UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

KINETIC AND KINEMATIC COMPARISON OF HOKA SHOES TO STANDARD RUNNING SHOES

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Clinical Exercise Physiology

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College of Science and Health
Clinical Exercise Physiology

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KINETIC AND KINEMATIC COMPARISON OF HOKA SHOES TO STANDARD RUNNING SHOES

By Kevin Arthur

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Clinical Exercise Physiology

The candidate has completed the oral defense of the thesis.

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ABSTRACT

Arthur, K. Kinetic and kinematic comparison of HOKA shoes to standard running shoes. MS in Clinical Exercise Physiology, December 2015, 52pp. (J. Porcari)

The purpose of this study was to compare the kinetics and kinematics of running in HOKA shoes to standard shoes. Sixteen subjects (8 male, 8 female) who ran at least 6 miles per week and had not had a lower extremity orthopedic injury within the 3 months prior to testing were included in this study. Subjects were also accustomed to running in shoes; however, none of the subjects had worn HOKA shoes prior to the study. Subjects ran 10-15 trials at a self-selected pace across two force plates to measure kinetics. To measure kinematics, subjects had retroflective markers placed at the 1st metatarsal head, 5th metatarsal head, calcaneal tuberosity, lateral malleolus, medial malleolus, mid-tibia (shank), lateral knee joint line, mid-femur (thigh), greater trochanter of the femur, anterior superior iliac spine, posterior superior iliac spine, and sacrum. Results found no significant differences in any kinetic variables measured except for greater IP when running in HOKA shoes ($p < 0.05$). Also, no significant differences were seen in any kinematic variables measured. These findings may suggest that HOKA shoes promote a more vigorous heel strike. However, most of the data suggests that there is no difference between HOKA and standard running shoes.

ACKNOWLEDGEMENTS

I would first like to thank Dr. Aminaka for her guiding hand in the testing process of my thesis. Her expertise and knowledge in the Biomechanics Lab helped make testing subjects as smooth as possible. I would not have been able to do everything without her commitment.

I would also like to thank my thesis committee chairperson, Dr. Porcari, for helping throughout the process of my thesis. His patience and vast experience in scientific studies helped me learn immensely and enjoy the journey not only in testing but also academic writing. In addition, I would like to thank Dr. Foster for his knowledge and suggestions to help improve my study. His questions pushed me to better my understanding of testing strategies.

I would like to thank all of the participants in my study and their flexibility when technical difficulties arose. I appreciate their time and cooperation. Thank you Lydia Storms for your helping hand and continuous support, it was much needed and welcomed.

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INTRODUCTION

Running has long been a popular form of physical activity for many Americans and its popularity continues to grow. From 1990 to 2013 the number of individuals finishing in U.S. running races increased by about 300% (2014 State of the Sport - Part III). While running can help decrease the risk of developing cardiovascular and metabolic disease, the high impact forces associated with running can result in a number of lower extremity injuries (Lopes et al., 2012). It has been reported that during a 12 month period, 31.6% to 57.1% of runners experience a lower extremity injury (Van Gent et al., 2007). Thus, shoe companies have designed many different styles of shoes in attempts to decrease the stresses that the body goes through during running.

Most runners run with a rear-foot strike (RFS) pattern, meaning the heel of their foot comes into contact with the ground first. The heel or calcaneus is rigid and stiff and has little physiological cushion, which results in high impact peak forces and loading rates (Lieberman et al., 2010). To counter this, shoe manufactures have tried to alleviate forces by adding cushioning to the soles of the shoes. Cushioning in the heel and mid-sole acts to slow down the rate of loading and decreases the chance of a running related injury (Lieberman et al., 2010; Logan, et al., 2010).

One of the latest trends is barefoot running or using minimalist shoes to mimic barefoot running. Individuals who run barefoot or with minimalist shoes tend to run in a fore-foot strike (FFS) pattern (Chambon et al., 2014). Fore-foot strike running tends to eliminate the more damaging impact peak and decrease the corresponding loading rate (Lieberman et al., 2010). This is because as the foot comes in contact with the ground it is plantarflexed, and as the body weight shifts over the foot it begins an eccentric dorsiflexion contraction as it descends to mid-stance. The dorsiflexion eliminates the impact peak because the energy is translated into rotational energy and creates a smaller loading rate.

While the latest shoe trend has been minimalist styled shoes, the company HOKA ONE ONE (Richmond, CA) has moved in the opposite direction and created shoes with an extra thick cushioning in mid-sole and a "Meta-Rocker" bottom sole in an attempt to lower ground reaction forces (GRFs) and improve running form. The maximum cushioned mid-sole is designed to act like a spring by extending the time that the forces are applied, thus lowering the loading rate. The curved, rocker sole is designed to facilitate the transition from heel strike to toe off. Rocker shoes have been used in diabetic populations who have had peripheral neuropathy for a number of years (Kimel-Scott et al., 2014). While diabetics may benefit from these shoes because of a decrease in plantar pressure, the curved nature of the sole decreases the effective base of the shoe, possibly creating more instability and changing joint angles. This is not ideal for patients who already have impaired sensory receptors, but could help strengthen stabilizing muscles and improve posture in other populations (Kimel-Scott et al., 2014). However, there is no empirical evidence supporting the potential changes in joint angles with the extra cushioning and curved-sole shoes.

To our knowledge, there has been no research investigating the effectiveness of HOKA shoes on running mechanics or resultant forces. Therefore, the purpose of this study was to compare the kinetics and kinematics of running in HOKA shoes to a standard (New Balance 890v4) shoe. Our question pertains to whether the extra cushioning in the mid-sole will help decrease the GRF that runners experience, and if the meta-rocker bottom changes one's gait due to the inherent instability of the design.

METHODS

Subjects

Subjects for this study were 8 male and 8 female volunteers who ran at least 6 miles per week and had not had a lower extremity orthopedic injury within the 3 months prior to testing. Descriptions of subject characteristics are presented in Table 1. Subjects were also accustomed to running in shoes; however, none of the subjects had worn HOKA shoes prior to the study. Subjects provided written informed consent prior to undergoing any testing procedures. The University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects approved this study.

Table 1. Subject demographics

	$\bar{X} \pm$ SD	Range
Age	27.9 ± 13.13	20 - 65
Weight (kg)	71.23 ± 10.14	53.6 - 92.7
Height (cm)	174.7 ± 6.51	162.6 - 185.4
Miles run per week	28.6 ± 21.3	6 - 78
Frequency	4.8 ± 1.47	3 - 7
Average running pace (mph)	7.7 ± 1.46	6 - 12

Values represent mean ± standard deviation.

Procedure

During one data collection session, each subject completed two separate running conditions in random order. One condition involved running in the HOKA shoes and the other condition was in the standardized shoes. Prior to data collection for each condition, subjects were given 5 minutes of running at a self-selected pace on an indoor track to become accustomed to the shoes. To ensure capture of joint angles, subjects had retroflective markers placed at the 1st metatarsal head, 5th metatarsal head, calcaneal tuberosity, lateral malleolus, medial malleolus, mid-tibia (shank), lateral knee joint line, mid-femur (thigh), greater trochanter of the femur, anterior superior iliac spine, posterior superior iliac spine, and sacrum (Figures 1a and 1b). Subjects then completed one set of 5-10 practice trials from a predetermined distance of 20 yards, to become accustomed to the testing setup. After 5 minutes of rest, subjects then proceeded to perform 10-15 running trials at a self-selected pace across two force plates (AMTI OR6-7 Force platforms, AMTI, Watertown, MA). Kinematics were recorded using 10, three-dimensional motion capture cameras (Bonita Motion Capture Cameras, Vicon, Centennial, CO) at 200 Hz. The cameras were integrated with streaming software (Nexus 2.0 Motion Capture Software, Vicon) and the data collection and processing software (The MotionMonitor™, Innovative Sports Training, Chicago, IL). Between trials, subjects were given 30 seconds of rest. Once data collection with the first shoe condition was completed, a 15-minute rest period was given. After the rest period, subjects were asked to switch shoes. Subjects then repeated the warm-up and testing procedure using the other shoe.

