ACUTE EFFECTS OF DIFFERENT CUSHIONED FOOTWEAR ON THE BIOMECHANICS OF RUNNING

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The purpose of this study was to investigate how different footwear (highly cushioned, standard, minimalist shoes) affect peak ground reaction forces, average loading rates and joint kinematics during running. Nine participants ran at a self-selected speed across all shod conditions, minimalist, highly cushioned and standard running shoe. Vicon Nexus was used to analyze joint kinematics of the ankle and knee, a Bertec Instrumented Treadmill was used to analyze the average loading rate and peak ground reaction forces. Results show consist of reductions in ankle and knee joint motion in the minimalist shoe during the stance phase with the standard and highly cushioned shoe being more similar to each other. Evidence suggests that a change in footwear alone, at least in the short-term, will not reducing injury rates in runners.

KEY WORDS: Footwear, Running, Joint Kinematics, Forces

INTRODUCTION: With the introduction of cushioned running shoes in the 1970’s, running experienced a “Running Boom”. Recreational running has steadily gained in worldwide popularity ever since and is the primary exercise modality for many individuals of all ages (State of the Sport, 2014). According to Running USA 54 million people ran at least once during 2013. Of those approximately 30 million ran at least 50 days during 2013. Additionally nearly 19 million people completed organized road races in 2014 (State of the Sport, 2016).

With more American’s participating in competitive and recreational running, the incidence of injuries has increased with nearly 80 percent of runners experiencing at least one lower extremity injury (Van Gent, et. al., 2007). It has been proposed that a change in footwear may have an impact in the reduction of injury. Two possible solutions in footwear alterations include decreasing the cushioning in the shoe to better mimic barefoot running or increasing the cushioning to help absorb impact forces on the runner.

Barefoot and minimalist footwear have been researched showing alterations in the gait cycle and impact forces (Bonacci, et.al. 2013, Shih, Lin and Shiang, 2013, Willy and Davis, 2014). These results may indicate that these “natural” running styles may assist with reducing injury; however, these results often show conflicting kinematic changes depending on the experience of the runners. For example, it is, has also been shown that minimalist shoes may increase the knee flexion with runners lacking experience in minimalist shoes (Shih, et. al., 2013, Willy and Davis, 2014) however, another study shows that footwear does not affect knee angles. In addition, data is lacking on the joint kinematics in highly cushioned shoes. Thus, more research is needed to understand the effects of these footwear designs.

Newer trends in footwear design have been towards increasing the cushioning in running shoes. The limited research on highly cushioned footwear have shown a possible increase in the vertical average loading rate compared to traditional shoes? with no other differences in variables related to ground reaction force (Ruder, Atimetin, Futrell, and Davis, 2015).

The purpose of this study was to investigate how different footwear (highly cushioned, standard, minimalist shoes) affect peak ground reaction forces, average loading rates and joint kinematics during running.

METHODS: Nine (5 male and 4 female) self-reported healthy runners (Age:29.3±8.27; Height:1.71m±0.11m; Weight:64.56kg±10.97kg) ran at a self-selected pace (average pace: 3.10m/s±0.40m/s) that could be maintained for all conditions. All participants were recreational runners who run at least 10 miles a week (average mileage: 25.67miles±10.89miles) and had been free of any lower extremity injury at least 6 months prior to participation in the study. Also, no participants in the current study have experience running in a minimalist or highly cushioned shoe. All participants signed an informed consent approved by the Utah Valley University Institutional Review Board.

Motion and force data were collected using a 16 camera Vicon Nexus system (Vicon, Inc, Oxford, UK) and a Bertec Instrumented Treadmill (Bertec, Inc., Columbus, OH), respectively. Participants completed running trials in a standard running shoe (ST), a highly cushioned running shoe (HC), and a minimalist running shoe (MN). Each participant was outfitted with 52 reflective markers on the lower extremity, pelvis and trunk. The markers were placed on the anterior superior iliac spine, posterior superior iliac spine, medial and lateral femoral epicondyle, medial and lateral malleolus, posterior superior and posterior inferior heel, medial and lateral heel, big toe, and first and fifth metatarsal on each leg, and the acromion process of each shoulder. A cluster of 4 reflective markers on a thermoplastic shell was placed on the lateral thigh, tibia, posterior pelvis, and posterior trunk.

