CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

COMPARISON OF AN OVERHEAD AND SINGLE LEG SQUAT IN BAREFOOT, MINIMALIST, AND SHOD CONDITIONS

A thesis submitted in partial fulfillment of the requirements

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By

Jennifer M Guiry

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The thesis of Jennifer M Guiry is approved:

Dr. Melissa Montgomery	Date

Dr. Shane Stecyk	Date

Dr. Sean Flanagan, Chair	Date

California State University, Northridge

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ABSTRACT

COMPARISON OF AN OVERHEAD AND SINGLE LEG SQUAT IN BAREFOOT, MINIMALIST, AND SHOD CONDITIONS

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The most analyzed activity in barefoot and minimalist conditions has been gait in relation to walking and running. However, there has been an increase in use of minimalist style shoes in activities other than running such as resistance training, hiking, cross training, etc.

When comparing barefoot and minimalist to shod conditions there have been positive adaptations found. While there are adaptations in running gait it is unknown if adaptations occur in other activities when comparing barefoot and minimalist to shod conditions. The goal of this study was to investigate biomechanical differences in an overhead and single leg squat in barefoot, minimalist, and shod conditions. It was hypothesized that (a) barefoot, minimalist, and shod conditions will result in differences in joint excursion and total mechanical energy expenditure at the ankle, knee, and hip (b) minimalist conditions will be similar to barefoot conditions when compared to shod conditions, and (c) ankle range of motion will exacerbate these differences.

A total of 32 able-bodied, Division I athletes that partook in strength and condition sessions with a certified strength and conditioning specialist (CSCS) participated in the current study. Participants had no history of lower leg injury in the previous six months. Participants were grouped based on their choice of daily footwear, minimalist style or traditional shod.. Participants completed ten repetitions of a single leg and overhead squat in barefoot and minimalist/shod conditions. Testing consisted of 3D motion analysis.

The results of the study found that ankle range of motion did not differ between groups (P= .566). During an overhead squat it was found that there was a significant effect at the hip by condition (P= .004), all other interactions, joint excursions, and total mechanical energy expenditure were not significant. In the single leg squat it was found that there was a significant effect at knee by condition (P= .040), all other interactions, joint excursions, and total mechanical energy expenditure were not significant. Clinicians and researchers can use the results of the study to further investigate differences in barefoot, minimalist, and shod activities in activities other than running.

CHAPTER 1

INTRODUCTION

Barefoot style shoes are most commonly used during running activities. However, they have recently become popular in other activities, such as resistance training, hiking, cross training, etc. Even with the increase in activities the minimalist style shoe is being used for, research has focused on walking and running activities. Despite the increased use for the minimalist style shoe, limited research has been done in other conditions such as landing. Despite the increase in technology that has gone into the making of a shoe to provide proper support for various foot conditions, there has not been a decrease in running related injuries (Jenkins & Cauthon, 2011). Therefore, researchers are starting to believe that it is the shoe that causes the injury more than the activity of running; however, there is no research to prove that the shoe is the cause of running related injuries (Jenkins & Cauthon, 2011). Due to a small research pool with varying running conditions, it has been found that barefoot and running in barefoot-style shoes can be beneficial, while other research finds it to be unsafe. A barefoot style shoe, also known as a minimalist shoe, can be described as a thin sole that is flexible, mimicking the bare foot. When barefoot, there are certain safety issues that need to be considered, such as environmental factors (where the temperature of running surfaces are either too hot or too cold) as well as sharp objects (such as nails and broken glass that could cause puncture wounds) (Jenkins & Cauthon, 2011). However, these safety issues could be decreased with the use of minimalist style shoes which offer the barefoot adaptations with the added protection of a rubber sole. As current research has been done on high impact activities, it is currently unknown if the effects of being barefoot or in minimalist shoes change the mechanics of an individual in a low impact activity. The purpose of this study is to investigate biomechanical differences in an overhead squat and single leg squat in barefoot, minimalist and shod conditions.

CHAPTER 2

LITERATURE REVIEW

Walking gait vs. running gait

Currently, when considering barefoot, minimalist, and shod conditions, gait has been the most studied activity. There are no differences in walking gait kinematics or kinetics between shod and barefoot conditions (Altmann and Davis, 2012), while there are differences in running gait between shod and barefoot. Running gait includes a phase of flight, whereas both limbs have a phase of support during walking. Gait differences are found once a flight phase is required. Those include a decrease in stride length, an increase in stride frequency, and a decrease in flight time. The benefits and risks of being barefoot and/or minimalist have not been heavily researched; the major focus has been on gait adaptations.

There is a plausible question if there are any benefits and/or risks of engaging in activities in a barefoot state. There are some safety concerns as well as the possible benefits of gait adaptations.

Benefits and risks

In the review done by Jenkins and Cauthon (2011), possible benefits and risks of running barefoot and shod were discussed. The benefits involve gait adaptations that lead to decreased impact forces. Changes in gait include: decreased stride length, decreased contact time, and decreased flight time (Jenkins and Cauthon, 2011). Jenkins and Cauthon (2011) also discussed an increased running economy, believed to be caused by the decrease in weight of the running shoe, increased proprioception of the ankle, and increased strength of the intrinsic plantar musculature. There has been no study to support or refute the claim that barefoot running reduces running related injuries (Jenkins and Cauthon, 2011).

In their review, Jenkins and Cauthon (2011) stated that a runner who is barefoot exposes him or herself to surface debris and high/low temperature extremes. Many of these risks can be avoided with a minimalist shoe. Other risks include the lack of transition instructions, which could lead to increased injuries due to improper use. A sufficient transition time to become barefoot involves thirty minutes a day for three weeks with a gradual increase in duration up to six weeks.

Companies such as Nike, New Balance, and Vibrum have developed shoes that mimic barefoot running that provide minimal protection as well as some of the comforts of being shod. In the review done by Jenkins and Cauthon (2011), it was found that the minimalist style shoes also allows for the same gait adaptations found in being barefoot. Risks still remain when using minimalist style shoes, such as a false sense of security. Researchers feel that a person may train at a pace or duration longer than a true barefoot condition would allow due to the thin layer of protection that the shoe provides (Jenkins and Cauthon, 2011).

The above studies have both noted that there are differences in running gait in a barefoot and shod condition. It was also noted that minimalist conditions are similar to barefoot conditions, with the benefit of protection of the foot from external factors such as temperature and sharp objects. However, the use of barefoot and minimalist shoes allows adaptations to occur. The most notable are changes in gait that include: decreased stride length, decreased contact time, and decreased flight time (Jenkins and Cauthon, 2011).

Adaptations

As no differences were found in the aforementioned study during a walking condition, it is a general consensus among researchers that the majority of the differences found between barefoot and shod conditions occur in running gait. This may be due to the higher impact forces associated with running compared to walking.

