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Acute Changes in Running Mechanics Across Footwear with Various Heel-to-Toe Height Differences

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ABSTRACT

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There are many different types of footwear available for runners in today's market. Many of these shoes claim to improve a runner's efficiency by altering their stride mechanics. Minimalist footwear claims to aid runners in running more on their forefeet whereas more traditional footwear provides more cushioning specifically for a heel-first landing.

The purpose of this research was to determine if runners who were accustomed to running in traditional footwear would acutely alter their running biomechanics when they ran barefoot or in various types of minimalist footwear.

Twelve subjects, who were accustomed to running in traditional 12 mm heel/toe differential footwear, ran in five footwear conditions on a treadmill at a controlled pace for 2 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 slower stride rate and greater vertical oscillation. There were not any significant differences in kinematic and kinetic variables when running in the shod conditions despite the varying heel/toe differentials. Foot strike angle did not change under any of the conditions either.

Running barefoot proved to be different than running in footwear in that stride rate increased, ground time decreased and vertical oscillation decreased. There were not any significant acute differences between any of the footwear conditions despite having different heel/toe differentials in subjects accustomed to wearing traditional heel-drop footwear. Wearing minimalist or cushioned minimal footwear appears to not be an effective means of changing running mechanics acutely but may need repeated bouts to alter running mechanics.

Keywords: running, barefoot, minimalist footwear

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Introduction

Running has experienced a renaissance in the last 40 years. There was an initial surge of interest in the 70's where running became popular in the United States, and running shoe companies developed the prototype for modern running shoes (Hsu, 2012). These shoes were typically twice as high in the heel (24 mm) as they were in the forefoot (12 mm). 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 modern-day running shoe tends to have a heel/toe difference of 10-12 mm (Bowles et al., 2012). Companies making footwear that has varying heel/toe differences are either trying to simulate barefoot running with the protection of a shoe or to help transition people into more minimalist footwear. Additionally, minimalist footwear tends to have a lower profile, greater sole flexibility, and a lack of motion control (Bonacci et al., 2013). To this point there has been very little research done on cushioned footwear with a 4 mm or 0 mm heel/toe differential (Bonacci et al., 2013; Willy et al., 2014).

Benefits attributed to barefoot and minimalist running are altered biomechanics (Lieberman et al., 2010; Lohman et al., 2011), increased running economy (Perl et al., 2012; Hanson et al., 2011), and decreased risk of knee injury (Altman and Davis, 2012; Daoud et al., 2012). Despite there being evidence of improved running economy and decreased risk of knee injury, there is also conflicting evidence of what causes the improved running economy (Divert et al., 2008; Franz et al., 2012) and what the recognized risks of barefoot and minimalist running are (Giuliana et al., 2011). Some of the identified concerns include: increased risk of Achilles and plantar fascia injury (Diebal et al., 2012) as well as metatarsal stress fractures (Ridge et al., 2013; Salzler et al., 2012). Since there are increasing numbers of shoes with varying heel/toe differentials on the market, it is pertinent that more research be done on the biomechanical effects on runners using cushioned minimalist footwear.

Research on cushioned minimalist footwear and how it affects lower leg biomechanics is in its infancy. It has yet to be explored how cushioned minimalist footwear with a 0 mm heel/toe differential will affect lower extremity biomechanics. The purpose of this study was to compare if and how runners accustomed to running in traditional 12 mm cushioned differential shoes (Mizuno Wave Rider (Norcross, GA)) yet "novel" to running in minimalist shoes would change their lower limb running kinematics and kinetics when running in a cushioned 4 mm differential shoe (Saucony Kinvara (Lexington, GA)), a cushioned 0 mm differential shoe (Altra Intuition/Instinct (Logan, UT)), a 0 mm differential noncushioned shoe (Vibram El-X/Entrada (Albizzate, Italy)) and BF. We defined a "novel" minimalist shoe wearer as someone who had never run previously in minimalist shoes.

We hypothesized that runners novel to running in minimalist footwear would demonstrate little change in their lower limb running kinematics and kinetics when running in 4 mm or 0 mm differential cushioned shoes compared to traditional 12 mm differential cushioned shoes. We also hypothesized the stride rate would be higher, the time on ground would decrease and the vertical oscillation would decrease in the unshod and lower heel/toe differential shoes than in traditional footwear. We did not expect to see any acute change in the footstrike angle and other lower body angles in the different footwear.

