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The Effect of a Barefoot Running Training Program on Running Economy and Performance

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By

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Acknowledgements

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Review of the Literature

Although barefoot (BF) running has recently become quite popular, this mode of exercise has been practiced for centuries amongst our ancestors. According to Lieberman *et al.* (7), the mass production of the modern running shoe was not until the 1970s. The development of this modern shoe included cushioning and stability features to offset the collision forces associated with the typical rear foot landing patterns that many endurance runners exhibited. However, prior to 1970, running shoes had little cushioning or stability features and endurance runners were more often described as mid- or fore-foot strikers.

Although endurance runners prior to 1970 wore running shoes with little cushioning and stability features, they were still capable of incredible physical feats. This is clearly portrayed in Krentz's book, *The Battle of Marathon* (2010), in which Pheidippides, a professional Greek distance runner, famous for his twenty-five mile journey from Marathon to Athens, logged nearly one-hundred and seventy-five barefoot miles in less than three days. Furthermore, many past and present elite distance runners located throughout Ethiopia, Kenya, Great Britain, South Africa, and India have experienced incredible success, training and racing BF. The most notable of these athletes is perhaps the great Ethiopian distance runner, Abebe Bikila, who captured the Olympic gold medal in the marathon at the Rome Olympic Games in 1960. Although Christopher McDougall's historical and inspirational book, *Born to Run* (2009), has heightened the public's awareness of shoe manufacturing, running technique, and performance, it is imperative that one understands the physical demands associated not only with BF running and SBR, but shod running as well.

Four years after his meeting with renowned distance running coach, Arthur Lydiard, legendary track coach, Bill Bowerman, published the book, *Jogging* (1966), which revolutionized the American approach to distance running. Following the book's publication, Americans gradually transitioned to shoes with more heel support and cushioning, in order to accommodate for the supposed heightened heel stress associated with rear-foot landing mechanics. Even though this shoe modification appeared to make sense logically, it failed to account for the resulting biomechanical alterations brought on by this additional heel support and cushioning.

According to Kerrigan *et al.* (5), who studied the effect of running shoes on lower extremity joint torques, they discovered that when shod individuals ran BF and shod at a controlled speed, the runners presented with heightened hip, knee, and ankle torques when running in shoes. More specifically, these subjects exhibited greater hip internal rotation, knee flexion, and knee varus torques while running in shoes compared to BF. Furthermore, a study published by Richards, Magin, and Callister (11), which challenged the available evidence supporting cushioned heel and pronation control running shoes, ultimately discovered that no mechanical evidence existed to support the need for such a shoe. Even more interesting was the conclusion on behalf of McCaw, Heil, and Hamill (8), which focused on the correlation between perceived shoe cushioning and ground reaction forces. Although the subjects walked in three shoes of varying levels of cushioning, the shoes perceived to provide the most support were often associated with elevated force readings. Even though this was valuable information, it must be carefully interpreted as force readings and human mechanics differ as the velocity of movement increases.

Regardless of the previous shod studies, only limited research has been conducted to study the potential benefits of BF running. Squadrone and Gallozzi (12) found that in a group of eight proficient BF runners, stride frequency, ground contact, stride length, oxygen uptake (VO_2) values, and foot mechanics were largely dependent on whether the subjects wore shoes or not, or if they wore minimalist footwear such as the Vibram FiveFingers (Figure 1).

Figure 1. The Vibram FiveFingers™ minimalist shoe.

Through the utilization of an instrumented treadmill, BF and the wearing of minimalist running shoes clearly demonstrated improved stride frequency, limited ground contact, reduced stride length, lower VO_2 values, and improved mechanics of the foot (12). The authors stated that impact forces were reduced and that this reduction was due to runners landing on their forefoot or midfoot as well as the elimination of shod features such as heel support, cushioning, and motion control. This study clearly showed that running BF or in minimalist shoes resulted in improved proprioception and proper mechanics, which in turn enhanced RE and performance.

According to Morgan, Martin, and Krahenbuhl (10), RE is known as the steady-state VO_2 for a given running velocity. These authors stated that many factors impact RE (i.e., physiological, environmental, structural, and/or mechanical factors), and more recently, several studies have demonstrated that BF running and training may play an instrumental role in developing more economical runners. For instance, Hanson *et al.*

(4), found that when experienced and non-experienced BF runners ran BF, heart rate and rate of perceived exertion were significantly lower than when running in shoes. The subjects also reported that when instructed to run BF at a pace simulating seventy percent of their VO_{2max}, it felt easier to maintain as opposed to wearing their normal training shoes. This implies that when running BF, more oxygen was being utilized in order to maintain pace, rather than being wasted in an effort to accommodate for low muscular strength and inefficient biomechanics. Hanson *et al.* believe these findings were due in large part to reduced weight (i.e., shoes) on the feet as well as enabling the arch of the foot to function appropriately (i.e., spring-mass model).

In spite of the positive results discovered by Hanson *et al.*, a designed training program teaching the subjects how to run BF, would have been appropriate. Since sixty percent of the subjects had limited experience running BF and the researchers did very little to prepare the participants in terms of BF training, it was not surprising that these same individuals were complaining of foot and lower leg soreness. Although discomfort is common following exercise of increased intensity or volume, attempting to run BF with no training after spending years in typical running shoes, is often a recipe for an increase in injury rates.