Investigating the mechanical differences in barefoot running, there is evidence of foot strike, ground reaction force, stride rate and frequency differences. A study done by Altman and Davis (2012) investigating foot strike patterns found that barefoot runners utilized a forefoot strategy (15) more often than a rearfoot strategy (2); whereas, shod runners utilized either a rearfoot (29) or forefoot strategy (25). The study done by Divert, Mornieux, Baur, Mayer, and Belli (2005) found that even when participants were instructed to have a rearfoot strategy, barefoot conditions showed significant differences in flight time, contact time, and stride duration when compared to shod conditions. Even in an instructed rearfoot strategy, barefoot running adaptations such as mid-foot and forefoot strikes occurred. This is in agreement with the study done by Wit, Clercq, and Aerts (2000), which found that during barefoot conditions, runners take smaller steps with a higher frequency - reducing contact time. In barefoot conditions, it was found that there is a flatter foot placement when compared to shod conditions. Running with a flatter foot during ground contact reduces pressures typically found at the heel and are dispersed through the plantar surfaces of the foot. Along with changes in foot contact, Wit et al. (2000) found that during the initial take off in barefoot running, the velocity at which knee flexion occurs is higher than normal, which correlates with decreased impact. Divert et al. (2005) determined that the adjustments made by decreased stride length and increase stride rate allows for the impact of the initial contact to be absorbed by the muscular-skeletal system, whereas Wit et al. (2000) determined that a flatter foot placement is adapted to limit pressure under the heel and allow for intrinsic musculature of the foot to aid in shock absorption. Finally, the review done by Jenkins and Cauthon (2011) supports the findings of the previously-mentioned research that barefoot running leads to certain changes in a person's running gait, such as adaptations of a forefoot/midfoot strike. The change of striking strategy leads to a reduction of impact forces, where intrinsic musculature and ligamentous arches absorb the ground reaction forces instead of the forces being directly absorbed by the heel pad and distributed up the shank.

Braunstein, Arampatzis, Eysel, and Bruggeman (2010), discuss that over the last two decades shoes have dramatically changed in their construction and abilities to reduce load. The results of their study are in agreement with other researchers that barefoot conditions result in decreased contact time when compared to shod conditions. However, Braunstein et al. showed in their study that in a barefoot condition the ground reaction force is decreased when compared to the average of the shod conditions.

Sekizawa, Sandrey, Ingersoll, and Cordova (2011) investigated shoe sole thickness and its correlation to joint position sense. Shoes with varying thickness and similar hardness were used and compared to a barefoot condition. The researchers found that thicker soles had greater error when compared to barefoot conditions in dorsiflexion. In a barefoot condition, there were more errors in plantar flexion than in inversion and eversion. Thin soled shoes had a similar observation in error in plantar flexion, inversion, and eversion; however, there was greater error in plantar flexion than the thick soled shoes

Gear ratio is defined as the moment arm of the ground reaction force (GRF) acting about a joint to the moment arm of the counteracting muscle tendon unit (Braunstein et al., 2010). The gear ratio is an important factor due to its ability to calculate mechanical efficiency and loading at a joint. In the study done by Braunstein et al. it was found that gearing at the ankle was higher in the beginning of stance phase but lower at the end of stance phase in a barefoot condition. At the knee, gear ratios were greater at the beginning of stance phase, smaller in the middle of stance phase and less negative at the end of stance phase in barefoot conditions when compared to all of the shod conditions. The researchers concluded that the changes in gearing at the ankle and knee alter the length of the moment arm of ground reaction forces. From an injury prevention view, shod conditions created an increased load at the knee joint due to the changes in gearing. When considering performance, there is an added length in the moment arm of the ground reaction force that allow for generation of forces at a lower shortening velocity in shod conditions (Braunstein et al., 2010). Braunstein et al. discuss that, when comparing barefoot and shod conditions, barefoot runners use a flatter foot strike therefore increasing plantar and knee flexion resulting in decreased plantar pressures due to increased contact area.

If changes in gait mechanics between shoe conditions are predicated upon decreasing impact forces, then other activities with high impacts may see similar alterations in biomechanics. One such activity is landing, both from a jump and a given height. These activities will be discussed next.

Shod vs. barefoot landing

A study done by Yeow, Lee, and Goh (2011) investigated the effects of shod and unshod double leg drop landings. The purpose of their study was to investigate biomechanical differences in terms of knee kinematics, kinetics, and energetics, between barefoot and shod landing from different heights. During the study, it was found that peak vertical ground reaction force was not significantly different between shod and unshod conditions (Yeow et al., 2011). Yeow et al., further found that knee range of motion and knee joint power is higher during shod landing when compared to barefoot landing due to the knee joint contributing more effectively to the ground reaction forces of landing. When comparing various landings from different heights, Yeow et al. found knee moment, knee range of motion, peak knee flexion angular velocity, and peak joint power were all significantly higher at 0.6 meters when compared to 0.3 meters in both shod and unshod conditions. This can and does occur due to the large contribution of the knee musculature which dissipates energy during shod landing through increased knee flexion and reduced stiffness at the knee joint (Yeow et al., 2011).

Shultz, Schmitz, Tritsch, and Montgomery (2012) also looked at joint energetics during drop jumps and drop landings in shod and unshod conditions. The study investigated the landing phase of a drop jump (landing with both feet and immediately performing a maximum vertical jump) and drop landing (landing with both feet and returning to a standing position) during barefoot and shod conditions. Their research found different results to Yeow et al. in that peak ground reaction force is greater in a shod condition; however, Shultz et al. found that there was a greater difference in a drop land than in a drop jump. Shultz et al. concluded that energy absorption varied at the hip, knee, and ankle; however, shoe condition had no effect on energy absorption. These results are not in agreement with Yeow et al., this could be due to differences in shod conditions and jumping/landing heights. Shultz et al., also found that joint excursions were not affected by shoe condition at the hip, however at the knee joint excursions were less and at the ankle joint excursions were higher when compared to barefoot conditions. Shultz et al. concluded that lower extremity landing biomechanics are influenced by shoe choice.

While gait has been the activity most analyzed activity when considering barefoot and shod conditions, there are only differences in running gait. This is due to the phase of flight requiring a higher ground reaction force during each foot strike. Due to the higher forces during running, barefoot and minimalist conditions adapted to having a forefoot or midfoot strike allowing for increase stride rate, decreased stride length, and decreased flight time. When investigating another high impact activity, there are significant differences in barefoot and shod landing tasks.

Mitigating impact forces might not be the only factor affecting mechanics between barefoot and shod conditions. There is a difference in heel height when barefoot compared to minimalist and when shod that could range from 2 to 12 mm. The difference in heel height could affect mechanics independent of impact. To examine this, barefoot versus shod conditions should be examined in a low impact activity, such as squatting.

