The Influence of Traditional Shoes, Minimal Shoes and Barefoot on Ankle Kinematics in Youth During Running

by
Hunter Hartman

A THESIS

submitted to

Oregon State University

Honors College

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degree of

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(Honors Scholar)

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AN ABSTRACT OF THE THESIS OF

Hunter Hartman for the degree of Honors Baccalaureate of Science in Kinesiology presented on March 9, 2021. Title: The Influence of Traditional Shoes, Minimal Shoes and Barefoot on Ankle Kinematics in Youth During Running.

Abstract approved:____

Christine Pollard

Introduction: Research has demonstrated that minimal shoes may help prevent ankle injuries by mimicking natural barefoot running. It has been proven that minimal shoes may help adults prevent injuries in the correct conditions, but little is known about the effect of minimal and barefoot running on youth kinematics. *Purpose:* To determine how minimal shoes compare to barefoot and traditional shoe conditions with respect to ankle kinematics in youth. *Methods:* 14 male adolescent participants were recorded running while three-dimensional kinematics were measured. Sagittal and frontal plane joint angles were measured for excursion and peak angles as well as on initial contact and toe off. *Results:* For the frontal plane significance was found between conditions in peak eversion, frontal plane excursion, inversion at toe off, and inversion at initial contact. For the sagittal plane significance was found between conditions in peak dorsiflexion and dorsiflexion at initial contact. *Conclusion:* There were many similarities and some differences in ankle kinematics between minimal shoe and traditional shoe conditions while running barefoot resulted in mostly unique kinematics. This information can assist individuals and healthcare practitioners in the selection of running footwear for youth and will help build the foundation for future research on this topic.

Key Words: Footwear, running, ankle, kinematics, motion analysis, children, minimal footwear, barefoot

Corresponding e-mail address: Hartmahu@oregonstate.edu

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Honors Baccalaureate of Science in Kinesiology project of Hunter Hartman presented on March 9, 2021.

APPROVED:

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Christine Pollard, Mentor, representing Program of Kinesiology

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Timothy Burnett, Committee Member, representing Program of Kinesiology

____

JJ. Hannigan, Committee Member, representing Program of Kinesiology

____

Andrew Traut, Committee Member, representing Program of Kinesiology

____

Kara Witzke, Committee Member, representing Program of Kinesiology

____

Toni Doolen, Dean, Oregon State University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

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Hunter Hartman , Author

CONTRIBUTION OF AUTHORS

Dr. Christine Pollard, Justin Ter Har, and Dr. JJ Hannigan helped with study design and data collection, data processing and data analysis. Dr. Pollard also helped with manuscript creation as well as interpretation of results.

INTRODUCTION

Human footwear is a relatively recent creation initially used in the Upper Paleolithic period to protect the foot from environmental factors such as cold and terrain. Footwear evolved from there into thicker soled shoes, and finally into what we see today (Trinkaus, 2005). The traditional running shoe gained popularity in the 1970's with a boom in recreational running and a subsequent increase in running related injuries. Traditional running shoes feature integral cushioning along the midsole as well as heel-to-toe drop which is characterized by more cushioning beneath the heel than the forefoot. These features were added in order to make running more comfortable and safer for recreational and competitive runners (Rixie et al., 2012). While traditional running shoes with cushion may have made running more comfortable for many, there are still high injury rates in the running population. At any given time twenty five percent of the running population is injured, and fifty percent are injured at some point each year, with the most common injuries being muscular strains and ligamentous sprains, tendinopathy and general pain (Fields et al., 2010; Marshall et al., 2020).

Variations in the traditional running shoe have persisted for decades. High injury rates have led to the more recent development of novel footwear such as minimal running shoes. Minimal running shoes are lightweight shoes with little to no cushion or heel-to-toe drop. They are designed to mimic natural barefoot running which has been theorized to prevent running injuries by promoting shock attenuation through musculature and joint pliability rather than relying on the cushion of the shoe. Minimal running shoes are designed to offer protection from the environment while minimizing restriction on foot motion. It is theorized that they also provide greater proprioception as the runner is able to feel the ground and adjust their running accordingly (Rixie et al., 2012). While minimal running shoes were initially developed to decrease the risk of injury, that was not the case. It has been theorized that transitioning directly from cushioned running shoes to minimal shoes or barefoot running without proper training or transition may lead to injury. This is because the direct transition does not give enough time for the muscles to build and the body to adapt to the lack of support from the shoe (Davis et al., 2017).

