Contemporary athletic shoes appear to attenuate loading since long-axis tibial acceleration was found to be reduced during shod running in children [12]. In addition, in preadolescent and adolescent athletes, those running shod were recorded with an increase in the prevalence of a rear foot strike pattern from 62% when barefoot to 97% when wearing training shoes [13]. Furthermore, it was recently presented that slimmer and more flexible children's shoes do not change foot motion as much as conventional shoes and could therefore be generally recommended for children [14].

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Interestingly, the majority of today's world-class middle- and long-distance runners who originated from East Africa were trained barefoot during their developmental age. However, very limited studies have evaluated shod and unshod running performance in preadolescent runners and those available were implemented only in laboratory conditions [15, 16]. Due to the fact that training with spikes is also widely used in running events, the aim of the present study was to evaluate 1000 m running times in a sample of preadolescent boys and girls while wearing training shoes, running shoes with spikes, and while barefoot.

### Material and methods

A total of 43 preadolescents aged  $10.6 \pm 1.1$  years were recruited from three local athletics clubs. The sample consisted of 22 boys and 21 girls with  $1.5 \pm 1$  years of athletics experience, exercising at least four times per week. None of the participants had any previous barefoot running experience. Written informed consent was obtained after the experimental protocol was fully explained to each participant although the true purpose of the study was not revealed. Parents or guardians were also informed about the study and provided their written informed consent. The study was performed according to the guidelines of the Ethics Committee of the Democritus University of Thrace in Greece.

Upon reporting to the laboratory, the participants received verbal information as to the testing procedures. Age, training experience, body mass and height, body fat, thigh and calf circumferences, and foot length were recorded and  $VO_{2max}$  was estimated. Participants were required to complete three trials of running 1000 m wearing training shoes, spikes, and barefoot. The task order was counterbalanced and each trial was separated with 72 hours rest. Participants were instructed to complete the 1000 m runs as fast as they could. Testing was conducted during the competitive season on the same 400 m synthetic surface (16 mm thick rubber) track the participants practiced on. Testing protocols were completed at the same time of day in identical testing conditions with ambient temperatures ranging from  $22^\circ$  to  $25^\circ\text{C}$ . Prior to the 1000 m runs, the athletes performed a standardized warm-up which included 20 min of jogging, stretching and dynamic exercises for the lower limbs, and  $6 \times 50$ –100 m runs.

Running times were recorded electronically with a Performance Pack (model 63520, Lafayette, USA) with the use of two pairs of 63501 Infrared photocell switches of the same manufacturer placed at the starting line and at the 1000m finish line. Time was measured according to the current procedures for international competitions.  $VO_{2max}$  was estimated with the Multistage 20 m Shuttle-Run Aerobic Test (MSRAT<sub>20m</sub>) and involved a portable CD player, a CD supplied with a booklet, measuring tape, and marker cones [17, 18]. Subcutaneous fat was

measured with a Harpenden Skin fold caliper (Baty International, UK), on the right side of the body. Body fat was determined from the sum of two skin fold thicknesses to the nearest 1 mm. Body mass was measured to the nearest 100 g on a calibrated floor scale (model 770, Seca, Germany) while standing shoeless with arms relaxed and wearing only light sportswear. Height was measured while barefoot with a stadiometer (model 240, Seca, Germany) to the nearest 0.1 cm with the head in Frankfurt horizontal plane.

Basic descriptive statistics were calculated for all variables. Scatter plots were used to determine whether a linear model was suitable for analyzing running performance in the three protocol conditions. One-sample Student's *t* tests were applied to compare mean finish 1000 m times when running with training shoes, spikes, and barefoot. One-way analysis of variance in a  $2 \times 3$  design with post-hoc Bonferroni corrections was employed to evaluate the differences among 1000 m finish times in all study protocols depending on sex. In addition, Receiver Operating Characteristic (ROC) curves were utilized in order to illustrate the discrimination between 1000 m times with training shoes, spikes, and barefoot relative to sex. Pearson's correlation coefficients were calculated to measure the linearity of the interactions between the variables: finish time, anthropometry (height, body mass, body fat, lower limb circumferences, foot length), and  $VO_{2max}$ . All statistical analyses were performed with PASW Statistics 18 (SPSS, USA). Statistical significance was defined at 5% ( $p < 0.05$ ).

### Results

The physical and physiological characteristics of the sample are presented in Table 1. Student's *t* tests showed that the preadolescent runners showed significantly better finish times in the 1000 m with the running spikes ( $4.58 \pm 0.7$  min) than with training shoes ( $5.21 \pm 0.7$  min) and barefoot ( $5.18 \pm 0.8$  min);  $t(1.42) = 44.51$ ,  $p = 0.001$ . ANOVA showed no significant differences for sex among all study protocols. In spite of the fact that the males' mean performance with spikes ( $4.46 \pm 0.4$  min) was better than with training shoes ( $5.15 \pm 0.3$  min) and barefoot ( $5.05 \pm 0.5$  min), ANOVA did not confirm any statistically significant differences;  $F(1.21) = 1.19$ ,  $p = 0.28$ . Similarly, the females showed no significant differences between training shoe (5.29 min), spike (5.09 min), and barefoot (5.30 min) finish times;  $F(1.22) = 1.25$ ,  $p = 0.27$ . Post-hoc Bonferroni comparisons showed that only the finish time of males with spikes (4.46 min) was significantly better than the female group's times with training shoes (5.29 min) and barefoot (5.30 min).