The force plate data were collected at 1000 Hz and impact peak (IP), loading rate (LR), and active peak (AP) were recorded during the run (Figure 2). Impact peak was measured as the maximum force applied during initial foot contact, LR was determined as IP/ time, and AP was measured as the maximum force at mid-stance. Trials were considered failed and then repeated if 1) the entire foot did not make contact with one of the two force plates, or 2) the subject altered his or her gait in order to make full contact with the force plate. The force plates were covered with carpet to blend into the surroundings and prevent any deviation of normal gait pattern.

Lower extremity joint kinematics during the running trials were measured using the aforementioned three-dimensional motion capture system. Measurements were made on the left and right leg in each shoe condition. The analysis looked at the differences in knee flexion, dorsiflexion, and foot inversion during initial shoe contact with the force plate and at the time of active peak. Dorsiflexion was measured in degrees less than 90° of the foot and lower leg (Figure 3). Inversion of the ankle was measured in degrees beyond 0° of the foot and shin in the frontal plane. Knee flexion was measured as degrees less than 180° in the sagittal plane.

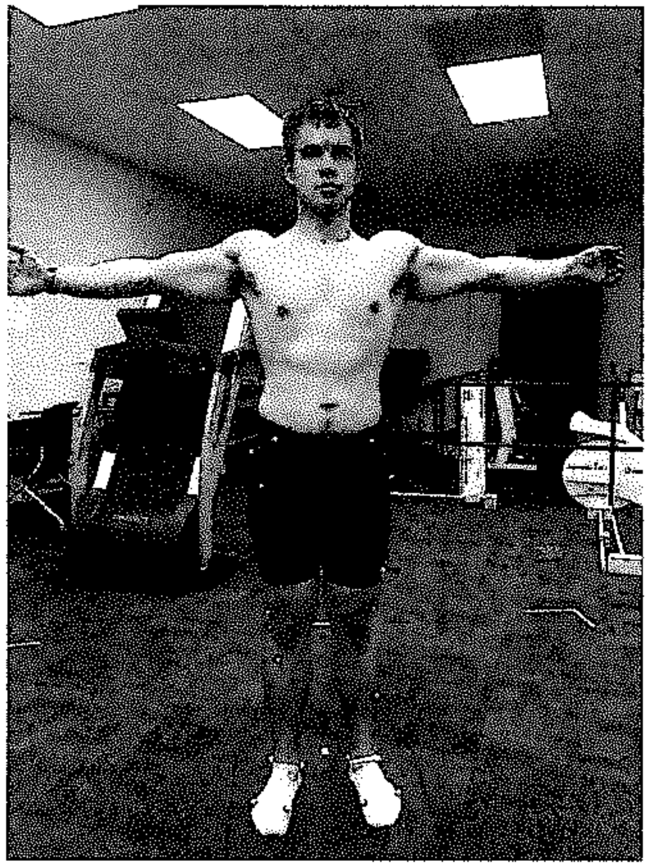

Figure 1a. Anterior view of retroflective markers placed at the 1st metatarsal head, 5th metatarsal head, calcaneal tuberosity, lateral malleolus, medial malleolus, mid-tibia (shank), lateral knee joint line, mid-femur (thigh), greater trochanter of the femur, anterior superior iliac spine, posterior superior iliac spine, and sacrum.

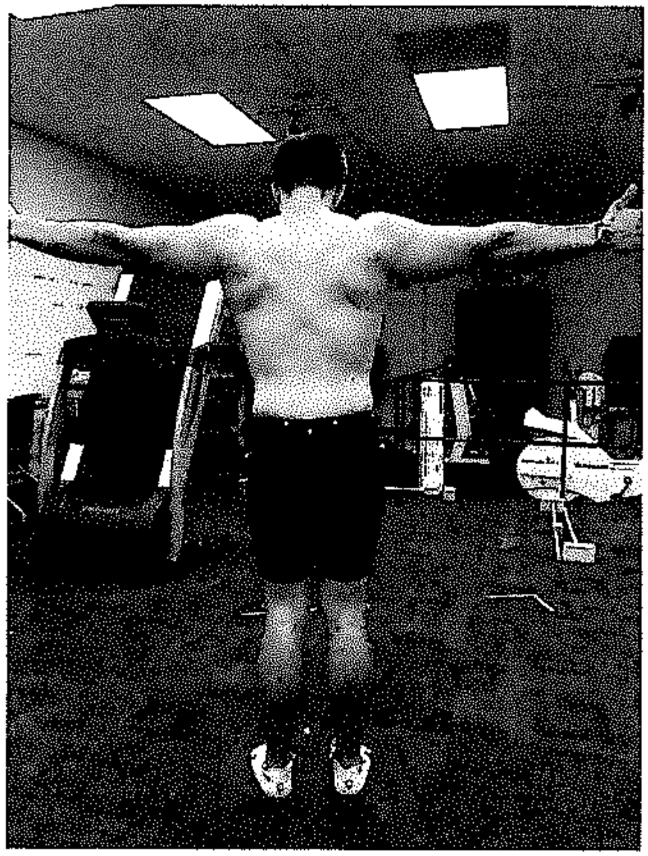

Figure 1b. Posterior view of retroflective markers placed at the 1st metatarsal head, 5th metatarsal head, calcaneal tuberosity, lateral malleolus, medial malleolus, mid-tibia (shank), lateral knee joint line, mid-femur (thigh), greater trochanter of the femur, anterior superior iliac spine, posterior superior iliac spine, and sacrum.

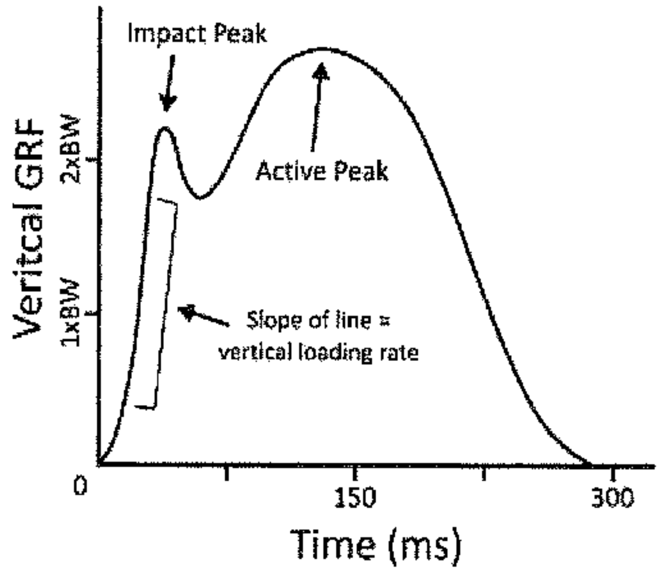

Figure 2. Depiction of a ground reaction forces graph, including the loading rate, impact peak, and active peak.

