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The effect of barefoot running on navicular drop: a randomized controlled trial

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THE EFFECT OF BAREFOOT RUNNING ON NAVICULAR DROP: A RANDOMIZED
CONTROLLED TRIAL

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A Scholarly Project Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine & Health Sciences
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In partial fulfillment of the requirements for the degree of
Doctor of Physical Therapy

Grand Forks, North Dakota
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This Scholarly Project, submitted by Corrie Fredericks, Alison Cygan, and Robert Plemel in partial fulfillment of the requirements for the Degree of Doctor of Physical Therapy from the University of North Dakota, has been read by the Advisor and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

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THE EFFECT OF BAREFOOT RUNNING ON NAVICULAR DROP: A
RANDOMIZED CONTROLLED TRIAL

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ABSTRACT

Background and Purpose: Gaining knowledge of the change in navicular drop/over-pronation of the foot in response to barefoot running training may allow sports medicine professionals, coaches, athletes, and others in the healthcare field to decrease the amount of injuries that may be caused by these motions. Effects of a running retraining program with conversion from a rearfoot strike pattern (RFSP) to forefoot strike pattern (FFSP) to determine impact on navicular drop is lacking in literature. Due to the increased correlation of over-pronation and lower extremity injuries, the purpose of this study was to determine if barefoot running training, with a FFSP compared to shod running using a RFSP, would affect the amount of drop during walking and running activities.

Material/Methods: Navicular movement was analyzed between shod and barefoot running groups by utilizing the VICON motion analysis system and the static navicular drop test before and after the six-week running program. This study implemented a six-week gait retraining program to convert from a RFSP to FFSP in the barefoot running group when compared to the controlled shod group. The VICON was specifically used to evaluate the navicular drop of the foot during the stance phase of gait in walking and running. A decrease in navicular distance traveled from pre- to post-test, may suggest a decrease in dynamic foot over-pronation. This result could support the effects of barefoot running with a FFSP, as a possible method for reducing pain and injuries associated with running.

Results: Results showed no statistical significance in the Standard Navicular Drop Test. There were statistically significant differences using the VICON Motion Analysis for assessing
dynamic navicular drop in Barefoot Walking (BW), Running Normal Barefoot (RNB), and Running on Toes Barefoot (RTB) on the right foot. Statistically significant differences were noted in the shod and barefoot training groups. Reduced post-training navicular movement was noted in the shod training group compared to increased navicular movement in the barefoot training group on the right foot.

**Discussion:** This current study determined that barefoot running did not improve the amount of navicular drop. Data showed that navicular drop significantly decreased on the right foot with shod training group in the conditions BW, RNB, and RTB indicating that shod training may be better for improving a pronated foot while performing these dynamic tasks. Limitations of this study included: a small sample size, narrow population, limited time spent barefoot running retraining, adverse training effects of the foot (blisters, metatarsal pain), and the VICON motion analysis process provided several inconsistencies during measurement of dynamic navicular drop during walking and running. Future research could address these limitations through creation of an ongoing study and/or open it to the public to improve subject population.
CHAPTER I

BACKGROUND AND PURPOSE

The biomechanics of running have been studied throughout history. In recent decades there has been increasing amounts of research and interest in the effects of barefoot running on the kinematics, kinetics, and recruitment of lower extremity muscles. It has been hypothesized that some of the benefits of barefoot running are due in part to an acquired forefoot strike pattern as opposed to a rearfoot strike pattern most often seen in shod running.\textsuperscript{1, 2, 3} According to a study by Hashish et al\textsuperscript{4}, without a shoe sole to help absorb the impact of running with a rearfoot strike pattern (RFSP), a trained barefoot runner often switches to a forefoot strike pattern (FFSP). This requires them to rely more on the posterior compartment muscles and structures of the lower leg: gastrocnemius, soleus, tibialis posterior, and Achilles tendon.

The hypothesis of this study is that barefoot running training will decrease the distance traveled of the navicular within the medial longitudinal arch of the foot compared to shod training. The primary role of the tibialis posterior is to support or maintain this arch during weight-bearing.\textsuperscript{5, 6} Because of the direct insertion of the tibialis posterior onto the navicular bone, strengthening of this muscle by changing into a FFSP in barefoot runners could result in a decreased navicular drop. Other deep posterior muscles of the leg that may contribute to improved support of the medial longitudinal arch of the foot include the flexor hallucis longus and flexor digitorum longus. The flexor hallucis longus produces the final push from the foot in the toe-off phase of the gait cycle. At this point in the cycle the gastrocnemius and soleus have already maximally contracted, and thus, great toe flexion by the flexor hallucis longus is the final
action produced before the foot is lifted from the floor before swing phase of gait. During the propulsion phase of walking, running or jumping, flexor digitorum longus pulls the toes downwards towards the ground to attain maximal grip and thrust during toe-off. Barefoot running may accentuate this motion produced by the toes in propulsion during running. By switching to a FFSP, all three of these deep calf muscles may be recruited more and strengthened enough to enhance their action at the ankle joint and improve support of the medial longitudinal arch. Therefore, by reducing the navicular drop height and limiting over-pronation, running-related pain and injuries may be decreased.

Overuse injuries have been associated with running. One in particular is excessive pronation or supination of the foot which has often led to overuse injuries in distance runners. Increased hip Q angle (a line representing the force of the quadriceps, made by connecting a point near the anterior superior iliac spine (ASIS) of the pelvis to the midpoint of the patella) and excessive pronation are predisposing factors of lower extremity stress fractures and plantar fasciitis when performing repetitive stress to the bone such as in running. By reducing the distance in which the navicular travels, in theory, it should reduce the amount of over-pronation. In turn this may indirectly reduce the Q angle at the knee and prevent subsequent injuries. In a study by Khamis et al, hyperpronation of the foot has been shown to cause internal rotation of the tibia and femur leading to increased anterior pelvic tilt and lordosis of the lumbar spine in standing. As a result, excessive pronation may cause impairments at multiple body segments over time, which may be exaggerated by the repetitive forces exerted during running.

Although there is increased interest on the impacts of barefoot running, there is a paucity of research pertaining to the impact barefoot running may have on navicular drop. Because the literature is so scarce, there is a need for research in this area. The purpose of this study is to
determine the effect barefoot running may have on the amount of navicular movement in order to prevent injury at multiple joints, musculature, and structures of the body.

**Biomechanics of the Lower Extremity**

The biomechanics of the lower extremity are discussed in further details below. Categories for discussion include the forefoot, ankle, knee, and hip as well as common links to biomechanical related injuries.

**Forefoot:**

It has been hypothesized that some of the benefits of barefoot running are due in part to an acquired forefoot strike pattern as opposed to a rearfoot strike pattern most often seen in shod running. It is believed that this forefoot strike pattern decreases the ground reaction forces experienced during barefoot running. Hashish et al. evaluated 22 recreational runners transitioning to barefoot running to determine carry-over into forefoot running. This study concluded that not all runners adopted a forefoot strike pattern independently. In the absence of instruction, 8 runners maintained a rearfoot strike pattern, 9 adopted a midfoot strike pattern and only 5 adopted the desired forefoot strike pattern. Hallux valgus angle is also an important measurement hypothesized to correlate with barefoot running and walking. In a systematic analysis performed by Hollander et al. which evaluated 15 studies with a total of 8,399 participants who performed either barefoot running or walking, concluded that there is little evidence to support the hypothesis of a lower measured hallux angle in barefoot running.

**Ankle:**

Barefoot running has significant implications in relation to ankle kinematics as well as the rest of the kinetic chain. It has been hypothesized that during barefoot running there is a reduced ankle dorsiflexion moment at foot strike. Hollander et al. concluded that there was limited evidence to support the hypothesis of reduced ankle dorsiflexion at foot strike when
compared to shod runners (pooled effect size \(-3.47\) (95% CI \(-5.18\) to \(-1.76\)). It has also been hypothesized that during barefoot running there is an increase in plantarflexion moments at foot strike.\(^2\) In a study conducted by Fredericks et al\(^{13}\) which evaluated 26 recreational runners either barefoot or shod in their own personal shoes, standardized shoes, or minimalist shoes, it was concluded that barefoot and minimalist runners had significantly greater plantar flexion moments at foot strike than the other 2 groups. In addition to plantarflexion/dorsiflexion moments, barefoot running is also hypothesized to have an effect on ankle eversion. Perkins et al\(^{14}\) suggests there is a decreased tendency for barefoot forefoot strike runners to evert their foot during running such as seen in shod rearfoot strike groups. This running position may support the hypothesis that barefoot runners experience less navicular drop than shod runners. Along with this, it was concluded that barefoot runners display an increase in power generation and absorption of ground reaction forces at the ankle illustrating the significance of the position of the ankle during foot strike in producing good biomechanics while running.\(^{14}\)

In addition, Hashish et al\(^4\) concluded the finding that midfoot and forefoot strike runners showed increased ankle energy absorption rates. This increase in ground reaction forces at the ankle helps support the claim that barefoot runners experience less ground reaction force at the knee which may decrease the stresses to the knee, thus salvaging soft tissues.