Methods

Participants

This study examined male and female recreational runners that had been running 30 or more minutes at least three times a week for 6 months. Subjects needed to be able to run comfortably at 3.3 m/sec for 2 minutes. The age of the participants ranged from 18-31 years. Power analysis for each of our dependent variables determined that vertical impact peak required the greatest number of participants (10) to afford a power of 0.8 with an alpha set at .05. The study was delimited to runners who had 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 6 months or lower extremity injuries that prevented them from running. One subject was excluded because of blisters developed while performing the barefoot trial. 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 classes, local running clubs and the local running specialty stores. Subjects read and signed a Brigham Young University Institutional Review Board-approved informed consent form before beginning the study.

Procedures

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

The subjects ran on an AMTI Force-Sensing Tandem Treadmill (Watertown, VA). This treadmill has a front and rear belt to distinguish between feet when they are both on the ground. Each testing condition consisted of a 5-minute warm-up at a self-selected pace in one of the conditions (which was maintained for each warm-up for the other conditions), followed by a 2-

minute trial at a standardized pace (3.3 m/sec) which was followed by 5 minutes to change shoes and reapply markers. A static trial was completed for each footwear condition. The 5-minute warm-up was done to help the subject acclimate to running on the treadmill and/or to running in the novel 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 (Willy and Davis, 2014). Subjects were not advised to run with any particular footstrike pattern.

Visual markers were placed according to the VICON full body plug-in gait model (Oxford, UK). The last 60-second period of each 2-minute trial was recorded by the VICON Nexus capture system (Oxford, UK)(Belli, 1995). During postprocessing, VICON calculated right maximum knee flexion during stance, right maximum knee flexion during swing, right hip flexion, right hip extension, right ankle at touch down, right ankle at toe off and right foot angle at touch down. The trial was visually analyzed to verify that the footstrikes were similar throughout the allotted time. The footstrikes were not found to differ throughout any given trial. Both kinetic and kinematic data were sampled from VICON cameras (240 hertz/sec) and the force plates (1200 hertz/sec). Ground reaction force data were collected and compared to determine if the impact forces were affected by the heel/toe drop and cushioning of the various shoes. Vertical oscillation was determined by subtracting the minimum value of center of mass from the maximum value during a single-leg stance–swing cycle. Footstrike angles were calculated when the vertical impact peak exceeded 50 Newtons. The kinetic-dependent variables were the vertical impact peak, and the footstrike patterns determined by force data; the kinematic-dependent variables were stride rate, time on ground, and the lower body angles in the sagittal plane (knee angle during swing and stance and footstrike angle).

Statistical Analysis

Temporospatial stride characteristics (time on ground, stride rate and joint kinematics) and kinetics were analyzed using SPSS statistical software (IBM Corp., Armonk, NY, USA). MANOVA was used to determine differences between the dependent variables for the various shoe conditions. Statistically significant variables ($\alpha \leq 0.05$) were further analyzed using Tukey post hoc comparisons.

Results

Stride Rate

Significant differences were detected between the 12 mm heel/toe differential shoe and the barefoot condition ($p = .036$). People running barefoot demonstrated a higher stride rate (Table 1) as has been demonstrated in previous literature (Squadrone and Gallozzi, 2009). There were no differences detected between any of the other conditions.

Ground Time

Results indicated that ground time varied significantly between the 12 mm heel/toe differential shoe and the barefoot condition ($p = .019$). Running barefoot decreased the time the foot was on the ground compared to when running in footwear with a 12 mm heel/toe offset (Table 2). These findings have also been identified in previous studies (Hall et al., 2013; Hsu, 2012). Significant differences were not found between any of the other conditions.

Vertical Oscillation

Running barefoot decreased vertical oscillation compared to running in a 12 mm heel/toe differential shoe ($p = .017$). Tukey post hoc analysis showed that running in other footwear conditions did not affect the runners' vertical oscillation.

Vertical Impact Peak

The conditions under which the subjects ran did not significantly affect the vertical impact peak produced by the landing (p = .533).

