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The Effect of Barefoot Running on Navicular and Pelvic Drop: A Randomized Controlled Trial

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

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This Scholarly Project, submitted by Alyssa Sandry, Danielle Gamel, and Ryan Cook 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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Permission

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

Department
Physical Therapy

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Doctor of Physical Therapy

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Table of Contents

List of Figures. ............................................................... vii
List of Tables. ............................................................... viii
Acknowledgements. ......................................................... ix
Abstract. ................................................................. x

Chapter I

I. Background and Purpose. ................................................. 1
   a. Biomechanics of the Lower Extremity. ......................... 3
      i. Forefoot............................................................. 3
      ii. Ankle............................................................ 4
      iii. Knee............................................................ 5
      iv. Hip/Pelvis...................................................... 6
   b. Injuries of the Lower Extremity. ................................ 7

II. Navicular Drop. ....................................................... 9
   a. Measurement using the Navicular Drop Test (NDT). ........ 9
   b. NDT Reliability.................................................. 11
   c. Rate of Drop...................................................... 11

III. Motion Analysis. ..................................................... 12

IV. Summary............................................................ 13

Chapter II

I. Methods. ............................................................. 15
   a. Subjects........................................................ 15
b. Informed Consent. ...................................................... 18

c. Measurements/Instruments. ..................................... 18
   i. Reliability Testing of the NDT. ............................... 18
   ii. Navicular Drop Test. ........................................... 19
   iii. VICON Background. ......................................... 21
   iv. VICON Pre-Testing. ........................................... 21

d. Training Program. ................................................ 24

e. Data Analysis. .................................................... 27

f. Ensuring Internal Validity. ..................................... 27

Chapter III

I. Results ............................................................... 29

   a. Participant Demographics. ................................. 29

   b. Standard Navicular Drop Test. ............................ 31

   c. VICON Motion Analysis. ................................... 31

Chapter IV

I. Discussion ........................................................... 34

   a. Training Effect. ................................................ 34

   b. Adverse Effects. .............................................. 35

   c. Limitations. ................................................... 35

      i. Navicular Drop Test. ...................................... 35

      ii. VICON Motion Analysis. ................................. 36

      iii. Sample Size. ............................................. 38

      iv. Barefoot Training Program. ............................ 38
d. Future Research. .................................................... 39

e. Conclusion. .......................................................... 39

APPENDIX A: Informed Consent. ........................................ 40

APPENDIX B: Exercise Log Sheet. ........................................ 46

BIBLIOGRAPHY. ......................................................... 47
LIST OF FIGURES

Figure 1. Subject Selection Process & Inclusion Criteria. .......................... 17

Figure 2. Static Navicular Drop Test Procedure. ................................. 20

Figure 3. VICON Testing Facility. ....................................................... 22

Figure 4. Sensor Placement. ............................................................. 23

Figure 5. Dynamic Warm-Up Stretches. ............................................. 26
LIST OF TABLES

Table 1. Data Collection. ................................................................. 29

Table 2. Standard Navicular Drop Test Data. ................................. 31

Table 3. Navicular Drop in Barefoot Running Group and Shod Running Group. .... 32

Table 4. Summarized Statistics of Pelvic Movement during Barefoot Trials vs. Shod Trials. ................................................................. 32
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ABSTRACT

Background and Purpose: Gaining knowledge of the change in navicular drop of the foot and pelvic movement 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 training program with conversion from a rearfoot strike pattern (RFSP) to forefoot strike pattern (FFSP) to determine impact on navicular drop and pelvic movement is lacking in literature. Due to the increased correlation of hip movement 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 and pelvic 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 training 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 pelvic movement and 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 method for reducing pain and injuries associated with running.

**Results:** Results showed no statistical significance in the Standard Navicular Drop Test. There were no statistically significant differences using the VICON Motion Analysis for assessing dynamic navicular drop or pelvic movement in Barefoot Walking (BW) and Running Barefoot with a forefoot strike pattern (BR). However, trends indicated that post 6 week training the barefoot training group showed decreased navicular drop and decreased pelvic movement in comparison to the shod training group.

