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Effects of Body Weight Loading on Arch Height

Anastasia Bjelopetrovich
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Honors Thesis

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Department: Physical Therapy

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Abstract

Deformation of the medial longitudinal arch under body weight loading is often assessed using the Arch Height Index Measurement System. This system assesses change in arch height between sitting and standing, estimated to be 10 and 50% of body weight, respectively. However, body weight forces during ambulation exceed these loads, therefore limiting our understanding of arch deformation under ambulatory load ranges. Thus, the study aims were 1) to assess if sitting and standing arch height differed from that seen under 10 and 50% body weight using a force target-matching procedure, and 2) to characterize the relationship between arch deformation and body weight loading throughout an ambulatory load range. Established sitting and standing arch height measurements were taken from 25 healthy subjects, who also underwent testing from 10 to 120% body weight loads in sequential 10% increments. Arch deformation in sitting was less than that of 10% body weight, whereas the standing and 50% condition did not differ. The incremental loading data revealed linear and curvilinear trends between arch deformation and loading through the ambulatory range, such that further deformation beyond that seen at 120% would be minimal using these procedures. These data suggest that sitting arch loads and deformation are less than those seen at 10% body weight, which affects known parameters such as arch stiffness. Further, the curvilinear trend in the arch height data suggests that most arch deformation occurs in the ambulatory load range for a healthy foot, and that greater static load magnitudes would deform the arch only minimally.

Acknowledgements

The author would like to thank Dr. Joaquin Barrios for his assistance in developing the study, training in the lab and advising of writing the manuscript. Additionally, the author would like to acknowledge the University of Dayton Honors Program for their financial support of this project through the Thesis Research Fellowship Award.

UNIVERSITY of DAYTON

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INTRODUCTION

Foot functionality is integral to normal human locomotion. Locomotor impacts, often measured in biomechanical analyses with ground reaction force data, are associated with structural foot deformations under body weight (BW) loading. Perhaps the most commonly assessed foot characteristic is the medial longitudinal arch region.

While a number of approaches exist for the assessment of the medial longitudinal arch, the most reliable is the Arch Height Index Measurement System (AHIMS) (Williams & McClay, 2000; Butler et al., 2008; Pohl & Farr, 2010). The AHIMS approach essentially normalizes dorsum height (taken halfway along the length of the entire foot) to a truncated foot length (the length of the foot from the heel to the first metatarsal head) to derive the AHI metric. The AHI value is then taken in sitting and standing to reflect unloaded and loaded conditions.

While AHI in sitting and standing reflect arch deformation under loading, two limitations should be noted. The first is that the AHI assessment is static. The AHI assessment, while concurrently validated against radiographic measures of dorsum height and truncated foot length (Williams & McClay, 2000), does not strongly reflect arch behavior during dynamic loading conditions. The second limitation is that only two loading conditions are generally tested, in sitting and in standing. In sitting, the resting weight of the shank and foot is considered to be approximately 10% of total BW. Williams and McClay (2000) defend the 10% BW estimate by suggesting that BW loading is approximately 10% when the foot becomes plantigrade during the stance phase of walking, and describe the condition as relatively unloaded. In standing, it is assumed that BW is even distributed between limbs, and the load is approximately 50% BW (McPoil et al., 2009; Butler et al., 2006; Pohl & Farr, 2010; Teyhen et al., 2009; Weimar & Shroyer 2013). These assumptions that sitting and standing produce accurate BW load estimates of 10% and 50% have not been directly tested.

Of importance, testing AHI under dynamic loading is not feasible due to the AHIMS hardware. However, dynamic ambulatory peak ground reaction forces are generally 120% BW (Keller et al., 1996), well above the 50% tested in the established

standing AHI assessment. Therefore, there were two primary aims for this study. The first aim was to assess if the established baseline sitting and standing AHI measures are actually representative of 10% and 50% of BW loading as determined using target-matching of real-time vertical ground reaction force data. It was hypothesized that the 10% sitting condition would differ from the force-matching magnitude at 10% due to variation in sitting forces and early loading during stance across subjects. However, it was hypothesized that the 50% conditions would not differ as healthy individuals would be able to evenly distribute BW between limbs in standing.

The second aim was to characterize the BW load and arch deformation relationship by incrementally increasing BW loading and AHI in standing using 10% load increments from 10% to 120% BW. While this method does not reflect velocity and acceleration-dependent inertial forces, using progressively increasing BW loads in the typical ambulatory range will allow for a quasi-static assessment of the arch deformation response. It was hypothesized that both linear and quadratic trends would be observed, with linear term reflecting a general progression of arch deformation and the quadratic term reflecting a ceiling effect in deformation with higher loads to due anatomic constraints to the applied loads.

METHODS

Participants

Twenty-five (17 females) healthy students were recruited from a university setting to participate in this study (age = 20.12 ± 0.97 years; height = 1.72 ± 0.08 m, weight = 73.7 ± 14.5 kg). All subjects reported no current or prior lower extremity injury. Subjects were excluded with my history of any condition preventing prolonged standing or shifting weight on their foot. The study procedures were approved by the university institutional review board, and subjects provided written consent to participate in the study in accordance with the approval.

Experimental Protocol

Subjects completed all testing barefoot. Height was measured using a stadiometer. Each subject was first weighed on floor-mounted force plate (Bertec Corp., Columbus, OH, USA) to establish baseline and 10% increments in body weight (BW). These increments were established with the aim of representing body weight loading from 10% to 120%. Overloading beyond 100% occurred with the use of an adjustable weighted vest (ZFO Sports, San Jose, CA, USA) loaded to 20-25% of BW. The right lower extremity was used for all testing.

First, sitting and standing AHI were measured using the well-documented AHIMS procedure. For the sitting assessment, the subject sat down in a chair with hips and knees flexed to 90 degrees. Using the AHIMS, the arch measurement was taken on the right foot. This included foot length, truncated foot length and dorsum height (Figure 1). Next, the subject would stand on both feet with weight evenly distribute, and the AHIMS procedure was repeated for the standing assessment.

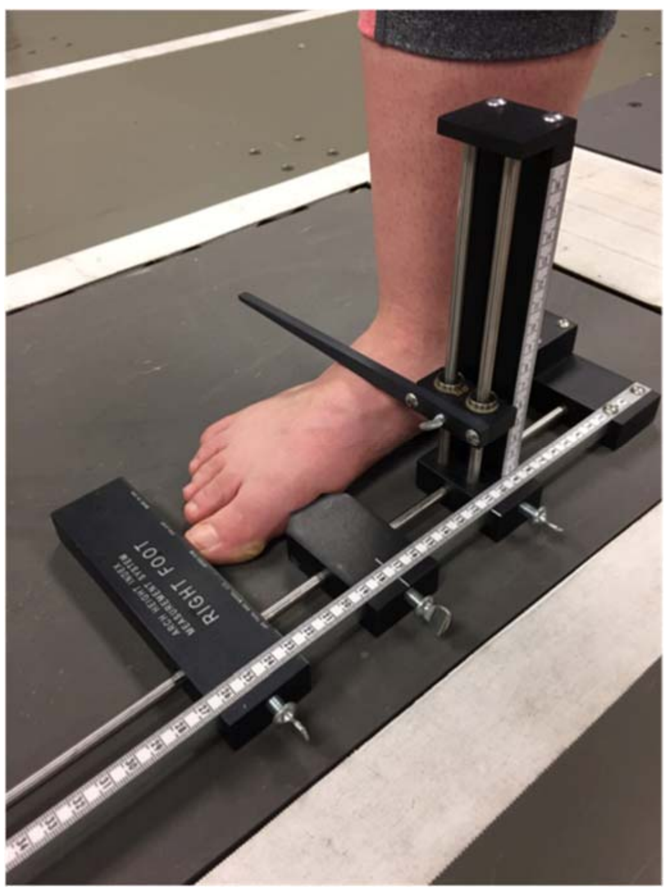

Figure 1. Arch Height Index Measurement System. The device used to measure the right foot of the study.