Squatting and Heel Height Differences

Sato, Fortenbaugh, and Hydock (2012) investigated kinematic differences in a back squat when comparing weight-lifting shoes and running shoes. A weight-lifting shoe on average has a firm heel lift of about 2.5cm. The heel lift creates a more plantar flexed foot, which is beneficial due to engaging greater muscle excitation in the knee extensor muscles. A major difference between a weight-lifting shoe and a running shoe is that running shoes are designed to absorb repetitive shocks, whereas the weight-lifting shoe possesses hard soles with stability in the sole and lateral aspects of the footwear (Sato et al., 2012). Running shoes also have a raised heel; however, the heel allows for the cushioning in the shoe to sink, creating a more dorsiflexed ankle. The firm 2.5cm heel height design of weight-lifting shoes when compared to running shoes resulted less trunk lean displacement and greater foot segment angle. There was no difference in thigh segment flexion angle (Sato et al., 2012). Weight lifting shoes showed an average difference of 3.5 degrees of plantar flexion when compared to running shoes. The results of this study have been used to identify differences in squatting mechanics based on footwear choice in regards to heel height.

Bell, Padua, and Clark (2008) conducted a research study comparing strength and range of motion of the hip and ankle musculature during an overhead squat when using a heel lift. The heel height used in this study was two inches in height, as a wooden 2 by 4 was used as the heel lift. The researchers found that without the use of a heel height their test group had an increase in medial knee displacement. However, with the use of a firm heel height there was a significant decrease in medial knee displacement. A heel lift of this height was used because the increase of two inches was theorized to increase plantar flexion and decrease the tension on the lateral ankle allowing for better control of knee valgus and foot pronation. Bell et al., found that the group with increased medial knee displacement had higher hip external range of motion and less ankle dorsiflexion when compared to the control group. The medial knee displacement group had significantly less plantar flexion strength and decrease dorsiflexion compared to the control group, which was in line with the researchers' hypothesis. Bell et al., (2008) determined through this study that a firm heel height and lack of range of motion at the ankle influences squatting mechanics.

It can be concluded that a firm heel height can make a difference in squatting mechanics. It can be speculated that minimalist and shod conditions will result in varying mechanics when compared to a barefoot condition because of the differences in heel height. As a smaller heel height leads to greater dorsiflexion at the ankle, these changes may be greater in someone with a smaller available range of motion at the ankle.

Ankle Range of Motion

Sato et al., (2012) found that altering the positioning of the ankle into a more plantar flexed position (weight lifting shoes versus athletic sneakers) encouraged participant kinematics to have less trunk displacement during a back squat, which they believe will help decrease the risk of injuries. A lower heel height creates a need for greater dorsiflexion at the ankle. If an individual has limited or decreased dorsiflexion, that may alter their squatting mechanics to account for their range of motion deficit. While the typical collegiate athlete utilizes athletic sneakers during their strength and conditioning sessions, we could speculate that ankle range of motion could affect squatting mechanics when performed in shoes other than weightlifting shoes, such as minimalist and/or regular athletic sneakers.

Schoenfeld (2010) conducted a review with the purpose of examining the hip, knee, ankle, and spinal joint kinematics and kinetics during the dynamic squat. In a squatting task, ankle range of motion is required to assist with balance and control on the ascent and descent of the movement (Schoenfeld, 2010). It has been found that thirty eight degrees of dorsiflexion are needed during a squat to keep the heels flat against the ground (Schoenfeld, 2010). When range of motion is limited in an individual, there is a tendency for their heels to rise off the ground; this could possibly lead to injury due to a decrease in balance and compensatory movements at the knee, hips, and spine. Schoenfeld (2010) states that an object can be placed under the lifters heels, having a heel lift is beneficial for a squatting task when ankle range of motion is lacking. This review is in line with Sato et al (2012) that having a firm heel height changes squatting mechanics. Sato et al., (2012) looked into trunk displacement and found that less occurs when there is a firm heel lift, as the review by Schoenfeld (2010) looked into medial knee displacement and discussed less displacement when a firm heel lift is present.

A study done by Macrum, Bell, Boling, Lewek, and Padua (2012) investigated the effect of simulated gastrocnemius/soleus tightness, which would limit dorsiflexion on lower extremity kinematics and muscle activation. To simulate tightness in the triceps surae, a wedge was placed under the forefoot. The researchers conducted this study by having participants perform a double leg squat with their feet flat against the floor as well as on a wedge that created 9.5 degrees of dorsiflexion in their feet. It was found that participants showed a decrease in knee flexion, with an increase in knee valgus and decreased dorsiflexion, with the wedge in place. Macrum et al., noted that other studies that placed a wedge under the heel creating a more plantar flexed foot resulted in less medial knee displacement when compared to not using a wedge. The results of this study can be used to determine that ankle range of motion influences mechanics during a squatting task. Barefoot, minimalist, and shod conditions vary in heel height greatly when compared to weightlifting shoes. Therefore, there is a plausible question has to how ankle range of motion affects the mechanics of squatting techniques.

Squatting

The purpose of this study is to determine whether biomechanical differences are present when performing an overhead and single leg squat in barefoot, minimalist, and shod conditions. When an overhead or single leg squat is performed, mechanics of the individual may be influenced by ankle range of motion and heel height of their footwear. While current research has emphasized gait analysis during walking and running tasks in barefoot and shod conditions, research has also investigated landing and squatting techniques in various shoe conditions as well. Researchers have concluded that walking gait mechanics show no differences between barefoot and shod conditions. However, gait mechanics while running result in alterations in foot strike pattern and ground reaction forces when comparing barefoot and shod conditions. There were no differences found in barefoot and shod landing mechanics at varying heights, however, there were significant differences found in varying landing tasks. There is a lack of research on the use of different types of shoe conditions in varying activities. There is still no definite answer if barefoot training improves the rate of lower extremity injuries and if there are effects at the knee and hip during activities other than running, etc. Finally, further studies should be done to investigate the ability to transfer the possible benefits and risks into other activities especially since many people use shoes other than athletic sneakers such as the minimalist style shoe in activities like walking, hiking, weight lifting.

Due to the limited amount of research investigating barefoot, minimalist, and shod mechanics, the aim of this study is to investigate the mechanics of barefoot and shod mechanics during an overhead and single leg squat. This study will investigate the mechanics of these two types of squats in healthy, physically active collegiate athletes. It was hypothesized that (a) barefoot, minimalist, and shod conditions will result in differences in joint excursion and total mechanical energy expenditure at the ankle, knee, and hip, (b) minimalist conditions will be similar to barefoot conditions when compared to shod conditions, and (c) ankle range of motion will exacerbate these differences. The finding of this study will help researchers in determining if the adaptations occur in activities other than running when in a barefoot or minimalist condition when compared to a shod condition.