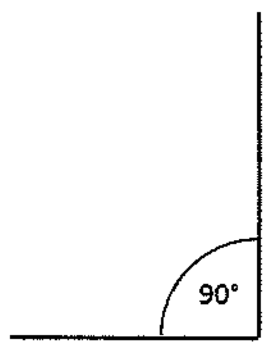

Figure 3. Depiction of the foot and lower leg at 90° in the sagittal plane.

Statistical Analysis

Data were analyzed using repeated-measures ANOVA to identify any significant differences in the kinematics or force data between shoe conditions. The level of significance was set a priority at $p < 0.05$. In case of statistically significant interactions, pairwise comparisons were performed using Bonferroni correction. IBM SPSS Statistics version 22 (IBM Corporation, Armonk, NY) was used for all statistical analyses.

RESULTS

Velocity

There was no significant difference in average running speed between conditions. (HOKA = 3.3 ± 1.5 m/s; Control = 3.02 ± 0.43).

Kinetics

Data for the ground reaction forces are presented in Figures 4-6, respectively. Forces were measured as a multiple of body weight (BW) or BW/sec. Running in HOKA shoes resulted in a significantly higher IP than the control shoes (Figure 4). For AP (Figure 5), there was no significant differences between shoes, however there was a trend for the control shoe to have higher values ($p = 0.053$). There was no significant difference in LR between shoe conditions (Figure 6).

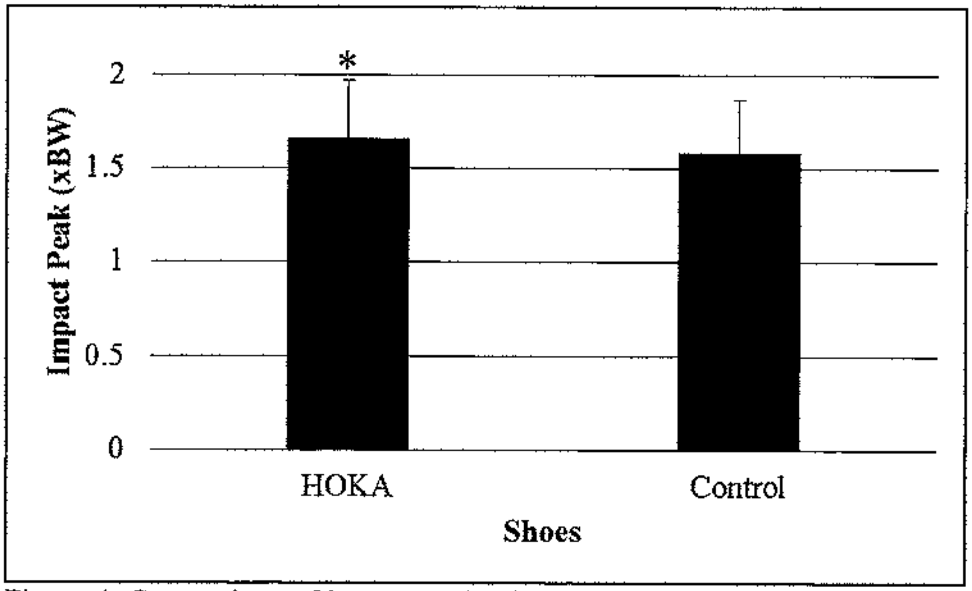

Figure 4. Comparison of impact peak when running in HOKA shoes vs. control shoes.

* Significantly greater than control shoes ($p < 0.05$).

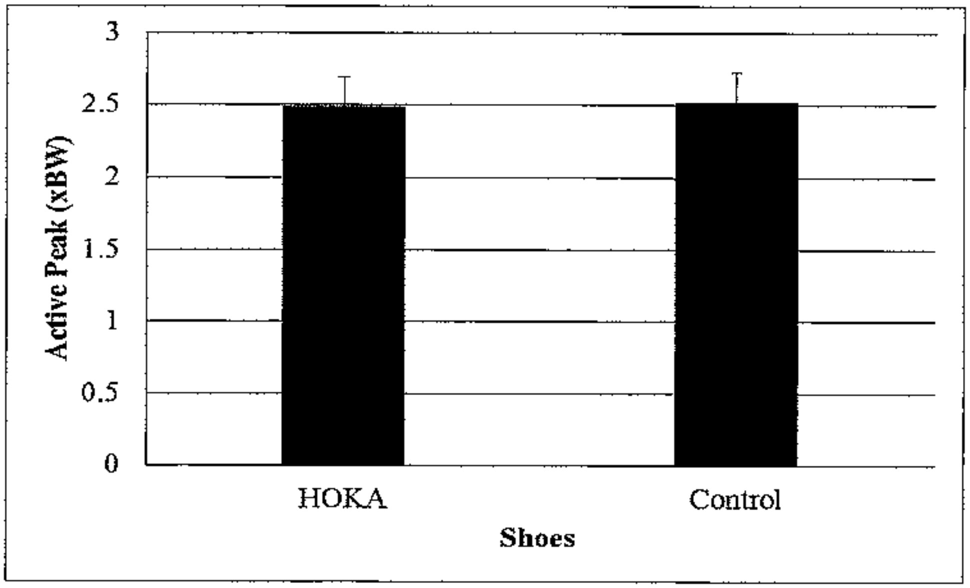

Figure 5. Comparison of active peak when running in HOKA shoes vs. control shoes.

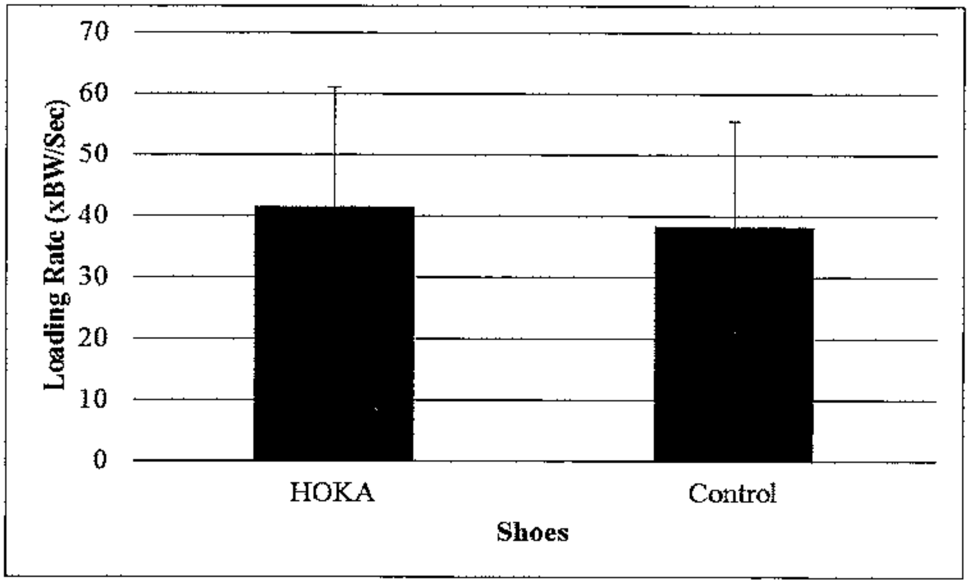

Figure 6. Comparison of loading rate measured in body weight per second when running in HOKA shoes vs. control shoes.

Kinematics

Joint angles were measured at initial contact with the force platform and during the AP. These data are presented in Figures 7-12, respectively. At initial contact, there were no significant differences between shoes for knee flexion (Figure 7), dorsiflexion (Figure 8), or foot inversion (Figure 9). At AP, there were also no significant differences between shoes for knee flexion (Figure 10), dorsiflexion (Figure 11), or foot inversion (Figure 12).