**Knee:**

The biomechanics of the knee are of interest in barefoot running secondary to a high incidence of knee injuries in runners. Barefoot running has been hypothesized to prevent certain type of running related knee injuries. One aspect of study during barefoot running is Q angle. Increased Q angle at the knee has been correlated with numerous pathologies at the knee. In a study conducted by Fredericks et al\(^{13}\) it was concluded that type of footwear had no significant effect on the knee Q angle during running. Although evidence suggests that barefoot running has
little effect on Q angle at the knee it appears to have an effect of knee flexion moments during running.\textsuperscript{2} In a systematic review conducted by Perkins et al\textsuperscript{14}, moderate evidence identified an increase in knee flexion at contact in barefoot/minimalist runners and increased knee flexion angle in stance phase of barefoot or minimalist running. This increased knee flexion at contact is hypothesized to reduce the knee extension moment arm and lessen the stress across the patellofemoral joint. In addition to increased knee flexion moments, barefoot runners also exhibited earlier knee flexion moments in a study conducted by Sinclair et al\textsuperscript{15} who evaluated female recreational runners. Finally, the loading rates at the knee are also of interest in the study of barefoot runners and its effects of the kinetic chain and possible injury prevention. In a study conducted by Hashish et al\textsuperscript{4}, loading rates in the knee increased in runners that maintained rearfoot strike patterns while barefoot running, while forefoot strike runners showed significantly decreased loading rates in the knee. Sinclair et al\textsuperscript{15} supported this claim as barefoot running showed significant reductions in patellofemoral loads.

**Hip:**

The biomechanical effects of barefoot running at the hip contribute to the mechanics of the kinetic chain above and below this joint. Inadequate strength and muscle activation at the hip have been correlated with a variety of hip and knee pathologies. Sinclair et al\textsuperscript{15} evaluated 20 experienced male runners performing either barefoot running or shod running and concluded the shod group displayed significantly more hip flexion while the barefoot group exhibited significantly more knee flexion and plantarflexion at the ankle. The shod group displayed greater peak force in their quadriceps and tibialis anterior. The barefoot group showed significantly higher peak forces in the gastrocnemius. In addition, a study performed on female recreational runners concluded when comparing the kinematics of barefoot running vs shod running, barefoot runners had a significant reduction in hip adduction, hip internal rotation, and contralateral pelvic
drop at initial contact. At 10% stance, they remained significantly lower than the shod group; however, there was no significant difference observed in peak stance.\textsuperscript{15}

**Injuries of the Lower Extremity**

Due to the altered biomechanics barefoot running may have on the lower extremity kinetic chain, it has been hypothesized that barefoot running may serve as a method of prevention of many lower extremity orthopedic pathologies. Hollander et al\textsuperscript{12} concluded that there was no difference in injury rates between shod and barefoot runners and walkers as compared to shod runners and walkers. A review by Perkins et al\textsuperscript{14} supported this conclusion stating there is not enough evidence to ascertain specific risks and benefits related to barefoot running vs shod running, however it is hypothesized due to the increased plantarflexion moment seen in barefoot running the Achilles tendon may be at increased risk for injury. In addition, moderate evidence supports the claim that barefoot running decreases ground reaction forces in the lower extremity which could decrease knee injuries.\textsuperscript{4, 14} It is important to note the authors attribute this decrease in ground reaction force to a forefoot strike pattern rather than the barefoot running itself. This transfer of ground reaction forces is further explained in a study conducted by Bergstra et al\textsuperscript{16} in which an increase in forefoot pressure was observed in female endurance runners who transitioned to a minimalist running shoe. This increase in pressure is thought to play a role in metatarsal stress fractures. The kinematic differences observed at the hip in the study performed by Sinclair et al\textsuperscript{15} may suggest a decrease in running pathologies at the knee due to decreased hip internal rotation at contact.

Rearfoot eversion, tibial rotation, knee adduction, and ankle inversion are biomechanical gait measures which have been identified as potential risk factors for lower limb injuries.\textsuperscript{17, 18, 19} Eslami et al\textsuperscript{20} found that navicular drop had significant positive correlations between peak knee
adduction moment and peak ankle inversion moment in participants during barefoot running. Their findings suggested that a low navicular drop could be associated with increasing tibial rotation excursion, while a high navicular drop could be associated with increased peak ankle inversion and knee adduction moments. Although not finding a correlation with rearfoot eversion excursion, Cornwall and McPoil\textsuperscript{21} did find a correlation with rearfoot eversion and navicular drop. These moments (rearfoot eversion, tibial rotation, knee adduction, and ankle inversion) in return could potentially lead to injury over time such as shin and knee injuries.\textsuperscript{22, 23, 24}

**Navicular Drop**

The measurement of navicular drop movement was conducted by utilizing the Navicular Drop Test (NDT). The reliability of the NDT will be discussed below along with the rate of drop that occurs during running.

**Measurement using the Navicular Drop Test (NDT):**

Brody was the first to determine the measurement of pronation in the foot by designing the navicular drop test. In most of the following literature review, Brody’s protocol for this measurement is used and will also be used in the current study to assess navicular drop via the explanation of Charlesworth and Johansen.\textsuperscript{25} This method of measurement placed the participant in a seated position with feet flat on the floor and hips and knees flexed to 90 degrees with the ankle in a neutral position. Identification of the most prominent point of the navicular tubercle was be marked. Subtalar neutral was found when talar depressions were equal on both sides of the ankle. One assessor maintained the subtalar neutral position and the other used a notecard to mark the height of the navicular tubercle. The participant then stood up without changing the position of the feet but to allow distribution of equal weight between both feet. Again, the most prominent point of the navicular tubercle was measured for height on the notecard. The
difference between the two markings were measured in millimeters. The same procedure was calculated for the opposite foot as well. Brody described values of 10 mm and under to be normal and 15 mm and over to be abnormal.\textsuperscript{25} In a separate study done by Loudon et al\textsuperscript{26}, the authors reported 6 mm was a low difference and reported equal to or greater than 9 mm was a high difference. Measure of navicular drop greater than 9mm have been associated with the development of shin splints along with predisposing factors associated with anterior cruciate ligament injuries in runners.\textsuperscript{13} In the present study, a difference of 7 mm will be the inclusion criteria.

McPoil et al\textsuperscript{27} suggested that there are issues in performing the traditional navicular drop test involving lower levels of inter-rater reliability: the identification of the navicular tuberosity bony landmark and the consistency of placing the subtalar joint in a neutral position using palpation. To overcome these shortcomings, the authors of this study developed an alternative method for assessing foot mobility by utilizing digital images to measure the change in dorsal arch height measured at 50\% of the foot during the sit to stand portion of the navicular drop test. In this method, the location of subtalar joint neutral was not performed due to the alternative method. This method can provide the clinician with a reliable and valid alternative to quantify foot mobility in comparison to the traditional navicular drop test. The only negative to the study was the amount of time it took to process the photos which can be solved using updated techniques.

Van der Worp et al\textsuperscript{28} looked at the NDT assessment in runners to identify whether hyperpronation of the foot along with decreased ankle joint dorsiflexion and the degree of the first metatarsalphalangeal joint extension are risk factors for running injuries and to determine possible sex differences. The cohort study performed the NDT using modified procedures by
both Vinicombe et al\textsuperscript{29} and McPoil et al\textsuperscript{27} using a stance and single limb-stance measurement. Interrater and intrarater ICCs were low for both NDT stance and single limb-stance. However, the authors did not determine subtalar joint neutral before taking measurements during this study and determined that this was one of their limitations in the study when comparing to ICC data from other literature. Sell et al\textsuperscript{30} suggests that subtalar neutral position can be measured reliably by palpating the talus equally between the thumb and the index finger of the examiner. Along with this, they also explained finding the navicular tuberosity in prone instead of sitting which proved to be reliable. The different ways of measuring marking the tibial tuberosity could a great alternative.