Upon coming into the lab participants were fitted with the reflective markers and a static position was recorded. The participants were asked to perform a 5 minute warm up consisting of light jogging on the treadmill at a self-selected pace. Following the warm-up, three shod conditions (standard, minimalist and max cushioning) were chosen randomly for each participant. The running pace was self-selected and the same across all the trials. Each running trial lasted for approximately three minutes. Participants were brought up to speed on the treadmill and allowed one minute to adjust to the speed. Once comfortable 5 trials each lasting 5 seconds were recorded.

The data were analyzed using Visual 3D (C-Motion, Inc, Germantown, MD). A repeated measures ANOVA was used in SPSS (IBM, New York, NY) to analyze condition differences ($\alpha=0.05$).

RESULTS: Several significant kinematic were observed between shoe conditions during the stance phase of running (See Table 1). The ankle sagittal range of motion (AROM) showed a main effect (p=0.040) a significant increase in HC (M=32.48º) over the MN (M=24.42º) condition (p=0.015); no significant effect exists between ST (M=29.22º) and HC (p=0.255) although between ST and MN there appears to a moderate to strong effect size ($\eta^2=0.363$) that may prove to be significant in a larger sample.

The knee sagittal range of motion (KROM) during stance showed significant main effect change (p=0.003) as well as changes across all pairwise comparisons. Specifically, ST (M=24.47º) showed the largest range of motion when compared to the HC (M=20.58º; p=0.006) and the MN (M=13.76; p=0.009). Although non-significant statistically (p=0.062), the comparison of KROM for the ST and HC showed a large effect size using a partial eta squared test ($\eta^2=0.635$) strong effect which may be significant with a larger sample size.

The peak knee flexion during weight acceptance showed a main effect (p=0.009) as well as a pairwise comparison between MN (M=39.58) and both ST (M=41.32) and HC (41.47) (p=0.004 and 0.030, respectively).

Knee extension velocity (KEV) showed a main effect (p=0.021) represented in the pairwise comparison showing a significant increase in the ST (188.72º/sec) condition when compared to MN (86.90º/sec; p<0.001); no significant differences were shown between HC (M=153.06º/sec) and ST or MN (p=0.378 and 0.139, respectively). Comparison of the MN and HC for effect size

showed a moderate to large effect (η^2=0.383) which also may be significant with a larger sample size.
All other sagittal plane ankle and knee kinematics were non-significant.

Table 1
Joint kinematic changes across shoe conditions

	Standard Shoe	Minimalist Shoe	Highly Cushioned Shoe
AROM	29.22±6.40º	24.42±6.80º *	32.48±4.82º *
KROM	24.47±2.16º *	13.76±10.34º *	20.58±2.80º *
PKF	41.32±4.53º *	39.58±4.66º *	41.47±5.43º *
KEV	188.72±50.33º/sec *	86.90±64.81º/sec *	153.06±102.85º/sec

*=significant (p<0.05)

Peak vertical ground reaction forces (PVGRF) normalized to body weight and vertical average loading rates (VALR) were found to be non-significant (p=0.464 and 0.513, respectively) (See Table 2)

Table 2
Peak ground reaction forces and peak loading rates shoe conditions

	Standard Shoe	Minimalist Shoe	Highly Cushioned Shoe
PVRGF (N/BW)	2.185±0.081	2.161±0.106	2.296±0.083
VALR (N/s)	52.47±13.33	58.43±11.23	54.28±10.19

DISCUSSION: There is evidence to suggest that shoe type can lead to alterations in joint kinematics at the knee and ankle in runners unfamiliar with minimalist or highly cushioned shoes. Previous studies have also suggested that these variables are altered when comparing different footwear (Fredericks, et. al., 2015, Shih, et. al., 2013, Squadrone, et.al., 2015, and Willy and Davis, 2014) These alterations in the current study consist of reductions in ankle and knee joint motion in the minimalist shoe during the stance phase with the standard and highly cushioned shoe being more similar to each other. Although not significant in the current study, there is a trend that shows the knee flexion and ankle dorsiflexion at contact may increase in the minimalist shoe. This could corroborate the findings of Willey and Davis (2015).
This finding combined with the decrease in the knee extension velocity during stance, and a decrease in the peak knee flexion during weight acceptance, may indicate that some runners may be altering muscle firing patterns. Potentially it seems that during weight acceptance participants move muscle activity away from those responsible for controlling knee flexion with gravity towards the hip when running in minimalist footwear. The decreased knee extension velocity during the propulsive phase suggests that the agonist muscles for knee extension may be working less during this phase in the minimalist shoe compared to the other conditions. This may allow for less fatigue at the knee joint during prolonged running, but it is important to consider if this then places a greater demand on the hip during the propulsive phase. An understanding of the hip joint would help to better understand if this redistribution of muscle function is occurring. The decrease in the knee range of motion may also indicate that there may be some co-contraction around the knee as part of a potential redistribution of moments within the lower extremity. This could potentially be due to the current runners being unfamiliar with minimalist shoes and attempting to compensate for the lack of cushioning within the shoe. However, the decrease in the range of motion at the knee may create a more rigid system that will not dampen the forces at the knee causing the potential for increased injury at that joint.
The ankle range of motion changes may further support the theory that there is a redistribution in the muscle activity in the lower extremity as the minimalist shoe significantly decreases, especially when compared to the highly cushioned shoes. Additionally, the shape and material