In order to avoid injury when transitioning to minimal shoes, it may be beneficial to change foot strike patterns. Davis et al. (2017) has shown that adults who grew up wearing traditional running shoes typically run with a rearfoot strike pattern (landing on the heel). In contrast, individuals who grew up not wearing shoes, exhibited a greater prevalence of forefoot striking (landing on the ball of the foot).

Based on work of Willems et al. (2017), some might expect that kinematics of barefoot and minimal running would be relatively similar. This theory is backed up by the popular idea that minimal shoes can mimic barefoot running while also protecting from the elements. It has been shown in adults that minimal running successfully imitates barefoot running in some kinematic variables, however, it remains to be seen whether the same holds true for youth.

Forefoot striking in adults has been shown to involve changes in the biomechanical variables of running. For example, Valenzuela et al. (2015) found that forefoot striking patterns had significantly lower dorsiflexion range of motion when compared to rearfoot striking patterns. Similarly, Bonacci et al. (2013) found that in 22 highly trained adult athletes, barefoot running was related to less dorsiflexion, but greater work done at the ankle. Although these forces are higher during forefoot striking, the body can adapt to these stresses through training and make forefoot striking comfortable (Sun et al., 2020; Valenzuela et al., 2015).

It has also been shown in a study by Ramanathan et al. (2011) that as footwear thickness increases, the peroneus longus muscle activates far sooner after initial contact. This activation happens to mitigate the sudden foot inversion caused by an increasing moment at the subtalar joint. This means that as footwear increases in thickness, the greater the foot inversion.

The ankle is one of the most injured joints in the body, as it supports a great deal of mass while maintaining dynamic motion. Because of this, footwear can affect joint motion and therefore ankle injury in the following ways. An analysis by Bekerom et al. (2012) found that having more motion in the ankle, specifically inversion and supination, significantly contributed to lateral ankle sprain. It was also found that about twenty five percent of all musculoskeletal injuries are inversion-related injuries at the ankle. This means that the added motion that comes with wearing a traditional shoe (and running with a heel strike foot pattern) may predispose runners to inversion ankle sprains. Morrison et al. (2007) further explored the link between inversion, extreme plantarflexion, and lateral ankle sprain. In a 52 week prospective cohort study on 225 recreational runners it was found that there were significantly more injuries when runners had late timing for maximal eversion (20.7% more injuries) (Morrison et al., 2007; Jungmalm et al., 2020).

Greater eversion also has implications for injury as greater peak eversion has been linked to shin splints in endurance runners (Hreljac, 2004; Messier et al., 1988). Furthermore, a study examining navicular stress fractures found that greater peak eversion was related to navicular stress fractures in adult runners compared to a control group (Becker et al; 2017). Pohl et al. (2009) reported that plantar fasciitis (a common running injury) was significantly linked to increased dorsiflexion. This kinematic variable can be mitigated using minimal footwear and may decrease the prevalence of plantar fasciitis. Lieberman et al. (2010) found that habitually unshod or minimally shod runners experienced greater plantarflexion at initial contact which may allow the foot to act as a spring and the ankle to have some flexibility to slow the impact of the runner. According to Rixie et al. 2012, “landing softly” on the forefoot (allowing the musculature and motion at the joint to absorb impact) and generally practicing good running form are adaptations that may reduce injury. It has also been theorized that youth may adapt better to these novel running patterns.

