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Comparison of Varying Heel to Toe Differences and Cushion to Barefoot Running in Novice Minimalist Runners

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ABSTRACT

International Journal of Exercise Science 11(1): 13-19, 2018. There are many different types of footwear available for runners in today's market. Many of these shoes claim to help runners run more efficiently by altering an individual's stride mechanics. Minimalist footwear claims to aid runners run more on their forefeet whereas more traditional footwear provides more cushioning specifically for a heel first landing. The purpose of this paper was to determine if runners, who were accustomed to running in traditional footwear would alter their running mechanics while running acutely in various types of minimalist footwear. Twelve subjects, accustomed to running in traditional 12 mm heel/toe differential footwear, ran in five footwear conditions on a treadmill at a controlled pace for two minutes after warming up in each condition for 5 minutes. While running in 12 mm heel/toe differential footwear compared to barefoot, subjects ran with a significantly longer ground time, a lower stride rate and greater vertical oscillation. There were not any differences in variables when running in the shod conditions despite the varying heel/toe differentials. Running barefoot proved to be different than running in traditional 12 mm drop cushioned footwear.

KEY WORDS: Footwear, impact, running mechanics

INTRODUCTION

Running has experienced a renaissance in the last 40 years. There was an initial running boom in the 70's where running became popular in the United States, and running shoe companies developed the prototype for the modern-day running shoe (12). These shoes emphasized cushioning to make the running experience more comfortable. Currently, barefoot (BF) and minimalist running is beginning to change the running industry. Minimalist footwear tends to have a heel/toe difference of 4 mm or 0 mm, whereas the traditional modern-day running shoe tends to have a heel/toe difference of 10-12 mm (5). Additionally, minimalist footwear tends to have a lower profile (closer to the ground), greater sole flexibility (softer midsole foams are used), and a lack of motion control (devices that are placed in shoes to limit foot pronation) (4). There is not unanimity in the scientific literature or running world, on an exact definition of a minimalist running shoe. To some, it is a shoe with very little padding or support that allows the runner to mimic the running style of running BF, while to others, it may resemble a more traditional shoe that includes greater amounts of cushioning and stability but with a lower heel/toe differential. To this point, there has been little research completed on cushioned footwear with 4 mm or 0 mm drop (4, 20).

Benefits attributed to BF and minimalist running are altered biomechanics (13, 14, 19, 20), increased running economy (15), and decreased risk of knee injury (1). Despite there being evidence of improved running economy and decreased risk of knee injury, there are recognized risks of transitioning to BF and minimalist running: increased risk of Achilles, metatarsal, and plantar fascia injury (6) and metatarsal stress fractures (8, 16, 17) have been reported. Due to the wide variety of running shoes available with various heel to toe drops, it is pertinent that more research be done on the biomechanical effects on runners using cushioned minimalist footwear.

Comparing BF and traditional running shoes show changes in foot strike type, stride rate, stride length, and various force measures (13, 9). Minimalist and zero drop shoes compared with traditional also observed similar findings (20). However, changes in kinematic descriptors of running mechanics across the range from 12mm to 0mm heel to toe drops are yet to be investigated.

The purpose of this study was to compare if and how runners accustomed to running with a traditional (12 mm) height difference from heel to toe alter running mechanics acutely when running BF and in different minimalist footwear. Running mechanics were compared under 5 separate conditions: A traditional 12 mm differential shoe, a cushioned 4 mm differential shoe, a cushioned 0 mm differential shoe, a 0 mm differential non-cushioned shoe and BF.

It was hypothesized that runners that are new to running in minimalist footwear will not demonstrate any change in their lower limb running kinematics when running in 4 mm or 0 mm differential cushioned shoes compared to traditional 12 mm differential cushioned shoes. It was also hypothesized the stride rate will be faster and time on ground will decrease in the BF and lower heel to toe differential shoes than in traditional footwear. We also hypothesized that with decreasesd heel/toe differential we would see less vertical oscillation. It was not expected to see any acute change in the foot strike angle and knee angle in the different footwear.

METHODS

Participants

This study examined male and female recreational runners that have been running 30 or more minutes at least three times a week for six months. The age of the participants was 18-31 years (Table 1). We determined 10 subjects would be needed after completing a power analysis for each of our dependent variables and it was determined that vertical impact peak required the greatest number of participants to afford a power of 0.8 with an alpha set at .05. The study was delimited to runners who have been using traditional (10-12 mm drop) footwear for at least 75% of their mileage. Subjects were excluded if they had surgery in the last six months or lower extremity injuries that prevented them from running. Competitive collegiate runners and elite runners were also excluded from the study. Footwear usage was self-reported. Participants were recruited through announcements in the university's jogging class, local running clubs and the local running specialty stores. Subjects read and signed a Brigham Young University Institutional Review Board approved consent form before beginning the study.

Table 1. Means and standard deviations for subjects.