ROC curves classifying the parameters of the three study protocols in the male group showed that they did not coincide with the reference no-discrimination line, precluding selection bias. The area under the curve (AUC) showed more true positives running with training shoes

Table 1. Mean (95% CI) physical and physiological characteristics of study participants

Variables	Males	Females
Age (years)	10.6 (10.1–11.1)	10.7 (10.2–11.1)
Body mass (kg)	36.7 (32.7–40.7)	41 (36–45.9)
Height (cm)	144 (139–149)	148 (143–153)
Body fat (%)	15.5 (13.4–17.7)	21.4 (18.3–24)
Thigh circumference (cm)	39.2 (37.7–40.8)	42.8 (40.3–45.4)
Calf circumference (cm)	28.7 (27.7–29.8)	30.8 (29.2–32.3)
Foot length (cm)	21.6 (20.7–22.4)	22 (21.4–22.7)
VO <sub>2max</sub> (ml/kg/min)	36.8 (34.4–39.3)	34.5 (32.9–3.2)

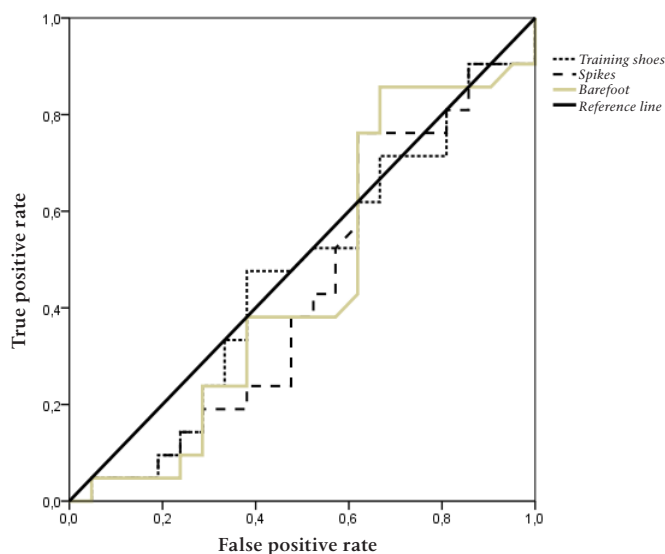


Figure 1. ROC curve intercept for boys 1000 m running performance with training shoes, spikes and barefoot

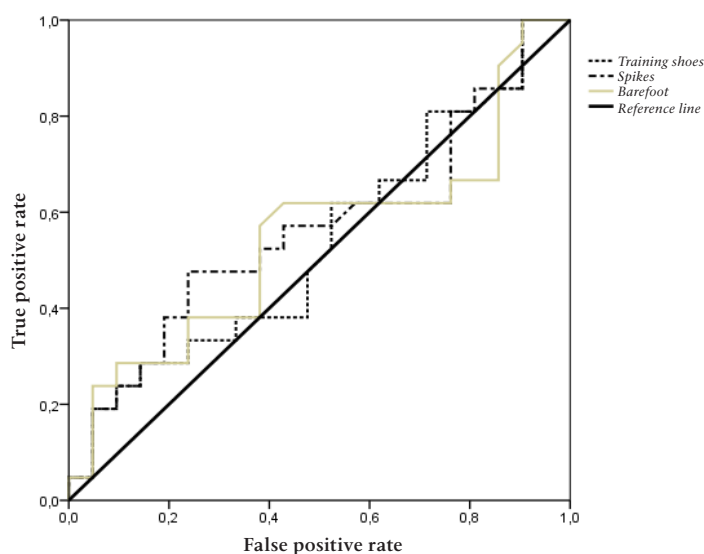


Figure 2. ROC curve intercept for girls 1000 m running performance with training shoes, spikes and barefoot

(0.46,  $p = 0.69$ ) than when barefoot (0.45,  $p = 0.60$ ) or with spikes (0.44,  $p = 0.48$ ). Similar to the above, binary classifier analysis illustrated that the testing protocols in females did not coincide with the discrimination threshold, also indicating a lack of bias. The AUC indicated stronger evidence for an actual positive state in females' running performance with spikes (0.56,  $p = 0.48$ ) compared with barefoot (0.54,  $p = 0.61$ ) or training shoes (0.53,  $p = 0.69$ ). Evaluation of the testing protocols by applying ROC analysis for sex is illustrated in Figures 1 and 2.