CHAPTER 3

METHODS

Participants

Thirty-two (16 women, 16 men) able-bodied, college athletes (ages 18-25) who were attending and participated on a Division I team that partook in strength and condition with a certified strength and conditioning specialist (CSCS) were recruited from the California State University, Northridge community. Participants also had to currently wear either minimalist style shoes or regular athletic sneakers, but not both. All participants were required to read and sign an informed consent after he/she understood the benefits and risks for participating in the study. Participants also completed a health questionnaire to ensure that it was in his or her best interest to participate in the study. Participants who had sustained a lower extremity injury in the past six months were excluded from the study. An injury was defined as missing practice/competition for seven consecutive days or longer. Participants were grouped based on the style of shoe that they habitually wear daily and during weight training. There were 16 participants in each group, (8 male and 8 female) shod and minimalist. Descriptive statistics are presented in Table 1. The female participants were on the women's basketball and women's water polo teams. The male participants were on the men's basketball, men's soccer, men's volleyball, and baseball teams. Participants wore their own shoes; therefore an adaptation period was not needed. The dominant foot in the study was defined as the foot used to kick a ball.

Group	Age (years)	Height (cm)	Weight (kg)
Shod	19 ± 1	179.45 ± 14.97	77.60 ± 16.14
Minimalist	20 ± 1	183.7 ± 10.5	80.54 ± 15.13

Table 1. Descriptive statistics for participants

Equipment

Minimalist or athletic sneakers were used for the current study provided by the participant. PVC pipe, motion analysis equipment (Vicon MX, Oxford Metrics, UK), force plate, reflective markers, metronome set to one beep per second, and a desktop computer for data storage provided by the researcher.

Procedure

Measurements of height, weight, age, and ankle range of motion were obtained at the beginning of the study. Ankle range of motion was taken by using a weight bearing lunge measure of dorsiflexion (Bennell et al, 1998). This procedure is done by having the participant in a standing lunge position, keeping the heel of the foot flat against the ground while touching their knee to the wall in front of them (Figure 1). If the participant could not reach the wall or was too close his/her foot was readjusted accordingly. Ankle range of motion was determined by measuring the distance from the participants' great toe to the wall in centimeters. This distance was normalized to the participant's leg length. Ankle range of motions was taken for both left and right feet, but only the right side was used for this analysis.

Figure 1. Ankle range of motion, knee to wall test.

Participants wore dark tights and a tight compression top. Any reflective materials on his/her shoes were covered with athletic tape, as to not interfere with the motion analysis equipment. Reflective markers were placed on the following anatomical landmarks (bilaterally) with adhesive tape: ASIS, PSIS, lateral malleolus, lateral epicondyle, calcaneus, and 2nd metatarsal head.

If the participant normally wore minimalist style shoe, he/she was tested in barefoot and minimalist shoe conditions. If the participant normally wore other athletic footwear, he/she was tested in barefoot and shod conditions. Since participants wore their own shoes, adaptation periods were not required.

The participant performed an overhead squat and a single leg squat in their shoe condition and barefoot. The order in which this was performed was counterbalanced. Starting with barefoot overhead squats, barefoot single leg squats, minimalist/shod overhead squats, and minimalist/shod single leg squats. The next participant started with barefoot single leg squats, and then completed the minimalist/shod overhead squats, minimalist/shod single leg squats, and barefoot overhead squats. This rotation was followed with all participants. The overhead squat was performed holding a PVC pipe above their head doing a 1.5 second descent and 1.5 second rise, totaling 3 seconds for a total of 10 separate repetitions. The single leg squat was performed with their dominant foot as their weight bearing leg doing a 1.5 second decent and 1.5 second rise, totaling 3 seconds for a total of 10 separate repetitions. The non-weight bearing leg was instructed to be held in front of the participant, (pistol squat technique). Participants were instructed to squat with the toes straight forward, if the participant had his/her foot rotated during their squat the trial was repeated. The depth of each squat was the individual's maximum squat depth. The pace of each squatting technique was normalized using a metronome, one beep per second. Participants were given as much practice time as needed with the metronome prior to recording data to ensure that they could perform the squat technique in the designated time frame. The participants were given as much rest as needed between each repetition.

Each trial of both squats was recorded using 3D motion analysis software (Vicon MX, Oxford Metrics, UK), at a sampling rate of 120Hz. The use of 7 cameras were set up surrounding 2 force plates (Kistler, Amherst, NY, USA) upon which the participants performed their squats. Ground reaction force data were collected at 1,200 Hz and then down-sampled to match the kinematic data. For the overhead squat, participants placed one foot on each force plate. For the single leg squat all participants utilized the same force plate.

Standard inverse dynamics techniques were used to determine the joint angles and net joint moments at the ankles, knees, and hips. Net joint moment power was determined as the dot product of the net joint moment and joint angular velocity. Mechanical energy expenditure (MEE) was determined as the area under the absolute power-time curve.

Statistics

The independent variables were shoe condition (barefoot, shod) and group (minimalist shoe, traditional shoe). The dependent variables were joint excursions and mechanical energy.

Data was collected on the left and right sides, but only the right side was used for analysis. It was suspected that individuals in the minimalist group would have a greater ankle range of motion. To determine if ankle range of motion between groups had differences prior to investigating joint excursions and mechanical energy expenditure an independent t-test was performed. It was anticipated that ankle range of motion may have influenced the results; therefore, the ankle range of motion was added as a covariate. 2 x 2 (condition by group) repeated measures MANCOVAs were conducted for each joint (hip, knee, and ankle) and for each exercise (overhead squat and single-leg squat) separately. All statistical analyses were conducted using PASW Version18 for Windows ® (IBM, Inc.). Alpha level was set at 0.05.

CHAPTER 4

RESULTS

ANKLE RANGE OF MOTION

Ankle Range of Motion (Figure 2) did not differ between groups (P = .566).