After baseline measurements were collected, a force target-matching procedure was carried out for each BW increment from 10-120% BW in standing. The weight of the AHIMS device (Jevek Solutions, Matawan, NJ, USA) was tared off so the force plate data did not include the device weight. The vertical force data (N) was then graphically streamed as a real-time line graph (Vicon Nexus, Centennial, CO, USA) to a large 42" high definition monitor placed approximately 2-3 meters in front of the plate. All subjects confirmed clear visibility of the data stream. The y-axis of the force data stream was positioned and scaled such that the entire vertical screen represented ± 1% of the % BW target for the condition for each subject. In effect, subjects adjusted body weight force to visualize the streaming data on the monitor while standing in the AHIMS device. Errors within 1% were observable on the screen, but errors beyond this range were not. Once the subject could steadily hold this position within the acceptable error range, arch height was measured. This process was repeated for each condition from 10% up through 120% in progressive fashion. At the 70% weight condition, the subject put on the weighted vest. This vest was used for the remaining conditions, up to 120%. The vest was used only for the higher load conditions to improve subject comfort, as wearing the loaded vest was reportedly uncomfortable when worn for a prolonged period of time. Subjects were allowed to use a balance aid to facilitate the weight shifting needed to target-match the force data. After each measure, subjects were asked to unload and re-position their foot for the following condition. Subjects were also allowed to rest between conditions in sitting. The same standing AHIMS procedures as described above were used for each condition.

Analysis

SPSS (version 21.0, IBM Corp., Armonk, NY, USA) software was used to calculate means and standard deviations for both the sitting and standing AHI, and each force target-match condition. A paired t-test was performed between the baseline sitting and the 10% condition, as well as between the baseline standing and 50% condition. The condition data were assessed using repeated measures analysis of variance, and pairwise comparisons were conducted between each pair of sequential loading conditions. Within-subjects contrasts were assessed for linear and polynomial trends. Significance was

determined using an alpha level of 0.05, and a Bonferroni adjustment was used for the repeated measures data.

RESULTS

The means and standard deviations for AHI for baseline sitting and standing were 0.365 (0.020) and 0.326 (0.023), respectively. The baseline sitting AHI was observed to be 7% greater than the force target-matched value at 10% of 0.342 (0.023) ($p<0.001$). The baseline standing AHI did not statistically differ from the force target-matched value at 50% at 0.323 (.020) ($p=0.206$).

The force target-match data is shown in Table 1. The first 6 pairs of sequential conditions, representing 10-70% BW, showed greater arch deformation. Of the remaining 5 sequential pairs, only 80-90% and 90-100% showed change. This trend of greater change during early loading (and less change during later loading) was consistent with the combined significant linear ($p<0.001$) and polynomial ($p<0.001$) trend terms (Figure 2).

Body Weight Condition	Foot Length	Dorsum Height	Truncated Foot Length	Arch Height Index	p-value
10%	25.396±1.511	6.480±0.443	18.976±1.183	0.342±0.023	-------
20%	25.492±1.459	6.360±0.452	19.024±1.131	0.335±0.022	0.000*
30%	25.588±1.467	6.292±0.442	19.088±1.119	0.330±0.021	0.002*
40%	25.636±1.497	6.224±0.439	19.112±1.129	0.326±0.021	0.001*
50%	25.688±1.519	6.172±0.410	19.156±1.129	0.323±0.020	0.008*
60%	25.708±1.503	6.148±0.416	19.196±1.110	0.321±0.020	0.025*
70%	25.744±1.505	6.064±0.421	19.216±1.114	0.316±0.019	0.001*
80%	25.756±1.495	6.04±0.420	19.228±1.118	0.314±0.019	0.400
90%	25.760±1.490	6.004±0.398	19.256±1.115	0.312±0.018	0.001*
100%	25.808±1.497	5.976±0.402	19.292±1.120	0.310±0.018	0.023*
110%	25.816±1.491	5.952±0.408	19.312±1.111	0.309±0.018	0.171
120%	25.824±1.498	5.936±0.410	19.316±1.118	0.308±0.019	1.00

Table 1. Force Target-Match Data. The average and standard deviation values for foot length, dorsum height, truncated foot length and arch height index are shown. Additionally, the p-value for each condition compared to the condition before it is represented.

* indicates a statistical significant difference.