Footstrike Angles

None of the conditions altered the subjects' footstrike angles, not even the barefoot condition (p = .565).

Lower Body Angles

The variables of right maximum knee flexion during stance (p = .081), right maximum knee flexion during swing (p = .639), right hip flexion (p = .948), right hip extension (p = .894), right ankle touch down (p = .756), and right ankle toe off (p = .683) were not affected by footwear conditions.

Discussion

The purpose of this study was to determine if runners accustomed to running in traditional footwear would acutely change their running mechanics when running barefoot or in footwear that had a lower heel/toe differential. The results showed that in all cases, running in footwear did not make a difference biomechanically in an acute running bout. Running without a shoe did cause biomechanical changes. Runners' stride rates increased, ground times decreased and vertical oscillations also decreased when running barefoot.

It is interesting to note that, although not statistically significant, the order of means across footwear for stride rate, ground time and vertical oscillation were identical (Tables 1-3). This order appears to be no cushioning to the most cushioning. Perhaps the amount of cushioning is of greater significance than the amount of heel/toe differential when transitioning from traditional to minimalist footwear.

Stride Rate

Previous research established that running barefoot increased stride rate when compared to running in shod conditions (Squadrone and Gallozzi, 2009). The results in this study confirmed those findings and expanded the scope to include various types of shoes that are advertised to produce barefoot running mechanics while in a cushioned environment. Even though some of the shoes had lower heels and varying amounts of cushion, stride rate did not change from running in traditional shoes. When protection around the foot was removed, 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 was able to move more quickly (Horvais and Samozino, 2013). Subjects commented that during the barefoot trial, they could feel the split between the front and rear belts of the treadmill. This could have also influenced why the stride rate was higher during the barefoot trial.

Ground Time

There is an inverse relationship between stride rate and ground time. As stride rate increases, ground time decreases (Hall et al., 2013). This relationship has been recognized in the findings of this study. When subjects ran in footwear that had 12 mm heel/toe differentials they had significantly longer ground time than when they ran barefoot. There were not any differences between the other conditions. The cushion and protection that a shoe provides may 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 (Aguinaldo and Mahar, 2003). Although there were not any differences between ground reaction forces, cushion makes the landing seem softer. Without a shoe, quicker steps might be taken to make running more comfortable, especially because of the aforementioned split in the treadmill.

Vertical Oscillation

Most studies that have looked at running biomechanics in shod vs. unshod conditions have not looked at vertical oscillation. In order to look at vertical oscillation a full body marker set is needed to identify center of mass in the subjects. Prior studies mainly used marker sets that focused on the lower body (Altman and Davis, 2012; Hatala et al., 2013; Lieberman et al., 2010; Williams et al., 2012).

Runners may reduce their vertical oscillation in unshod conditions to lower the amount of force with which they are landing. Less vertical oscillation allows less time to fall. It has been found that when running unshod, runners tend to rearfoot strike less often than when running shod. A rearfoot strike is associated with an impact transient that indicates a short period of time when the foot lands where force is produced quickly (Lieberman et al., 2010). Many unshod runners avoid landing with a rearfoot strike because it is uncomfortable; although we did not find any change in the footstrike patterns of unshod runners. These subjects may instinctively be trying to make the landing more comfortable. This may be the reason for the reduced vertical oscillation.

Footstrike Angles

Footstrike angles did not change while running in any of the conditions. It has been shown that running at faster self-selected paces can also affect footstrike (Nigg et al., 1987). Pace for this study was controlled at a speed that has not been shown to affect footstrike (3.3 m/s), whereas the uncontrolled and faster paces used in previous research have been shown to influence footstrike (Lieberman et al., 2010). The surface that people run on has also been theorized to influence footstrike. Habitually unshod populations have been shown to rearfoot strike (Hatala et al., 2013) as well as mid- and forefoot strike (Lieberman et al., 2010). The fact that our subjects ran on a treadmill, which is known to have varying degrees of hardness, at a controlled pace and after warming up for 5 minutes with the shoe (Belli, 1995) could have reduced all the chance of subjects changing their footsrike. A large variability between subjects decreased our ability to detect significance between running conditions, although similar studies that have found significance have used fewer subjects (Squadrone and Gallozzi, 2009).