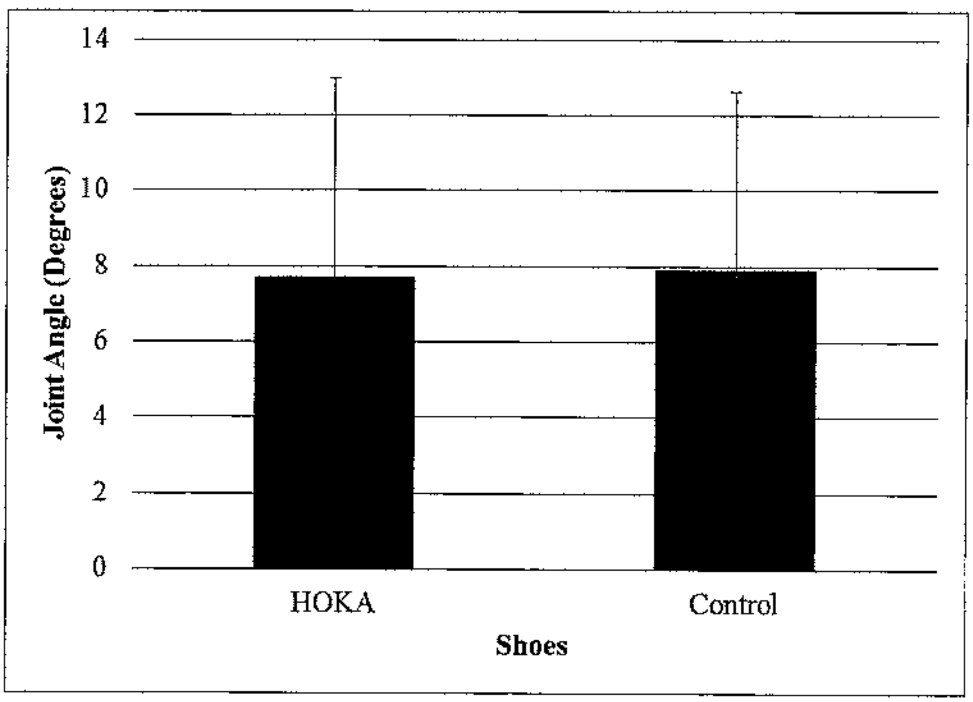

Figure 7. Comparison of knee flexion at initial contact with force platform when running in HOKA shoes vs. control shoes.

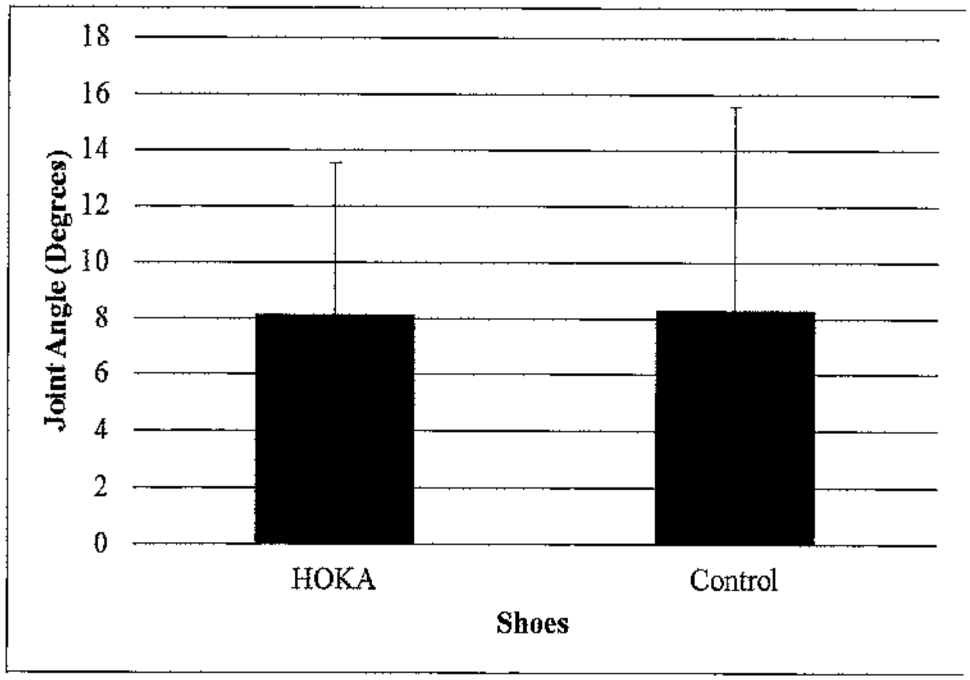

Figure 8. Comparison of dorsiflexion at initial contact with force platform when running in HOKA shoes vs. control shoes.

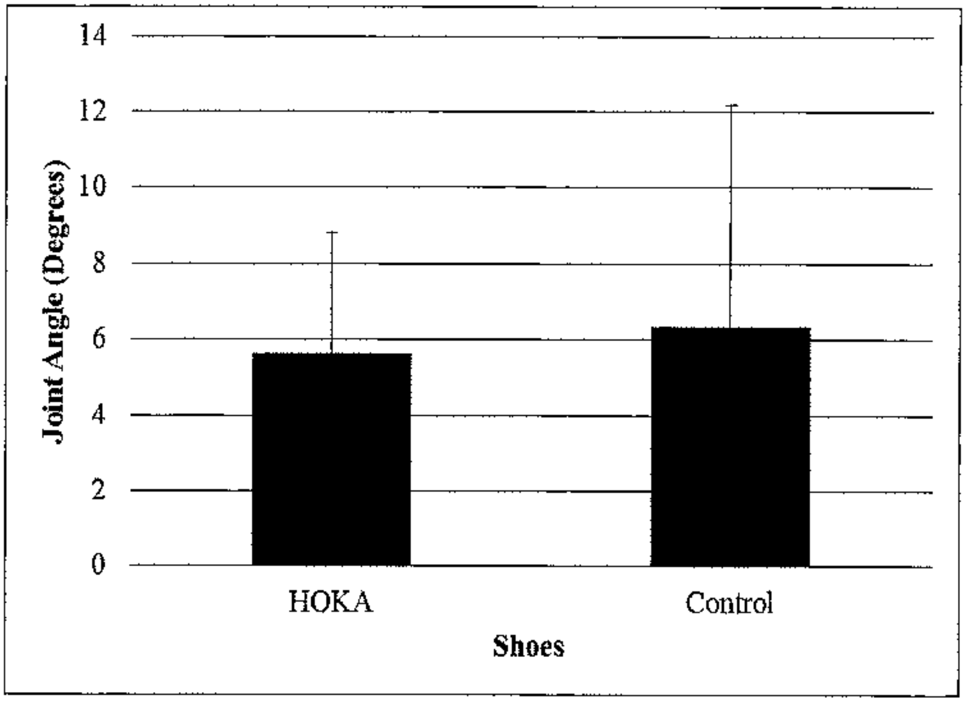

Figure 9. Comparison of foot inversion at initial contact with force platform when running in HOKA shoes vs. control shoes.