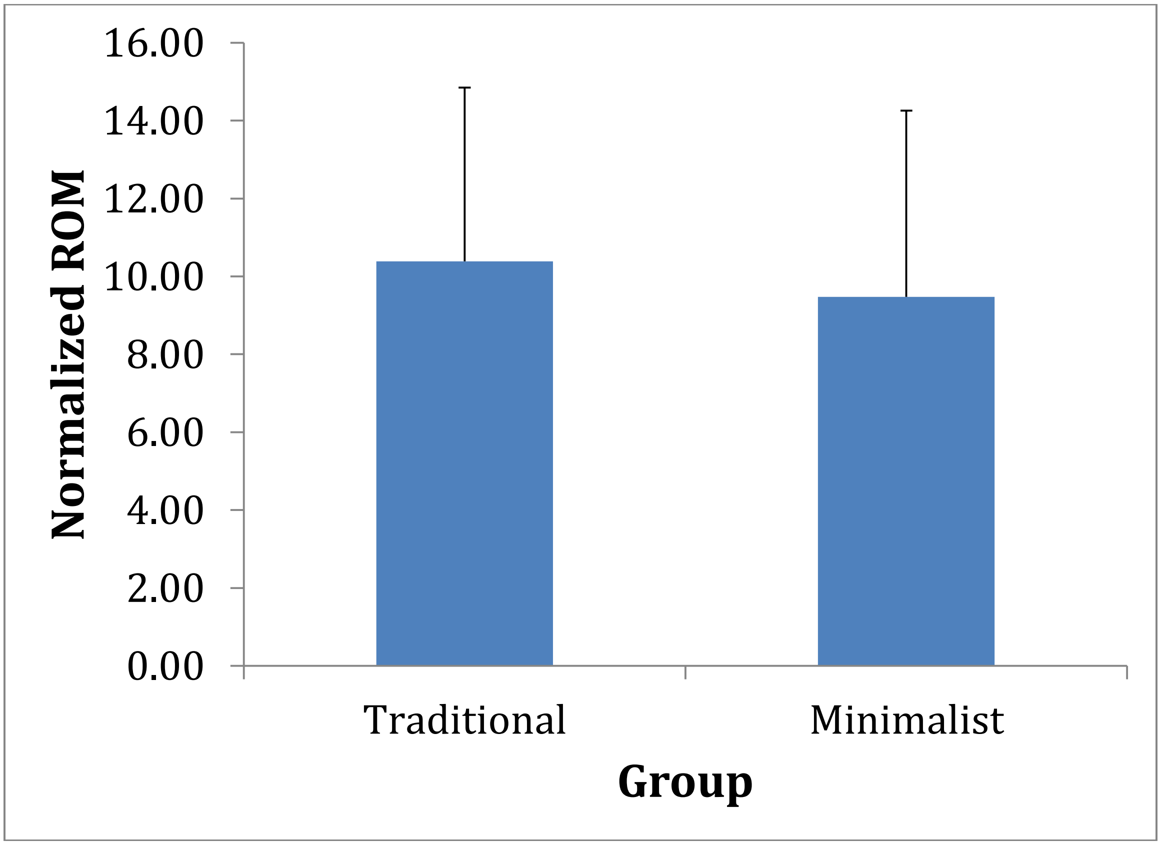

Figure 2. Comparison of Ankle ROM between athletic sneakers and minimalist style shoe users.

OVERHEAD SQUAT

Data for the overhead squat are presented in Figures 2 and 3. When accounting for the main effects and interactions, ankle ROM was not significantly correlated with the hip (P = .061), but was significantly correlated with the knee (P < .001) and ankle (P < .001).At the hip, the results of the MANCOVA reveal a significant effect for condition (P = .004), with no significant effect for group (P = .235), or significant interactions for condition x ROM (P = .234) or condition x group (P = .667). The hip joint excursions were ~1.3% larger (P = .091), and the hip MEE was ~14% larger (P = .001) in the shod condition. At the knee, the main effect for condition (P = .120) and group (P = .327), as well as the condition by range of motion (P = .988) and condition by group (P = .177) interactions, were not significant. Similarly, the main effect for condition (P = .057) and group (P = .057), as well as the condition by range of motion (P = .087) and condition by group (P = .487), were not significant at the ankle.

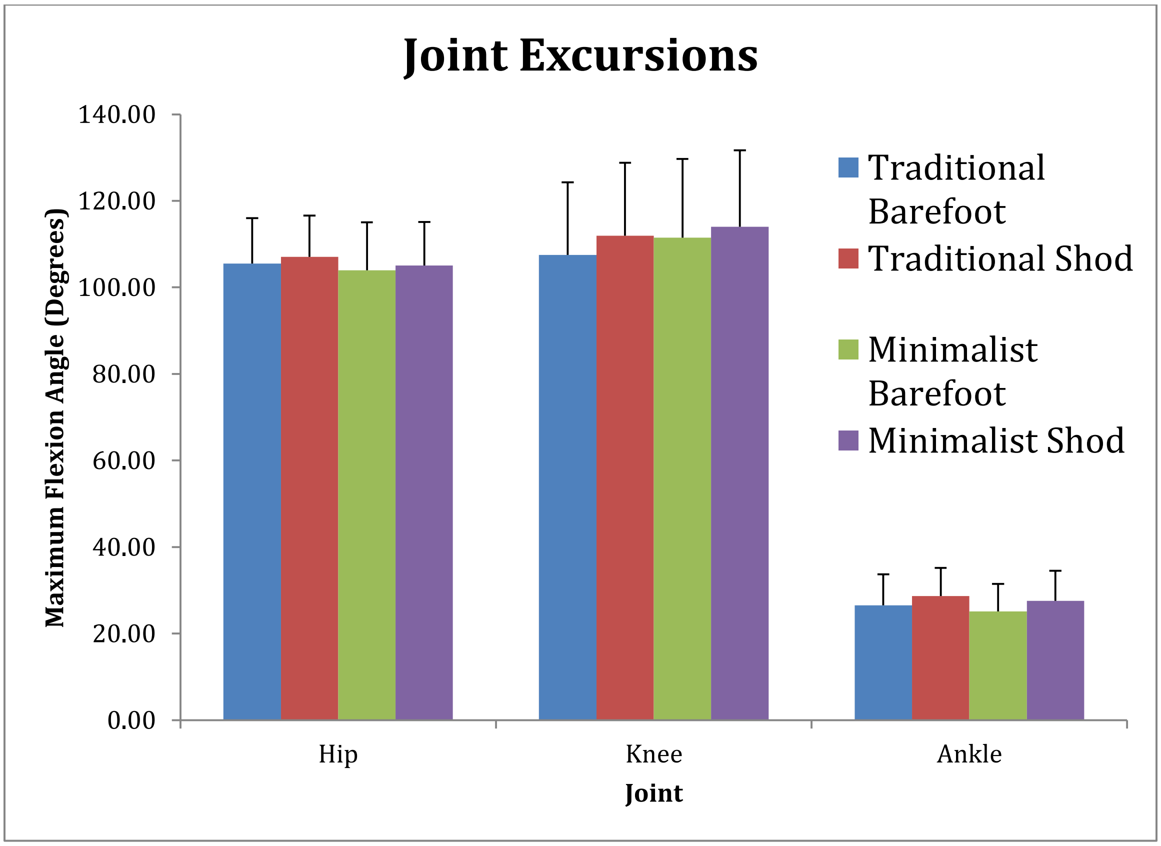

Figure 3. Comparison of joint excursions at the hip, knee, and ankle in barefoot, minimalist, and shod conditions during the overhead squat.