Pearson's correlation analysis showed significant intercorrelations only among finish time, VO<sub>2max</sub>, and body fat in all study protocols. The correlation between running performance with training shoes and VO<sub>2max</sub> was as high as 0.73 ( $p < 0.001$ ), while the correlation between running performance with training shoes and body fat percentage was found to be average (0.45,  $p < 0.05$ ). Furthermore, Pearson's  $r$  values between barefoot performance and VO<sub>2max</sub> were found to be high ( $-0.63$ ,  $p < 0.001$ ), while the correlation between body fat percentage and barefoot performance was average (0.46,  $p < 0.05$ ). Similarly, the obtained values in-

dicated significant correlations between running performance with spikes and lean body mass (0.45,  $p < 0.05$ ) as well as between VO<sub>2max</sub> and running performance with spikes ( $-0.65$ ,  $p < 0.05$ ). The correlation coefficients for the shod and unshod conditions and between the physical and physiological parameters are presented in Table 2.

**Discussion**

For modern humans who have grown up wearing shoes, barefoot locomotion is difficult to become accustomed to. Currently, no field studies are available evaluating competitive barefoot running performance in children and adolescents. The present study revealed that barefoot performance in the 1000 m was marginally better than finish times recorded with training shoes, which are widely used by preadolescents for running. In addition, an improvement in running performance was recorded in both males and females when they ran barefoot when comparing the times recorded with training shoes (5.18 min vs. 5.20 min). This finding is in accordance with recent studies indicating that shod

Table 2. Linearity evaluation (Pearson's correlation coefficients) of 1000 m running performances with training shoes, spikes and barefoot with physical and physiological parameters

Variables	<i>r</i>	<i>p</i>
Training shoes performance		
Body mass	0.03	0.87
Body height	-0.30	0.06
Body fat	0.45	0.03*
Thigh circumference	0.17	0.28
Calf circumference	0.06	0.72
Foot length	-0.30	0.06
VO <sub>2max</sub>	-0.73	0.001**
Barefoot performance		
Body mass	0.17	0.29
Body height	-0.18	0.26
Body fat	0.46	0.002*
Thigh circumference	-0.23	0.15
Calf circumference	0.16	0.32
Foot length	0.20	0.21
VO <sub>2max</sub>	-0.63	0.001**
Spikes performance		
Body mass	0.08	0.63
Body height	-0.28	0.08
Body fat	0.45	0.05*
Thigh circumference	0.17	0.27
Calf circumference	0.12	0.52
Foot length	-0.30	0.06
VO <sub>2max</sub>	-0.65	0.001**

\*  $p < 0.05$ , \*\*  $p < 0.001$

and unshod performance do not significantly differing preadolescent runners [7, 19].

Moreover, regarding running speed in the 1000 m, the present preadolescents performed better when they wore running spikes (3.33 m/s) that in the other conditions of barefoot (3.16 m/s) and training shoes (3.12 m/s). A possible explanation for improved running speed may be due to modified foot mechanics during the landing phase. Thus, instead of landing on the heel as is usual in training shoes during a running stride, the participants improved running pace by contacting the track with the ball of the foot, activating the calf and foot muscles [20, 21].

Furthermore, the findings of this study were similar to those reported in the literature, where running performance in training shoes was worse than when barefoot. One possible reason may be due to the energy cost associated with shod running. Oxygen consumption at 12 km/h is 4.7% higher when wearing training shoes weighing 700 g [6]. Training footwear is also believed to compromise the ability of the lower limb to act like a spring. With bare feet, the limb returns ~70% of stored energy stored but with shoes the return was found to

be considerably less [10]. One obvious explanation for the increased energy cost of running with training shoes is the continual acceleration and deceleration of foot wear in each stride [22]. Another possibility for the above finding is that the external work in compressing, flexing and rotating the sole against the ground accounts for a maximum 13% of the work done in running [23].

Among the runners who participated in the present study, the females were reported with greater height, body mass, body fat, and thigh and calf girth values than the males. In contrast, male VO<sub>2max</sub> was slightly better than among the females. Regardless of gender, higher VO<sub>2max</sub> and greater lean body mass strongly correlated with 1000 m running performance in all study protocols. Thus, males with higher VO<sub>2max</sub> and lower body fat performed better than the females not only with training shoes (5.15 min vs. 5.29 min) but also when comparing barefoot running (5.05 min vs. 5.30 min) and when wearing spikes (4.46 min vs. 5.09 min). The results of the present study confirm that high aerobic capacity and low body fat percentage positively affect endurance running performance in preadolescents [24, 25].

## Conclusions

In summary, the present results lead to the conclusion that barefoot running performance in the 1000 m was marginally better than with training shoes, which are widely used by preadolescents for running purposes. As there is a lack of scientific evidence supporting barefoot running, this study's findings can be valuable for coaches designing longitudinal training plans. Due to the nature of running events, future research is needed to further evaluate if barefoot training during the developmental age could offer a significant competitive advantage in future world-class endurance runners.

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