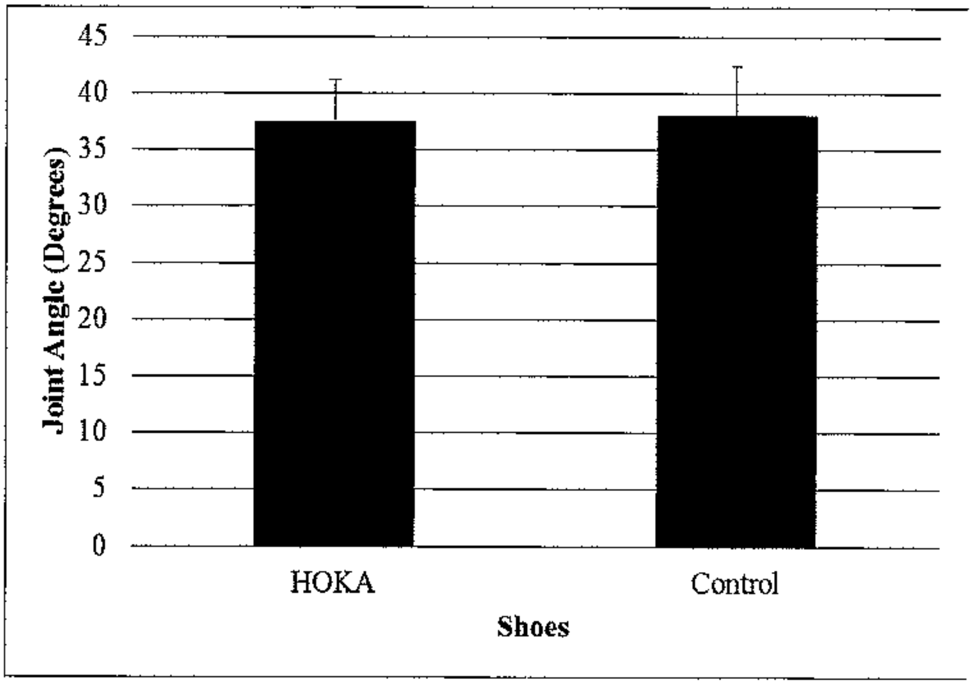

Figure 10. Comparison of knee flexion at active peak when running in HOKA shoes vs. control shoes.

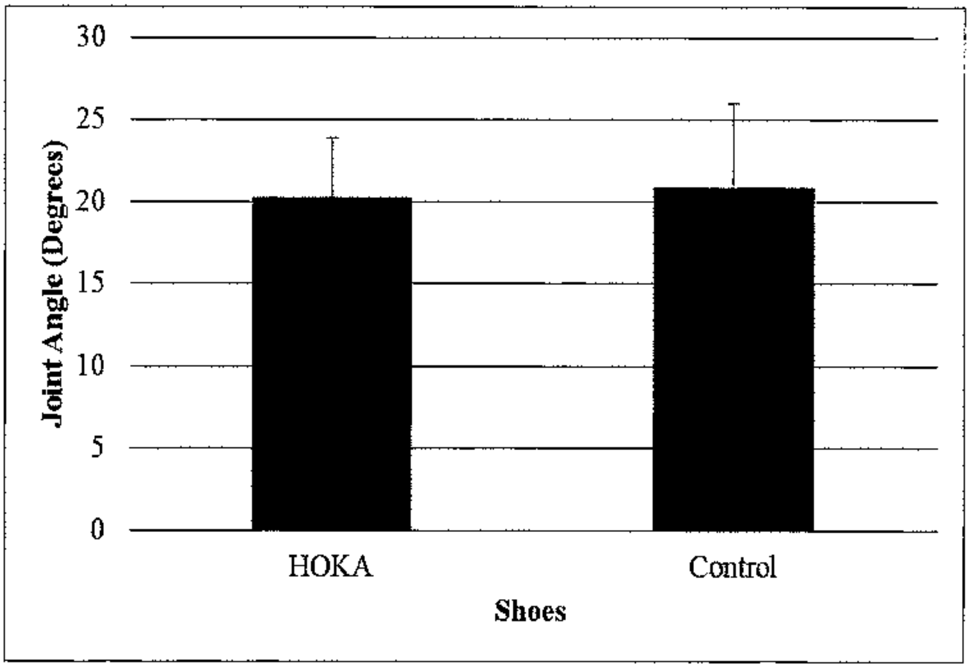

Figure 11. Comparison of dorsiflexion at active peak when running in HOKA shoes vs. control shoes.

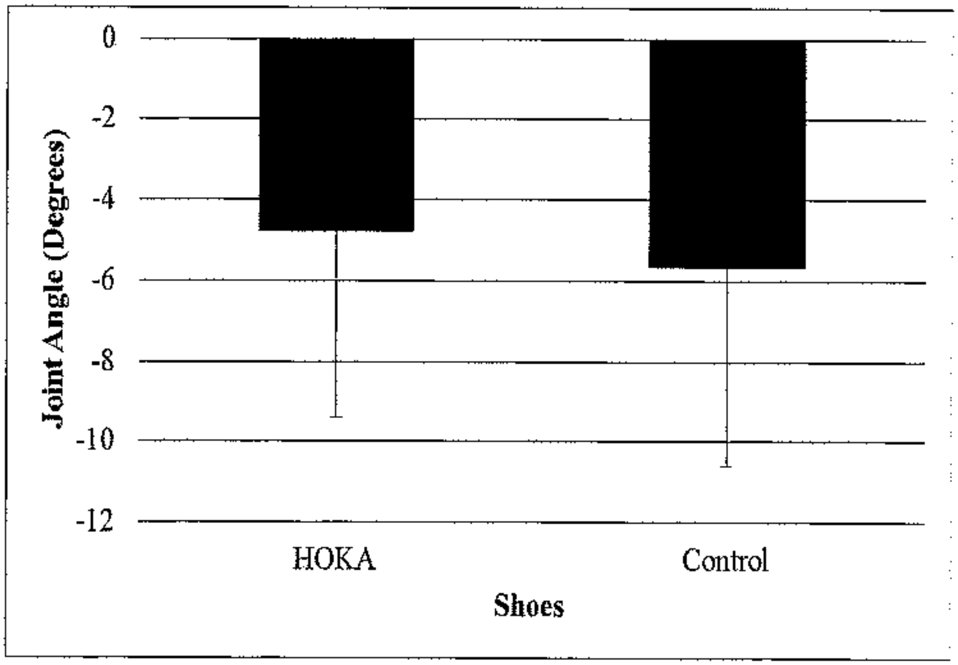

Figure 12. Comparison of foot inversion at active peak when running in HOKA shoes vs. control shoes.

DISCUSSION

The purpose of this study was to analyze kinetic and kinematic differences between running in HOKA shoes and a control running shoe. Since kinetics is influenced by running velocity, we controlled this by having subjects run at a consistent self-selected pace. Allowing subjects to run at a self-selected pace also reduces any abnormalities in their gait (Keller et al., 1996, Munro et al., 1987, Nigg et al., 1987). It was found that running in the HOKA shoes resulted in a 4.5% overall higher IP. This finding is in agreement with a study performed on the Masai Barefoot Technology (MBT) shoes which also has a highly cushioned midsole (Sacco et al., 2012). It is thought that extra cushioned shoes create a perceived increase in protection from the high ground reaction forces (GRFs) when a person runs. In addition, the rocker bottom sole may promote a more rear-foot strike (RFS) gait pattern, which suggests that the runner will initiate contact with the ground with the heel more vigorously, resulting in a higher IP (Sacco et al., 2012). Although a higher IP would suggest a greater damaging risk on the runner, we can speculate that an increase in the surface area of the sole could reduce this risk. In contrast to the finding of the present study, Boyer and Andriacchi found no differences in IP between the MBT and regular running shoes (2009).