\textit{NDT Reliability:}

The intra- and inter-rater reliability of the navicular drop test has only been proven to be moderate. In a study performed by Vinicombe et al\textsuperscript{29}, two methods for quantifying foot posture were evaluated: navicular drop and navicular drift. Twenty nonpathological participants were measured by 5 clinicians on two different occasions. The authors found that intratester reliability was slightly better than intertester reliability for both measurements, but intraclass correlation coefficients and standard error of measurement findings for navicular drop (0.33 to 0.76 and +/- 1.5mm to +/-3.5, respectively) were only slightly better than navicular drift (0.31 to 0.62 and +/-3mm to +/-5mm, respectively). This indicates that both techniques are only moderately reliable.

In comparison, Sell et al\textsuperscript{30} found good intrarater and interrater reliability when evaluating measurements of navicular drop in 30 healthy subjects. These authors reported a mean value of 0.6 cm in navicular drop and an ICC for intra- and inter-rater reliability of 0.73 and 0.83, respectively.
Rate of Drop:

Previous research suggests that the rate of pronation may contribute to running-related injuries. Hoffman et al\textsuperscript{31} conducted a study using dynamic, biplane X-ray imaging to assess the effects of three footwear conditions (barefoot, minimalist shoes, motion control shoes) on the magnitude and rate of navicular drop during running. Their purpose was to also determine the association between static and dynamic measures of navicular drop. The difference in shoes had no effect on magnitude but motion control shoes had a slower navicular drop rate than running barefoot or minimalist shoes. Static assessment was found to be a poor predictor of dynamic navicular drop in all footwear conditions.

Motion Analysis

Development of a stretch-sensor that allowed for in-shoe measurement of navicular drop was investigated for its reliability for measuring navicular drop and concurrent validity of the stretch-sensor compared to the static navicular drop test.\textsuperscript{32} Twenty-seven participants were tested by walking on a treadmill on two separate days for six minutes before navicular drop was measured. Placement of the stretch-sensor was 20 mm posterior to the tip of the medial malleolus and 20 mm posterior to the navicular tuberosity. Results showed acceptable reliability for dynamic barefoot measurement of navicular drop and also showed concurrent validity compared with the static navicular drop test. Conclusions drawn from this research article on the development of stretch-sensors to measure navicular drop is very new and needs more research before it can be recommended but it holds promise for future assessments. In another study by Barton et al\textsuperscript{33}, stretch sensors were used to evaluate dynamic navicular motion difference between walking and running and between over-ground and treadmill conditions. The authors’ conclusion was that the presence of footwear has minimal impact on navicular motion during
walking. Differences in navicular motion between walking and running, and treadmill and over-ground conditions highlight the importance of task specificity during gait analysis. Therefore, task specificity should be taken into consideration when deciding what conditions to run.

An alternate use of sensors to detect motion was conducted in a study by Klein and Dehaven. These authors investigated the accuracy of three-dimensional linear and angular estimates obtained with the Ariel Performance Analysis System. This system is a method of evaluating human kinematics using computer-assisted motion analysis. This instrument was shown to be valid and reliable to the degree required in most clinical applications. Suggestions for using marker placement and marker movement on human subjects were given to decrease the amount of error. Although this was a reliable source, the 3D motion analysis tool, VICON, has been used as a gold standard for many studies analyzing human movement.

VICON was utilized in a study which investigated the reliability and validity of the Stride Analyzer in persons with knee osteoarthritis. The VICON used a 16-camera-infrared optoelectronic motion capturing system. When comparing the Stride Analyzer to the VICON system is was found to be valid and reliable as well. By using the sensor and motion analysis instruments, navicular drop may be measured at a much higher level (greater evidence of validity and reliability). The VICON system in the current study will be using 10 cameras to capture the distance and rate of navicular movement during walking and jogging activities.

Summary

By utilizing the VICON motion analysis system and the traditional navicular drop test, navicular drop of the shod and barefoot participants can be analyzed before and after the six-week running program. Effects of a running retraining program with conversion from a RFSP to FFSP to determine impact on navicular drop is lacking in literature. This study implemented a
six week gait retraining program to convert from a RFSP to FFSP in the barefoot running group when compared to the controlled shod group. The intention of this study is to determine if barefoot running with a FFSP compared to the typical RFSP of shod runners will result in changes of the navicular drop height.

The concept for a reduction in navicular drop height and limited pronation of the foot may potentially lead to a decrease in running-related pain and injuries. The VICON was specifically used to evaluate the navicular drop of the foot during the stance phase of gait in walking and running. A decrease in navicular distance traveled from pre-test to post-test, may suggest a decrease in dynamic foot over-pronation. This result could support the effects of barefoot running with a FFSP, as a possible method for reducing pain and injuries associated with running.

Because of high increases in injury rate due to over-pronation of the foot, the current study will investigate the effects of barefoot running with a forefoot strike to determine if this mechanism of running will decrease the amount of navicular drop, indirectly reducing injury rate.
CHAPTER II

METHODS

The following chapter includes information as to how this study was organized and includes: information regarding the subjects and recruitment, informed consent, measurements/instruments, the study’s retraining program, post- survey, data analysis, and measuring internal validity. Study design for this research utilized VICON video analytics for dynamic monitoring of navicular drop during pre- and post-testing, inclusion criteria allowed participants’ pre-running requirements to be between 2 and 15 miles per week, and running retraining started at 10 minutes, followed by increasing total running time by 2 min weekly, for a maximum of 18 minutes by the final training week.

Subjects

To ensure the rights and welfare of human subjects in this study were protected, this study’s investigators obtained prior approval from the Institutional Review Board of the University of North Dakota (UND). See Appendix A for approval letter. Following approval, recruitment of subjects was initiated verbally and via email to all first and second year physical therapy students at UND. This email included a description of the study along with inclusion/exclusion criteria so that each recipient was able to independently assess their ability to participate. The inclusion criteria included: no pain or injury to the lower extremities in the past 6 months, age between 20-30 years old, greater than or equal to a 7 mm navicular drop, must run with a rear foot striking pattern, no current use of NSAIDs, no cardiopulmonary pathologies or significant medical history, and must currently complete a minimum of 2-15 miles of running per
week. Interested students attended pre-testing to affirm that their navicular drop was greater than 7mm. Once their inclusion/exclusion criteria were confirmed, participants were evaluated dynamically for navicular drop during walking and running using VICON video analytics software. Subjects were also evaluated using a standardized, static Navicular Drop Test. Fifteen subjects were recruited; however, one subject was removed from the study prior to the pretesting, secondary to acute knee pain that resulted during exercise prior to the initiation of the training program. Fourteen subjects underwent pre-testing using the static Navicular Drop Test. The subjects were then randomly assigned into either the shod or barefoot running group using blind name drawing with the subject names written on a piece of paper and drawn from a hat. The first subject drawn was placed into the barefoot running group and the second placed in the shod group. This method was repeated until all subjects were placed into the two different groups. Seven subjects were selected for the barefoot group and seven were selected for the shod group. Each subject was informed of their assignment confidentially via email. Of the fourteen participants, 3 were excluded due to navicular drop heights of less than 7 mm for each foot. One student was also not included in final data collection due to a lower extremity injury acquired during the barefoot training program. Subject selection based on inclusion and exclusion criteria is diagrammed in Figure 1.
**Figure 1: Subject Selection Process & Inclusion Criteria**

Research e-mail sent to 104 UND Physical Therapy Students for recruitment

- 89 Student elected not to participate in the research study
- 15 Students volunteered to participate in research study
- 1 Student excluded due to acute lower extremity pain prior to initiation of study
- 14 Students meet inclusion criteria* and can participate in NDT
  - 3 Students excluded due to navicular drop < 7 mm bilaterally
  - 1 Student excluded due to injury acquired during barefoot training

10 Students meet NDT inclusion criteria of ≥ 7 mm, finished running training program, and can be included in final data collection

**NDT = Navicular Drop Test**

*Inclusion Criteria:*
- No pain or injury to the lower extremities in the past 6 months
- Age between 20-30 years old
- Greater than or equal to a 7 mm navicular drop
- Must run with a rear foot striking pattern
- No current use of NSAIDs
- No cardiopulmonary pathologies or significant medical history
- Must currently complete a minimum of 2-15 miles of running per week

**Informed Consent**

Prior to pre-testing, each subject completed and signed an informed consent for detailing the study design and risks/benefits of taking part in the study. See Appendix B for the full
consent form. The consent form described the purpose of the study, the training protocols, and the risks/benefits that could occur as a result of participation in the study. Subjects were informed that they would receive no financial compensation for their participation, and that there was no funding attached to this study. Subjects were reminded that their participation in this study was completely voluntary, and would be permitted to terminate their participation at will. The process of participant confidentiality included a unique 5 digit code that would be assigned to each participant. This code was constructed using the first two digits being the subject’s mother’s day of birth, while the last three digits were the zip code of their residence while attending high school.