According to Lieberman *et al.,* people who run in shoes are often rear foot strikers. Due to the mechanics of the foot, impact forces are distributed over the surface area of the heel, as opposed to the whole foot when mid- or forefoot striking. When attempting to run BF without a systematic training regimen, the years spent in a traditional running shoe have not only significantly de-conditioned the musculature of the foot, but have also limited the runner's ability to properly distribute impact forces due to reduced proprioception. Furthermore, a study conducted by Bramble and Lieberman (3), which researched the relationship between endurance running and the development of Homo sapiens, concluded that the ankle joint has an incredible ability to store elastic energy on behalf of the extensor muscle-tendons. Therefore, when individuals attempt to run BF without properly programming their body to handle the ensuing stress, they will be incapable of training consistently due to the increased susceptibility to injuries.

Regardless of the fact that Hanson *et al.* failed to implement a training program, teaching the subjects how to run BF, Warne and Warrington (13) recently explored the effects of exposing experienced runners to simulated barefoot running (SBR). Similar to the study conducted by Squadrone and Gallozzi, the subjects were instructed to utilize minimalist footwear such as the Vibram FiveFingers (Figure 1).

Prior to initiating a four-week habituation to SBR, the subjects completed two RE tests, which were separated by twenty-four hours. During the assessments, the runners wore regular running shoes and SBR shoes and data were recorded for oxygen uptake, heart rate, stride frequency, and foot strike patterns.

Following a four-week program to learn to run in minimalist footwear, the subjects were re-tested for RE and the previously listed variables. Even though these individuals were trained shoe runners, the four-week retests demonstrated improvements in RE during SBR, but not shod running.

Regardless of the findings presented by Warne and Warrington, it is important to remember that BF running requires no support or protection between one's sole and the ground surface. With this in mind, Bonacci and colleagues (1) performed a study, which compared running mechanics pertaining to BF running, SBR, and shod running in trained runners.

In regards to the data concerning ground reaction forces and kinematics, the authors discovered that when the subjects ran BF overground, they demonstrated reduced midstance knee flexion, knee extension, abduction, negative work at the knee, and dorsiflexion upon ground contact. Lastly, the researchers also determined that BF running presented with improved peak power and positive work at the ankle joint.

Since Bonacci *et al.* failed to unravel similar ground reaction force and kinetic advantages on behalf of SBR and shod running, they were capable of concluding that SBR running was not the same as BF running, despite significant reductions in shoe stability, cushioning, protection, and weight.

Although the previously mentioned studies have progressed in terms of specificity many questions regarding BF running remain unanswered. Despite the fact that the most recent studies have aided in the discovery of the anatomical and physiological benefits of BF running, there have been no studies that have physically prepared subjects for the rigors of BF running, in an effort to not only improve RE, but also performance.

Research Question

Therefore, the following research question seems pertinent: Can experienced shoe runners improve their running economy and race performance with minimal injury or soreness by undergoing a ten-week structured program to teach them how to run barefoot?

Research Hypothesis

It was hypothesized that a ten-week structured training program to teach shod runners to run barefoot would yield an improved running economy and a faster race performance with minimal injury or soreness.

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Abstract

Barefoot (BF) running has developed into a recent training technique for elite and sub-elite endurance runners. BF running is a recent type of training that may improve (RE) and performance by allowing for an enhancement of the foot and lower leg musculature leading to improved running biomechanics. In spite of the many anecdotal statements that have been raised suggesting the benefits of BF running, there has been limited research evaluating a systematic training program designed to teach this skill and then test the outcome of this training on RE and race performance. **Purpose:** To determine if the use of a systematic BF running training program would result in an improved RE and race performance. **Methods**: Three, young adult males were recruited to participate. Each participant reported to the laboratory four times. On Day 1, informed consent was completed and subject characteristics were determined including height, body mass, and body composition followed by a VO_2max test. Four to seven days later (Day 2), subjects underwent RE tests on a motorized treadmill under three conditions: flat ((4 m•s^{-1}), decline (4.5 m•s^{-1} at -5% grade), and incline (3 m•s^{-1} at +5% grade)) and a 5k time trial. Oxygen uptake was measured using a portable telemetric gas analysis system (Cosmed K4b2). Following testing, subjects underwent a 10-week systematic barefoot training program. After ten weeks of barefoot running, Days 1 and 2 were repeated. **Principle Measures:** RE and performance (5-K race time) were the dependent variables of this study. **Results:** Compared to the shod condition, BF run training resulted in no change in VO_{2max}, an improved RE (4.0% on the flat, 3.3% on the incline, and 0.1% on the decline), and a slight improvement (1.0%) in race performance. **Conclusions:** These preliminary findings suggested that a progressive, 10-week barefoot running training program resulted in improved RE that, in turn, yielded a faster race performance.