Overall, footwear design greatly affects ankle kinematics during running in adults. It has been theorized that minimal footwear should mimic barefoot running in adults but has had mixed results in practice. It has been shown that traditional footwear may increase the risk of injury in adults through increases in eversion and dorsiflexion. While there are numerous studies examining the influence of minimal footwear on running biomechanics in adults, there are few studies examining this relationship in youth. Therefore, the purpose of this study was to examine the influence of traditional shoes, minimal shoes, and barefoot on ankle kinematics during running in youth.

METHODS

Prior to data collection, all participants signed an informed consent form approved by the Institutional Review Board. To be included in the study, participants needed to be between 9 and 12 years old (prepubescent), report no major injuries for at least the previous 6 months, have never worn a minimal or maximal running shoe, and be considered a rearfoot striker (determined by the research team). All foot strike patterns were confirmed visually by inspecting the 2D video of each trial. Fourteen male participants met these criteria and were included in this study.

Participants were outfitted with 21 reflective markers and 6 rigid marker clusters. Individual reflective markers were placed bilaterally over the following anatomic landmarks: the first and fifth metatarsal heads, distal interphalangeal joint of the second toe, medial and lateral malleoli, medial and lateral femoral epicondyles, greater trochanters, anterior superior iliac spines, and iliac crests. A single marker was placed on the joint space between the fifth lumbar and the first sacral spinous processes. Four marker clusters containing quadrads of reflective markers were attached bilaterally to the participant's thigh and leg with a custom adhesive taping system. In addition, two marker cluster triads were placed bilaterally on the heel counter of the shoe for the shoe conditions and directly on the posterior aspect of the calcaneus for the barefoot condition. Markers were always placed by the same researcher. The traditional running shoe used in this study was the New Balance 880 (drop: 13.3mm; heel height: 32.5mm; forefoot height: 19.2mm), the minimal running shoe in this study was the Xero Prio Youth (drop: 0mm; heel height: 11.0mm; forefoot height: 11.0mm).

The order of conditions (barefoot, minimal shoe, traditional shoe) was randomly assigned prior to data collection. After marker placement on the first shoe, a static standing calibration trial was conducted. The participant then switched to the second randomized condition, individual markers and marker triads were re-placed on the new shoe or foot, and another static calibration was collected. This was then repeated for the third condition. After all calibration trials were complete, all markers were removed except the six marker clusters and individual pelvis markers.

Participants completed three to five practice trials so that they could acclimate to running in the laboratory with the reflective markers and determine their comfortable running pace. Once their comfortable pace was established, timing gates within the capture volume measured running speed for each trial. Their comfortable pace was determined for the rest of the data collections, and only trials which fell within ±5% of their established comfortable pace were considered successful. This pace was maintained for each shoe condition.

After the practice trials, participants completed five successful trials landing on the force plate with their dominant limb (the leg a participant would use to kick a soccer ball) for each condition. For each trial, participants ran overground toward two force platforms located in series within the capture volume. Runners generally ran between 7–10 meters before the first force platform, and continued to run for 3–5 meters after the second force platform. In addition to matching the prescribed pace, trials were considered successful if the participant was able to contact the specified foot entirely on the force platform. Following completion of the five successful running trials, this procedure was repeated for the next two shoe conditions.

Ankle joint kinematics were collected using an 8-camera Vicon motion capture system (Oxford Metrics Ltd) sampling at 250 Hz, while ground reaction forces were collected using two AMTI force platforms (Advanced Mechanical Technologies, Inc., Newton, MA, USA) sampling at 1000 Hz. The force platforms were interfaced to the same computer used for kinematic data collection via an analog to digital converter, which allowed for synchronization of kinematic and kinetic data in Vicon Nexus 1.8.5 motion capture software.

The first four trials where the participant successfully hit the force platform were selected for analysis. Marker trajectories were identified using Vicon Nexus motion capture software and were smoothed using a low-pass, fourth-order, zero-lag Butterworth filter with a 12 Hz cutoff, while kinetic data were filtered with a fourth-order zero-lag Butterworth 50-Hz low-pass filter. Visual3D software (C-Motion, Inc) was used to calculate ankle kinematics using a joint coordinate system approach. Peak angles were defined as the maximum joint angle during stance phase, while excursion was defined as the difference between the maximal and minimal angle during the stance phase in that plane of motion.