**Discussion:** Barefoot running training did not illustrate statistically significant improvement in navicular drop or pelvic drop movement during this study. Data showed that navicular drop presented a trend towards having less movement during barefoot running and barefoot walking post training program in comparison to the shod running group. Due to the limitations of this study (small sample size, narrow population, limited time spent barefoot running training, and specifics of the VICON motion analysis process) future research could address these limitations through conducting an ongoing study and/or open it to the public to improve subject population.
Chapter I

Background and Purpose

Interests and studies conducted in the biomechanics, kinetics, and kinematics of running are becoming more prevalent within the last decade; specifically, the effects of barefoot versus shod running. One aspect that has shown to differ between the two running methods, is the significance of forefoot striking among barefoot runners as opposed to rear foot striking. According to a study done by Hashish et al.,\(^1\) without the impact absorption that of a supportive shoe sole, a barefoot runner changes their dynamics by relying on lower leg posterior musculature (gastrocnemius, soleus, tibialis posterior, and Achilles tendon) and a forefoot striking pattern to reduce the load.

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, due to the muscular attachment of the tibialis posterior (TP) tendon. The TP is a the primary stabilizer during dynamic activity of the rearfoot and medial longitudinal arch due to its multiple attachments, such as, the navicular tuberosity, tarsal bones, middle three metatarsals, and the flexor hallucis brevis muscle.\(^2\) Additional medial longitudinal arch support includes the contribution of the flexor hallucis longus (FHL) and flexor digitorum longus (FDL) muscles.\(^3,4\) The FHL arises from the posterior fibula and attaches to the distal phalanx of the great toe on the plantar surface.\(^3\) The FDL arises from the posterior tibia and continues on the plantar surface to then insert on the
The distal phalanx of the second through fifth toes. Together these muscles act as toe flexors and assist in plantarflexion of the ankle. Functionally, they (FHL and FDL) are strong in the toe-off phase and propulsion of gait prior to the swing phase; great toe flexion necessary for final propulsion (FHL) and toe flexion necessary for gripping and balance during running, walking, and jumping. Barefoot running may then accentuate this phase of gait when utilizing the forefoot striking method and therefore recruit the necessary musculature to enhance the support of the medial longitudinal arch and decrease the navicular drop.

Common causes of injuries in runners are due to anatomical factors such as, excessive pronation or supination of the foot or an 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). With the repetitive stress on these maligned structures and forces generated from running, particular injuries include plantar fasciitis and stress fractures. 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, a translation effect of hyper pronation of the foot cause a kinematic chain reaction, finding that the shank has a great effect on the alignment of the foot and pelvis-translating to the lumbar spine. Thus, adjusting the foot alignment may create proper distributions of forces during running, decreasing the likelihood of injury.

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 to an acquired forefoot strike pattern as opposed to a rearfoot strike pattern, most often seen in shod running. Forefoot strike pattern is believed to decrease the ground reaction forces experienced during barefoot running which decreases the risk of injury to the lower extremity. Hashish et al.\(^1\) evaluated 22 recreational runners transitioning to barefoot running to determine carry-over into forefoot running. It was concluded that not all runners adopted a forefoot strike pattern. Without instruction, 8 runners maintained rearfoot strike pattern, 9 runners adopted midfoot strike pattern, and 5 runners adopted the desired forefoot strike pattern.

Hallux valgus angle has been hypothesized to correlate with barefoot running and walking. A systematic analysis, performed by Hollander et al.\(^8\) evaluated barefoot running or walking in a total of 8,399 participants across 15 studies. This analysis
concluded that there is little evidence to support the hypothesis of a lower measured hallux angle in barefoot running or walking.