Introduction

Running economy (RE) is a measure of how "efficiently" a person moves and is often the limiting factor that determines successful elite endurance performances. RE is measured as the submaximal volume of oxygen (VO_2) required to run at a given speed. Barefoot (BF) running is a recent type of training that may improve a runner's RE and ultimately performance, by allowing for an enhancement of the foot and lower leg musculature, which, in turn, could improve running biomechanics by allowing the runner to land on the mid- or fore-foot. This mid- or fore-foot landing pattern allows for a person's center of gravity to stay forward (slight lean forward) and this leads to continual forward propulsion. On the other hand, most runners who train in shoes land on their heel causing the center of gravity to shift behind the body's centerline (slight lean backwards) leading to a short phase of deceleration, which must be overcome with each step. In addition, the shoe absorbs most of the impact force, which results in the foot and lower leg musculature being inadequately trained. Landing on the heel limits pre-activation of the involved muscles of the foot and lower leg, which reduces stiffness of those muscles, ultimately leaving them unprepared for contact. This reduced stiffness results in a reduction of the elastic capabilities of the Achilles tendon and arch of the foot, running stride is lengthened, and RE is decreased. In the elite and sub-elite endurance athlete it is often the most economical runner who wins the race. Therefore, anything a runner can do to enhance RE is vitally important to successful performances.

Only limited research has been conducted to study the potential benefits of BF running. Squadrone and Gallozzi (12) found that in a group of eight proficient BF runners, stride frequency, ground contact, stride length, oxygen uptake (VO_2)

values and foot mechanics were largely dependent on whether the subjects wore shoes or not, or were wearing minimalist footwear such as the Vibram FiveFingers (Figure 1).

Figure 1. The Vibram FiveFingers™ minimalist shoe.

Through the utilization of an instrumented treadmill, BF and the wearing of minimalist running shoes clearly demonstrated improved stride frequency, limited ground contact, reduced stride length, lower VO_2 values, and improved mechanics of the foot (12). The authors stated that impact forces were reduced and that this reduction was due to runners landing on their forefoot or midfoot as well as the elimination of shod features such as heel support, cushioning, and motion control. This study clearly showed that running BF or in minimalist shoes resulted in improved proprioception and proper mechanics, which in turn enhanced running economy (RE) and performance.

Hanson *et al.* (4), found that when experienced and non-experienced BF runners ran BF, heart rate and rate of perceived exertion were significantly lower in comparison to running in shoes. The subjects also reported that when instructed to run BF at a pace simulating seventy percent of their VO_{2max}, it felt easier to maintain as opposed to wearing their normal training shoes. This implies that when running BF, more oxygen was being utilized in order to maintain pace, rather than being wasted in an effort to accommodate for low muscular strength and biomechanics. Hanson *et al.* believe these findings were due in large part to reduced weight on the feet as well as enabling the arch of the foot to function appropriately.

In spite of the positive results discovered by Hanson *et al.,* a designed training program teaching the subjects how to run BF, would have been appropriate. Since sixty percent of the subjects had limited experience running BF and the researchers did very little to prepare the participants in terms of BF training, it was not surprising that these same individuals were complaining of foot and lower leg soreness. Although discomfort is common following exercise of increased intensity or volume, attempting to run BF with no training, after spending years in typical running shoes, is often a recipe for injury. According to Lieberman *et al.* (7)*,* people who run in shoes are often rear foot strikers. Due to the mechanics of the foot, impact forces are distributed over the surface area of the heel, as opposed to the whole foot when mid- or forefoot striking. When attempting to run BF without a systematic training regimen, the years spent in a traditional running shoe have not only significantly de-conditioned the musculature of the foot, but have also limited the runner's ability to properly distribute impact forces due to reduced proprioception. This leads to a potentially high rate of injury.

Therefore, when individuals attempt to run BF without properly programming their body to handle the ensuing stress, they will be incapable of training consistently due to the increased susceptibility of injuries. The purpose of this study was to determine whether a training program to learn how to run BF correctly resulted in improved RE and performance in a group of traditional shod runners. It was believed that the subjects would not only learn how to run efficiently, but that they would progressively develop the proper foot and lower leg musculature and proprioception required to run BF. Our hypothesis was that this training program would result in improved biomechanics associated with BF running, thus leading to improved RE and performance as compared to running with shoes.

Methods

Subjects: Thirty-one competitive runners were recruited for this two-part study with half being trained BF runners and the other half being shod runners. Runners from the two groups were matched on fitness levels and performance. The first part of this study compared the two groups relative to RE and performance. The second half of this study involved taking the habitual shoe runners and training them to run BF and then measuring their RE and performance after their BF training had concluded. Each subject was briefed regarding the possible dangers associated with the study and they signed an informed consent form approved by the Institutional Review Board at the University of New Hampshire. Participants also completed a health history form prior to participating.

Once the subjects had been selected and the required paperwork had been completed, each participant was given the opportunity to experiment with the testing treadmill and oxygen mask in order to prepare for the ensuing VO_2 max and RE tests. Once the participants had gained enough experience with the treadmill and oxygen mask, they returned to the Robert Kertzer Exercise Physiology Laboratory for initial testing of VO_2 max, body mass and composition, RE, and 5K performance. The three shod runners underwent ten weeks of structured BF running training, which supplemented their current training. Then, after those ten weeks of training to run BF, VO_2 max, body mass and composition, RE and 5K performance were retested in order to determine the effectiveness of the prescribed training regimen. Table 1 shows the baseline subject characteristics.

Table 1. Subject characteristics prior to the 10-week barefoot running training program (n=3).