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 during the various treatment conditions. The post hoc power of these variables was lower than projected which indicates that the variability found in these variables decreased our ability to find significant differences with the sample size that was used. Post hoc power analyses ranged from .11 to .35 on the lower body angle variables. Most of these angles were not included in our initial power analysis.

Limitations

The scope of this study only applies to runners that have been training in traditional footwear. As well, we only examined what the acute kinematic and kinetic responses were when changing to novel footwear (shoes with reduced heel/toe differential and cushioning) and barefoot running. It is not known how these same runners would react to running in any of the conditions for a prolonged period of time. More research needs to be done with runners that are using minimalist cushioned footwear as the running shoe in which they primarily run. This is important because almost every running shoe company offers a cushioned minimalist shoe and some big shoe companies, such as Saucony, almost exclusively make shoes that no longer have the traditional heel/toe differential. It is unknown how or if prolonged running in cushioned minimalist shoes will change runners' biomechanics from what has been observed in runners that began their running in traditional running footwear.

Conclusion

Our research indicates that the purported benefits of changed running mechanics accredited to minimalist running shoes does not happen acutely when runners accustomed to running in traditional cushioned 12 mm heel/toe differential shoes first run in the minimalist shoes.

Running barefoot compared to traditional footwear is apparently a dramatic enough difference for the body to alter stride rate, ground time and vertical oscillation. More research needs to be done to see if longer periods of transitioning from traditional footwear to minimalist footwear results in kinematic and kinetic changes in running mechanics. We also recommend that future research address the differences in cushioning of various footwear when transitioning from traditional to minimalist shoes.

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Table 1 Stride Rate

Condition	Mean (strides/second)	Standard Deviation
Barefoot	1.487*	.116
Vibram	1.425	.099
Four mm Drop Shoe	1.391	.089
Zero mm Drop	1.387	.089
Twelve mm Drop Shoe	1.367*	.075

Note. An asterisk (*) indicates differences between groups at $p < .05$ in the Tukey post hoc analysis.

Table 2 Ground Time

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

Note. An asterisk (*) indicates differences between groups at $p < .05$ in the Tukey post hoc analysis.

Table 3 Vertical Oscillation

Condition	Mean (cm)	Standard Deviation
Barefoot	7.722*	1.316
Vibram	8.196	1.182
Four mm Drop Shoe	8.908	1.291
Zero mm Drop Shoe	8.956	1.541
Twelve mm Drop Shoe	9.031*	1.197

Note. An asterisk (*) indicates differences between groups at $p < .05$ in the Tukey post hoc analysis.

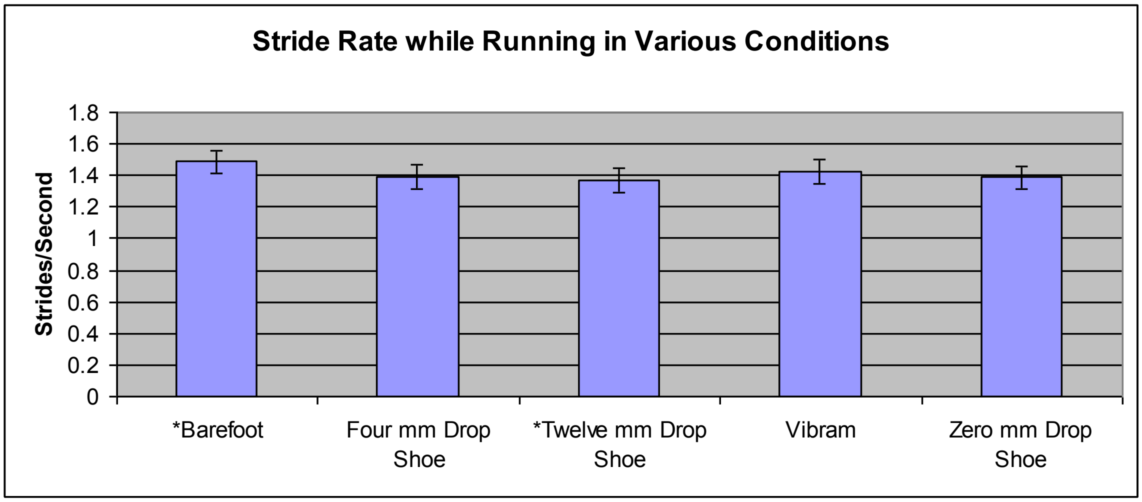

Figure 1 Stride Rate

Note. An asterisk (*) indicates differences between groups at $p < .05$ in the Tukey post hoc analysis