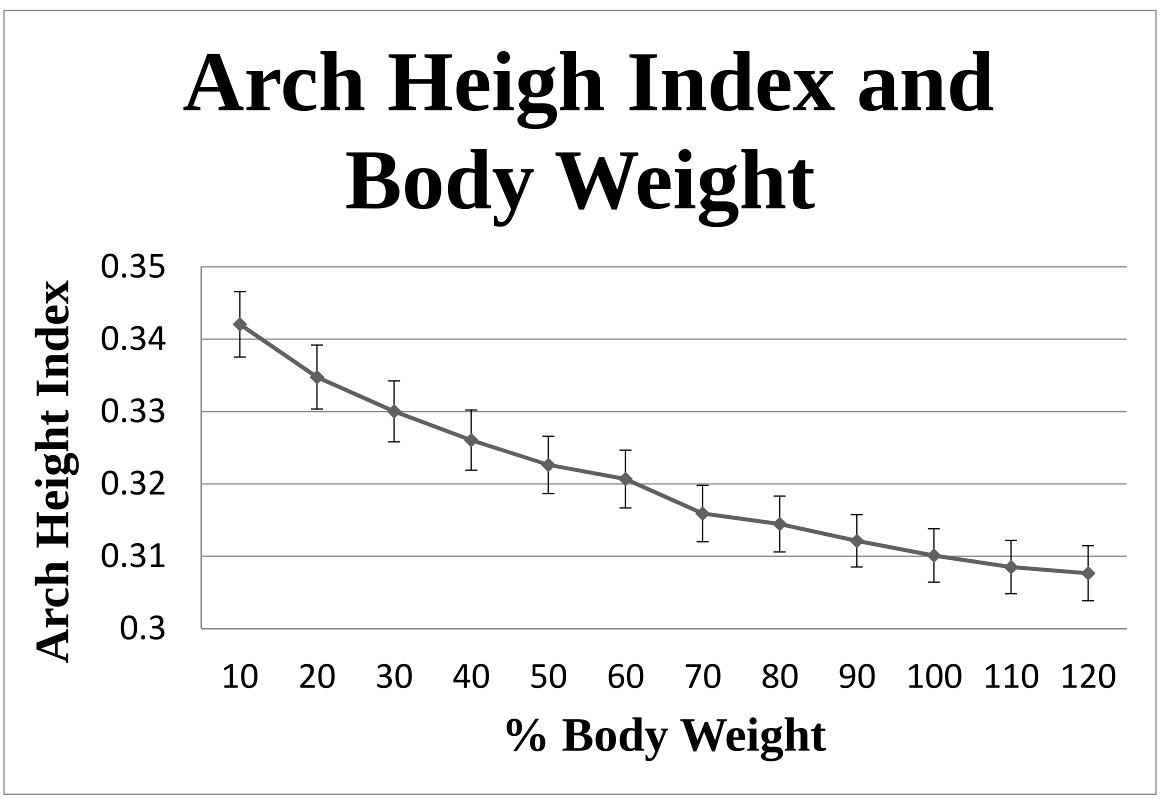

Figure 2. Arch Height Index v. BW Condition. The mean values and standard deviations of arch height index for each body weight condition.

DISCUSSION

The primary aims of this research were two-fold. First, the validity of the sitting and standing BW conditions used in AHI calculations was directly tested using force target-matching as a reference standard. It was observed that the standing condition did not differ from the 50% loading condition. However, the sitting condition tends to underload the arch structures relative to the 10% loading condition, as evidenced by higher AHI values. Taken together, these data support the continued use of the standing condition as a 50% BW load condition for arch height testing. However, the data call into question any inferences or further calculations based on the sitting condition being representative of 10% BW loads, as sitting loads do not appear to reach this magnitude. A primary example is the calculation of arch stiffness (Zifchock et al., 2006; Butler et al., 2006), which assumes a 40% change in load from the sitting to the standing condition. These studies multiply static BW by 0.4, and then divide by the change in AHI from sitting to standing. As such, previously calculated stiffness values may underestimate arch stiffness.

The second aim was to characterize the BW load – arch deformation relationship based on a progressive, quasi-static loading protocol using AHI for experimental measures. As expected, both linear and quadratic trends were observed. These data are partly supported by the findings of Pohl and colleagues (2010), who compared 10%, 50% and 90% BW loads in 20 healthy males and found AHI differences when moving from the 10% to the 50% condition, but no further change between 50% and 90% condition. In the current, it was similarly observed that AHI decreased between 10% and 50%. In contrast, however, AHI change still occurred between 50% and 90%. This discrepancy may be due to the male-only gender profile and smaller sample in that study.

While arch deformation occurred with BW loading, a ceiling effect was observed suggesting further deformation past 120% BW would be minimal using this experimental approach. However, as non-significant deformation was still observed in the mean data up through 120% BW, any future attempts to characterize this curvilinear relationship may consider higher BW loads. One previous study attempted to predict a measure of dynamic AHI from static AHI using stepwise linear regression techniques (Teyhen et al.,

2009). The findings in the current study call these calculations into question, as the non-linear behavior of these data were not accounted for.

A number of important considerations should be acknowledged. First, a quasi-static approach essentially eliminates the contribution of momentum and load rate to arch deformation that is present in actual dynamic locomotion. This experimental limitation is likely to underestimate deformation at a given BW load in the testing range. Second, the application of the current data should be limited to healthy adults without a history a history of foot disorders. Indeed, previous work evaluating AHI parameters in early-stage posterior tibial tendon dysfunction observed lower AHI in sitting but not standing, suggesting this population presents with lower arches when relatively unloaded (Rabbito et al., 2011). This population would likely demonstrate less AHI change using the current experimental approach. Other populations with non-normal arch characteristics should continue to be tested. Third, all AHI metrics are taken in a plantigrade foot, which does not reflect foot positioning before and after the gait event window between foot flat and heel rise. Inferences outside this event range should be approached with caution.

In summary, the data obtained in this experiment suggest that while a standing AHI assessment is a is valid method to assess 50% BW load, the sitting assessment underloads the arch and does represent 10% BW load as described in the literature. Further, the load-deformation relationship throughout typical ambulatory loads is curvilinear, although arch deformation beyond 120% appears likely in healthy persons.

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Appendix A

Approved IRB Application

Application for Non-Exempt Human Research

Instructions

Please use this form for your Institutional Review Board (IRB) application by directly entering information into each section or copying and pasting into the appropriate sections from your own document. Please direct all QUESTIONS and submit all APPLICATION MATERIALS Electronically to IRB@UDayton.edu.

~NO HARD COPY APPLICATIONS WILL BE ACCEPTED~

1a. DATE OF SUBMISSION: 1/23/15

1b. PRIMARY INVESTIGATOR INFORMATION

Name: Anastasia Bjelopetrovich
Department: Health and Sports Science
Contact Phone: 847-513-2580
Email: bjelopetrovicha1@udayton.edu
Position in University (if student, must indicate faculty sponsor): Student
Faculty Sponsor Name: Joaquin Barrios
Faculty Sponsor Department: Department of Physical Therapy
Faculty Sponsor Contact Phone: 937-229-5609 Email: jbarrios1@udayton.edu

2. PROJECT TITLE:
Effects of Body Weight Loading on Arch Height

3. PROJECT TIME FRAME – Anticipated beginning and ending dates of Research Project:

Start Date: 01/18/15 End Date: 05/10/16

4. PROJECT EVALUATION - Please **Check** ALL of the following that apply.

Target Populations Include:

- ☐ Athletes
- ☐ Children 0-12 (Parental Consent required)
- ☐ Children 13-18 (Parental Consent required)
- ☐ Developmentally disabled
- ☐ Elderly
- ☐ Elected officials
- ☐ Mentally ill
- ☐ Non-English speaking persons
- ☐ Military personnel
- ☐ Persons convicted of a crime
- ☐ Persons in treatment for a physical, mental, or emotional ailment
- ☐ Persons on parole
- x Persons over the age of 18 ONLY
- ☐ Persons with English as a second language
- ☐ Physically impaired
- ☐ Political appointees

- ☐ Pregnant women
- ☐ Prisoners
- ☐ Teachers
- X UD staff
- x UD students
- ☐ College Students (non-UD)
- ☐ Victims of crime

Site of Data Collection:

- ☐ Classroom
- ☐ Health care facility
- ☐ Public place
- ☐ Off-campus
- ☐ Military or government-operated installation
- ☐ Non-UD campus
- x UD campus
- ☐ Other – Specify:

Type of Data Collected/Method of Storage:

- ☐ Archives
- ☐ Audio-recordings will be made (must be noted in consent document!)
- ☐ Collection of existing data or records
- ☐ Data will be collected anonymously
- x Data will be kept confidential
- x Data will be linked to participants through code numbers
- ☐ Data will be linked to participants through pseudonyms
- ☐ Data will be stored anonymously
- ☐ During the data collection, participants will be deceived
- ☐ Medical records (HIPAA releases and HIPAA Training may be required)
- ☐ Photographs will be taken (must be noted in consent document!)
- ☐ Publicly available data
- ☐ Specimens or data collected for non-research purposes
- ☐ Participant data will be stored with participant's identity
- ☐ Video recordings will be made (must be noted in consent document!)