Variable	Mean ± SD
Age (yrs)	**34.0 ± 9.8**
Height (cm)	**171.0 ± 6.9**
Body mass (kg)	**63.9 ± 10.0**
Body fat (%)	**10.5 ± 2.0**
VO_{2max} (ml•kg^{-1}•min^{-1})	**57.0 ± 5.6**
VE_{max} (L•min^{-1})	**136.7 ± 25.6**
RER_{max}	**1.33 ± 0.0**
Average 5-K (mins)	**19.37 ± 0.4**

Principle Measure: Running economy (oxygen uptake) and performance (5K race) were the dependent variables of this study. Each subject's RE was determined while running on the flat, uphill (+5% grade), and downhill (-5% grade) treadmill, as well as a 5K time trial race (performance measure) before and after the ten-week systematic training program. Since the subjects maintained their training volume while learning how to run BF, it was expected that through improved foot and lower limb mechanics, force distribution, and utilization of the arch and achilles heel, the participants would not only learn how to correctly run BF, but through improved running biomechanics, would have an enhanced RE and would run a faster 5K.

Procedures: *Day One.* Subjects completed the informed consent forms while also undergoing body mass and body composition measurements. Body mass was determined through the use of an electronic scale (General GE 510 Digital Body Mass Scale). A skilled technician took skinfold measurements of the triceps, chest, midaxilla, subscapula, abdomen, suprailiac, and thigh and percent body fat was determined.

After completion of the body composition measurements, the subjects also underwent a VO_2 max test in order to determine the subject's ability to utilize oxygen at maximal aerobic effort while wearing their training shoes. The subject warmed-up for five minutes and self-selected the pace (speed) of the motorized treadmill, while the grade was increased by 2.0% each minute until exhaustion. The participant's VO_{2max} was determined from this test. Heart rate and rating of perceived exertion were determined each minute. Oxygen uptake was measured using a previously calibrated Cosmed $K4b^2$ portable telemetric gas analysis system.

Day Two. Subjects reported back to the lab 4-7 days after the first day to perform the RE tests and the 5K race. All testing was performed by the subjects while wearing their training shoes. A force-plate equipped treadmill was used to evaluate RE while running on a flat, uphill, and downhill surface in five minute time periods. Subjects rested for ten minutes after each bout to limit the effects of fatigue. In terms of the flat terrain simulation, the treadmill was set at a speed of 4 $m•sec^{-1}$, while a speed of 3 $m•sec^{-1}$ as implemented to compensate for a five percent incline (uphill portion). The downhill running speed was increased to 4.5 $m•sec^{-1}$ with a five percent decline. Throughout the tests, additional RE indicators such as step rate, width, and length, as well as contact time, weight acceptance, push-off, and impact peak force, were collected to analyze the participant's movement quality. The Cosmed $K4b^2$ portable telemetric gas analysis system was utilized to measure oxygen uptake and RE.

Following completion of the treadmill tests, the participants walked to the Field House in order to complete a 5K time trial on the Paul Sweet Oval Indoor track. Participants ran while wearing the Cosmed $K4b^2$ portable telemetric gas analysis system throughout the time trial. Understanding that the subjects would have to run 31.25 laps of the Paul Sweet Oval Indoor track, to complete the 5K, while wearing the oxygen uptake system, the test proctors not only cheered them on, but also recorded their time splits at each mile and notified the subject of how many laps they had completed.

Training Program. Over the course of a ten-week time period, the shod runners engaged in a systematic training program to learn how to run BF. The outline of the training program can be viewed in Table 2 below.

Table 2. Progressive, 10-week barefoot running training program.

	Monday	Wednesday	Friday	Saturday
Week 1	Walk 9 mins/Run 1 min x 3 (30 mins Total)	Walk 9 mins/Run 1 min x 3 (30 mins Total)	Walk 9 mins/Run 1 min x 3 (30 mins Total)	Walk 9 mins/Run 1 min x 3 (30 mins Total)
Week 2	Walk 8 mins/Run 2 mins x 3 (30 mins Total)	Walk 8 mins/Run 2 mins x 3 (30 mins Total)	Walk 8 mins/Run 2 mins x 3 (30 mins Total)	Walk 8 mins/Run 2 mins x 3 (30 mins Total)
Week 3	Walk 7 mins/Run 3 mins x 3 (30 mins Total)	Walk 7 mins/Run 3 mins x 3 (30 mins Total)	Walk 7 mins/Run 3 mins x 3 (30 mins Total)	Walk 7 mins/Run 3 mins x 3 (30 mins Total)
Week 4	Walk 6 mins/Run 4 mins x 3 (30 mins Total)	Walk 6 mins/Run 4 mins x 3 (30 mins Total)	Walk 6 mins/Run 4 mins x 3 (30 mins Total)	Walk 6 mins/Run 4 mins x 3 (30 mins Total)
Week 5	Walk 5 mins/Run 5 mins x 3 (30 mins Total)	Walk 5 mins/Run 5 mins x 3 (30 mins Total)	Walk 5 mins/Run 5 mins x 3 (30 mins Total)	Walk 5 mins/Run 5 mins x 3 (30 mins Total)
Week 6**	Walk 3 mins/Run 7 mins x 3 (30 mins Total)	Walk 3 mins/Run 7 mins x 3 (30 mins Total)	Walk 3 mins/Run 7 mins x 3 (30 mins Total)	Walk 3 mins/Run 7 mins x 3 (30 mins Total)
Week 7	Walk 2 mins/Run 8 mins x 3 (30 mins Total)	Walk 2 mins/Run 8 mins x 3 (30 mins Total)	Walk 2 mins/Run 8 mins x 3 (30 mins Total)	Walk 2 mins/Run 8 mins x 3 (30 mins Total)
Week 8	Walk 1 mins/Run 9 mins x 3 (30 mins Total)	Walk 1 mins/Run 9 mins x 3 (30 mins Total)	Walk 1 mins/Run 9 mins x 3 (30 mins Total)	Walk 1 mins/Run 9 mins x 3 (30 mins Total)
Week 9**	Run 10 mins/Short Recovery x 3 (30 mins Total)	Run 10 mins/Short Recovery x 3 (30 mins Total)	Run 12 mins/Short Recovery x 3 (36 mins Total)	Run 12 mins/Short Recovery x 3 (36 mins Total)
Week 10**	Run 15 mins/Short Recovery x 2 (30 mins Total)	Run 15 mins/Short Recovery x 2 (30 mins Total)	Run 20 mins/Short Recovery x 2 (40 mins Total)	Run 20 mins/Short Recovery x 2 (40 mins Total)