**Measurements/Instruments**

**Reliability Testing for the Navicular Drop Test**

A single researcher was utilized to assess navicular drop in this study. This researcher was blinded to subject assignment throughout the study and was not permitted to attend training sessions. Prior to pre-testing the reliability of this researcher was confirmed via evaluation of navicular drop in first and second year physical therapy students. Previous training of intra-rater reliability was performed until instrumentation results reached 0.90 reliability as recommended by Portney and Watkins. The final reliability results yielded an intraclass correlation equals 0.92 for the right foot and 0.94 for the left foot. The process of measuring navicular drop was the same that was used in the current study, except for the third intra-rater reliability study which used two researchers which one held the subject’s foot in subtalar neutral as the other researcher marked the height. Days between measurements also varied between the four different reliability studies; the most was within 4 days and the least was within 1 day. Overall, the researcher
continued to practice and improve testing skills throughout these intra-rater reliability studies prior to pre-testing.

**Navicular Drop Test**

Navicular drop was assessed in each participant during pre-testing and post-testing at the conclusion of the training program using the standardized sit to stand test developed originally by Brody. Charlesworth and Johansen describe this method in detail and was used for this study. Only one researcher was in charge of performing this test and was blinded to which participant was placed in the barefoot group or shod group. Prior to beginning the test, identification of the most prominent point of the navicular tubercle was marked using a fine tip Sharpie marker (Figure 2a). The researcher then placed the participant in an upright sitting position with feet flat on the floor and hips and knees flexed to 90 degrees with the ankle in a neutral position. Subtalar neutral was found when talar depressions were equal on both sides of the ankle (Figure 2b). The participant was asked to maintain this subtalar neutral position and while the researcher used a notecard to mark the height of the navicular tubercle. The patient was asked to relax the foot but not remove it from the ground; the opposite was then put in subtalar neutral and marked as well. The participant then stood up without changing the position of the feet but to allow distribution of equal weight between both feet and to be in a relaxed position. Again, the most prominent point of the navicular was measured for height on the notecard on both feet (Figure 2c). The difference between the two markings for both right and left were measured in millimeters. Table 1 provides pre- and post-testing results for the Navicular Drop Test. Subjects were then escorted out of the room to complete dynamic testing using the VICON system.
The post-testing procedure was identical to pre-testing procedure to assess navicular drop. At the completion of post testing, participants completed a post-test survey to evaluate their experiences during the study.

Figure 2: Static Navicular Drop Test Procedure

(a) Navicular tubercle marking in sitting, (b) Finding subtalar neutral with feet shoulder-width apart, relaxed position, and hips/knees/ankles at 90 degrees of flexion, (c) Measuring the difference in navicular tubercle height between sitting and standing. Instructions were given to stand up without moving feet, equal weight-bearing, and in a relaxed position.

VICON Background & Pilot Study

VICON, a video analysis software, was utilized in this study to assess dynamic navicular drop during walking and running. This system uses a series of 10 cameras (Figure 3) recording infrared data from sensors placed on the subject to determine the positions specific points on the
body during dynamic activity. Prior to pre-testing for the current study, a pilot study was completed using the VICON system for measuring navicular drop of 6 volunteer athletic training students and 3 physical therapy students from UND. This pilot study aided the researchers in determining the most efficient method for sensor application and VICON recordings to be implemented during pre- and post-testing in the current barefoot versus shod running study. The full testing process that was utilized is explained below.

**Figure 3: VICON Testing Facility**

![VICON Testing Facility](image)

**VICON Pre-Testing**

Each foot was cleaned and prepped by a towel with rubbing alcohol solution to remove dirt and sweat prior to sensor application. This helped ensure the sensors on each foot would not move or fall off during running and walking. Small reflective sensors were then placed on each participant’s foot using adhesive backing by 2 researchers (one researcher completed placement and the other researcher verified the correct placement). Three sensors were placed per foot as follows: one on the most prominent portion of the navicular bone, another on the inferior portion of the posterior medial portion of the calcaneus, and the final sensor on the medial aspect of the first metatarsal head (Figure 4). The same process was then repeated on the opposite foot. This
process was completed for each participant prior to beginning the pre-testing VICON analysis procedure.

**Figure 4: Sensor Placement**

Markers were positioned on the following anatomical landmarks: (1) base of first metatarsal head (2) most prominent part of navicular tuberosity (3) inferior portion of the posterior-medial aspect of the base of the calcaneus.

After placement of the sensors, calibration of the VICON system was completed using a wand with multiple sensors being waved in random manner in front of each camera to orient the system to the 3D environment. In order to calibrate the exact position of the floor, sensors were placed in a straight line approximately 12 inches apart running the length approximately 10 feet in the center of the testing area. This sensor placement allows the cameras to measure the exact height of the floor to compensate for any deviations in floor height of the testing area. Upon calibration, each participant was placed in subtalar neutral position in the center of the testing area for the right foot by the researcher who conducted the static Navicular Drop Test. Once set, a static frame shot was taken using the VICON system to determine each participant's navicular height in standing. This was completed on the opposite foot as well. The participants then completed 3 trials of normal speed barefoot walking, normal speed barefoot running, and normal speed running with emphasized forefoot striking while being recorded by the VICON system.
Once each participant’s trials were recorded, the data was evaluated using the VICON system to determine the amount of navicular drop of the navicular sensor from heel strike to terminal stance during walking and running of two to three steps of each foot in the center of the testing area as compared to the subtalar neutral navicular height previously recorded. Navicular drop was calculated using trigonometry equations created by Dr. Jesse Rhoades in Microsoft Excel with the calcaneus, navicular, and forefoot sensors each making up one vertex of a scalene triangle. This equation provided the maximum navicular travel for each step which will be referred to as navicular drop from this point forward. The amount of navicular drop in each step was inputted into an Excel file that compared the total distance of the navicular sensor drop to the static subtalar neutral navicular sensor height, then averaged over the three steps and three trials in both walking in and running. The post-testing procedure was identical to pre-testing procedure to assess dynamic navicular drop.

Post Survey

At the post testing procedure, subjects were asked to complete a post-test survey. Surveys were identified via their 5 digit code written on the top of the survey. Subjects were asked to provide demographic information including age, gender, height and weight, as well as running activities prior to the study. After this point, the subjects were asked to complete their respective sections of the survey based on the group they were assigned, barefoot or shod. The remainder of the survey was concerned with any perceived effects the training program may had on the participant, as well as how satisfied the patient was with the overall study design. See Appendix C for the post-survey in its entirety.
Retraining Program

The retraining program randomly assigned the participants to either the barefoot or shod running group. The study included a total of 14 subjects, 7 subjects were selected to run barefoot and 7 were selected to run in their personal athletic shoes. All individuals completed an identical 6-week running program irrespective of group designation on Tuesday and Thursday mornings at the UND Wellness Center. The running program was reduced to one session per week during the final two weeks of training. This decision was made in order to provide sufficient amount of time off for the barefoot runners to help reduce metatarsal pain levels that were experienced during longer training sessions. The training routine consisted of an identical warm-up, running program, and cool-down procedures for each participant.

At each session, prior to the warm up procedure, subjects were asked to report adverse effects they were experiencing. The warm up consisted of stationary biking (3 minutes at a moderate, self-selected pace), dynamic stretching and one minute of treadmill walking at 3.0 miles per hour (mph), one minute of treadmill walking at 4.0 mph, and light treadmill jogging for one minute at 5.0 mph. Each participant assigned to the barefoot group was required to wear socks while on the treadmill due to the hygiene policy of the UND Wellness Center. Shod runners were allowed to wear athletic shoes of their own preference so long as they remained the same throughout the length of the study.

Each subject biked for three minutes on either a LifeFitness 95R Lifecyle® recumbent bike or LifeCycle GX® upright exercise bike followed by dynamic stretches. These stretches included: hip flexion/extension leg swings for 10 repetitions on each leg, hip abduction/adduction leg swings for 10 repetitions on each leg, lunge with a twist for 5 repetitions on each leg, knee to chest for 5 repetitions on each leg, and lunge with a twist to the ceiling for 5
repetitions on each leg. Demonstrations of these exercises can be found in *Figure 5*. Upon completion of stretching, each participant completed a 3 minute walking-jogging warm-up by gradually increasing from 3.0 mph, to 4.0 mph, to 5.0 mph on a Precor TRM® 885 treadmill.
Following the warm-up, the subjects began the retraining program (see Appendix D). All subjects were set to identical training speeds and time. Following the warm-up phase, each subject was asked to progress their speed to 6.0 mph by the end of the three-minute mark. Once at this speed, subjects in the barefoot group were instructed to “run on their toes” for the duration of the training program. During the first week of the training program subjects ran a total of 10 minutes on both days. At each successive week participants were asked to increase this time by 2 minutes. If subjects felt they were unable to complete the required running time for the week, they were permitted to cease training perform a cool down immediately. Their total run time was recorded following termination. Subjects were reminded at this point that if they experienced pain or discomfort that was too intense for them, they would be permitted to terminate training for that day and try again on the next training day or withdraw from the study. Each participant completed up to a total of 140 minutes of running during the 6 week training program. A few participants did not complete 1-2 training sessions due to increased foot pain. The running program was shortened by 1 week due to time constraints to complete the research. Treadmills were not assigned to each individual participant and were chosen on a first come, first serve basis.