Condition	Age (years)	Mass (kg)	Height (m)
4 Females	25.2 ± 3.9	58.6 ± 7.2	1.7 ± 0.1
6 Males	26.8 ± 4.1	71.3 ± 7.1	1.8 ± 0.1

Protocol

The subjects ran in each of the following randomized conditions: 1) Mizuno Wave Rider (cushioned 12 mm differential), 2) Saucony Kinvara (cushioned 4 mm differential), 3) Altra The One (cushioned 0mm differential), 4) Vibram El-X/Entrada (non-cushioned 0 mm differential) and 5) BF. The independent variables were the four shod conditions and BF. This allowed us to examine the effect of the cushion as well as the heel-toe differential. Shoe companies report the amount of heel and toe cushion in the shoes in millimeters. The cushioned minimalist shoes were selected because of their company reported heel/toe differences.

The subjects ran on an AMTI Force-Sensing Tandem Treadmill (Watertown, VA) which allowed us to obtain stride rates and ground contact time. Each testing condition consisted of a five-minute warm-up at a self-selected pace that was not allowed to exceed the standardized pace (which was maintained for each warm-up for the other conditions) in one of the shoes, followed by a two-minute trial at a standardized pace (3.3 m/sec) which was followed by five minutes to change shoes and reapply markers. The order of shoe conditions were randomized. The statistical analysis showed no significant effect of order. The two-minute trial allowed for multiple steps well-above the number recommended by Belli to obtain an acceptable measure of variability of running mechanics (3). The five-minute warm-up was done to help the subject acclimate to running on the treadmill and to running in the unfamiliar footwear. The warm-up pace was advised as an easy pace, not to be faster than the pace during the trial. The trial pace was determined by looking at the speeds used in similar studies (19). Subjects were not advised to run with any particular FS pattern.

Visual markers were placed using the VICON full body plug in model (Oxford, UK). The lower body model included markers at the medial and lateral malleoli, the medial and lateral condyles of the tibia, and the greater trochanter of the femurs. Markers were also placed on the shoes in the approximate area of the calcaneus (medial and lateral aspect), the base of the first and fifth metatarsal, and above the toenail of the hallux. The arm model included markers at the acromioclavicular joint, between the elbow and shoulder marker, on the lateral epicondyle, on the lower arm between the wrist and elbow markers, radial styloid and ulnar styloid processes. The torso markers were placed on the spinous process of the 7th cervical vertebra, the spinous process of the 10th thoracic vertebra, the jugular notch and the xiphoid process of the sternum, and the middle of the right scapula. The head markers included a marker placed over the left and right temple, a left back of the head marker and a right back of the head marker that lie in the same horizontal plane with the front markers. The markers aided in determining lower leg extension, plantar/dorsiflexion of the ankle, and inversion/eversion of the ankle. The placement of the markers was done in a way to establish the center of the joint. Upper body markers were used so that we could establish center of mass, which was used to determine vertical oscillation.

Once the joint centers are known the joint angles can be determined. The last 60-second period of each two-minute trial was recorded by the VICON Nexus capture system (2). Kinetmatic data were sampled. Impact angles were calculated when vertical impact peak reached over 50 N. The temporal dependent variables were the stride rate, force data produced by the foot strike (time on ground), and the kinematic dependent variables were footstrike angle in the sagittal plane (angle using the heel to toe line relative to horizontal at the instant of ground contact), and the knee angle in the sagittal plane upon FS.

Statistical Analysis
Temporo-spatial stride characteristics (time on ground, stride rate and joint kinematics) was analyzed using SPSS statistical software (IBM Corp, Armonk, New York, USA). MANOVA was used to determine differences between the dependent variables for the various shoe conditions. Statistically significant variables ($p < 0.05$) were further analyzed using Tukey post hoc comparisons.

RESULTS

Stride Rate: Significant differences were detected between the 12mm heel/toe differential shoe and the BF condition (Table 2) ($p = .036$). People running BF demonstrated a higher stride rate as has been demonstrated in previous literature (18). There were no differences detected between any of the other conditions.

Table 2. Means and standard deviations for stride rate across footwear. Statistical differences were found between barefoot and 12mm conditions ($p = .036$).

Condition	Mean (Strides/Sec)	Std. Deviation
Barefoot	1.487*	.116
Vibram	1.424	.099
Zero mm drop	1.387	.089
Four mm drop	1.391	.089
Twelve mm drop	1.367*	.075

Ground Time: Results indicated that ground time varied significantly between the BF condition and the 12mm heel/toe differential shoe (Table 3) ($p = .019$). These findings have also been identified in previous studies. Significance was not found between any of the other conditions.

Vertical Oscillation: Running BF decreased vertical oscillation compared to running in a 12mm heel/toe differential shoe (Table 4) ($p = .017$). Otherwise, running in footwear did not affect the runners' vertical oscillation.

Table 3. Means and standard deviations for ground time across footwear. Statistical differences were found between barefoot and 12mm conditions (*p = .019).