Post-training Testing. After completion of the ten-week training program, body mass, body composition, VO_{2max}, RE, and the 5K race performance were retested as previously described, to determine changes. All post-training testing was done in the BF condition.

Statistical Design

To date, three subjects have completed the study and, therefore, no statistical analyses have been performed. However, Mean ± S.D. are reported for all of the pre and post training measurements.

Results

As mentioned previously, the three subjects completed a VO_{2max} before and after the completion of the 10-week BF running training program. Prior to initiating the training program, the three shod subjects registered an average VO_{2max} of 60.1 ± 3.0 ml•kg^{-1}•min^{-1}. However, after ten weeks of BF training, the same three individuals recorded an average VO_{2max} of 61.3 ± 2.1 ml•kg^{-1}•min^{-1} (Figure 1).

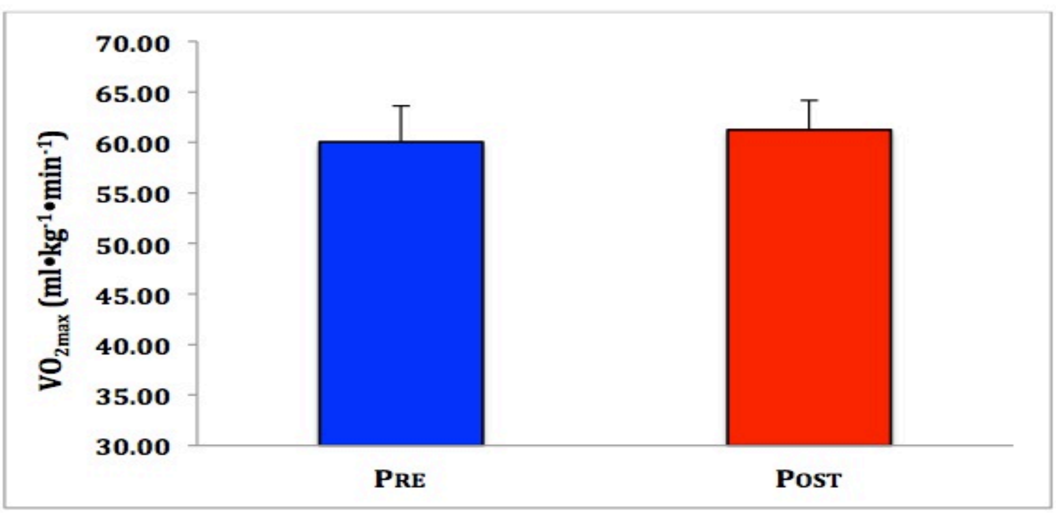

Figure 1. VO_{2max} pre (shod) vs post (BF) training.

Figure 2 shows that prior to the 10-week BF running training program, the subjects recorded an average VO_2 of 48.3 ± 4.1 ml•kg^{-1}•min^{-1} when running at a speed of 3.5 m•sec^{-1} on a +5% incline, a VO_2 of 49.8 ± 5.5 ml•kg^{-1}•min^{-1} when running at a speed of 4.0 m•sec^{-1} on a flat surface, and a VO_2 of 48.5 ± 6.8 ml•kg^{-1}•min^{-1} when running at a speed of 4.5 m•sec^{-1} on a 5% decline. Following the ten weeks of BF training, the same three subjects registered an average VO_2 of 48.8 ± 1.4 ml•kg^{-1}•min^{-1} when running at a speed of 3.5 m•sec^{-1} on a 5% incline, a VO_2 of 50.7 ± 1.2 ml•kg^{-1}•min^{-1} when running at a speed of 4.0 m•sec^{-1} on a flat surface, and a VO_2 of 50.3 ± 2.1 ml•kg^{-1}•min^{-1} when running at a speed of 4.5 m•sec^{-1} on a 5% decline.