Instrument/Method of Data Collection:

- ☐ Deception will be used
- ☐ Focus groups
- ☐ Includes follow-up contact with participants
- ☐ Includes interaction with children
- ☐ Includes observation of children
- ☐ Interviews – e-mail/text/on-line
- ☐ Interviews – face to face

- ☐ Interviews -- telephone
- ☐ Non-UD personnel will collect data
- ☐ Observation of public behavior
- ☐ Oral History
- ☐ Psychological tests
- ☐ Questionnaires
- ☐ Cognitive Performance Tests
- x Physical Performance/Endurance Tests
- ☐ Research on established educational practices, using normal educational practices
- ☐ Students will collect data
- ☐ Participants will be compensated
- ☐ Surveys - anonymous
- ☐ Surveys – online
- ☐ Surveys - paper
- ☐ Uses educational or aptitude tests
- ☐ Use of physiological devices

<u>Reason for Research:</u>

- ☐ Faculty/Staff research
- x Undergraduate honors thesis
- ☐ Undergraduate research
- ☐ Graduate research – masters thesis
- ☐ Graduate research – doctoral dissertation
- ☐ Graduate research – non-thesis
- ☐ Classroom project
- ☐ Other reason for research (specify)

<u>Does Your Research Involve Any of the Following Topics?</u>

- ☐ Alcohol use
- ☐ Drug use
- ☐ Emotional stress
- ☐ Illegal activities
- ☐ Gambling
- ☐ Law enforcement
- ☐ Public welfare programs
- ☐ Sexual habits
- ☐ Sexual orientation

5. PROJECT STAFF

Please list personnel, including students, who will be working on this protocol (insert additional rows as needed). This includes anyone who interacts with participants or handles non-anonymous data. All personnel conducting non-exempt research must have completed CITI Program Training in Human Research Protections within the past three years.

Name, Title & Degree	**Role** (*Specify whether person is authorized to obtain consent*)	**Dates of CITI Training** (Attach certificates)
Anastasia Bjelopetrovich, Student	Student researcher	01/02/15, 01/03/15, 01/07/15
Joaquin Barrios, Faculty, PhD	Faculty adviser	On record

6. SITE INFORMATION:

Where will data be collected? (include ALL locations!) NOTE: Documentation of site approval is required for all off-campus data collection! If such documentation is not practical, please contact IRB@udayton.edu to request a waiver. If multiple IRBs are reviewing this application, which IRB will have major oversight? Indicate if the PI is the lead investigator.

Location(s): Motion Analysis Lab (University of Dayton, Fitz Hall room 220F)

Multi-Site Studies (if applicable): N/A

7. RESEARCH ABSTRACT: *Please provide a brief description in LAY language of the aims of this project. Use the following headings: Background and Purpose, Participants, Methods. (Suggested length 1 page)*

Response:

Background and Purpose

Foot functionality is an integral part of the human body. All forces and impacts normally start at the feet due to standing, walking or running. If the foot does not function how it is supposed to, it can lead to major injuries and pain that can make getting around difficult for those who have these ailments. One major component of foot functionality is arch structure. Previous studies have examined how the arch structure changes from an unloaded condition to a loaded condition (usually full body weight). This can show how our foot changes during gait in order to better understand how injuries may occur. As well, it can have an impact on balance and gait speed depending on the type of arch a person may have.

While many previous studies have examined the arch of the foot, the studies do not go in depth. These studies take baseline measurements and sometimes one additional loaded measurement. The aim of our study is to expand the knowledge of arch structure due to body weight loading. The study will address this by not only taking baseline assessments, but also adding incremental measurements of a loaded condition. These measurements will create a continuous loading spectrum, allowing us to asses the changes in arch structure. This can

help us better understand the anatomy of the arch during gait, as well as different loaded positions.

Participants
30 participants will be used in the study. Any undergraduate or graduate student as well as any staff 18 years or older at the University of Dayton may be considered. These participants will be healthy individuals. Any person weighing more than 300 pounds will excluded in the study. Any person with any current or past history of a self-reported leg injury will be excluded from the study. The subjects will be recruited by use of flyers and posters placed throughout the University of Dayton campus. The subjects' identity will be kept confidential by the use of code numbers.

Methods
The subject's arch height will be taken at different weight bearing conditions. The subject will be seated in a chair with legs bent at 90 degrees in order to take a baseline measurement will be taken. The Arch Height Index (AHI) measurement system will be used to assess the arch. Arch height will also be measured while standing on both feet. After these initial baseline measurements are taken, the subject will be weighed on the force plate in the Motion Analysis Lab. This will determine 10% body increments for later use. Once these increments are calculated, the subject will stand on the force plate with the one foot that is being measured. This will allow accurate force loading by using the computer screen. The subject will be wearing a weighted vest for each measurement that contains some weight in order to achieve the increment being tested. The subject will simulate 10%-120% of body weight in 10% increments in order to determine how the arch changes with specific weight bearing conditions.

8. RESEARCH QUESTION OR HYPOTHESIS: *What question do you hope to answer with your research? Are you expecting a certain result? (Please limit to 1 – 2 sentences!)*

Response: What is the dose-response relationship between progressive body weight loading and arch height deformation? It is expected that with greater loads of body weight there will be a greater deformation of arch height until a ceiling effect is reached.

9. LITERATURE REVIEW: *Please provide a brief review of the literature that provides support for the research question being asked and methods being used. List references at end of application (section 20). (Please limit to 1 – 2 pages)*

Response:

The structure of the foot plays an integral role in biomechanics. The foot consists of 26 bones that make up the structure that loads most of the force placed on the human body. Thus, the arch structure can influence the orientation of the foot and ultimately the lower leg (1). The biomechanics of the arch may also implicate foot pathology. One example is the common foot pathology of plantar fasciitis. This is when there is heel pain and inflammation. This can be linked to arch type of those affected. There are many different pathologies of the foot that are due to a deformity in arch structure (2, 3).

To measure arch structure, the Arch Height Index (AHI) is a commonly used measurement system. This was developed by Williams and McClay (2000) in order to have a more reliable system than using other navicular drop assessment methods. The AHI is the ratio of arch height to the length of the foot. A ratio less than 0.275 is considered low arched, 0.275 to 0.375 is normal and a ratio greater than 0.375 is high arched (2). This is considered a reliable assessment of static arch height (3, 4, 5, 6, 8, 11). It was found that 60% of people have a normal arch, where high and low arches both make up 20% of the population (13). Although this assessment is effective for arch height, the methods of measuring the arch were improved by Richards et al. (2008) (3).