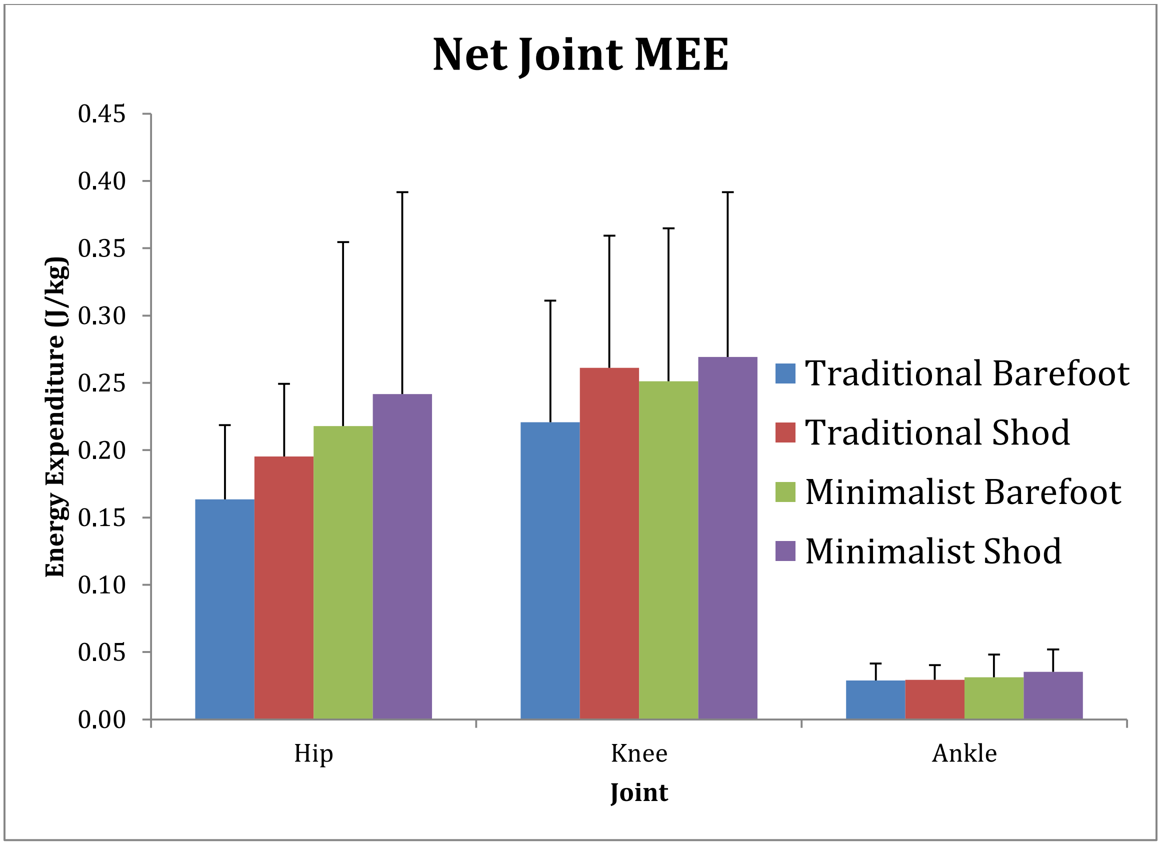

Figure 4. Comparison of Mechanical Energy Expenditure at the hip, knee, and ankle in barefoot, minimalist, and shod conditions during the overhead squat.

SINGLE LEG SQUAT

Data for the single-leg squat are presented in Figures 4 and 5. When accounting for the main effects and interactions, ankle ROM was significantly correlated with the hip (P = .017) and the knee (P = .027), but not the ankle (P = .231). At the hip, the main effect for condition (P = .157) and group (P = .735), as well as the condition by range of motion (P = .270) and condition by group (P = .338) interactions, were not significant. At the knee, there was a significant main effect for condition (P = .040), and a significant condition by range of motion (P = .040) interaction, but the main effect for group (P = .865) and the condition by group (P = .631) interaction were not significant. The shod conditions produced ~6% larger joint excursions (P < .001) and required ~11.5% greater

MEE (P< .001). At the ankle, the main effect for condition (P = .059) and group (P = .619), as well as the condition by range of motion (P = .293) and condition by group (P = .360) interactions, were not significant.

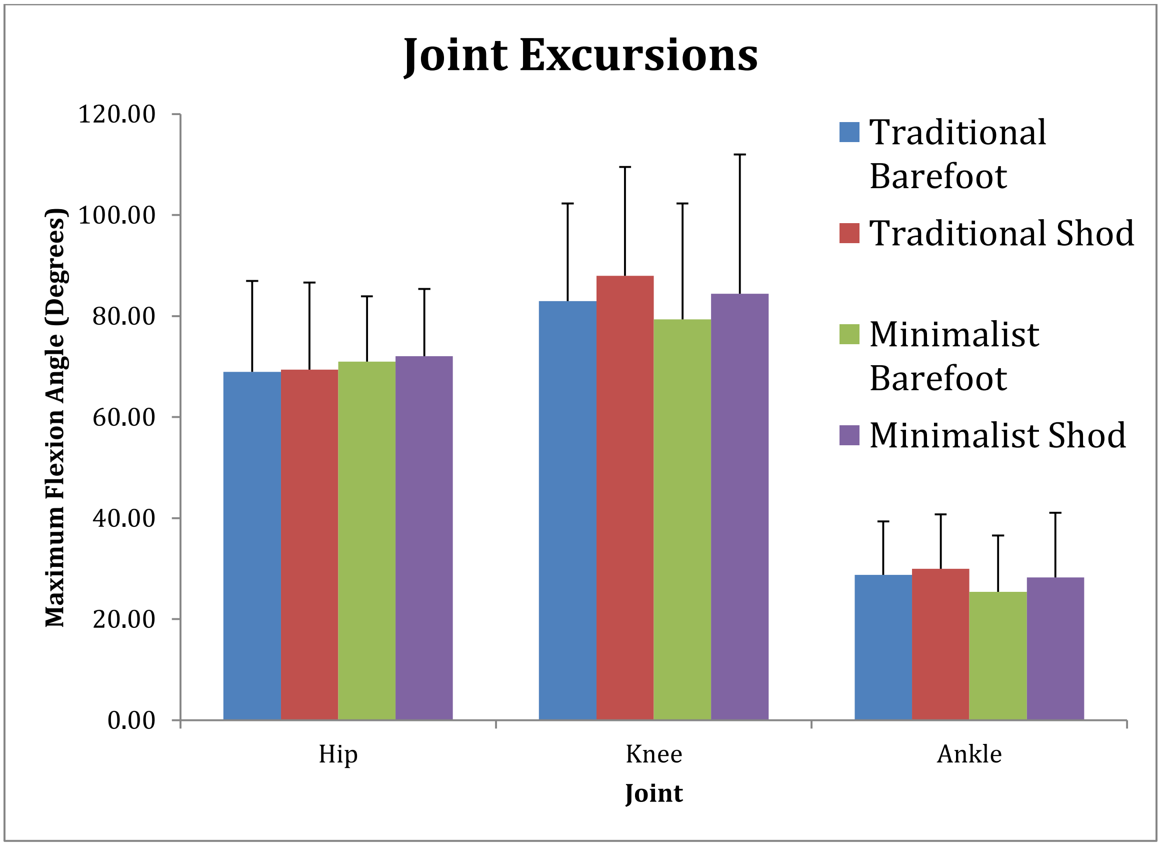

Figure 5. Comparison of joint excursions at the hip, knee, and ankle in barefoot, minimalist, and shod conditions during the single leg squat.