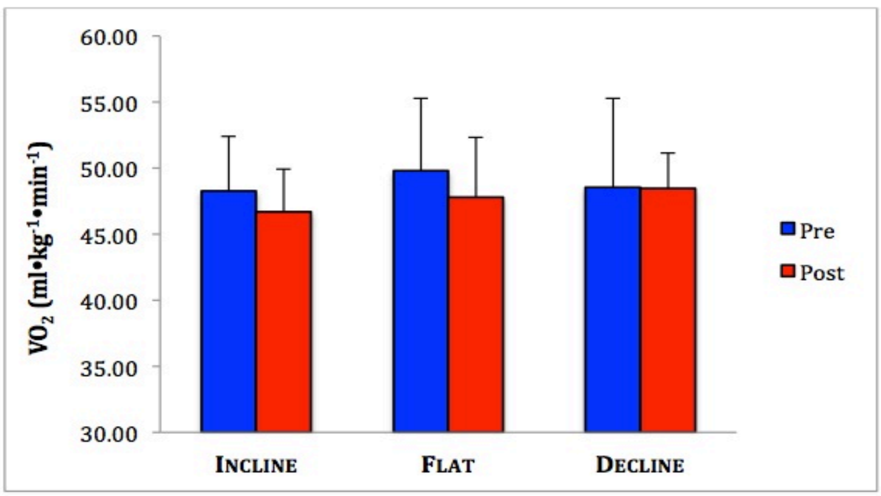

Figure 2. Running economy pre (shod) vs post (BF) training while running on an uphill, flat, and downhill treadmill grade.

Incline=5% uphill grade; 3.5 m•sec^{-1}
Flat=0% grade; 4.0 m•sec^{-1}
Decline=5% downhill grade; 4.5 m•sec^{-1}

Prior to undergoing the ten-week BF training program, the three subjects recorded an average one-mile split of 6.01 ± 0.25 minutes, an average two mile split of 6.27 ± 0.23 minutes, and an average three mile split of 6.37 ± 0.31 minutes. Following ten weeks of BF training, the same subjects registered an average one mile split of 5.99 ± 0.25

minutes, an average two mile split of 6.23 ± 0.43 minutes, and an average three mile split of 6.23 ± 0.51 minutes (Figure 3).

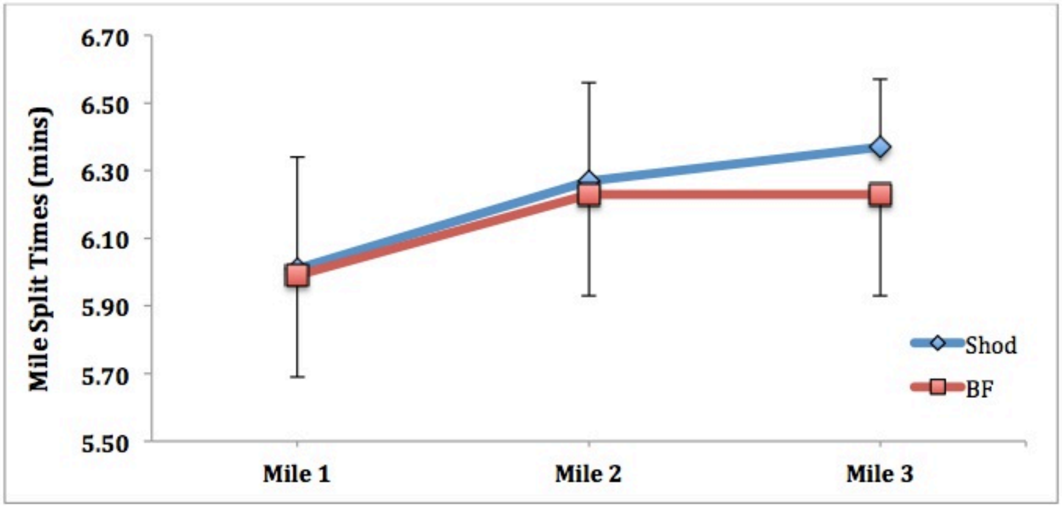

Figure 3. Mile splits (mins) pre (shod) vs post (BF).

Figure 4 shows that prior to the ten-week BF training program, the three shod subjects completed the five-kilometer time trial in an average time of 19.37 ± 0.59 minutes. However, following ten weeks of BF training, the subjects completed the same distance in an average time of 19.17 ± 1.25 minutes.

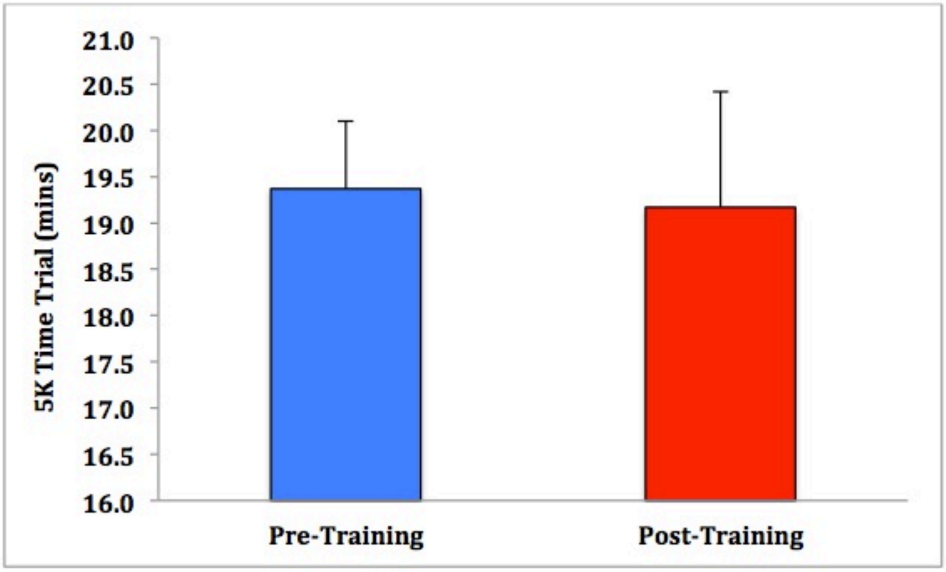

Figure 4. Five-kilometer time trial (mins) pre (shod) vs post (BF) training.