Following the retraining program subjects completed a cool down procedure in which they walked on their treadmill at 3.0 mph for 3 minutes to allow for adequate recovery time. They then completed lower extremity and core static stretching with 30 second hold on each leg for two repetitions. These stretched included standing gastrocnemius stretching with a straight leg, followed by bent leg soleus stretching. Standing quadriceps stretching was also performed on each leg. Seated hamstring stretching was performed on each leg by reaching toward that leg’s respective foot. Standing hip flexor stretching was performed in a lunge position with the
rear knee on contact with the ground and upper body vertically oriented. In supine, each participant stretched their piriformis with one leg extended and the other knee bent and brought towards and across their chest. Demonstrations of each of these stretches can be found in Figure 6. Upon completion of static stretching, the participants retraining program was finished for the session.

Figure 6: Static Cool-Down Stretches; (a) Gastrocnemius, (b) Soleus, (c) Quadriceps, (d) Hip Flexors, (e) Hamstrings, and (f) Piriformis.

Data Analysis

Data collected for the standard navicular drop test reliability studies were analyzed using the ICC Model 3 Two-Way Mixed method per Portney and Watkins. This test looked at the intraclass correlation of the left and right navicular drop that was measured during pre- and post-tests. The current study used the Statistical Package for Social Sciences to interpret difference in
groups for the standard navicular drop test. Two researchers analyzed the data that was collected using the VICON system for both the pre- and post-test. This pre- and post-test VICON analysis data was analyzed by the Statistical Package for Social Sciences (SPSS) software. Independent variables were barefoot or shod running group subject placement. Dependent variables included the following: navicular drop height and navicular drop rate from the VICON system. All dependent variables were taken bilaterally. Other dependent variables that may be considered for analysis include subject BMI and any change in body weight. Confounding variables that were identified in this study involved adverse training effects, running surface, subjects’ ability to maintain subtalar neutral in VICON data collection, and effectiveness of retraining program.

**Ensuring Internal Validity**

Steps to ensure internal validity were taken by performing identical protocols for collecting data for both the static Navicular Drop Test and the dynamic VICON walking and running series. Navicular drop intra-rater reliability was determined prior to testing to increase the validity of this study as well as blinding the researcher who performed the navicular drop test from knowing which subjects were in each assigned groups. The VICON equipment and pre-and post-testing procedures were also previously assessed in a pilot study to ensure the most efficiency of the current study. In addition to these set protocols, all subjects completed an identical warm-up, training program, and cool down which were performed at the same location, at the same time of day, on the same type of treadmills, and in the same order. Finally, pre- and post-testing was conducted in the same facility, using the same software and equipment.
CHAPTER III

RESULTS

Participant Demographics

Before pre-testing began information was gathered from the participants and was completed in a semi private room. Subjects filled out the informed consent form before being allowed to proceed with pre-testing. Each subject entered the room and provided their unique five-digit confidentiality code that was written on their 4”x6” pre-testing note card. Subjects were then asked to remove their socks and shoes where height and weight were taken using a Detecto™ Scale and standard tape measure. These measurements along with the calculated BMI were also added to the participant’s note card. Along with this information, sex and foot dominance were recorded on the note card as well. Table 1 provides the participant demographics for this study.

Table 1: Data Collection. Participant demographics & randomized group distribution.

<table>
<thead>
<tr>
<th>#</th>
<th>Participants</th>
<th>Weight (lbs)</th>
<th>Height (in)</th>
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<th>Sex</th>
<th>Foot Dominance</th>
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<td>F</td>
<td>R</td>
<td>Shod</td>
</tr>
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</table>
Standard Navicular Drop Test

The results of the Standard Navicular Drop Test when analyzing the difference from pre- to post-test were not statistically significant with either the left or right foot. Table 2 illustrates the raw data collected during the pre- and post-tests of the sit to stand navicular drop test (standard). For all groups (Table 2), there was an average difference of 0.4 mm on the left and 1.0 mm on the right. When analyzing the data between groups (Table 3), the barefoot group had a difference of 0.75 mm in the left foot with a standard deviation of 0.96 and 1.25 mm in the right foot with a standard deviation of 0.96. The shod group had a difference of 0.17 mm in the left foot with a standard deviation of 3.31 and 0.83 in the right foot with a standard deviation of 0.98. Although the participants on average had a decrease in navicular drop, there was no statistically significant differences between groups. This data illustrates the barefoot group having had the largest drop in navicular height in the right foot (1.25 mm).

### Table 2. Standard Navicular Drop Test Data (n = 10)

<table>
<thead>
<tr>
<th>Participants</th>
<th>Pre-test (mm)</th>
<th>Post-test (mm)</th>
<th>Difference (mm)</th>
<th>Group</th>
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<tbody>
<tr>
<td></td>
<td>Left</td>
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<td>Left</td>
<td>Right</td>
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<td>14</td>
<td>9</td>
<td>13</td>
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<tr>
<td></td>
<td>Average</td>
<td>Difference</td>
<td>0.4</td>
<td>1.0</td>
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</table>
The results of the VICON testing for navicular drop showed a trend for training effect in both barefoot and shod running for reduced drop from pretesting to post-testing, however there was no statistically significant difference between barefoot training and shod training for most of the dynamic testing conditions. When comparing only the 10 subjects that completed the entire training protocol, statistically significant results were observed in the conditions of BW, RNB, and RTB in the right lower extremity; however, the results showed a greater reduction in navicular drop for the shod running group in these conditions. The mean difference from pre- to post-testing for the condition barefoot walking was -1.63 mm for the right foot of the barefoot group with a standard deviation of 1.78 mm, and 1.79 mm for the right foot of the shod group with a standard deviation of 2.44 mm. The mean difference from pre- to post-test for the condition running normal barefoot was -1.69 mm for the right foot of the barefoot group with a standard deviation of 1.93 mm, and 2.50 mm for the right foot of the shod group with a standard deviation of 3.50 mm. The mean difference from pre- to post-testing for the condition running on toes barefoot was -1.84 mm for the right foot of the barefoot group with a standard deviation of 3.07, and 2.89 mm for the right foot of the shod group with a standard deviation of 2.55. Table 4 summarizes the data collected for the VICON motion analysis.

### Table 3. Standard Navicular Drop Test Results (n = 10)

<table>
<thead>
<tr>
<th></th>
<th>Left</th>
<th>SD</th>
<th>Right</th>
<th>SD</th>
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</thead>
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<tr>
<td>Barefoot</td>
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<td>0.96</td>
<td>1.25</td>
<td>0.96</td>
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<tr>
<td>Shod</td>
<td>0.17</td>
<td>3.31</td>
<td>0.83</td>
<td>0.98</td>
</tr>
</tbody>
</table>

**VICON Motion Analysis**

The results of the VICON testing for navicular drop showed a trend for training effect in both barefoot and shod running for reduced drop from pretesting to post-testing, however there was no statistically significant difference between barefoot training and shod training for most of the dynamic testing conditions. When comparing only the 10 subjects that completed the entire training protocol, statistically significant results were observed in the conditions of BW, RNB, and RTB in the right lower extremity; however, the results showed a greater reduction in navicular drop for the shod running group in these conditions. The mean difference from pre- to post-testing for the condition barefoot walking was -1.63 mm for the right foot of the barefoot group with a standard deviation of 1.78 mm, and 1.79 mm for the right foot of the shod group with a standard deviation of 2.44 mm. The mean difference from pre- to post-test for the condition running normal barefoot was -1.69 mm for the right foot of the barefoot group with a standard deviation of 1.93 mm, and 2.50 mm for the right foot of the shod group with a standard deviation of 3.50 mm. The mean difference from pre- to post-testing for the condition running on toes barefoot was -1.84 mm for the right foot of the barefoot group with a standard deviation of 3.07, and 2.89 mm for the right foot of the shod group with a standard deviation of 2.55. Table 4 summarizes the data collected for the VICON motion analysis.
Table 4. VICON Motion Analysis Results - Right Foot (n = 10)