Interestingly, although HOKA had a higher IP, there were no significant differences in the LR. There are many studies which have found that mid-sole thickness does not influence LR (Clarke et al., 1983, Chambon et al., 2014, Sacco et al., 2012, Boyer and Andriacchi, 2009). One theory why mid-sole thickness does not affect LR is due to gait adaptations on the part of the subjects. Specifically at the ankle joint, it is thought that the body is able to change gait patterns when influenced by external forces (Boyer and Andriacchi, 2009). However, some studies have shown that an increase in mid-sole thickness has a protective LR reduction (Lieberman et al., 2010; Logan, et al., 2010).

In this study we also found that there was no significant difference in AP between shoes. However, there was a trend of the control shoe having a higher value ($p = 0.053$). While it was not significantly different, this trend could be attributed to the greater surface area of the sole which absorbed more of the ground reaction forces. This result is supported by previous studies (Chambon et al., 2014, Sacco et al., 2012, Boyer and Andriacchi, 2009). Mainly, Wright et al., found that GRFs did not change between a soft-sole and a hard-sole shoe when compared in a passive mechanical body (1998).

This study found no significant differences in kinematics at either initial contact or AP. This is also supported by both Boyer and Andriacchi (2009), and Wang (2010), who failed to show differences in pelvis, hip, or knee angles when subjects ran or walked in rocker shoes vs. standard shoes. However, one explanation for no difference is that the shoes act like a spring and absorb some of the GRFs that otherwise would result in kinematic changes.

To help prevent any discrepancies between kinetics or kinematics in experienced runners and non-runners, we chose to study subjects who were experienced runners, but had not worn HOKA shoes previously. Investigators also blinded the subjects to the force plate, to protect against variations in gait. Although the force plates were covered and none of the subjects seemed to have noticed where it was, a visible outline of the plates was noticeable. Data from the three-dimensional motion capture cameras appeared to have a delayed response when subjects ran at high speeds, and as a result kinematic data became faulty and caused failed tests. In a few subjects, data collection lasted for an extended period of time. We ensured that the subject received adequate rest between trials; however, a slight fatigue may have been present in some individuals. Although the room was small, subjects appeared to have reached a steady state prior to reaching the force platform. Since we did not investigate the medial/lateral or anterior/posterior GRFs, it is unknown whether the forces were directed in other directions. Future studies could look at forces in all directions and further test the effects that more subjects, selected age groups, or selected running speeds have on the kinetics or kinematics.

CONCLUSION

The purpose of this study was to identify if any kinetic or kinematic differences could be determined from the maximum cushioned sole and meta-rocker bottom. Results found no significant differences in any kinetic variables measured except for greater IP when running in HOKA shoes ($p < 0.05$). Also, no significant differences were seen in any kinematic variables measured. These findings may suggest that HOKA shoes promote a more vigorous heel strike. However, most of the data suggests that there is no difference between HOKA and standard running shoes.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

Kinetic and Kinematic Comparison of HOKA Shoes to Standard Running Shoes

Purposes and Procedures

I, ______________________________, give my voluntary informed consent to participate in this study that is designed to determine kinetic and kinematic differences while wearing two different types of footwear. The footwear in this study will be regular running shoes and HOKA running shoes. HOKA running shoes are designed to absorb shock and create a guided gait cycle by using the curved bottom and thick cushioned sole.

I have been informed that my participation in this study will involve one visit to the Biomechanics Laboratory in the Health Science Center, on the UW-La Crosse campus. The length of the visit will be approximately 1 hour. Prior to testing, I will have adhesive retroflective markers placed at the 1st metatarsal head, 5th metatarsal head, calcaneal tuberosity, lateral malleolus, medial malleolus, mid-tibia (shank), lateral knee joint line, mid-femur (thigh), greater trochanter of the femur, anterior superior iliac spine, posterior superior iliac spine, and sacrum. I will then jog for 5-7 minutes while wearing each type of shoe at my own pace to become accustomed to the footwear. I will then run over a force plate at my own pace while wearing both types of footwear. Ground reaction forces and joint movement values will be recorded for each types of footwear while I am running across the force plate. I will also be filmed to compare the IP, LR, AP, joint angles, and rotation among the two shoes.

Potential Risks

Because of the extra midsole cushioning and curved nature of the sole of the shoe I may experience some muscle soreness following the testing session. I may also have some mild abrasions associated with the placing of the tracking markers. As with any exercise, there exists the possibility of a cardiovascular complication (e.g., heart attack or stroke). However, in healthy, well-trained individuals such as myself, the risk of serious complications is thought to approach zero. If an emergency should occur, individuals trained in CPR will be in the laboratory at all times. Additionally, the laboratory has a standard emergency plan and an Automated External Defibrillator (AED) is readily available.

Rights and Confidentiality

My participation in this study is entirely voluntary and I can withdraw from the study at any time, for any reason, without penalty. In the event that the results of this study are published in the scientific literature, my name and personal information will not be identified. My results will remain confidential. Only the investigator and appropriate laboratory personnel will have access to my individual data.

Possible Benefits

The general public may learn more about the relative benefits of exercising in this new type of footwear.

Questions

I have read the information provided on this consent form. I have been informed of the purpose of this test, the procedures, and expectations of myself as well as the testers, and of the potential risks and benefits that may be associated with volunteering in this study. I have asked any and all questions that concerned me and received clear answers so as to fully understand all aspects of this study.

If I have any other questions that arise I may feel free to contact John Porcari, the principal investigator, at (608) 785-8684. Questions in regards to the protection of human subjects may be addressed to the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects at (608) 785-8124.

______________________________ ______________________________

Subject Name (please print) Signature Date

______________________________ ______________________________

Witness Name (please print) Signature Date

APPENDIX B

REVIEW OF LITERATURE

LITERATURE REVIEW

Although many four-legged animals can sprint faster than a human, humans have the advantage when it comes to running long distances. In fact, humans are the only primates capable of sustained endurance running. As *Homo sapiens* evolved from walking quadrapedal to bipedal, humans improved specialized structures for running. Such structures include; "an extensive systems of springs in the leg and foot that effectively store and release significant elastic energy during running; hypertrophied gluteus maximus and spinal extensor muscles that contract strongly to stabilize the trunk in running" (Bramble & Lieberman, 2004). In past decades, recreational running has become one of the most popular forms of physical activity (Lopes Jr et al., 2012). Although shoes have always been an important part of human history, the modern-day running shoe was not created until the 1970's (Lieberman et al., 2010). It has been shown that runners decrease their risk of developing cardiovascular and metabolic diseases. Unfortunately, their risk of injuries increases due to the high ground reaction forces (GRFs) experienced while running (Lopes Jr et al., 2012; Medicine, 2013). Several studies regarding GRFs, various shoe types, and shoe thickness have yielded inconclusive results. Therefore, further research is necessary in order to minimize injuries. One new style of shoe is known as the maximal cushioning shoe. This type of shoe is becoming popular because it is believed to lower GRFs while running; however, shoe companies have little research to back this claim.