Ankle

Ankle kinematics has significant implications in relation to barefoot running. Ankle plantar flexion and dorsiflexion are often hypothesized to be affected in various time frames of the gait cycle during barefoot vs. shod running. It has been thought that during foot strike there is a reduction of ankle dorsiflexion and an increase in plantar flexion during barefoot running. Hollander et al.,\(^8\) concluded that there is 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). A study conducted by Fredericks et al.,\(^31\) evaluated 26 recreational runners either barefoot or shod in their own personal shoes, standardized shoes, or minimalist shoes, concluded that barefoot and minimalist runners had significantly greater plantar flexion moments during foot strike than the other two groups. In addition to plantarflexion/dorsiflexion moments, barefoot running is also hypothesized to have an effect on ankle eversion.

Perkins et al.,\(^9\) suggests there is a decreased tendency for barefoot forefoot strike runners to evert their foot during running compared to shod rearfoot strike runners. This running position may support the hypothesis that barefoot runners experience less navicular drop than shod runners. 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.\(^9\) In addition, Hashish et al.,\(^1\) concluded the finding that midfoot and forefoot strike runners showed increased ankle energy absorption rates. The
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 preserving soft tissues.

*Knee*

Due to the high incidence of knee injuries in runners, the biomechanics of the knee has a significant level of interest in barefoot running. 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. A study conducted by Fredericks et al,\textsuperscript{31} 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 has an effect of knee flexion moments during running.\textsuperscript{2} A systematic analysis conducted by Perkins et al,\textsuperscript{9} 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, barefoot runners also exhibited earlier knee flexion moments in a study conducted by Sinclair et al,\textsuperscript{11} who evaluated female recreational runners. The loading rates at the knee have a significant effect of the kinetic chain during barefoot running and have a possibility of injury prevention.

Hashish et al,\textsuperscript{1} found that loading rates in the knee increased in runners that maintained rear foot strike patterns while barefoot running, while forefoot strike runners
showed significantly decreased loading rates in the knee. Sinclair et al,\textsuperscript{11} supported this claim as barefoot running showed significant reductions in patellofemoral loads.

**Hip/Pelvis**

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{11} 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 plantar flexion at the ankle. The shod group displayed grater peak force in their quadriceps and tibialis anterior. The barefoot group showed significantly higher peak forces in the gastrocnemius. Another study, performed on female recreational runners, concluded when comparing the kinematics of barefoot running vs shod running, barefoot runners had 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}

The gluteus medius (GM) acts as stabilizer at foot strike, preventing the knee from moving into genu valgum. During single leg stance, the force of gravity pulls the pelvis into relative adduction. The ipsilateral hip abductors provide a counterforce to stabilize the pelvis and control the magnitude of pelvic drop.\textsuperscript{26} GM activation has been well documented for shod running and weight bearing activities. The GM has the largest mean peak muscle force of all hip muscles during running. This peak mean muscle force occurs during the initial stance phase of running to help control lateral pelvic tilt.\textsuperscript{27} The
shape and size of the GM is favorable for a large abduction moment arm which is a key component to proper hip alignment and stability when performing weight bearing activities.\textsuperscript{28} The stance phase of running recruits the GM to prevent excessive pelvic drop. Without sufficient GM activation during the stance phase of gait, excessive pelvic motion can result and may cause injury.\textsuperscript{29}

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{8} 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{9} then 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 plantar flexion 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{1,9} 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{10} 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{11} 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{12,13,14} Eslami et al\textsuperscript{15} 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{16} 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{17,18,19} Which is why we are conducting this study to hypothesis if barefoot running training will decrease the distance traveled of the navicular within the medial longitudinal arch of the foot compared to shod training.

Recent studies indicate an omnipotent association of hip flexor and abduction weakness with lower extremity running injuries.\textsuperscript{26} In one study, they analyzed thirty injured runners with overuse injuries to thirty non-injured runners.\textsuperscript{29} Muscle testing of all six hip muscle groups revealed that hip abductors and hip flexors were significantly weaker in the injured group in comparison to the non-injured control. Further, the hip rotators also have been found to uphold greater stress and discomfort when gluteus medius weakness is present. Eccentric strength has been emphasized as a successful
treatment method to restore ideal biomechanics of gait.\textsuperscript{26} By strengthening the gluteus medius, the amount of pelvic drop will be reduced, encouraging ideal mechanics of gait and reducing abnormal repetitive stress due to excessive motion of the pelvis.