Condition	Mean (seconds)	Std. Deviation
Barefoot	.210*	.022
Vibram	.228	.021
Zero mm drop	.236	.023
Four mm drop	.233	.024
Twelve mm drop	.243*	.024

Table 4. Means and standard deviations for vertical oscillation across footwear. Statistical differences were found between barefoot and 12mm conditions (Barefoot compared with 12mm conditions were approaching significance at p = 0.19).

Condition	Mean (cm)	Std. Deviation
Barefoot	7.722*	1.316
Vibram	8.196	1.182
Zero mm drop	8.956	1.541
Four mm drop	8.908	1.291
Twelve mm drop	9.031*	1.197

Lower Body Angles: The variables of right maximum knee flexion during stance, right maximum knee flexion during swing, right hip flexion, right hip extension, right ankle touch down, right ankle toe off and right foot ankle were not affected by footwear condition.

DISCUSSION

The purpose of this study was to determine if runners accustomed to running in traditional footwear would change their running mechanics when first put in footwear that had a lower heel to toe differential and with no footwear. The results showed that there was no biomechanical difference when running in all footwear in an acute running bout. Running BF will cause a runner's stride rate to increase, his/her ground time will decrease and their vertical oscillation will also decrease.

Stride Rate: Research previously established that running BF increased stride rate when compared to running in shod conditions (18). This study confirmed those findings and expanded the results to various types of shoes that are supposed to produce BF running mechanics while in a cushioned environment. Even though some of the shoes had higher heels and more cushion, when subjects ran in those shoes, there were not any stride rate changes. When protection around the foot was removed, running BF, the subjects may have taken faster steps as a means to make their landing feel more comfortable or simply that without the weight of a shoe, the foot is able to move more quickly. These shorter, faster strides are associated with smaller impact forces than with the shod conditions (18). It appears that having protection on the foot is enough to prevent subjects from altering their stride rate.

Ground Time: There is an inverse relationship between stride rate and ground time. As stride rate increases, ground time decreases (9). This relationship has been recognized in the findings of this study. Subjects who ran in footwear that had 12mm heel/toe differentials had significantly longer ground time than subjects who ran BF. There were not any significant differences between the other conditions. The cushion and protection that a shoe provides will allow the feet to perform in ways that are not as comfortable without shoes. Cushioning helps make the impact at the shoe to foot interface of the landing less forceful. Without a shoe, each stride becomes very noticeable to the runner and quicker steps are taken to make running more comfortable. If cushioning is the deciding factor with respect to ground time, it appears that all shoe conditions, including Vibram, provided enough cushioning to differentiate them from the BF condition.

Vertical Oscillation: Most studies that have looked at running biomechanics in shod versus BF conditions have looked at vertical oscillation using methods other than tracking center of mass. In order to look at center of mass vertical oscillation, a full body marker set is needed. Prior studies mainly used marker sets that focused on the lower body creating difficulties for direct comparisons to this study.

No differences were observed across footwear in the current study (Table 4). A relationship appears to exist between running economy and vertical oscillation (2). However, footwear does not appear to affect vertical oscillation.

Lower Body Angles: The results of this study did not show that there were any differences in the way the hip, knee and ankle were positioned as the legs went through the gait cycle. The power of these variables was low which indicates that the variability found in these variables were too high for significant differences to be found with the sample size that was used. Differences may have existed but more subjects would be needed to determine if these differences truly existed. This is a limitation of this study.

Another limitation of this study was that only the acute setting was examined for the aforementioned conditions. In habitually BF populations, there are runners that vary from expected foot strike parameters (11). However, when someone switches to BF or different footwear, adjustments may be made over time.

When looking for shoes, runners should also consider factors outside of how footwear is related to temporo-spatial stride characteristics and kinematics. Injury has been a major focus of footwear studies and should be considered when deciding whether to transition to new footwear. Performance is also worth consideration. The original “minimalist shoe”, a racing shoe, has been on the market for a long time but is sparingly used because of its low durability and lack of cushion. But low shoe mass and some amount of cushioning improve running economy and likely performance (7, 10).

Greater forces seem to be a concern for injury risk. However, according to Wolff’s Law, greater forces also lead to greater adaptation of tissues, so the body will likely be able to handle greater forces if the increased stresses are graduated over sufficient time to allow tissue adaptation to occur. The real trouble is likely when forces which a runner is unaccustomed to are placed upon the body (16). Changes in footwear can lead to altered forces which may put various tissues at risk of injury, so gradual changes are necessary if someone decides to change to a different footwear type.

Runners looking for footwear to help them run a certain way need to be aware that running in footwear with lower heel/toe differentials does not appear to affect runners kinematically, at least in the short term. Running BF is a dramatic enough difference for the body to alter stride rate, ground time and vertical oscillation. When running BF the legs will move at a faster rate while the length of the stride and vertical oscillation is decreased. However, more research should be completed to identify whether these results change when training in minimalist and reduced heel-to-toe differential shoes for a prolonged period of time as opposed to an acute setting.

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