<table>
<thead>
<tr>
<th></th>
<th>Barefoot Walking (BW)</th>
<th>WB Standard Deviation</th>
<th>Running Normal Barefoot (RNB)</th>
<th>RNB Standard Deviation</th>
<th>Running on Toes Barefoot (RTB)</th>
<th>RTB Standard Deviation</th>
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<tbody>
<tr>
<td>Barefoot</td>
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<td>1.78</td>
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<td>1.93</td>
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<td>Shod</td>
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</table>

*Figure 7 and 8 indicates the pre- and post-test changes in the barefoot and shod group, respectively, for the conditions Barefoot Walking (BW), Running Normal Barefoot (RNB), and Running on Toes Barefoot (RTB). This is with n = 10 with the average of the right foot navicular drop calculated. Although the results for the left foot were not statistically significant, the trend was in favor of our hypothesis in decreasing navicular drop for the barefoot group. In Figure 7, an overall change in navicular movement within the barefoot training group (n = 4) was observed with BW showing a slight increase in navicular drop of 0.04 mm, RNB showing a slight increase in navicular drop of 0.3 mm and RTB showing a decreased in navicular drop of 0.36 mm in the right foot for all conditions; the data was not statistically significant. In Figure 8, the shod group (n=6) showed an overall trend toward decreased navicular drop with RTB showing the greatest change of 2.4 mm followed by RNB showing a decrease of 1.38 mm and BW showing a decrease of 0.99 mm in the right foot.

Across all three BW, RNB, and RTB groups there is a general trend toward decreased navicular drop when comparing pre- and post-testing results however it is not statistically significant for all 10 participants. As displayed in Figure 9, there was a trend in which the more dynamically forceful the movement, the greater reduction in navicular drop between pre- and post-testing with RTB showing the greatest reduction in navicular drop of 1.38 mm followed by RNB showing a drop of 0.54 mm, and finally BW with the least reduction in navicular drop of 0.48 mm.*
**Figure 7: Barefoot Training Group Results**

VICON pre- and post-test changes in the Barefoot Training Group for the conditions of Barefoot Walking (BW), Running Normal Barefoot (RNB), and Running on Toes Barefoot (RTB) in the right foot.

**Figure 8: Shod Training Group Results**

VICON pre- and post-test changes in the Shod Training Group for the conditions of Barefoot Walking (BW), Running Normal Barefoot (RNB), and Running on Toes Barefoot (RTB) in the right foot.
Figure 9: Dynamic Navicular Drop Results

VICON pre- and post-test changes in Dynamic Navicular Drop for the Conditions of Barefoot Walking (BW), Running Normal Barefoot (RNB), and Running on Toes Barefoot (RTB) in all 10 participants.
CHAPTER IV
DISCUSSION

Overall, the data that was collected during the pre- and post-tests after 10 training sessions over a 6 week period provided minimal statistically significant results regarding navicular movement using the Standard Navicular Drop Test for both shod and barefoot runners. The groups did have an improvement in navicular drop height, so this may be clinically significant and should be kept in mind for future research.

Only three conditions in the VICON motion analysis data yielded statistically significant differences in the right foot: barefoot walking (BW), running normal barefoot (RNB), and running on toes barefoot (RTB). However, the significant difference occurred as producing more navicular drop from pre- to post-test for all of these conditions of the right foot for barefoot participants. From this analysis, the data indicates that barefoot training may have a slight influence on navicular drop in a negative manner. The shod group actually illustrated a statistically significant decrease in navicular drop in the right foot for BW, RNB, and RTB conditions. The left foot of the shod training group also improved, however, the data was insignificant. One may conclude shod running may be the preferred method of training due to a significant decrease in navicular drop, the amount of injuries that did not occur with the shod group, and the fact that running with shoes is a more practical or common form of exercise.

Training Effect

Although only a small amount of data collected during this test was shown to be statistically significant, the results do indicate an overall training effect of reduced navicular drop...
for the shod training group for both left and right foot. The results also indicate a trend toward the greatest reduction in navicular drop being the most dynamically forceful movements when foot is in the toe off position of the gait cycle. This trend may suggest that the overall strength and rigidity of the arch increased during training and may reduce injury by helping prevent the arch of the foot from reaching its terminal limit of elasticity. Future studies of this kind should focus on obtaining a larger sample size to obtain greater power and increasing the duration of training in order to help corroborate these findings in a statistically significant manner.

**Adverse Effects**

With any new running retraining, adverse effects can be expected to occur from stress to the participants’ feet and lower extremity musculature. The most common adverse effects that resulted from barefoot running training included muscle soreness - specifically in the triceps surae muscles, skin irritation (redness and/or blisters), and pain near the metatarsal heads. These adverse effects may be attributed by one or a combination of the following: transition in running style from a rearfoot strike pattern to forefoot strike pattern, friction from feet hitting the treadmill, and having no or limited prior experience in barefoot running. In general, muscle soreness gradually dissipated over the 6 weeks, as the participants adapted to the barefoot running training and completed stretches as necessary on their own. To accommodate for the skin irritation after the first week of barefoot training, gel squares were applied to the participants who sustained any blisters in order to prevent any further or worsening skin breakdown. A certified athletic trainer and two of the physical therapy student researchers helped secure the gel squares into place with pre-wrap and athletic training tape. Socks were worn by the barefoot group throughout training, as required by the UND Wellness Center facility regulations for means of sanitation on the treadmills. This factor may have contributed to more of the adverse
effects from friction in addition to the hard surface of the treadmill track. Future studies may decrease adverse effects of this manner by switching the running surface to grass or turf. Two participants experienced metatarsal pain that required them to skip some of the training days. One out of the eleven participants was unable to complete training, and therefore was not included in the data collection and statistical analysis for the final results of the study.

**Limitations**

**Navicular Drop Test**

While there has been research that indicates the reliability of this test, there is also research that suggests parts of the test to be inadequate. First, is the location of the most prominent, medial part of the navicular tuberosity. This same mark was not kept throughout the 6 weeks and was therefore relocated at post-assessment. Second, the placement of the foot in subtalar neutral can be difficult to find and be consistent in placing the foot in this position. Along with these limitations includes the inexperience of the examiner which could have produce error in the assessment of both locating the navicular tuberosity and finding the placement of the foot in subtalar neutral; these errors could have skewed the data results. Picciano et al\(^\text{37}\) found that both open and closed kinetic chain subtalar joint neutral positions yield poor intra- and inter-tester reliability and the NDT does poor to moderate intra-tester and poor inter-tester reliability. Their research recommends that the examiner for static navicular drop testing would benefit the results with increased practice and experience. In addition, this test is limited to the participant holding their foot in the subtalar neutral position while the examiner marks the point of the navicular tuberosity. While making the mark, it is possible that some participants might have moved their foot out of the assigned placement which could have caused error in our measurements.
**VICON Motion Analysis**

The VICON system while highly reliable and accurate did have a few inherit issues. One of the issues related to the VICON system had to do with the amount of error. While there are no concrete measures of error related to the VICON system, it is reasonable to infer that the amount of error would be in relation to the size of the sensor used. The VICON system maps sensors in three dimensional space by marking the center of each sensor. It can be assumed that during any point of the gait cycle this exact center of the circular sensor could be in a slightly different location as the angle of the camera to the sensor has changed as the gait cycle progressed. This issue may not be a problem when dealing with large movements such as when calculating hip and knee angles during gait, but presents a unique obstacle when calculating small movements such as navicular drop which is measured in millimeters. The error of the system may be partially to blame for the inconclusive data obtained in the study. Another issue with the VICON system was related to the filters used after data collection. These filters were applied to the data in order to prevent interference and mislabeling of points due to reflections picked up by the cameras that were not caused by the applied sensors. They also aided in smoothing out the trajectories of the sensors during the gait cycle that may have been caused by the system mislabeling points as a result of poor sensor reflection, or extra reflections picked up by the system. This smoothing may have also introduced an amount of error in the system. Since this study was concerned with millimeters of change even small changes caused by the filters could have had significant negative effects on the final results of the study.

Another limitation of this study was during data collection to find navicular height at subtalar neutral for each subject. In both pre- and post- testing one researcher placed the subjects’ right, then left foot in subtalar neutral and instructed the subject to hold this position
while data was collected. While this entire process from placement of subtalar neutral to data collection only lasted a few seconds, it is possible that the participant could have moved during the collection process - thus, altering their subtalar neutral navicular height. Since this procedure was performed during both pre- and post- testing, it may have been possible that different subtalar neutral navicular heights were obtained for each subject which may have skewed the results of this study. In order to ensure this problem was not a factor in our study, final data was calculated against pre-testing subtalar neutral navicular height, as well as post testing subtalar neutral navicular height and no significant differences were found. It is important to note that although the VICON system has been used previously to assess navicular drop, this study is the first study to use it dynamically during walking and running.