Another common assessment used with these measurements is known as Arch Height Stiffness. This measure reflects the change in arch height between the sitting condition and standing (5, 7). Stiffness affects the ability of the arch to fall and the ability to have a normal gait. Those with higher arches typically have more stiffness to their arch (14).

The body weight load in sitting is estimated to be the amount of force from your lower legs. This is typically thought to be 10% of body weight (2, 4, 6, 10, 13, 15). These measurements can be taken in two ways. One way is to sit in a chair. This is done with knees flexed ninety degrees flat on the ground (1, 3, 8, 13, 14). Another option to take this measurement is while standing. The subject would stand on a force plate and only 10% of their body weight onto their foot in order to simulate a sitting condition (2).

The testing surface may play a role in the measurement of arch height. In some studies, there are platforms placed under the heel and metatarsal heads. This is to allow the arch to be unsupported and allow it to maximally fall to its resting potential (3, 8, 15). A separate study had the entire plantar surface of the foot in contact with the floor in order to give the arch support that is normal for 10% weight bearing (13). This shows that there are discrepancies with how this non-weight bearing condition is established. Some use the generic assumption that sitting is acceptable for this condition, whereas others try to stimulate this by only loading 10% of a subject's body weight while standing. As well, the arch is sometimes supported and other times it is not. This can change the measurements made for arch height.

Arch Height Index can also be assessed in standing. When standing on one foot, standing has been considered in some studies to constitute forces that are 90% of the subject's body weight. These studies also provided a countertop or handrail for balance in order to maintain the 90% load while taking the measurement without the subject falling over (2, 3, 6, 14). However, some researchers take these measurements while standing on both feet to equally distribute

weight. This would then be considered 50% of the subject's body weight (1, 4, 8, 11, 12). It is unclear as to why some studies use 90% of body weight during a standing mechanism to take measurements of standing arch height. When a person stands on two feet, weight is normally distributed between both feet on the ground. Therefore, it would seem logical to only load 50% of body weight onto the arch. Those studies that load 90% may be trying to stimulate the arch during gait or even just heavy loading. This shows the two ways to take a standing measurement, on one-foot or with both feet on the ground. One study also emphasized the importance of keeping a relaxed foot posture as much as possible. If the foot was flexed in any way, it could change the measurement by making the arch more rigid (1).

It is known that gait does contribute up to two times the subject's body weight as previously stated. There is no research on arch height under these higher loading conditions. Therefore, it is important to investigate the arch during higher loads of body weight to see exactly how the arch reacts. If the arch was studied under experimental loads similar to gait-related loads, it would improve the understanding of how the foot responds to naturally occurring load magnitudes.

10. PROCEDURES and METHODS: *Describe in detail all procedures involving human participants for this protocol. Include electronic copies of all surveys and outcome measures used. Include here all tests, measurements, equipment, interventions, manipulations, etc. used in data collection. Use as much space as required to provide a complete description of the procedures proposed.*

Study Design: Cross-sectional cohort study

Outcome Measures - Surveys, Questionnaires, Physical or Cognitive Performance Measures (*include copies of forms with your application*):
On arrival, have subject read and ask any questions about the consent form. If they agree to participate in the study, have the subject sign the bottom of the form. After the form is signed, place the Arch Height Index Measurement System onto the force plate. The force plate will be zeroed again to account for the weight of the measurement system.

Next, ask the subject to take off his/her shoes and socks and sit down in a chair. Use the measurement system to take a sitting arch measurement of the subject's right foot. This number will be recorded on the data sheet. Next, repeat this measure with the subject standing with his/her weight distributed between both feet. Record this number on the data sheet.

Next, have the subject stand still on the force plate in order to obtain his/her body weight measurement. Record this number and calculate 10% increments of the subject's body weight needed for experimental testing. There will be 12 total body weight measurements calculated (10%-120%).

The weighted vest (ZFO Sports) will be placed on the subject. The vest will be loaded with at least 20% of the subject’s body weight. This overloading is to minimize the need to remove the vest or adjust the arch height instrumentation between each measurement. The subject will achieve the different increments by shifting his or her weight onto the right foot.

The subject will stand with just his/her right foot on the force plate. The right foot is used for consistency in the experimental setup. There are no known differences between the left and right foot in healthy individuals. The monitor of the computer screen will be turned to face the subject, so they can focus on obtaining a certain body weight. The subject will hold the incremental weight on his/her right foot. A cane will be provided for support if the subject wants to use it. The screen will show a red line of the force that the subject is loading. A marker will be placed on the monitor in order to give a target for where the subject should focus on trying to hold his/her weight. Once the subject can steadily hold this amount of body weight, the arch data will be recorded. The software will record the average force in order to ensure it was near to the increment being measured.

This process will be completed until each measurement has been made (12 times).

Materials, Instruments and Equipment:
Arch Height Index system of measurement. Vicon hardware and software will be used to interpet data from the Bertec force plate. Attached is a copy of the data sheet used to collect the data of each subject.

Deception: *Will the participants be deceived in any way? Please explain why deception is necessary and justify its use. Fully describe the nature of any deception either by actively misleading or lying to the participant, or through the omission of pertinent information***.**
The participants will not be deceived in any way.

11. STUDY POPULATION, RECRUITMENT PROCEDURES, SCREENING PROCEDURES: *Attach electronic copies of advertisements/brochures used for recruitment.*

Method of Participant Identification and Recruitment: Advertise with flyers
Total number of Participants: 25-30
Age range of Participants: 18-50 y.o.
Inclusion Criteria: Healthy individual without past or present self-reported foot or ankle injury
Exclusion Criteria: Individuals with a self-reported (past or present) leg injury. Any condition that can prevent the subject from standing for long periods of time, whether it is musculoskeletal or neural. Any person over 300 pounds will excluded in the study due to the limitations in the weighted vest.

12. RISKS AND BENEFITS:

Potential Risks *(these should be listed in the consent document!):*
Slip, trip, fall while trying to balance on one foot during the study

Steps taken to minimize risk:
Orient the subject to the force plate as to be comfortable. Provide a cane and chair in order to decrease any risk of falling.

Potential Benefits:
No direct individual benefit. There is a large scale benefit in the nature of deformity and problems associated with arch height. As well, there will be use in application of shoes and orthotics.

Use of Deception, if applicable: *Investigators cannot deceive participants about significant aspects of the study that would affect their willingness to participate such as physical risks, etc. When participants are deceived, they must be offered the opportunity to withdraw their data from the study during the debriefing.*

Emergency procedures, if applicable *(must address if research is greater than minimal risk):*

13. COMPENSATION: *Will participants be compensated for participation? If so, please include details. Please review the IRB Guidance on Tax Implications of Research Incentives. Describe in detail how compensation will be administered. Describe how recordkeeping will be handled. What is the source of the funds?*
No compensation will be given to participants.

14. DATA:

Sample Size Determination (if applicable): 30 subjects will be used for this study. This is based on past dose-response relationship tests performed in the Motion Analysis Lab (Tipnis et al., 2014). This lab study utilized twenty-five subjects. This was sufficient to provide adequate data for analysis of conditions (9).