Kinematic variables of interest included eversion and dorsiflexion angles (angle at initial contact, peak angle, excursion in that plane, and angle at toe-off). Biomechanical differences between the three conditions were determined using repeated measures ANOVAs with the omnibus alpha-level set to 0.05. Follow-up pairwise comparisons with Bonferroni corrections were made when a main effect of shoe was present. All statistics were calculated using SPSS version 25 (IBM) and a significance level of $p<.05$.

RESULTS

Of the 14 participants that were included in this study (average age 10±1.12 years; average height: 1.42±.06m; mass: 35.35±5.9kg), all continued using a rearfoot striking pattern across all three conditions determined by reviewing the 2D high speed footage.

Frontal Plane Kinematics

Participants exhibited greater peak eversion in the traditional and minimal shoe conditions compared to the barefoot condition (traditional shoe: 10.03°±4.26° vs. barefoot: 4.54°±2.86°: $p=.004$) (minimal shoe 9.98°±3.55° vs. barefoot 4.54°±2.86°: $p<.001$) but there was no significant difference between the traditional and minimal shoe conditions (Figure 1A). Participants exhibited significantly less frontal plane excursion in the barefoot condition compared to the minimal shoe condition (barefoot: 9.05°±2.02° vs. minimal shoe: 12.60°±3.64°; $p=.002$). In addition, they exhibited significantly less frontal plane excursion in the traditional shoe compared to the minimal shoe (traditional shoe: 10.29°±3.82° vs. minimal shoe: 12.60°±3.64°; $p=.002$). There was no significant difference in frontal plane excursion between the barefoot and traditional shoe conditions (Figure 1B). There was a significant difference in inversion at toe off across all conditions (barefoot vs. traditional shoe p<0.001: barefoot vs. minimal shoe p<0.001; minimal shoe vs. traditional shoe p=0.02) with greatest inversion at toe-off occurring during the barefoot condition (8.92°±2.94°) followed by the minimal shoe condition (4.02°±3.80°), and then finally the traditional shoe condition (0.31°±4.30°) (Figure 1C).

The traditional shoe condition produced significantly lower inversion at initial contact compared to the barefoot condition (traditional shoe 0.26°±5.59° vs. barefoot 4.51°±3.02°; p=0.034). No significance was found between the minimal shoe and the other variables. (Figure1D).