**Patient Population**

Because the small sample size of participants (n = 10) included in this study involved only physical therapy students younger than age 30, our results may not be correlated or generalizable to most of the adult population. A majority of the participants represented an overall healthy sample population based on BMI, age, and non-significant past medical histories. Gender was represented equally with 5 males and 5 females. Many of the participants only met the navicular drop criteria by a few millimeters, so a larger sample size may have yielded more significant results for improvement in navicular drop height with barefoot running training.

**Barefoot Training Program**

Time constraints may have been a significant contributor to the lack of statistically significant changes in navicular drop from pre- to post-testing. The running retraining program had to be limited to 6 weeks-time for the subjects’ participation window and research deadlines.
This relatively short amount of time spent training (a total of 140 minutes) may not be sufficient enough for training effects to occur in the participants.

In regards to running speed, a standard of 6 mph was utilized for both the men and women’s training pace. The researchers attempted to control as many training variables as possible for each participant, but it was observed that some participants altered their running biomechanics to accommodate for the pre-determined pace. For example, the tall and/or male participants needed to jog at a slower speed than they may self-select on their own, which resulted in visibly shortened stride lengths. This may have caused alterations in foot strike pattern and different muscle engagement throughout the barefoot training. Ideally, each participant could jog at a comfortable, self-selected pace and achieve the same total training time in order to preserve running body mechanics of each individual.

The treadmill running surface directly caused adverse effects (blisters and metatarsal pain) to some of the participants’ feet as a result of the friction forces and contact onto a firm surface. Future studies may limit the amount of adverse effects by switching to a more forgiving surface such as turf or grass. This may be more practical and applicable to barefoot running training by helping absorb the impact when transitioning to the new forefoot strike pattern, in addition to limiting foot injuries.

**Future Research**

Based on the results and limitations discovered in this randomized controlled trial, future researchers may want to consider the following recommendations. As stated previously, utilizing a different, shock-absorbing running surface may decrease the number of adverse effects caused by barefoot running on a treadmill. Turf may be ideal for future studies if facilities are accessible and available for conducting research. Another change to consider may be opening up the sample
size to a more diverse participant population in order to make correlations of the results with the general adult population.

Future researchers may also want to increase the length of the running training program to allow for sufficient time to see changes in the subjects’ navicular drop. Switching to a forefoot strike pattern elicited by barefoot training for a longer period of time may yield more habitual changes in the participants’ running biomechanics. This newly adopted foot strike pattern could potentially lead to a decrease in the maximum navicular drop deflection observed during running. The researchers embraced a new method for calculating navicular drop in this study. Future studies may want to carry out this method of measuring dynamic navicular drop, using the VICON system to ensure the most accuracy.

**Conclusion**

In conclusion, barefoot running training did not illustrate statistically significant improvement in navicular drop movement during this study. Data showed that navicular drop significantly decreased on the right foot with shod training group in the conditions barefoot walking, running normal barefoot, and running on toes barefoot indicating that shod training may be better for improving a pronated foot while performing these dynamic tasks. It should be taken into consideration the limitations in this study such as the small sample size, the population of only student physical therapists, and the adverse effects of barefoot running on a treadmill (blisters and metatarsal pain). Since this is the first study utilizing the VICON motion analysis to measure dynamic navicular drop, further research is recommended in this area.
APPENDIX A
UND IRB Approval

Principal Investigator: Gery Schindler, PT, DPT, Ph.D.
Project Title: Barefoot Versus Shoe Running: Training Effects on Navicular Drop and Foot Pressure Analysis
IRB Project Number: IRB-201003-339
Project Review Level: Expedited 4
Date of IRB Approval: 04/04/2017
Expiration Date of This Approval: 04/03/2018
Consent Form Approval Date: 04/04/2017

The Protocol Change Form and all included documentation for the above-referenced project have been reviewed and approved via the procedures of the University of North Dakota Institutional Review Board.

Attached is your revised consent form that has been stamped with the UND IRB approval and expiration dates. Please maintain this original on file. You must use this original, stamped consent form to make copies for participant enrollment. No other consent form should be used. It must be signed by each participant prior to initiation of any research procedures. In addition, each participant must be given a copy of the consent form.

You have approval for this project through the above-listed expiration date. When this research is completed, please submit a termination form to the IRB. If the research will last longer than one year, an annual review and progress report must be submitted to the IRB prior to the submission deadline to ensure adequate time for IRB review.

The forms to assist you in filing your project termination, annual review and progress report, adverse event/unanticipated problem, protocol change, etc. may be accessed on the IRB website: http://und.edu/research/research/human-subjects/

Sincerely,

Michelle L. Bowles, M.P.A., CIP
IRB Coordinator

MLBish

Enclosures

Cc: Chair, Physical Therapy
APPENDIX B
Informed Consent

THE UNIVERSITY OF NORTH DAKOTA
CONSENT TO PARTICIPATE IN RESEARCH

TITLE: Barefoot versus Shod Running: Training Effects on Navicular Drop and Foot Pressure Analysis

PROJECT DIRECTOR: Gary Schindler

PHONE #: 701-777-6081

DEPARTMENT: Physical Therapy

STATEMENT OF RESEARCH

A person who is to participate in the research must give his or her informed consent to such participation. This consent must be based on an understanding of the nature and risks of the research. This document provides information that is important for this understanding. Research projects include only subjects who choose to take part. Please take your time in making your decision as to whether to participate. If you have questions at any time, please ask.

WHAT IS THE PURPOSE OF THIS STUDY?

You are invited to be in a research study that is interested in investigating how training barefoot running versus shod (shoe) running affects navicular drop (the amount that the navicular bone drops to the ground with weight bearing activities) and surface Electromyography (EMG) activity of the Tensor Fasciae Latae (TFL) and Gastrocnemius (GM) during walking and running activities. Literature identifies the barefoot runners complete more of a forefoot strike than shod runners (rear foot) which can lead to more gastrocnemius (calf) activation creating more supinated (walking/running more on the outside of the foot) foot mechanics. In addition, literature has not investigated the EMG activity of GM and TFL musculature during barefoot walking and running. This study aims to investigate whether training in barefoot running versus shod running reduces the amount of navicular drop and surface EMG activity of the TFL muscle, while increasing EMG activity of the GM muscle during walking and running activities. You have been identified as a potential participant because you are a first, second, or third-year physical therapy, athletic training, or occupational therapy student at the University of North Dakota, a novice runner (2-15 miles per week), and meet this study’s inclusion criterion.

The purpose of this research study is to understand what effect barefoot training has on navicular motion and EMG activity of the TFL and GM muscles during walking and running activities, which may assist in future injury prevention.

HOW MANY PEOPLE WILL PARTICIPATE?

Approval Date: April 1, 2017
Expiration Date: April 3, 2018
University of North Dakota IRB

Date: ____________________________
Subject Initials: __________________
A minimum of 6 participants will be take part in this study at the University of North Dakota. Each participant will be randomly placed in either the shoe running group or barefoot running group with each group having a minimum of 3 participants. Each group will complete pre- and post-test navicular drop, walking/running analysis utilizing the VICON motion analysis system, and surface EMG of the TFL/OM muscles during shod/barefoot walking and running and complete a post-survey analysis to determine compliance and training schedule. The Vicon Motion Analysis system utilizes 10 separate cameras in order to obtain a 3D motion analysis image of lower limbs and joints. This system will assist in detecting the amount and speed of navicular drop and measure changes in pelvis and knee angles during barefoot walking/running activities between training groups. In between the pre- and post-tests each individual will complete a 6-week training schedule involving running on a treadmill with a gradual progression of distance and time per week as symptoms allow. Surveys will be completed at the time of the post-testing at the Hyslop Sports Center on the campus of the University of North Dakota.

HOW LONG WILL I BE IN THIS STUDY?

Your participation in the study will last approximately 8 weeks. Each participant will complete a pre-test navicular drop test, a walking/running analysis utilizing the Vicon Motion Analysis system, and surface EMG analysis of the TFL and OM during shod and barefoot walking/running. Following the pre-testing, each participant will complete a 6-week training program in either the barefoot running or shod running groups with a gradual progression of both distance and time per week as symptoms allow. Following the 6-week training period, each participant will complete a post-test navicular drop test, a walking/running analysis utilizing the Vicon Motion Analysis system, and surface EMG analysis of the TFL and OM during shod and barefoot walking/running and complete a post-survey analysis to determine compliance and training schedule.