Discussion

The purpose of this study was to determine whether a training program to learn how to run BF would result in improved RE and performance in a group of traditional shod runners. As mentioned previously, only limited research has been conducted to study the potential benefits of BF running, but no studies to date have implemented baseline and post-training measures in an effort to determine if traditional shod runners can learn to run BF, in an effort to improve RE and performance. Before the onset of this experiment, it was hypothesized that a 10-week structured training program to teach shod runners to run BF would yield an improved running economy and a faster race performance with minimal injury or soreness.

Based on the average means, it was found that after ten weeks of training how to run BF, subjects improved their RE while running on flat, incline, and decline treadmill terrains without significant increases in VO_{2max}. Furthermore, these same individuals improved their mile one, two, and three mile timed splits and they also averaged a faster 5k-race performance following the ten weeks of BF running. More specifically, the subjects managed a 4% increase in RE on flat terrain, a 3.3% improvement in RE on an incline, and a 0.1% increase in RE on a decline, despite only improving their average VO_{2max} from 60.1 ± 3.0 ml•kg^{-1}•min^{-1} at baseline, to 61.3 ± 2.1 ml•kg^{-1}•min^{-1}, following the ten weeks of BF training.

Furthermore, the subjects improved their mile one split from 6.01 ± 0.25 minutes to 5.99 ± 0.25 minutes, their average two mile split from 6.27 ± 0.23 minutes to 6.23 ± 0.43 minutes, and their average three mile split from 6.37 ± 0.31 minutes to 6.23 ± 0.51 minutes (2.2% improvement). Due in large part to the more noticeable improvement of the mile three split, the runners bettered their average 5k-race performance by 1.0% after the ten weeks of BF running.

By recalling that RE is the steady-state VO_2 for a given running velocity (8), the pre-training and post-training VO_{2max} tests could have served as limiting factors if the implementation of the BF running training program was not properly incorporated and monitored. More specifically, the subjects were required to maintain their current training volume throughout the ten weeks of BF training in order to compensate for a gradual increase in BF running volume. In greater detail, if the subjects failed to maintain their current training volume or if they added unnecessary amounts of mileage, their fitness would be expected to improve or decline, which would have negative influences on their RE and performance.

In a study conducted by Mujika and Padilla (6), who researched the physiological and performance adaptations on behalf of detraining, they were able to conclude that highly trained athletes typically associated with a noticeable decrease in VO_{2max} and performance, after less than four weeks of detraining. Comparatively, in an overtraining syndrome review, compiled by Kreher and Schwartz (9), the authors were able to conclude that when overreaching and recovery are not properly balanced, negative effects such as central nervous system (CNS) fatigue and hormonal alterations can lead to performance decrements. Thus, in an effort to improve the RE and performance of the subjects, it was imperative that the BF training regimen and the normal training volumes of the athletes were appropriately balanced to prevent unwarranted increases or decreases in aerobic capacity. Therefore, based off the relative maintenance of the subject's average VO_{2max} following ten weeks of BF running, it is reasonable to conclude that the present training volumes of the subjects were maintained in accordance with the BF running training program.

Based off the fact that the subjects did not detrain or overtrain over the course of the 10-week BF running training program, it was more likely that the BF running played a significant role in the RE and performance improvements. As mentioned previously, the subjects, on average, improved their running economy on the flat, incline, and decline treadmill terrains and they also managed a faster average 5k and mile splits, following the ten weeks of BF training. Regardless of the fact that the training volumes were appropriately managed, other factors such as a decrease in shoe mass, an increase in elastic energy, training consistency, and coaching cues may have also played important roles in the positive results.

Since each of the subjects were experienced shod runners, the BF running training program served to provide each subject with a steady and progressive dose of BF running over the course of a 10-week period. Due to the careful programming of BF training, the subjects were capable of completing the post training RE and performance tests BF, which demonstrated the importance of training consistently in an effort to yield acceptable biomechanical alterations. Based off the data collected by Bonacci *et al.* (1), the researchers determined that when previously trained subjects ran BF overground, they demonstrated reduced midstance knee flexion, knee extension, abduction, negative work at the knee, and dorsiflexion upon ground contact. Furthermore, they also presented with improved peak power and positive work at the ankle joint.

Even though much of improvements found in the Bonacci study could be attributed to the implementation of BF running, it is important to understand that the subjects were healthy, highly trained, and had been training consistently for at least three months. Similar to the subjects who participated in the 10-week BF running training program, it is likely that the runners who partook in the study conducted by Bonacci and colleagues, had exhausted all of their previous training resources, which enabled them to conclude that a safe and consistent dose of BF training could pay positive dividends in their future race results. The effectiveness of BF running in consistently trained and healthy runners, by means of increased proprioception, force distribution, foot conditioning, and foot strike was also supported through the work of Hanson *et al.* (3), Lieberman *et al.* (7), and Warne and Warrington (12).