\textbf{Navicular Drop}

The measurement of the navicular drop movement was managed 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.

\textbf{Measurement Using the Navicular Drop Test (NDT)}

The Navicular Drop Test was developed by Brody to help determine the measurement of pronation in the foot.\textsuperscript{20} In majority of the studies, the NDT protocol was used to determine the measurement of the navicular drop and will also be used in the current study. To perform the test, the participant was placed in a sitting position with their feet flat on a firm surface with hips and knees in 90 degrees and ankles in neutral position. Subtalar neutral was found when there were equal depressions on both the medial and lateral side of the ankle. The most prominent point of the navicular tubercle was identified and marked, to be referred to during the NDT. One assessor maintained subtalar neutral and the other marked the height of the navicular tubercle on an index card. Without changing the position of the foot, the participant then stood up and bared weight equal through both feet. Using the same mark on the navicular tubercle, the height was measured on the same index card. The difference in height between the two markings was measured in millimeters. The same procedure was performed to calculate
the measurements on the opposite foot as well. For normal values of navicular height drop, Brody described values of 10mm and under to be normal and 15mm and over to be abnormal.

McPoil et al\textsuperscript{21} proposed that there are issues in performing the traditional navicular drop test involving lower levels of inter-rater reliability, including the identification of the navicular tuberosity bony landmark and the consistency of placing the subtalar joint in a neutral position using palpation while the patient is in a seated position. To overcome these issues, the authors of this study developed an alternative method for assessing foot mobility during the sit to stand portion of the navicular drop test by utilizing digital images to measure the change in dorsal arch height measured at 50\% of the foot. In this method, the location of subtalar joint neutral was not performed due to the alternative method.

Van der Worp et al\textsuperscript{25} looked at the NDT assessment in runners to identify whether hyper pronation of the foot along with decreased ankle joint dorsiflexion and the degree of the first metatarsophalangeal joint extension are risk factors for running injuries and to determine if there are differences between males and females. The cohort study performed the NDT using modified procedures by both Vinicombe et al\textsuperscript{22} and McPoil et al\textsuperscript{21} using a stance and single limb-stance measurement. Inter- 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{23} 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.

NDT Reliability

The inter- and intra-rater reliability of the navicular drop test has only been proven to be moderate. In a study performed by Vinicombe et al, two methods of quantifying foot posture were evaluated: navicular drop and navicular drift. Five clinicians measured twenty nonpathological participants on two occasions, using both methods. The authors had 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 found good interrater and intrarater reliability when evaluating and measuring the navicular drop in 30 healthy participants. These authors reported a mean navicular drop value of 0.6 cm and an ICC for intra- and inter-rater reliability of 0.73 and 0.83 respectively.

Rate of Drop

Previous studies have suggested that an increase of pronation of the foot may contribute to running-related injuries. Hoffman et al conducted a study using dynamic, biplane X-ray imaging to address the effects of three different footwear conditions
(barefoot, minimalist shoes, motion control shoes) on the impact of navicular drop during running. The purpose of the study was also to determine the association between dynamic and static measures of navicular drop. The motion control shoes had a slower navicular drop rate than running barefoot or minimalist shoes but there was no effect on magnitude comparing the difference in 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.\(^{32}\) 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,\(^{33}\) 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.\(^{11}\)
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 it was found to be valid and reliable. 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 navicular drop test and the VICON motion analysis system, navicular drop, and pelvic movement of the barefoot and shod participants can be analyzed before and after the six-week running program. There is little literature determining the impact of navicular and pelvis drop on the effects of a running retraining program with conversion from a RFSP to FFSP. 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 and pelvic movement.