Data Analysis and Reporting: Vicon Nexus software, Microsoft Excel, and SPSS will be used to conduct an analysis of variance on the data. A repeated ANOVA will be performed on each weight condition with correction for multiple comparisons. Different means will be compared to assess the relationship between body weight and arch height on a quasi-static basis. Descriptive statistics will also be expressed for the cohort as means and standard deviation.
Data Management, Storage and Destruction: Data will be managed on laboratory workstations backed by university servers and firewall. Data will be stored in a locked laboratory.

15. CONFIDENTIALITY: *How will participant identity and confidentiality be protected? Will participants be audiotaped, photographed or videotaped during this study? (must be mentioned in consent document!) How long will identifiable data be kept?*

Response: Each subject will have a code number assigned as to remain as anonymous as possible. No subject will be audiotaped, photographed or videotaped. Data will be kept throughout the duration of the study and up to 2 years after study closure.

16. ATTACHMENTS/APPENDICES. Send by e-mail to IRB@udayton.edu. (You must include all that apply)

- ☒ Documentation of Training in Human Research Protections (i.e. CITI training).
- ☒ Consent forms (Use UD consent form template; for anonymous surveys, use introduction template only, and do not ask for signatures!). If you do not plan to use Consent Forms, you MUST justify your request for a waiver.
- ☐ Child assent forms (if applicable).
- ☐ If you will be accessing or gathering personal health information, include HIPAA authorization form or use UD's HIPAA template.
- ☒ Data collection forms to be used in this research, if applicable.
- ☒ Advertisements used to recruit participants (e-mail, brochure, fliers, etc.)
- ☐ Survey or questionnaire to be used in this research, if applicable.

17. OTHER APPROVALS - Submit ALL that apply with application.

- ☐ Has this protocol been submitted to any other IRBs? If so, please list along with protocol title, number, and expiration date. Please submit all the associated documentation with your application.

- ☐ If you will be collecting data OFF-CAMPUS, you will need to provide documentation of approval by an administrator at that site (e.g., school principal, clinic director). This can be sent by e-mail to IRB@udayton.edu. If such documentation is not practical, please contact IRB@udayton.edu to request a waiver.

- ☒ If you are a STUDENT, you will need to provide documentation that your faculty advisor (1) has read your IRB application, and (2) approves of the research as proposed. This can be sent by e-mail by the faculty advisor to IRB@udayton.edu.

18. IS THIS PROJECT EXTERNALLY FUNDED? *(If so, please list the funding source, award number, award period, award title)*

Response: No, it will be internally funded though the University Honors Program.

19. DISCLOSURE OF FINANCIAL INTERESTS - *Investigator(s) must identify any financial interests or relationships related to this research. All researchers must disclose any personal financial interest (i.e. income, honoraria or other payment for services), equity (i.e., stock, stock options or other ownership interests, and royalties) for the researcher or his/her spouse or domestic partner and dependent children, or relationship with a for-profit company that either directly supports research being conducted by that individual or is related to research being conducted by that individual, such as financial interests that are related to federally funded studies. All personal financial interests related to research activities must be reported, regardless of dollar amount.*

Response: N/A

20. REFERENCES (*list references used in your literature review here*)
Response:

1. McPoil TG, Cornwall MW, Medoff L, Vicenzino B, Fosberg KK, Hilz D. Arch height change during sit-to-stand: an alternative for the navicular drop test. *J Foot Ankle Res*. 2009; 2:17-.

2. The Arch-Height-Index Measurement System: A New Method of Foot Classification. *Athletic Therapy Today*. 2006; 11(5):56-7.

3. Butler RJ, Hillstrom H, Song J, Richards CJ, Davis IS. Arch height index measurement system: establishment of reliability and normative values. *J Am Podiatr Med Assoc*. 2008; 98(2):102-6.

4. Butler RJ, Davis IS, Hamill J. Interaction of Arch Type and Footwear on Running Mechanics. *Am J Sports Med*. 2006; 34(12):1998-2005.

5. Hillstrom HJ, J Song, AP Kraszewski, et al. Foot type biomechanics part 1: Structure and function of the asymptomatic foot. *Gait Posture*. 2013; 37: p. 445-51.

6. Howard JS, Fazio MA, Mattacola CG, Uhl TL, Jacobs CA. Structure, Sex, and Strength and Knee and Hip Kinematics During Landing. *Journal of Athletic Training (National Athletic Trainers' Association)*. 2011; 46(4):376-85.

7. Mootanah R, J Song, MW Lenhoff, et al. Foot Type Biomechanics Part 2: Are structure and anthropometrics related to function?. *Gait Posture*. 2013; 37: p. 452-6.

8. Pohl MB, Farr L. A comparison of foot arch measurement reliability using both digital photography and calliper methods. *J Foot Ankle Res*. 2010; 3:14-.

9. Tipnis RA, Anloague PA, Laubach LL, Barrios JA. The dose–response relationship between lateral foot wedging and the reduction of knee adduction moment. *Clin Biomech*. 2014; 29(9):984-9.

10. Teyhen DS, BE Stoltenberg, KM Collinsworth, et al. Dynamic plantar pressure parameters associated with static arch height index during gait. *Clin Biomech*. 2009; 24: p. 391-6.

11. Weimar, Wendy, H., Shroyer, Justin F. Arch Height Index Normative Values of College-Aged Women Using the Arch Height Index Measurement System. *Journal of the American Podiatric Medical Association*. 2013; 103(3):214-7.

12. Williams DSB, Tierney RN, Butler RJ. Increased medial longitudinal arch mobility, lower extremity kinematics, and ground reaction forces in high-arched runners. *J Athl Train*. 2014; 49(3):290-6.

13. Williams DS, McClay IS. Measurements Used to Characterize the Foot and the Medial Longitudinal Arch: Reliability and Validity. *Phys Ther*. 2000; 80(9):864-71.

14. Williams I, D., Davis IM, Scholz JP, Hamill J, Buchanan TS. High-arched runners exhibit increased leg stiffness compared to low-arched runners. *Gait Posture*. 2004; 19:263-9.

15. Zifchock RA, Davis I, Hillstrom H, Song J. The Effect of Gender, Age, and Lateral Dominance on Arch Height and Arch Stiffness. *Foot & Ankle International*. 2006; 27(5):367-72.

Appendix B

IRB Approval Letter

Anastasia Bjelopetrovich
<bjelopetrovicha1@udayton.edu>

March 3, 2015

Anastasia Bjelopetrovich
University of Dayton
300 College Park
Dayton, OH 45469

SUBJECT: "**Effects of Body Weight Loading on Arch Height**"

Dear **Anastasia**,

The subject proposal has been reviewed through expedited procedures, as described in ***45 CFR 46.110*** **Category (4).*** I am pleased to **approve** your IRB Application, and you may begin your data collection immediately.