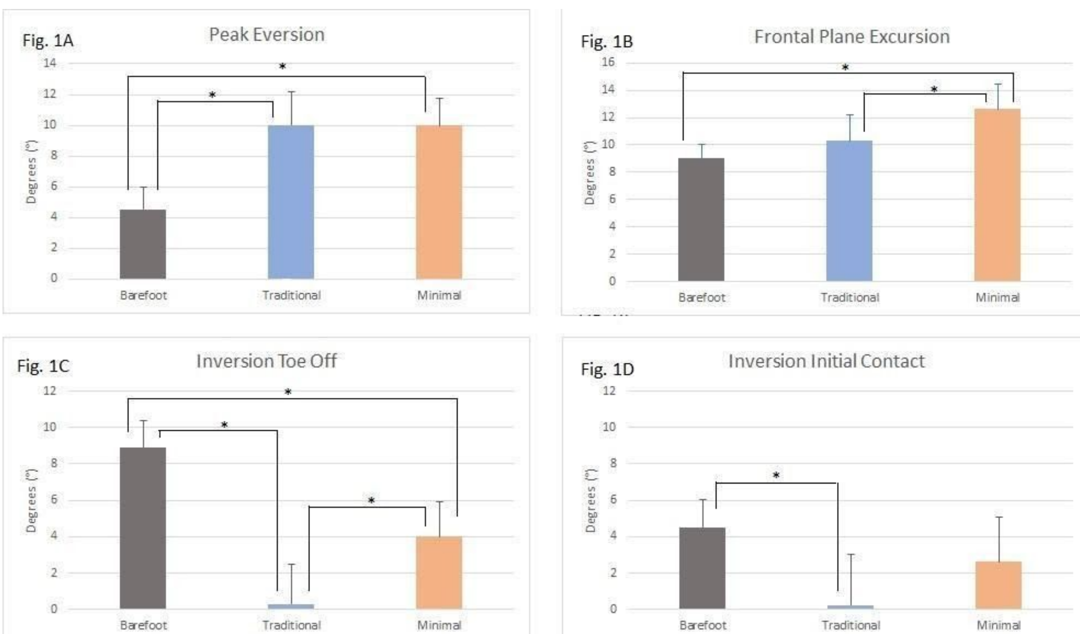

Figure 1: *Frontal plane ankle kinematics during the stance phase of running in barefoot, traditional and minimal shoe conditions. Significance of p<0.05 indicated by asterisk.*

Sagittal Plane Kinematics

Participants exhibited significantly lower peak dorsiflexion in the barefoot condition compared to the traditional shoe conditions (barefoot: 14.03°±3.10° vs. traditional shoe: 20.06°±2.74°; p<0.001) (Figure 2A). Participants exhibited significantly less dorsiflexion at initial contact in the barefoot condition compared to the traditional shoe condition (barefoot: 0.24°±2.65° vs. traditional shoe: 3.43°±3.95°; p=0.045) (Figure 2B). There were no other differences in dorsiflexion at initial contact and there were no differences in sagittal plane excursion between conditions (Figure 2C).

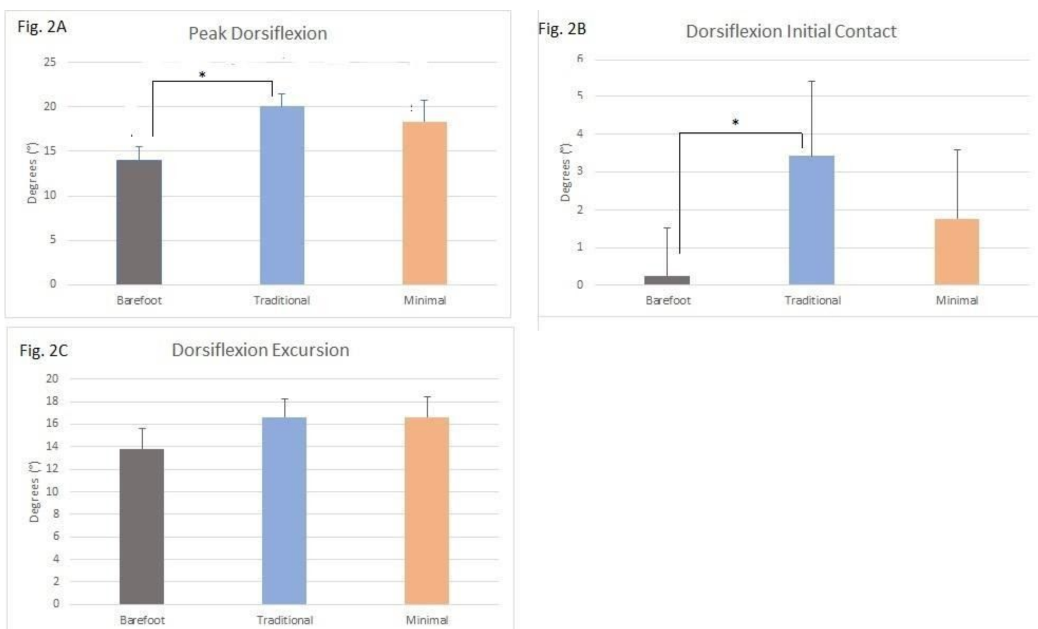

Figure 2: *Sagittal plane ankle kinematics during the stance phase of running in barefoot, traditional and minimal shoe conditions. Significance of p<0.05 indicated by asterisk.*

DISCUSSION

Our findings demonstrate that when youth run in minimal shoes, they exhibit ankle kinematics that are mostly unique when compared to running in traditional shoes or barefoot. The barefoot condition produced significantly lower peak dorsiflexion than the traditional shoe condition or the minimal shoe condition (see Figure 2A). This was expected and supported by current research (Valenzuela et al., 2015; Bonacci et al., 2013; Sun et al., 2020; Pohl et al., 2009). The traditional shoe condition also promoted significantly more dorsiflexion than the barefoot condition, as expected. The minimal shoe, however, had no significant difference in dorsiflexion compared to the traditional condition. This was unexpected as De Wit et al. (2000) has shown that there is a significant difference in dorsiflexion between thicker and thinner shoe soles.