The VICON was specifically used to evaluate the navicular drop of the foot and the lateral pelvic tilt during the stance phase of gait in walking and running. A decrease in navicular distance traveled from pretest to posttest, which may suggest a decrease in dynamic foot over-pronation. This result could support the effects of barefoot running with a FFSP, as a 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. With training, a decrease in pelvic drop during walking and running will indicate proper pelvic control and stability that has shown to minimize the risk of acquiring musculoskeletal syndromes.
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 and pelvic movement during pre- and post-testing, inclusion criteria allowed participants’ pre- running requirements to be between 0 and 20 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 18-35 years old, must run with a rear foot striking pattern, must be a habitual shod runner, no current use of NSAIDs, no cardiopulmonary pathologies or significant medical history, and must currently complete a minimum of 0-20 miles of running per week.

Once their inclusion/exclusion criteria were confirmed, participants were evaluated dynamically for navicular drop and pelvic movement during walking and running using VICON video analytics software. Subjects were also evaluated using a standardized, static Navicular Drop Test. Twenty five subjects were recruited; however, three subjects were removed from the study for the following reasons: one subject was removed secondary to bilateral quad strains obtained outside of the research study, another participant was removed from the study due to medical issues that did not pertain to the research study, and the last participant was removed due to being a habitual forefoot runner.

Twenty-two 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 placed into an electronic random group generator. 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. Thirteen subjects were selected for the barefoot group and nine were selected for the shod group. Each subject was informed of their assignment confidentially via email. Of the twenty-two participants, subject selection based on inclusion and exclusion criteria is diagrammed in Figure 1.
NDT = Navicular Drop Test

*Inclusion Criteria:
- No pain or injury to the lower extremities in the past 6 months
- Age between 18-35 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 0-20 miles of running per week

Figure 1. Subject Selection Process & Inclusion Criteria
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 0.964 for the right foot and 0.956 for the left foot. The process of measuring navicular drop was the same that was used in the current study. 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 shown in 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 depressions were equal on both sides of the ankle noted in 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 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, marking the height of the navicular on the notecard; the opposite foot was then put in subtalar neutral and marked as well, repeating the stand without moving the foot from the ground. Again, the most prominent point of the navicular was measured for height on the notecard shown in
Figure 2c. The difference between the two markings for both right and left were measured in millimeters. Subjects then completed EMG testing the same or following day. 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: Manual Navicular Drop
(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

VICON, a video analysis software, was utilized in this study to assess dynamic navicular drop and pelvic movement 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 the last conducted 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 prior 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.
Prior to 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 12 inches apart running the length 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.

Each area where the sensor was placed 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, knee joint and hips would not move or fall off during running and walking. Small reflective sensors were then placed on each participant’s foot, knee, and hips 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; one sensor placed on the lateral knee joint; and three sensors placed per hip as follows: ASIS (anterior superior iliac spine) and PSIS (posterior superior iliac spine). The same process was then repeated on the opposite foot, knee, and hip. 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 placements of the sensors, 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 each of the following categories of their normal pace: barefoot walking (BW), barefoot
running with forefoot striking (BR), shod walking (SW), and shod running (SR) 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 same procedure was then performed to determine the amount of pelvic drop during the three trials using the ASIS and PSIS sensors. The post-testing procedure was identical to pre-testing procedure to assess dynamic navicular drop and pelvic movement.

Training Program

The training program randomly assigned the participants to either the barefoot or shod running group. The study included a total of 22 subjects, 13 subjects were randomly selected to run barefoot with a forefoot striking pattern and 9 were randomly 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 High Performance center. 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 walking on the track, (3 minutes at a moderate, self-selected pace), and dynamic stretching. Each participant assigned to the barefoot group was required to wear socks while on the turf due to the hygiene policy of the UND High Performance 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.