of the highly cushioned sole may allow for more "play" in the shoe which may allow for a greater range of motion, however it does not appear that this is effective in reducing the average loading rate, which has been related to injury potential, or the peak ground reaction forces.
This study is not without limitations. The use of a treadmill may not compare completely with running overground (Sinclair, 2014). Also, the current participants were not habituated to the minimalist or highly cushioned running. Additionally, further research is needed to examine the role of the hip and the musculature in the lower extremity to further understand the acute alterations from a muscular, kinematic and kinetic stand-point.

CONCLUSION: The goal of the current project was to examine the acute changes in joint kinematics at the ankle and knee and ground reaction forces that occur with changing footwear. It appears as if much of the alterations in joint kinematics of the ankle and knee, at least in the initial adaptations to a new shoe, may be greater in a minimalist shoe than those of cushioned shoes. However, it does not appear, at least in the short term, that footwear alone will reduce injury rates in regular runners.

REFERENCES:

Bonacci, J., Saunders, P.U., Hicks, A., Rantalainen, T., Vicenzino, B.T. and Spratford W. (2013) Running in a minimalist and lightweight shoe is not the same as running barefoot: a biomechanical study. *British Journal of Sports Medicine* 47,387-392.

Fredericks, W., Swank, S., Teisberg, M., Hampton, B., Ridpath, L., and Hanna, J.B. (2015) Lower Extremity Biomechanical Relationships with Different Speeds in Traditional, Minimalist and Barefoot Footwear. *Journal of Sports Science and Medicine* 14, 276-283.

Kerrigan, D.C., Franz, J.R., Keenan, G.S., Dicharry, J., Della Croce, U. and Wilder RP. (2009) The effect of running shoes on lower extremity joint torques. *Pain Management & Rehabilitation* 1, 1058-1063.

Ruder, M., Atimetin, P., Futrell, E. and Davis, I. (2015) Effect of Highly Cushioned Shoes on Ground Reaction Forces during Running. *Medicine & Science in Sports & Exercise* 47,293-294

Shih, Y., Lin, K-L. and Shiang, T-Y. (2013) Is the foot striking pattern more important than barefoot or shod conditions in running? *Gait & Posture* 38, 490-494.

Sinclair, J. (2014) Effects of barefoot and barefoot inspired footwear on knee and ankle loading during running. *Clinical Biomechanics* 29, 395-399.

Squadrone, R., Rodano, R., Hamill, J., and Preatoni, E. (2015) Acute effect of different minimalist shoes on foot strike pattern and kinematics in rearfoot strikers during running. *Journal of Sports Sciences* 33, 11, 1196-1204.

State of the Sport (2014, June 15). Part II: Running Industry Report. Retrieved September 28, 2016, from http://www.runningusa.org/2014-state-of-the-sport-part-ii-running-industry-report

State of the Sport (2016, May 6). 2016 - U.S. Road Race Trends. Retrieved September 28, 2016, from http://www.runningusa.org/state-of-sport-us-trends-2015

Van Gent, R.N., Siem, D., van Middlekoop, M., van Os, A.G., Bierma-Zienstra, S.M.A., and Koes, B.W. (2007) Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. *British Journal of Sports Medicine* 41, 5, 469-480.

Willy, R., and Davis, I.S. (2014) Kinematic and kinetic comparison of running in standard and minimalist shoes. *Medicine & Science in Sport and Exercise* 46, 2, 318.