WHAT WILL HAPPEN DURING THIS STUDY?

Those who choose to participate will be screened to determine eligibility to participate in the study according to the inclusion criteria which includes: no injury to the lower extremities in the past 6 months, age between 20-30, greater than 7 mm navicular drop, must be a rear foot striker, no current use of NSAIDs, no cardiopulmonary pathologies or significant medical history, and must currently complete between 2-20 miles of running per week. If you are included in this research, this study will take place over approximately an 8-week period. A bilateral navicular drop test, foot/pelvis motion analysis utilizing the Vicon Motion Analysis system, and surface EMG of your TFL and OM musculature will be performed on you during shod/barefoot walking and running prior to beginning the program. Then you will be randomly placed into either the barefoot or shod group. Each group will complete the same 6-week training program. You will run 2 mornings per week (Tuesday and Thursday) progressing from 10 minutes per session during the first week to 20 minutes per session upon week 6 resulting in 2-minute increment increases per week. After completing the program, a navicular drop test, foot/pelvis motion analysis, and surface EMG of TFL/OM musculature will be performed again. In addition, each:

Approval Date: _______ 2017
Expiration Date: _______ 3 2018
University of North Dakota IRB

Date:______
Subject Initials:________
participant will complete a post-program survey. No personal identifiers are used on any written document and all descriptions of participants are anonymous. Participants are allowed to skip any questions in the survey that he/she would prefer not to answer.

WHAT ARE THE RISKS OF THE STUDY?

There are no foreseeable risks of physical, emotional, or financial risks to the participants with this study; however, since physical activity is taking place there may be a chance of muscle strains, fatigue, tendinitis, stress fractures, delayed onset muscle soreness (DOMS), or a general pain response, but minimal risk is anticipated. A certified athletic trainer, licensed physical therapist, sports/orthopedic specialist, and certified strength and conditioning specialist will be on site for all training sessions to answer any questions and to direct activity progression to limit adverse reactions. If adverse reactions occur the participant will be evaluated by the primary investigator and will be referred for further medical evaluation if deemed necessary.

WHAT ARE THE BENEFITS OF THIS STUDY?

Each participant may not benefit personally from being in this study. It is possible that the participants may see a decrease in static/dynamic muscular drop, decreased TFL EMG activity, and increased GM EMG activity, which may aid in injury prevention. Participants may also see improved cardiorespiratory fitness and a decrease in BMI. Also, we hope that in the future other people might benefit because a better understanding of how barefoot running training may affect muscular placement and movement and alter foot pressure, which may assist in reduced pain, improved function, and prevention of future overuse injuries for some patients. It will also provide evidence supporting or refuting the impact barefoot running training may have on arch dynamics, while TFL/GM EMG activity between shoe runners and barefoot runners. This research may impact how physical therapists practice clinically, therefore impacting the lives of their patients and their families. This research may lead to alterations in exercise training that may lead to less future injuries.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will not have any costs for participating in this research study.

WILL I BE PAID FOR PARTICIPATING?

You will not be paid for participating in this research study.

WHO IS FUNDING THE STUDY?

No funding is needed for this study. The University of North Dakota and the research team are receiving no payments from any agencies, organizations, or companies to conduct this research.

<table>
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<th>Approval Date:</th>
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<td>Expiration Date:</td>
<td>Apr 1 2018</td>
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<td>University of North Dakota IRB</td>
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study. Treadmills at the Wellness Center on the campus of the University of North Dakota will be utilized for this study.

CONFIDENTIALITY

The records of this study will be kept private to the extent permitted by law. In any report about this study that might be published, you will not be identified. Your study record may be reviewed by Government agencies, the UND Research Development and Compliance office, and the University of North Dakota Institutional Review Board.

Any information that is obtained in this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. You should know, however, that there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court or to tell authorities if we believe you have abused a child, or you pose a danger to yourself or someone else. Confidentiality will be maintained with anonymous surveys conducted. All data collections will be kept anonymous by means of a 5-digit code that will include the participant’s mother’s or father’s day of birth and the last three digits of their zip code while in high school. Consent forms will be kept in a locked and secure location for a minimum of three years, with only Gary Schindler having access to the consent forms and personal data.

If we write a report or article about this study, we will describe the study results in a summarized manner so that you cannot be identified.

IS THIS STUDY VOLUNTARY?

Your participation is voluntary. You may choose not to participate or you may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Your decision whether or not to participate will not affect your current or future relations with the University of North Dakota.

If you decide to leave the study early, we ask that you inform Gary Schindler that you would like to withdraw.

CONTACTS AND QUESTIONS?

The researchers conducting this study are Gary Schindler. You may ask any questions you have now. If you later have questions, concerns, or complaints about the research please contact Gary Schindler at 701-777-6083 or at gary.schindler@med.und.edu.
If you have questions regarding your rights as a research subject, you may contact The University of North Dakota Institutional Review Board at (701) 777-4279 or UND.IRB@research.UND.edu.

- You may also call this number about any problems, complaints, or concerns you have about this research study.
- You may also call this number if you cannot reach research staff, or you wish to talk with someone who is independent of the research team.
- General information about being a research subject can be found by clicking “Information for Research Participants” on the web site: http://und.edu/research/resources/human-subjects/research-participants.cfm

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Subjects Name: ___________________________________________

Signature of Subject ___________________ Date __________

I have discussed the above points with the subject or, where appropriate, with the subject’s legally authorized representative.

Signature of Person Who Obtained Consent ___________________ Date __________

Approval Date: 6/1/2017
Expiration Date: 6/1/2016
University of North Dakota IRB

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APPENDIX C
Barefoot Running Survey

1. Please provide your ID code: ______________

2. Gender
   ☐ Male
   ☐ Female

3. Age in years _____

4. Height: ___ft ___inches

5. Weight: ______

6. What ethnicity do you most associate with?
   ☐ Caucasian
   ☐ Hispanic
   ☐ African American
   ☐ Asian
   ☐ Native American
   ☐ Pacific Islander

7. Weekly running mileage
   ☐ I don't run
   ☐ 0-2 miles
   ☐ 2-4 miles
   ☐ 4-6 miles
   ☐ 6-8 miles
   ☐ 8-10 miles
   ☐ 10+ miles

8. Do you currently use orthotics?
   ☐ Yes, while running
   ☐ Yes, while walking
   ☐ Yes, during running and walking
   ☐ No

9. Which running group were you in?
   ☐ Barefoot running group
   ☐ Shod running group
10. Which of the following apply to your experience with barefoot running? (Click all that apply)
   - I felt great while running barefoot
   - I will continue to run barefoot
   - I would recommend barefoot running to my friends
   - I would not recommend barefoot running to my friends
   - I never want to run barefoot again
   - I did not run barefoot

11. I felt the training intensity was appropriate?
   - Strongly Agree
   - Agree
   - Neutral
   - Disagree
   - Strongly Disagree

12. I felt the program was well structured?
   - Strongly Agree
   - Agree
   - Neutral
   - Disagree
   - Strongly Disagree

13. I felt there was sufficient amount of time to complete the program?
   - Strongly Agree
   - Agree
   - Neutral
   - Disagree
   - Strongly Disagree

14. Did you have any adverse effects from this study? If yes, please describe the injury and where it occurred.
   - Yes ________________________________________________________________
   - No

15. Did you abide by the study’s protocol? If no, please describe what you did outside of the program (i.e. run additional miles, started resistance training program, etc.).
   - Yes
   - No ________________________________________________________________
16. Did you have a prior lower extremity injury? If yes, please provide the type of injury and date in which injury occurred.

- Yes ____________________________________________________________
- No

17. Please comment on any concerns which you may have regarding the structure of this study.

18. Is there anything else you would like to comment on regarding this study?
## APPENDIX D

### Exercise Log Sheet

<table>
<thead>
<tr>
<th>Day</th>
<th>ID CODE: Navicular marked</th>
<th>Bike 3 minutes</th>
<th>FLEX/EXT Swings x10</th>
<th>ABD/ADD Swings x10</th>
<th>Lunge with Twist x5</th>
<th>Knee to Chest x5</th>
<th>Lunge with Twist to Ceiling x5</th>
<th>Walk 1 minute</th>
<th>Run: 3 mph</th>
<th>Step 1 4 mph x 1'</th>
<th>Step 2 5 mph x 1'</th>
<th>Time @ 6 mph</th>
<th>Walk 3 minutes</th>
<th>Streatches: 2x30'</th>
<th>Soleus</th>
<th>Quadriceps</th>
<th>Hip Flexors</th>
<th>Hamstrings</th>
<th>Piriforms</th>
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<td>Day 1 (10)</td>
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REFERENCES