Following the initial warm up walk, the dynamic stretches were performed. 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 then completed the timed run at a self-selected pace around the perimeter of the track for the required time of that designated week.
Figure 5: Dynamic Warm-up Stretches: (a) Hip flexion/extension swings, (b) Hip abduction/adduction swings, (c) Lunge with twist, (d) Knee to chest, and (e) Lunge with twist to ceiling.
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 training 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 group. The
VICON equipment and pre- and post-testing procedures were also previously assessed in a previous 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

Prior to pre-testing being completed, information was gathered from the participants which 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. Participant’s 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. Participation demographics and randomized group distribution

<table>
<thead>
<tr>
<th>Which running group were you in?</th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid Barefoot running group</td>
<td>13</td>
<td>59.1</td>
<td>59.1</td>
<td>59.1</td>
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<tr>
<td>Shod running group</td>
<td>9</td>
<td>40.9</td>
<td>40.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>100.0</td>
<td>100.0</td>
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</table>
### Gender

<table>
<thead>
<tr>
<th></th>
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<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
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</thead>
<tbody>
<tr>
<td>Valid</td>
<td>Male</td>
<td>8</td>
<td>36.4</td>
<td>36.4</td>
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<tr>
<td></td>
<td>Female</td>
<td>14</td>
<td>63.6</td>
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<tr>
<td>Total</td>
<td>22</td>
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### Weekly running mileage

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<th>Percent</th>
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<th>Cumulative Percent</th>
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<td>Valid</td>
<td>I don't run</td>
<td>7</td>
<td>31.8</td>
<td>35.0</td>
</tr>
<tr>
<td></td>
<td>0-2 miles</td>
<td>3</td>
<td>13.6</td>
<td>15.0</td>
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<tr>
<td></td>
<td>2-4 miles</td>
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<td>9.1</td>
<td>10.0</td>
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<tr>
<td></td>
<td>4-6 miles</td>
<td>3</td>
<td>13.6</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>6-8 miles</td>
<td>3</td>
<td>13.6</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>8-10 miles</td>
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<td>4.5</td>
<td>5.0</td>
</tr>
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<td></td>
<td>10+ miles</td>
<td>1</td>
<td>4.5</td>
<td>5.0</td>
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<tr>
<td>Total</td>
<td>20</td>
<td>90.9</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

|       | System   | 2 | 9.1 |
| Missing| System   | 2 | 9.1 |
| Total  | 22       | 100.0 |

### Age

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
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<td>1</td>
<td>4.5</td>
<td>4.5</td>
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<td></td>
<td>21</td>
<td>1</td>
<td>4.5</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>9</td>
<td>40.9</td>
<td>50.0</td>
</tr>
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<td></td>
<td>23</td>
<td>4</td>
<td>18.2</td>
<td>68.2</td>
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<td>18.2</td>
<td>86.4</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>3</td>
<td>13.6</td>
<td>100.0</td>
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<tr>
<td>Total</td>
<td>22</td>
<td>100.0</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>
Standard Navicular Drop Test

When analyzing the difference from pre- to post-test, the results of the Standard Navicular Drop Test were not statistically significant with either the left or right foot. When analyzing the data between groups, Table 2 shows a trend for training effect in barefoot versus shod when comparing pre and post testing for standard navicular drop test. The mean average data indicates that there is a decrease in navicular drop during barefoot running and walking compared to shod in pre and post testing.

**Table 2. Standard Navicular Drop Test Results**

<table>
<thead>
<tr>
<th></th>
<th>Running Group</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>Barefoot</td>
<td>13</td>
<td>1.2308</td>
<td>3.00427</td>
</tr>
<tr>
<td></td>
<td>Shod</td>
<td>8</td>
<td>.6250</td>
<td>1.99553</td>
</tr>
<tr>
<td>Post</td>
<td>Barefoot</td>
<td>13</td>
<td>1.0000</td>
<td>2.48328</td>
</tr>
<tr>
<td></td>
<td>Shod</td>
<td>8</td>
<td>.3750</td>
<td>3.58319</td>
</tr>
</tbody>
</table>