REMINDERS TO RESEARCHERS:

- If this study is not completed by **(3/2/2016)** you are required to seek re-approval from the IRB prior to that time. You can find the Application for Renewal/Closure on the IRB web site (see link below).
- The IRB must approve all changes to the protocol prior to their implementation, unless such a delay would place your participants at an increased risk of harm. In such situations, the IRB is to be informed of the changes as soon as possible.
- The IRB is to be informed immediately of any ethical issues that arise in your study. Adverse Event forms can be found on the IRB web site.
- You must maintain all study records, including consent documents, for three years after the study closes. These records should always be stored securely on campus.
- It is the researcher's responsibility to notify the IRB when this study is closed. You can find the Application for Renewal/Closure on the IRB web site.

Please let me know if you have any questions. Best of luck in your research!

Best regards,

Mary S. Connolly, PhD
Chair, Institutional Review Board (IRB)
Office for Research
University of Dayton
Dayton, OH 45469
(937) 229-3493
(937) 620-7151 cell
Email: IRB@udayton.edu
http://www.udayton.edu/research/compliance/irb/index.php

Appendix C

Data Sheet

Arch Height Index Measurement System (AHIMS)

	Measurement
Sitting Foot Length	
Sitting Arch Height (½ foot length)	
Sitting Truncated Foot Length	
Sitting AHI (Arch Height/Truncated Foot Length)	
Standing Foot Length	
Standing Arch Height (½ foot length)	
Standing Truncated Foot Length	
Standing AHI (Arch Height/ Truncated Foot	

Length)	
10% BW Foot Length	
10% Arch Height **(½ foot length)**	
10% Truncated Foot Length	
10% AHI **(Arch Height/ Truncated Foot Length)**	
20% BW Foot Length	
20% Arch Height **(½ foot length)**	
20% Truncated Foot Length	
20% AHI **(Arch Height/ Truncated Foot Length)**	

30% BW Foot Length	
30% Arch Height **(½ foot length)**	
30% Truncated Foot Length	
30% AHI **(Arch Height/ Truncated Foot Length)**	

40% BW Foot Length	
40% Arch Height **(½ foot length)**	
40% Truncated Foot Length	
40% AHI **(Arch Height/ Truncated Foot Length)**	

50% BW Foot Length	

50% Arch Height **(½ foot length)**	
50% Truncated Foot Length	
50% AHI **(Arch Height/ Truncated Foot Length)**	

60% BW Foot Length	
60% Arch Height **(½ foot length)**	
60% Truncated Foot Length	
60% AHI **(Arch Height/ Truncated Foot Length)**	

70% BW Foot Length	
70% Arch Height **(½ foot length)**	

70% Truncated Foot Length	
70% AHI **(Arch Height/ Truncated Foot Length)**	

80% BW Foot Length	
80% Arch Height **(½ foot length)**	
80% Truncated Foot Length	
80% AHI **(Arch Height/ Truncated Foot Length)**	

90% BW Foot Length	
90% Arch Height **(½ foot length)**	
90% Truncated Foot Length	
90% AHI	

(Arch Height/ Truncated Foot Length)	

100% BW Foot Length	
100% Arch Height (½ foot length)	
10% Truncated Foot Length	
100% AHI (Arch Height/ Truncated Foot Length)	

110% BW Foot Length	
110% Arch Height (½ foot length)	
110% Truncated Foot Length	
110% AHI (Arch Height/ Truncated Foot Length)	

120% BW Foot Length	
120% Arch Height **(½ foot length)**	
120% Truncated Foot Length	
120% AHI **(Arch Height/ Truncated Foot Length)**	

Appendix D

Honors Student Symposium Presentation

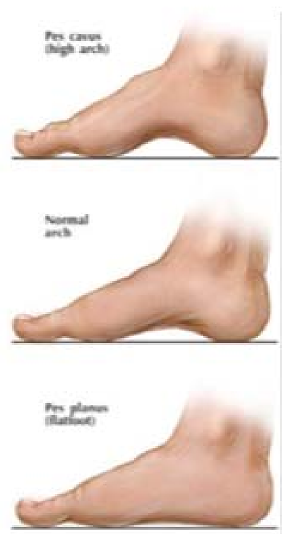
Effects of Body Weight Loading on Arch Height

By: Annie Bjelopetrovich

Advisor: Joaquin Barrios, DPT, Ph.D.

Background

- Foot functionality and locomotion
- Foot deformation
- Medial longitudinal arch



Arch Height Index Measurement System

- Assessment of arch deformity
- Jig to measure
  - Foot length
  - Truncated length
  - Dorsum height
- AHI= Dorsum Height/Truncated
- Sitting and Standing measures
- Limitations
  - Static
  - 2 conditions tested

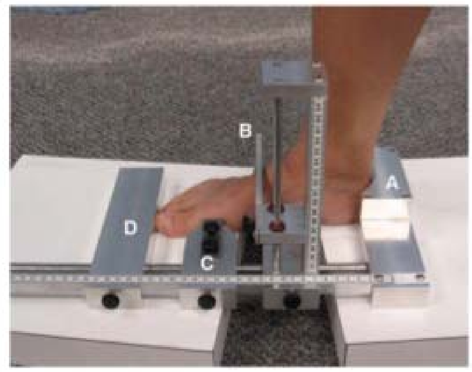


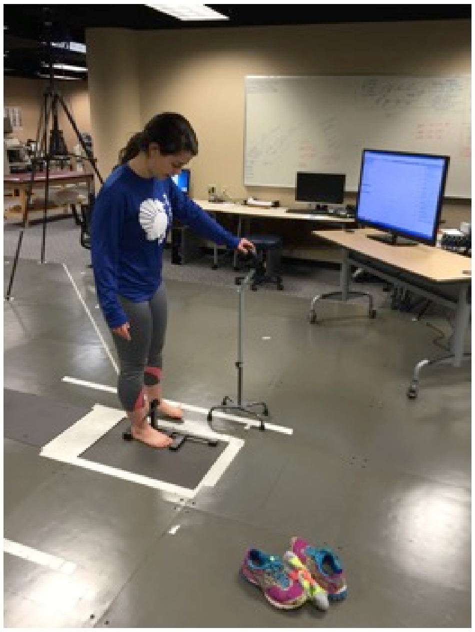
Figure 1 The Arch height index measurement device (AHIMS). The heel is placed against the heel cup (A) and the sliding callipers D and C are aligned against the distal phalanx and first metatarsal head respectively. A third calliper (B) is lowered to the dorsal arch at 50% of the FL. Pohl, M., Farr, L.. (2010)