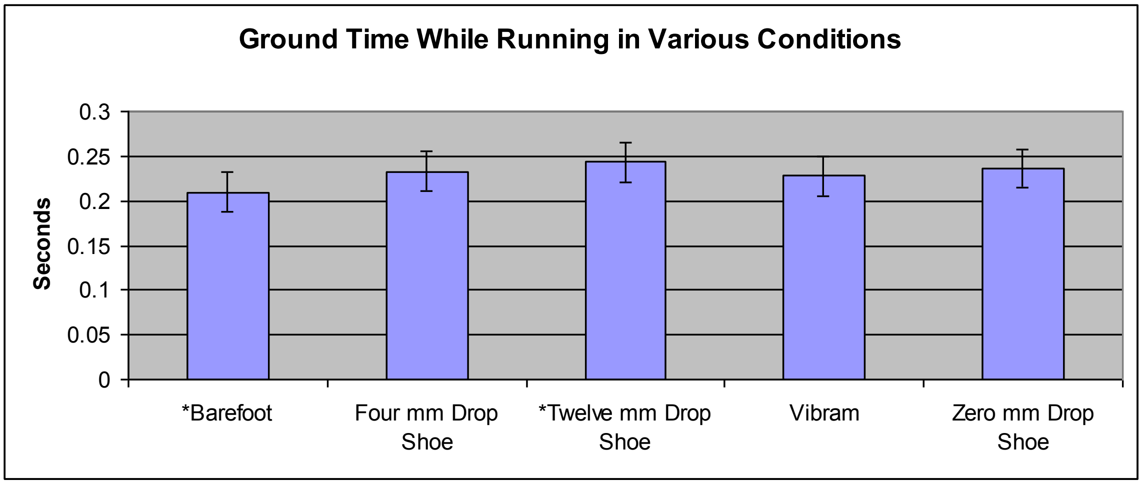

Figure 2 Ground Time

Note. An asterisk (*) indicates differences between groups at $p < .05$ in the Tukey post hoc analysis

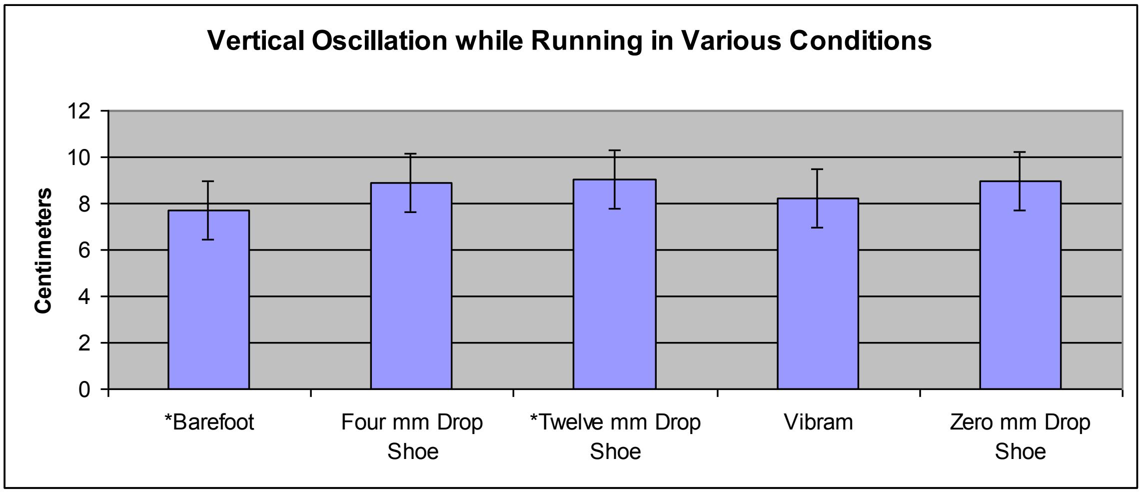

Figure 3 Vertical Oscillation

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