VICON Motion Analysis

The results of the VICON testing for navicular drop and pelvic movement showed a trend for training effect in barefoot walking and barefoot running. This trend found reduced navicular drop and pelvic movement from pretesting to post-testing, however there was no statistically significant difference between barefoot training and shod training for all of the dynamic testing conditions. Table 3 summarizes the data collected for the VICON motion analysis for navicular drop. The mean average data indicates that there is a decrease in motion of the navicular during barefoot running and walking, post training, in comparison to shod running and walking.
Table 3. Navicular Drop in Barefoot Running Group and Shod Running Group

<table>
<thead>
<tr>
<th>Running Group</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right BW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barefoot</td>
<td>13</td>
<td>2.0741</td>
<td>4.60275</td>
</tr>
<tr>
<td>Shod</td>
<td>9</td>
<td>1.1359</td>
<td>3.16924</td>
</tr>
<tr>
<td>Left BW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barefoot</td>
<td>13</td>
<td>1.33919</td>
<td>2.77355</td>
</tr>
<tr>
<td>Shod</td>
<td>9</td>
<td>1.0962</td>
<td>2.16472</td>
</tr>
<tr>
<td>Right BR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barefoot</td>
<td>13</td>
<td>3.3414</td>
<td>4.2269</td>
</tr>
<tr>
<td>Shod</td>
<td>9</td>
<td>-.0567</td>
<td>5.25428</td>
</tr>
<tr>
<td>Left BR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barefoot</td>
<td>13</td>
<td>.5768</td>
<td>5.0080</td>
</tr>
<tr>
<td>Shod</td>
<td>9</td>
<td>.3379</td>
<td>3.10830</td>
</tr>
</tbody>
</table>

There is no statistical significance that a training program of 6 weeks is able to significantly improve navicular drop during barefoot running and barefoot walking. These results are caused by a low subject number and a short training period. Further research is recommended to establish statistical significance for decreasing navicular drop during running barefoot and running. In comparison, Table 4 summarizes the data collected from the VICON motion analysis for the pelvic movement pre and post testing.

Table 4. Summarized Statistics of Pelvic Movement during Barefoot Trials vs. Shod Trials

<table>
<thead>
<tr>
<th>Running Group</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right BW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barefoot</td>
<td>13</td>
<td>.0937</td>
<td>1.39094</td>
</tr>
<tr>
<td>Shod</td>
<td>9</td>
<td>-.5378</td>
<td>1.48884</td>
</tr>
<tr>
<td>Left BW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barefoot</td>
<td>13</td>
<td>-.7459</td>
<td>1.57592</td>
</tr>
<tr>
<td>Shod</td>
<td>9</td>
<td>-.9915</td>
<td>1.91075</td>
</tr>
<tr>
<td>Right SW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barefoot</td>
<td>13</td>
<td>-.1237</td>
<td>1.28153</td>
</tr>
</tbody>
</table>
In terms of pelvic movement looking at the means of pre and post training program, with the exception of two trials when grouping the statistics (Left WS and Left RS), there was trending evidence that supported decreased pelvic movement while barefoot running and walking. Although there were no significant findings, this positive trend promotes the need for continued randomized control trials to be conducted due to the fact that this current study consisted of a small sample size.
Chapter IV

Discussion

Overall, the data that was collected during the pre- and post-tests after 12 training sessions over a 6 week period provided the groups did not have any statistically significant findings that navicular drop or pelvic movement is decreased after a 6 week training period, however mean average data showed that navicular drop was less in the barefoot running group than the shod running group. Trending data also showed that pelvic movement was less in the barefoot running group than the shod running group.

These results show clinical significance that after training in barefoot running, navicular drop, and pelvic movement have the ability to show statistical significance that less movement occurs at the navicular and at the pelvis in comparison to shod running and shod walking.

Training Effect

The 6-week training effect shows 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. The training effect also shows a trend toward the greatest reduction in pelvic movements when the contralateral leg is in
midstance of the gait cycle. 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 track, 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. Socks were worn by the barefoot group throughout training, as required by the UND High Performance Center regulations for means of sanitation on the track.