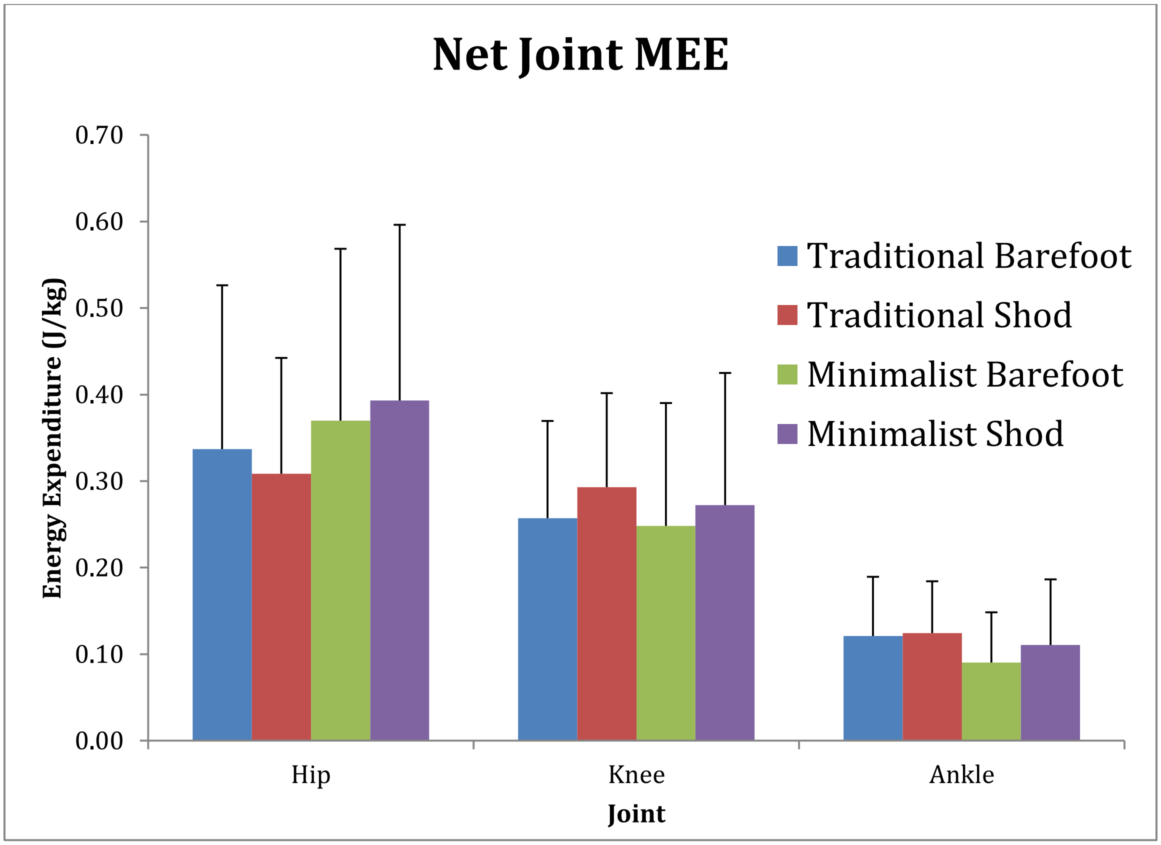

Figure 6. Comparison of Mechanical Energy Expenditure at the hip, knee, and ankle in barefoot, minimalist, and shod conditions during the single leg squat.

CHAPTER 5

DISCUSSION

This study does not support the hypothesis of (a) barefoot, minimalist, and shod conditions will result in differences in joint excursion and total mechanical energy expenditure, (b) minimalist conditions will be similar to barefoot conditions when compared to shod conditions, and (c) ankle range of motion will exacerbate these differences.

We investigated biomechanical differences in an overhead and single leg squat in barefoot, minimalist, and shod conditions. When comparing minimalist and shod conditions to the barefoot during an overhead squat, wearing shoes increased the mechanical energy expenditure at the hip. The choice of footwear (traditional or minimalist) was not a significant factor. Wearing shoes increased the joint excursions and mechanical energy expenditure at the knee during the single-leg squat. Choice of footwear (traditional or minimalist) was not a significant factor.

The aim of this study was to determine if biomechanical differences are present when performing an overhead squat and a single leg squat in a barefoot, minimalist, and shod condition. We hypothesized that differences in mechanics due to footwear could be due to an individual trying to mitigate impact and/or differences in heel height. Further we thought that, if there is a difference due to heel height, these differences could be exacerbated for those individuals with limited range of motion at the ankle. However, it was found during this study that shoe condition and varying heel heights did not have a large influence on squatting technique. Ankle range of motion influences squatting mechanics, but there was not an interaction with the shoe condition.

In gait, differences in mechanics between barefoot and shod conditions appear to be related to loading rates. Regardless of shoe selection, a walking gait has the same heel strike pattern (Lohmann et al., 2011), whereas, shod conditions during running result in striking patterns that are dependent on the choice of footwear (Divert et al., 2005). The differences in a running gait could be due to higher ground reaction forces when compared to walking. Previous research has shown equivocal results in landing during barefoot and shod conditions. Yeow et al., 2011 found that knee range of motion and joint power was higher in shod landings when compared to barefoot. There were significant differences between landing heights, however, there were no differences for shoe conditions, while Shultz et al., 2012 found that shoe condition was a significant factor in landing task. Squatting may be related to landing the way walking is related to running; lower impacts (loading rates) may decrease the differences seen in joint kinematics and kinetics between shod and barefoot conditions.

The current study found that ankle range of motion influenced the knee joint during the single leg squat, however there were no significant findings in either squatting task for the various footwear conditions. There was a significant finding for mechanical energy expenditure at the hip and knee during the overhead squat. There were significant findings for joint excursion and mechanical energy expenditure at the knee and mechanical energy expenditure at the ankle during the single leg squat. With squatting, the amount of overall load varies dependent on how much the individual is attempting to lift, but regardless of the load, there loading rates are low. Walking and squatting are similar as they are activities with lower rates of loading. In this instance, squatting had small differences in mechanics during a barefoot, minimalist, and shod condition. The differences found in the current study could be a result the lack of a high loading rate when compared to activities with higher impacts, such as running and landing.