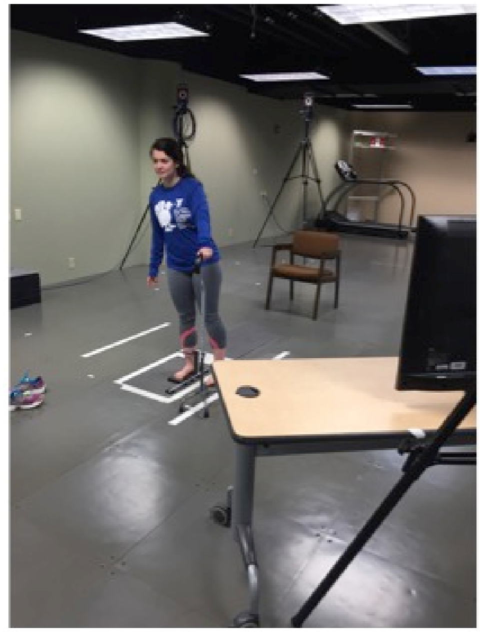
Aims

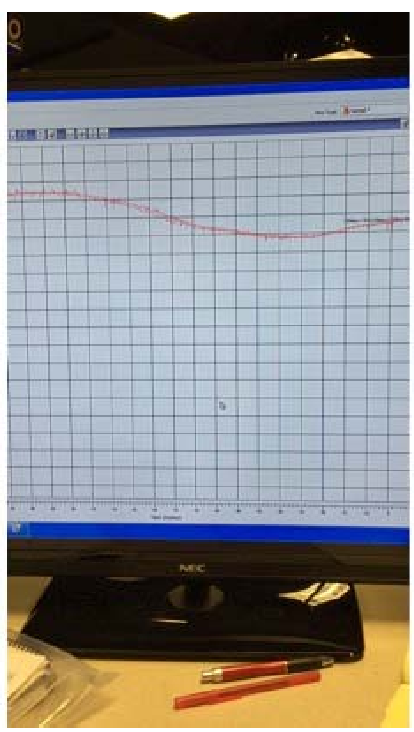
1. Assess if baseline measures actually represent their BW loaded conditions
   a. 10% and baseline sitting would be different
   b. 50% and baseline standing would be the same
2. Characterize BW load and arch height relationship
   a. Ambulatory range using quasi-static assessment
   b. Linear and quadratic trends would be seen
      i. Linear: General progression
      ii. Quadratic: "Ceiling Effect"

Methods

- Participants
  - 25 (17F) healthy students with no current or prior lower leg injury
  - Age=20.12 (0.971) years; Height=1.722 (0.087) meters; Weight=73.725 (14.582) kg
- Protocol
  - Weight and vest adjustment
  - Baseline measurements
  - Target-matching
    - 10-120% in sequential fashion
    - Use of force plate to display real-time line graph
    - 2% margin of error (1% on either side of target)
    - Hold position, take measurement
    - 70% BW condition→ vest added







Methods

- Analysis
  - Mean and SD for each condition
  - Paired t-test between sitting & 10% as well as standing & 50%
  - Pairwise comparisons
  - Within-subject contrasts for linear and polynomial trends
  - Bonferroni adjustment

Results

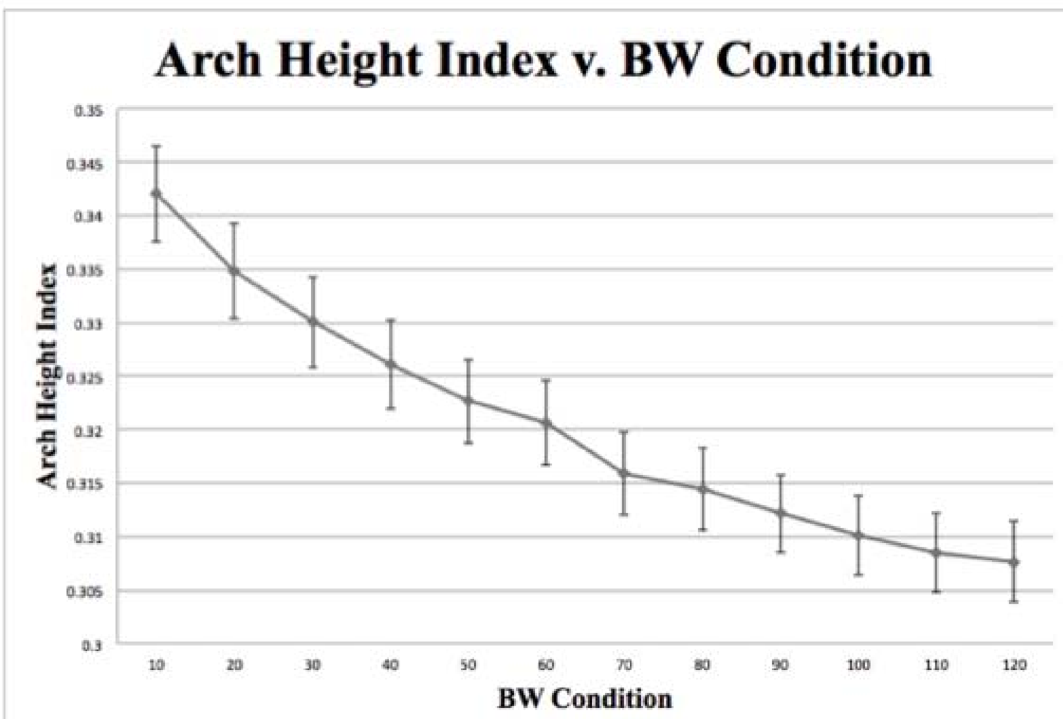
- Baseline measurement analysis
  - Sitting= 0.365 (0.020) & 10% BW= 0.342 (0.023)
  - Standing= 0.326 (0.023) & 50% BW = 0.323 (0.020)

- Target-Matching
  - No significant difference between conditions:
    - 70-80%
    - 100-110%
    - 110-120%

Results

Target-Match Data

Condition	Length	Dorsum Height	Truncated Length	AHI	p-value
0.1	25.396±1.511	6.480±0.443	18.976±1.183	0.342±0.023	-------
0.2	25.492±1.459	6.360±0.452	19.024±1.131	0.335±0.022	0.000*
0.3	25.588±1.467	6.292±0.442	19.088±1.119	0.330±0.021	0.002*
0.4	25.636±1.497	6.224±0.439	19.112±1.129	0.326±0.021	0.001*
0.5	25.688±1.519	6.172±0.410	19.156±1.129	0.323±0.020	0.008*
0.6	25.708±1.503	6.148±0.416	19.196±1.110	0.321±0.020	0.025*
0.7	25.744±1.505	6.064±0.421	19.216±1.114	0.316±0.019	0.001*
0.8	25.756±1.495	6.04±0.420	19.228±1.118	0.314±0.019	0.400
0.9	25.760±1.490	6.004±0.398	19.256±1.115	0.312±0.018	0.001*
1.0	25.808±1.497	5.976±0.402	19.292±1.120	0.310±0.018	0.023*
1.1	25.816±1.491	5.952±0.408	19.312±1.111	0.309±0.018	0.171
1.2	25.824±1.498	5.936±0.410	19.316±1.118	0.308±0.019	1.00



Discussion

- Trends
  - Both linear and quadratic were seen
  - Further deformation possible
  - Elimination of momentum
- Healthy Adults
  - Pathologic populations
  - Arch structure
- Baseline measurements
  - Standing is valid assessment of 50% BW
  - Sitting was an underload of 10% BW
  - Continued use of standing and re-evaluation of sitting

Sources

http://www.eggeller.com/category/foot-health

Pohl MB, Farr L. A comparison of foot arch measurement reliability using both digital photography and calliper methods. *J Foot Ankle Res*. 2010; 3:14-.