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\textsuperscript{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.

\textit{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 one of the subjects’ foot in subtalar neutral and instructed the subject to hold this position while data was collected. Then was completed the same way on the opposite side. 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.

Sample Size

Because the smaller sample size of participants (n = 22) 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. 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.

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 short amount of time spent training (a total of 140 minutes) may not be sufficient enough for training effects to occur in the participants.

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. Open 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 dynamic 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 or pelvic drop movement during this study. Data showed that navicular drop presented a trend towards having less movement during barefoot running and barefoot walking post training program in comparison to the shod running group. It should be taken into consideration the limitations in this study such as the small sample size, and the population of only student physical therapists.
APPENDIX A
Informed Consent

<table>
<thead>
<tr>
<th>INFORMED CONSENT DOCUMENT TEMPLATE: NON-MEDICAL PROJECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 701-B                    04/18/2013</td>
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</table>

THE UNIVERSITY of NORTH DAKOTA

INSTRUCTIONS FOR WRITING AN INFORMED CONSENT DOCUMENT
NON-MEDICAL CONSENT TEMPLATE

INSTRUCTIONS:
- This consent document template is recommended for non-medical studies because it contains all required elements of consent.

- The text in bold throughout this document offers suggestions and guidance. It should be deleted and replaced with information specific to your study. The headers and footers are not meant to be edited and should remain on your consent document.

CONSENT DOCUMENT INSTRUCTIONS:
- Consent documents should be written in the second person (e.g., “You are invited to participate”). Use of the first person (e.g., “I understand that…”) can be interpreted as suggestive and can constitute coercive influence over a subject.

- The consent form should be written at about an eighth grade reading level. Clearly define complicated terms and put technical jargon in lay terms.

- The consent form must be signed and dated by the subject or the subject’s legally authorized representative. The signed consent from each subject must be retained by the investigator and a copy of the consent form must be provided to the subject.

CONSENT DOCUMENT FORMAT:
- To facilitate the IRB review process, the sample format below is recommended for consent forms.

- Prepare the entire document in 12 point type, with no blank pages or large blank spaces/paragraphs, except for a 2 inch by 2 ½ inch blank space on the bottom of each page of the consent form for the IRB approval stamp.

- Multiple page consent documents should contain page numbers and a place for the subject to initial each page.

ASSISTANCE
- If you have questions about or need assistance with writing an informed consent please call the Institutional Review Board office at 701 777-4279.
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 effects 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 Gluteus Medius (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 (0-20 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?

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/GM 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 lever arms 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 GM 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 GM 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 qualification to participate in the study according to the inclusion criteria which includes: no significant injury in the lower extremities in the past 6-months, age between 18-35, 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 0-20 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 GM 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/GM musculature will be performed again. In addition, each participant will complete a post-program survey. No personal identifications 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 navicular 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 navicular 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 shod 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 study. The 6-week training will take place at the High Performance Center on the campus of the University of North Dakota.

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 701-777-6081 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
# APPENDIX B

**Exercise Log Sheet**

<table>
<thead>
<tr>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
<th>Day 8</th>
<th>Day 9</th>
<th>Day 10</th>
</tr>
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<tr>
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</table>

**ID CODE:**
- Navicular marked
- Bike 3 minutes
- Dyn. Warm-Up: One leg on a chair
- ABD/Add Swings: x 10
- Lunge with Twist x 5
- Knee to Chest x 5
- Lunge with Twist to Ceiling x 5
- Walk 1 minute 3 mph
- Run: 4 mph x 1 min
- Step 1: 5 mph x 1 min
- Walk 3 minutes 3 mph
- Stretches: 2x30°
- Quad/ecs
- Soleus
- Hip flexors
- Hamstrings
- Piriforms
Bibliography


doi:10.1016/j.gaitpost.2015.02.017.