EXERCISE AND RUNNING RELATED INJURIES

"The scientific evidence demonstrating the beneficial effects of exercise is indisputable, and the benefits of exercise far outweigh the risks in most adults" (Medicine, 2013). According to the *ACSM's Guidelines for Exercise Testing and Prescription,* the healthy, average adult should attain a minimum of three to five days a week of moderate to vigorous aerobic physical activity for 30-50 minutes. Furthermore, it is suggested that 150 minutes should be the minimum amount of time per week spent undergoing moderate aerobic physical activity, or 75 minutes on vigorous. In accordance with the American College of Sports Medicine (ACSM) and American Heart Association (AHA) recommendations, a dose-response relationship exists between physical activity, fitness, fatness, and multiple diseases. Specifically, an inverse dose-response relationship exists between the amount of physical activity and numerous diseases including; heart disease, diabetes mellitus, metabolic syndrome, osteoporosis, hypertension, stroke, breast and colon cancer (Medicine, 2013; Physical Activity Guidelines Advisory Committee, 2008).

Habitual runners typically meet and surpass these recommendations, thus lowering their risk of developing sedentary type diseases. However, due to continual stresses on the lower extremity (LE) during running, their risk for developing a running related musculoskeletal injury (RRMI) increases. In an RRMI systematical review of literature, Lopes Jr et al. reported the prevalence of injuries pertaining to runners (2012). The results concluded that in habitual runners, two of the most prevalent RRMIs were plantar fasciitis, (Ranging from 5.5% to 17.5%) and medial tibial stress syndrome (9.5%). Medial tibial stress syndrome is common in runners because of the posterior tibial, soleus, and/or flexor digitorum longus muscles that are constantly recruited during running. These muscles apply forces that stress the periosteum of the tibia, which may cause inflammation. In addition, stresses applied by the muscles and vertical GRFs while running contributes to the inability of the bone to remodel. Weak and inflamed bones may result. Plantar fasciitis was prevalent in this study, and is also one of the most common injuries to the foot. This is due to the heel strike while running, which can create repetitive forces of up to three times an individual's total body weight. As a result, deterioration of the plantar fascia and pain of the medial calcaneus tubercle ensues (Lopes Jr et al., 2012).

Exercise has been shown to increase fitness, while lowering fatness and the risk of various diseases. Therefore, the ACSM and AHA have established guidelines to help improve and maintain a healthy lifestyle (Medicine, 2013; Physical Activity Guidelines Advisory Committee, 2008). However, due to the repetitive nature of stresses during running, RRMIs are common in habitual runners (Lopes Jr et al., 2012). Although this population typically exceeds the ACSM and AHA guidelines for exercising, they experience a greater risk of RRMIs.

KINEMATICS AND KINETICS OF RUNNING

In order to understand the kinematics of running, a review of gait cycle literature is necessary. The gait cycle, or stride period, is the time that it takes the foot to complete a full stride. Rodgers describes the gait cycle as; "the period of time for two steps and is measured from initial contact of one foot to the next initial contact of the same foot" (1988). A single gait cycle can be further broken down into two different stages. However, these stages are different depending on whether individuals run with a rear-foot strike (RFS) or fore-foot strike (FFS).

For runners who experience a RFS, the first stage, also known as the swing stage, is the amount of time that the foot is elevated from the ground. During this stage the LE begins to medially rotate, dorsiflex, and pronate in preparation for contact with the ground. Next, stage two contains three sub-events; the heel-strike (HS), mid-stance (MS), and toe-off (TO), respectively (Rodgers, 1988). As illustrated in Figure 1, the impact transient occurs during the HS. Impact transients can be defined as; "sudden forces with high rates and magnitudes of loading that travel rapidly up the body" (Lieberman *et al.*, 2010). In addition, the slope of the line illustrating the impact transient is called the loading rate (Figure 2). The loading rate is a measure of how quickly the GRFs are applied to the body. Finally, peak vertical force is experienced during MS (Figures 1 and 2).

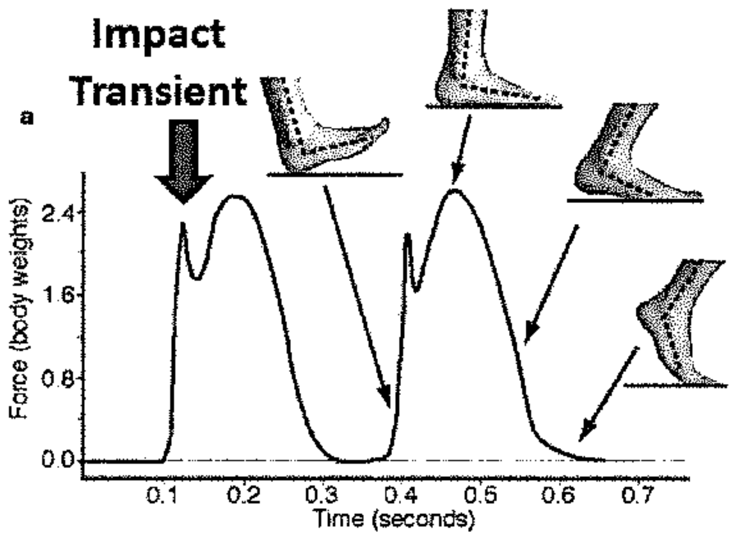

Figure 1. Depiction of a RFS on a GRF graph. The individual stages of the gait cycle are shown, including the impact transient.

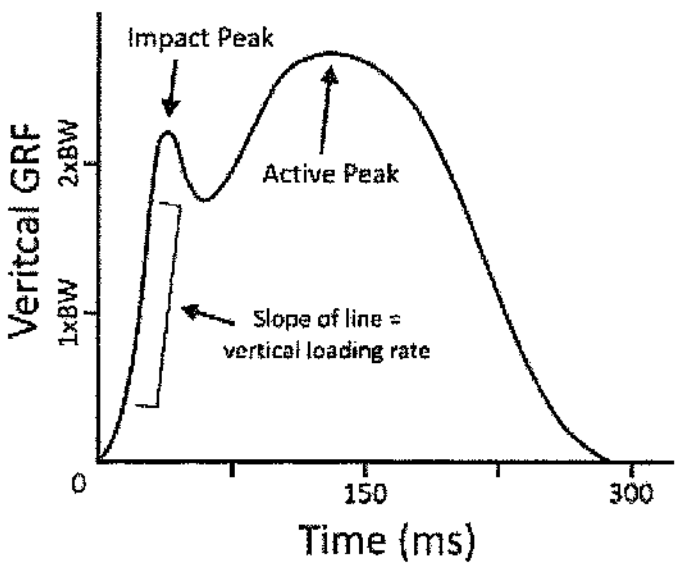

Figure 2. Depiction of a RFS on a GRF graph, including the loading rate, impact peak, and active peak.

On the other hand, people who prefer the FFS running style experience different stages of the gait cycle. During stage one (swing stage) of a FFS, the LE medially rotates and plantarflexes to prepare for contact with the ground. Then, stage two consists of a toe-strike (TS) followed by MS and TO. The initial TS allows the ankle to dorsiflex due to an eccentric contraction of the triceps surae muscle. This leads into a controlled drop to MS. The controlled descent is the reason that FFS runners do not experience an impact transient (Figure 3) as seen in RFS runners (Lieberman *et al.*, 2010).

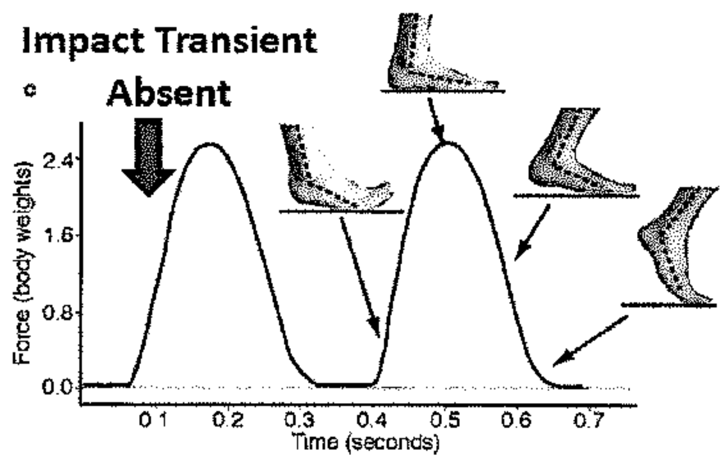

Figure 3. Depiction of a FFS on a GRF graph. The individual stages of the gait cycle are shown.