It was hypothesized that heel height could have an influence on the mechanics of the overhead and single leg squat. A study done by Sato et al. (2012) found that when comparing weight lifting shoes that have a firm heel lift of approximately 2.5cm resulted in a more plantar flexed foot and less forward lean of the trunk when compared to running shoes. These results are due to the differences in heel height in the weight lifting and running shoes as well as the firmness of the heel height, which resulted in differences in squatting mechanics.

In the current study, there was a heel height difference when comparing barefoot, minimalist, and shod. However, those differences were not as great as a weight lifting shoe. Conventional running shoes have a heel height of 2.5 to 4.0cm, whereas minimalist style shoes have a heel height of 2 to 8mm depending on the brand of shoes. The heels in minimalist and traditional shoes are also not a firm heel height. Not having a firm heel allows for depression in the heel of the shoe when squatting, making the difference in heel heights even smaller. Firm heel heights allow for the foot to stay in a more plantar flexed position, therefore still allowing those wearing weight lifting shoes to squat lower and maintain a more erect posture. While it was expected that heel height in the various shoe conditions would have an effect on the mechanics of the squatting tasks, it did not. The heels in the shod and minimalist conditions may compress, in turn making the heel heights less than what they are without a load placed on them. This could be the reason why heel height in the vary shoe conditions did not affect the results of the squatting task.

It was hypothesized that ankle range of motion would also play a role in squatting mechanics. Lack of range of motion was thought to exacerbate these differences. This study found that ankle range of motion did have a significant effect at the knee and ankle during an overhead squat and at the hip and knee during a single leg squat. This is in agreement with other research such as the studies done by Macrum et al., 2012 and Shoenfeld et al., 2010 where ankle range of motion was manipulated into dorsiflexion and plantar flexion respectively. Footwear choice was not a factor when considering ankle range of motion and its effects on the squatting tasks. It is unknown as to why the differences in heel height in the various shoe conditions did not make a difference as they did in the replicated situations of plantar flexion (Schoenfeld, 2010) and dorsiflexion (Macrum et al., 2012) done in previous research. It can be theorized that due to the compressive nature of the heel heights, there were little to no differences in the height of the heels in minimalist and shod conditions.

Research has mainly investigated the changes in gait adaptations with the use of barefoot, minimalist, and shod conditions during running and walking activities. There is little research on other activities in various shoe conditions, such as barefoot and shod landings. The current study took place in a controlled fashion where the participants were of the similar athletic ability, have been properly instructed on how to perform an overhead and single leg squat by a certified strength and conditioning specialist for a minimum of one year, and were given adequate time to warm up as well as any needed breaks between repetitions.

Limitations

Limitations of the current study are: the participants were instructed to squat with their feet in a neutral position, to help eliminate possible factors that may or may not have directly affected the results of this study. This is a limitation because when some of the participants of the current study perform various squatting techniques they externally rotate their feet to allow for a greater depth in their squat. Another limitation of the study is that the shoes used in the shod and minimalist condition were not regulated, as the participants were allowed to participate in the shoes that they typically wear. This could have resulted in the shoe being a direct result of the participants squatting technique due to shoe structure. Lastly, a limitation of the current study is that the heel heights of the participants' shoes were not measured. There was a slight heel height difference between all shoe conditions; however, a specific difference was not determined due to not controlling the specific shoes each participant wore during the study. One could speculate that the range of differences is from 2mm to 12mm in all shoe conditions.

Future studies should look at specific shoe models and allow an adaptation period before testing the participants

CHPATER 6

CONCLUSION

In conclusion, performing an overhead and single leg squat in a barefoot, minimalist, and shod condition does not alter an individuals' biomechanics. Previous research confirms that gait adaptations occur in the three above shoe conditions, however, adaptations were not found in squatting activities. Future studies should investigate specific shoe models and activities other than squatting techniques.

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APPENDIX

Table 1. Statistical comparisons for overhead squat

Dependent variable	Statistic	Significance
Range of Motion		
ROM x hip	F (2,29) = 3.081	P = .061
ROM x knee	F (2,29) = 23.205	P < .001
ROM x ankle	F (2,29) = 10.662	P < .001
HIP		
Between Subjects		
Group	F (2,29) = 1.524	P = .235
ROM	F (2,29) = 3.081	P = .061
Within Subjects		
Condition	F (2,29) = 6.791	P = .004
Condition x ROM	F (2,29) = 1.530	P = .234
Condition x group	F (2,29) = .411	P = .667
Excursion	F (1,30) = 3.056	P = .091
MEE	F (1,30) = 12.971	P = .001
KNEE		
Between Subjects		
Group	F (2,29) = 1.163	P = .327
ROM	F (2,29) = 23.205	P < .001
Within Subjects		
Condition	F (2,29) = 2.285	P = .120
Condition x ROM	F (2,29) = .012	P = .988
Condition x group	F (2,29) = 1.840	P = .177
Excursion	F (1,30) = 2.201	P = .148
MEE	F (1,30) = 4.181	P = .050
ANKLE		
Between Subjects		
Group	F (2,29) = 1.008	P = .377
ROM	F (2,29) = 10.662	P < .001
Within Subjects		
Condition	F (2,29) = 3.159	P = .057
Condition x ROM	F (2,29) = 2.663	P = .087
Condition x group	F (2,29) = .737	P = .487
Excursion	F (1,30) = 3.558	P = .069
MEE	F (1,30) = 1.389	P = .248

Table 2. Statistical comparisons for single leg squat

Dependent variable	Statistic	Significance
Range of Motion		
ROM x hip	F(2,29)=4.731	P = .017
ROM x knee	F (2,29) = 4.094	P = .027
ROM x ankle	F (,2,29) = 1.634	P = .231
HIP		
Between Subjects		
Group	F (2,29) = .311	P = .735
ROM	F(2,29)=4.731	P = .017
Within Subjects		
Condition	F (2,29) = 1.972	P = .157
Condition x ROM	F (2,29) = 1.372	P = .270
Condition x group	F (2,29) = 1.127	P = .338
Excursion	F (1,30) = 2.894	P = .099
MEE	F (1,30) = .354	P = .557
KNEE		
Between Subjects		
Group	F (2,29) = .145	P = .865
ROM	F (2,29) = 4.094	P = .027
Within Subjects		
Condition	F (2,29) = 11.147	P = .000
Condition x ROM	F (2,29) = 3.599	P = .040
Condition x group	F (2,29) = .468	P = .631
Excursion	F (1,30) = 21.187	P = .000
MEE	F (1,30) = 10.681	P = .003
ANKLE		
Between Subjects		
Group	F (2,29) = .488	P = .619
ROM	F (,2,29) = 1.634	P = .231
Within Subjects		
Condition	F (2,29) = 3.134	P = .059
Condition x ROM	F (2,29) = 1.282	P = .293
Condition x group	F (2,29) = 1.060	P = .360
Excursion	F (1,30) = 3.837	P = .059
MEE	F (1,30) = 4.221	P = .049