In accordance with the findings supported by Bonacci *et al.*, Hanson *et al.*, Lieberman *et al.*, and Warne and Warrington, it is important to keep in mind that the ability of the shod subjects to train consistently over the course of the ten-week BF running training program, enabled them to experience improvements in RE and performance. Since the BF running was appropriately implemented in accordance with the current training volume of the subjects, a basic level of fitness was maintained (Figure 1), which enabled the athletes to safely progress to higher intensities of BF running. According to a study performed by Hoier *et al.* (4), who studied the influence of intense intermittent exercise in regards to vascular endothelial growth factor (VEGF) secretion and capillary growth in skeletal muscle, they determined that when trained males performed moderate exercise before intense training (as opposed to performing intense intermittent exercise before intense training), they experienced an increase in muscle capillary growth by means of an effective angiogenic stimulus.

Since the subjects appropriately monitored their training volume, they trained consistently, and they maintained their aerobic fitness, they were not only capable of progressing to higher volumes of BF running, but they were ultimately prepared to perform the post-training RE and performance tests, BF. According to Hanson *et al.*, who reported lower heart rates and rates of perceived exertion when experienced and non-experienced BF runners ran BF, they believed these findings were due in large part to the reduced weight on the feet. Warne and Warrington also supported this finding, after discovering that four weeks of SBR demonstrated improvements in RE on behalf of SBR, but not shod running.

In accordance with the results of Bonacci *et al.*, Hanson *et al.*, Lieberman *et al.*, and Warne and Warrington, which supported the need for BF training consistency, in an effort to yield increased proprioception, force distribution, foot conditioning, and foot strike, it is likely that the shod subjects also improved their ability to store and utilize elastic energy by means of their ankle joint extensor muscle tendons (2). Therefore, by coupling these findings with the likely potential improvements in midstance knee flexion, knee extension, abduction, negative work at the knee, and dorsiflexion upon ground contact (1), the runners may have experienced an enhancement of the foot and lower leg musculature, which, in turn, could improve running biomechanics by allowing the runner to land on the mid- or fore-foot.

With the ability to land on the mid- or fore-foot, the athletes were likely capable of enabling their center of gravity to stay forward (slight lean forward), which would result in continual forward propulsion and reduced ground reaction forces by means of improved force distribution. Due to a heightened stiffness of the foot and lower leg musculature, the subjects were prepared for ground contact, which potentially lead to an increase in the elastic capabilities of the Achilles tendon and arch of the foot, and ultimately an increase in running stride length (11).

Since the subjects trained four days per week without shoes, they likely experienced a reduction in heel contacts, which would cause their center of gravity to shift behind the body's centerline (slight lean backwards), thus resulting in a short phase of deceleration that would have to be overcome with each step. Without shoes, the subjects were likely forced to exhibit a mid- or fore-foot strike in an effort to reduce discomfort upon ground contact, which would also allow for improved force distribution. Since running in shoes is typically associated with heightened hip, knee, and ankle torques (5), as well as the previously mentioned biomechanical downfalls, evidence fails to support the need for shoes involving cushioned heels and pronation control (10).

Although training consistency, a decrease in shoe mass, and appropriate training management played a role in the potential biomechanical improvements that ultimately lead to improvements in RE and performance, various coaching cues also served an instrumental role (3, 12). In greater detail, the subjects were instructed to run with a tall posture with their shoulders down, their faces relaxed, while simultaneously stepping over tall grass with their arm swing being generated through the shoulder joint. Furthermore, it was important that the hands moved posteriorly past the hip with the elbow slightly extended, prior to initiating slight elbow flexion upon moving the hand to the level of the corresponding face cheek.

Even though RE has a profound influence on running performance, this can only be accomplished through persistent diligence in regards to training consistency, shoe mass, training management, and biomechanical awareness. Therefore, by completing four BF training sessions each week, in accordance with a reasonable training volume, the shod subjects who completed the study requirements exemplified the necessary dedication, determination, and hard work for success. Furthermore, by attending weekly meet ups in an effort to gauge biomechanical patterns and responses to training volume, the athletes improved their ability to manage their training load, which demonstrated the importance of proper biomechanics and training management. As a result, the runners were capable of training on a consistent basis, which served to improve the anatomical and physiological processes required for improved RE and performance.

Conclusion

The purpose of this study was to determine whether a 10-week systematic barefoot running training program, implemented to teach habitual shod runners how to run BF correctly, would result in improved RE and performance. By recalling that the research hypothesis stated that this regimen would yield an improved running economy and a faster race performance with minimal injury or soreness, this statement was ultimately supported on behalf of the data collected.

Based off the evidence, the subjects who participated in the pre-training testing, the ten-week program, and the post-training testing, presented with no average increase or decrease in VO_{2max}, a 4% increase in RE on flat terrain, a 3.3% improvement in RE on an incline, and a 0.1% increase in RE on a decline. Therefore, based off the ensuing improvements in race performance, it is reasonable to conclude that the faster post-training 5k time trials were due to enhanced RE, rather than the development of the subjects' aerobic capacities.

More specifically, the subjects recorded a faster mile three split, following the 10-week BF training program, which ultimately resulted in an approximate 1.0% improvement in 5k-race performance. Although this is a small percentage change, elite performances are often separated by the slimmest of margins. Since the athletes were capable of postponing the onset of fatigue until later stages of the time trial (post-training), it is reasonable to conclude that small improvements in RE could determine if someone reaches the podium or not.

Although this study generated noteworthy conclusions in regards to VO_{2max}, RE, and performance, more subjects are needed so that statistical analyses may be run. As a result of an improved subject population and the resulting statistical analyses, it may be possible to determine if such programs could serve as future training tools for coaches and athletes, who are seeking to improve RE and performance.

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