The foot undergoes different stresses while running, therefore, it is important to understand the gait cycle and analyze the kinetics. As FFS runners land on their toes, the achilles tendon converts the energy into rotational energy. On the other hand, RFS runners impact the ground heel first, and the calcaneus is the first part of the body to hit. The calcaneus is hard and does not absorb the initial contact, so the forces exert stress on the LE. Thus, a spike (impact transient) is the beginning of the vertical GRF graph

(Figures 1 and 2) (Lieberman et al., 2010). It is believed that the impact transient and loading rate are responsible for causing harmful stresses which can lead to RRMIs. Thus, shoe companies are challenged to create a shoe that minimizes or eliminates the impact transient and high loading rate (Chambon et al., 2014).

VARIOUS SHOE TYPES AND THICKNESSES

It is important to note that in various studies, the speed at which the subject runs changes the forces acting on the body (Keller et al., 1996; Munro et al., 1987; Nigg et al., 1987). Specifically, GRFs increases with speed. In addition, studies have found that increases in speed can result in adapting gait strikes to use an FFS more often than an RFS (Lieberman et al., 2010). Thus, it is important to note the speed that test subjects run at, since changes in gait pattern results in altered morphology of GRF graphs.

In one study, Lopes et al. found that barefoot runners tend to have a FFS, while 75-80% of runners using shoes ran with either a mid-foot strike (MFS) or an RFS (2012). RFS is more popular in shod runners because of the extra heel cushioning. The cushion allows the shoe to spread the GRFs over a longer period of time, creating a smaller loading rate when compared to running barefoot with an RFS. However, FFS barefoot runners allow the natural mechanics of the foot and ankle to cope with, and eliminate the presence of the GRF impact transient (Figure 3). Research has shown that impact transients associated with RFS runners correlate with tibial stress fractures and plantar fasciitis (Lopes Jr et al., 2012). Furthermore, Lieberman and colleagues found that those who ran with a RFS experienced three times the peak vertical force than that of FFS runners (2010).

In the study conducted by Lieberman et al., they concluded that the transient impact and loading rate and magnitude decreased when shoes were worn during an RFS. In addition, RFS runners with shoes had seven times a lower rate of average impact loading than those without shoes (69.7+- 28.7 BW/s and 463.1+-141 BW/s respectively) (2010). Similarly, another study tested collegiate athletes to measure the different forces when running at a constant speed over a force plate. It was found that there were several significant differences between male athletes in running shoes and racing spikes. Wearing running shoes significantly decreased peak vertical impact force (3.06 +- .48 to 2.36 +- .55 BW), loading rate (232 +- 117 to 151 +- 47 BW/s), vertical stiffness (151 +- 114 to 70 +- 28 BW/m), and peak breaking force (-.88 +- .21 to -.67 +- .14 BW). On the other hand, significant decreases in female athletes were recorded in stance time (.160 +- .008 to .167 +- .009 s), and peak propulsion force (.58 +- .04 to .54 +- .05 BW) when comparing running shoes to flats (Logan et al., 2010).

When human reflexes and active adaptations are removed from the kinematics, an entirely different result surfaces. In a study conducted by Wright et al., they created a three-dimensional model of the LE. Patterns of musculoskeletal movements were mimicked by a prosthetic leg to create a non-adapting LE. Wright and colleagues isolated the forces generated while wearing soft and hard soled shoes. They concluded that in a passive mechanical body, there is no significant difference between peak impact forces for hard and soft soled shoes. In addition, the vertical loading rate was significantly higher in hard soled shoes. Since the force is applied over a short amount of time, a smaller impulse (N*s) is created with hard soled shoes (Wright et al., 1998).

In a similar study, Clarke et al. conducted a study that measured the GRFs in a hard sole and a cushioned sole shoe. Ten male subjects ran at a constant speed of 4.5 m/s over a force plate. It was observed that the impact transient took longer in the soft sole shoes. However, the peak impact forces in both shoes did not differ significantly. Additionally, there were no significant differences in total impact time (2.27 s hard, 2.83

s soft) with the force plate and total vertical force impulse (0.354 BW/s hard, 0.357 BW/s soft) (Clarke et al., 1983).

Another study observed the effect of midsole thickness on GRFs during a 3.3 m/s run over a force plate. For this study, 15 active male college students were tested wearing shoes with varying midsole thickness. The differences in thickness used were; barefoot, 0 mm, 2 mm, 4 mm, 8 mm, and 16 mm. Results indicated that there was no significant difference between all midsole thicknesses and impact transient or loading rate. However, contact time significantly increased as midsole thickness increased. As the contact time with the ground increases, the harmful GRFs are spread out thus lessening their effect on the LE (Chambon et al., 2014).

Similar to the HOKA One One® shoes, Masai Barefoot Technology® (MBT) has created a shoe with a curved, rocker sole. In one study, female subjects walked across a force plate to compare GRFs between barefoot, standard running shoes, and MBT. It was found that there were significantly higher forces in the first vertical peak and weight acceptance in MBT shoes. Other forces examined were not significantly different amongst the three conditions (Sacco et al., 2012).

Likewise, Boyer and Andriacchi examined the running kinetics and kinematics of MBT shoes versus standard (control) running shoes. The subjects ran across a force plate, and the end results were comparable to Sacco et al. Boyer and Andriacchi concluded that there was no significant kinetic difference between the MBT shoes and the control shoe. However, there was a significant difference in ankle kinematics when wearing MBT shoes. Specifically, greater dorsiflexion was observed throughout the entire gait cycle (2009).

Rocker shoes have recently become more popular, and are implemented in the treatment of individuals with diseases such as rheumatoid arthritis or diabetes mellitus. This type of shoe is beneficial due to its inherent property of limiting joint movement, and reducing pressure on the feet (Cham et al., 2014). However, one drawback is that the shoe design decreases stability due to the smaller base of support and thick mid-sole. Kimel-Scott *et al*. conducted a study observing how the instability of rocker shoes affected posture in adults. The subjects encountered a posterior moving platform in order to analyze the reflexive postural response in both rocker and standard shoes. Retroreflective markers were used to aid in joint movement analysis, and were placed on the head, abdomen, pelvis, and LE. The results determined that joint movement was highest in rocker shoes. In particular, significant differences in joint movement of the ankle and knee were observed. These findings suggest that the instability of rocker shoes increases the potential to strengthen stabilizing muscles, thereby improving posture (2014).

CONCLUSION

While there have been many studies on mid-sole shape and thickness, the correlating GRF and kinematics seem to vary. Thus, the purpose of this study is to understand the kinetic and kinematic effects that HOKA shoes has on the human body while running. We will be comparing HOKA to normal standard shoes when running on top of a force plate while being filmed. Following the study we will then be able to analyze the kinetic ground reaction forces and kinematic joint angles for each respective shoe. We hypothesize that when running at a similar speed, there will be no significant kinetic or kinematic differences in HOKA shoes to standard shoes.

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