The minimal shoe condition produced significantly less dorsiflexion at initial contact compared to the traditional shoe condition and slightly more dorsiflexion at initial contact compared to the barefoot condition. This agrees with current research that the traditional shoe condition should produce the greatest dorsiflexion at initial contact and the barefoot the least (Liberman et al., 2010; Bonacci et al., 2013).

These sagittal plane differences may have implications for injury. Becker et al. (2017) found a link between increased dorsiflexion while running and navicular stress fractures, a common chronic running injury. In addition, Messier et al (1988) suggests that greater dorsiflexion at initial contact may be related to shin splints in runners. This may be because greater dorsiflexion at initial contact may increase the impact forces, impact peak and loading rate and cause injury (Davis et al., 2017; Willy et al., 2013; Milner et al., 2006; Zadpoor et al., 2011). Therefore, significantly less dorsiflexion in the barefoot condition (and slightly less in the minimal shoe condition) may reduce the incidence of injury in runners.

While the barefoot condition produced the least dorsiflexion, there was no incidence of forefoot striking. This was unexpected as this result contradicts research on adults, which shows that as the amount of cushion increases, so does the prevalence of heel striking (Davis et al., 2017; Hamill et al., 2011). This difference may be because this study focused on running biomechanics in youth where there is relatively scant literature.

When examining the frontal plane, peak eversion did not follow the same pattern across conditions. The barefoot condition produced the lowest peak eversion, and the minimal shoe and traditional shoe produced almost identical values which were over fifty percent higher than the barefoot condition. Therefore, the minimal shoe did not change peak eversion; rather, the participants everted similarly to how they would in a traditional shoe which was not expected. Our frontal plane ankle findings also demonstrate that both inversion at initial contact and at toe off were greatest in the barefoot condition, next greatest in the minimal condition, and lowest in the traditional condition. This contrasts with De Witt and colleagues (2000) who found that as shoe sole thickness increases, so does inversion at initial contact. It may be the case that when running barefoot, these youth utilized their musculature to stabilize the ankle in the frontal plane which, in turn, reduced and/or eliminated eversion throughout the stance phase of running.

These frontal plane findings have implications for injury risk as greater peak eversion has been linked to shin splints in endurance runners (Hreljac et al., 2004; Messier et al., 1988). A study examining navicular stress fractures found that greater peak eversion was related to navicular stress fractures in adult runners compared to a control group (Becker et al., 2017). A study by Pohl et al. (2008) shows that a history of tibial stress fractures was associated with peak eversion during running. Therefore, the greater peak eversion produced by the traditional condition may be more likely to cause tibial stress fractures than the barefoot and minimal condition which produces less peak eversion.

A limitation to this study is that it was conducted in a laboratory setting which may have caused the participants to run differently than how they would normally. This may be due to several factors such as the hard floor and force platform targeting. Marker placement also has inherent limitations as markers for the traditional and minimal shoe conditions were placed on the heel counter of the shoe which may not reflect calcaneal movement. Future studies are needed to examine these different footwear conditions in a greater diversity of participants including males and females with a wider range of ages.

CONCLUSION

In conclusion, youth exhibit different ankle kinematics when running in a traditional running shoe versus a minimal running shoe versus barefoot. There were many similarities and some differences in ankle kinematics between a minimal shoe and traditional shoe while running barefoot resulted in a mostly unique kinematic pattern. This information can assist individuals and healthcare practitioners in the selection of running footwear for youth and will help build the foundation for future research on this topic.

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