Measurement of Medial Malleolar Drift and Medial Longitudinal Arch Height: A Reliability Study of Two Novel Devices

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Abstract

This study evaluated two novel devices for quantifying the measurement of medial malleolar drift and arch height ratio of the foot. Two licensed physical therapists and one physical therapy student measured 23 asymptomatic participants on two occasions. Intrarater intraclass correlation coefficients (ICCs) ranged from 0.772 to 0.991 for the arch height ratio device (AHRD) and from 0.881 to 0.983 for the medial drift device (MDD). Interrater ICCs ranged from 0.791-0.919 (AHRD) and from 0.536-0.776 (MDD). Test-retest reliability ranged from 0.905-0.923 for the AHRD and from 0.687-0.889 for MDD. Intrarater reliability was higher than interrater reliability for both measurement devices. It is determined that these devices are reliable and can be implemented into clinical use with knowledge of potential sources of error and measurement tool reliability.

Introduction

A fundamental premises of clinical podiatric biomechanics is that static foot posture abnormalities are associated with dynamic foot pathologies.[1] During gait, the foot functions as the base of an inverted pendulum where the body's center of mass is transferred forward from posterior to anterior over the stationary foot.[9] This process is repeated for the contralateral foot and then continued during gait. Throughout the initial contact and early midstance phases of gait, the subtalar joint (STJ) pronates.[8] The increased range of motion of the midtarsal and intertarsal joints occurring with STJ pronation, allows the foot to adapt to uneven terrain and absorption of shock.[5, 8] Subtalar joint pronation acts as a momentum converter during the initial contact phase of gait and functions by dissipating the shock of impact throughout the lower extremity and pelvis.[8] Inadequate STJ pronation during the initial contact phase commonly leads to impact related injury.[8] Discrepancies in supinatory or pronatory motion of the STJ during late midstance can lead to compensatory gait deviation of abductory twist at heel raise.[8] Late midstance pronation of the STJ is likely responsible for many biomechanically induced pathologies such as plantar fasciitis, inter-metatarsal neuroma, hallux limitus, hallux valgus, sesamoiditis, and low-back pain.[10]

Root first described the STJ neutral position in 1977.[5] Once considered the "gold standard", Root's theory continues to be highly debated.[17,18,20] Currently no widely accepted method for the assessment of STJ neutral has been shown to be accurate or reliable.[18,19,21] Root's original definition states, STJ neutral is "the neutral position when the foot is neither supinated or pronated".[8] Subtalar joint neutral was originally found in a non weight bearing position via goniometric measurements to determine the total inversion and eversion range of the STJ.[8] Further research has expanded upon Root's original protocol leading to modern day palpatory techniques in bipedal weight bearing. Many other techniques have been described (arch height ratio (AHR) of the foot, assessing the medial longitudinal arch (MLA), the navicular drop test, and the medial malleolar drift (MMD) in the literature for the clinical assessment of static foot posture in an effort to find a more accurate and feasible measure than non weight bearing STJN.

A study by Williams and McClay found that abnormality in the structure of the MLA of the foot is commonly thought to be a predisposing factor to injury.[11] Twenty feet were evaluated (both feet 10

subjects) to determine intra tester and inter tester reliability. Five foot measurements were taken in 2 stance conditions: 10% of weight bearing and 90% of weight bearing. Upon analysis of the data, of the 7 measures tested, the most reliable and valid method of clinically assessing arch height (across 10 and 90% WBing) was dividing the dorsum height at 50% of foot length by truncated foot length.[11] In this way, Williams and McClay were able to circumvent subject anatomical variability. This method provides clinicians a more reliable measurement than navicular height as a result of not having to palpate a bony landmark.[11]

Frontal plane rearfoot measurements do not always accurately represent dynamic motion of the rearfoot during walking. In a study conducted by Cornwall and McPoil, the assessment of the position and motion of the navicular bone was utilized to analyze TNJ function, due to its easy landmark accessibility.[2] Navicular position and motion may provide more useful information about the function of the foot in normal walking than frontal plane rearfoot measurements due it having a greater displacement than the calcaneus. TNJ measurements are also beneficial in the clinical assessment of patients with overuse lower extremity injuries.[8] Furthermore, Weiner-Ogilvie et. al[14], compared 3 methods of measuring foot position and found that the navicular height measurements exhibited the least intratester and intertester variability. However, a major limitation found was that navicular displacement was only measured in the sagittal plane, and motion of the navicular actually takes place in the frontal, sagittal, and transverse plane simultaneously.[15] Although the frontal plane motion is minimal the transverse plane motion is larger and may be more clinically relevant.[15] To address this, Menz et. al[15], proposed the measurement of the navicular drift to provide an indicator of the change in medial prominence of the TNJ when the foot moved from neutral to a resting position. The reliability of the navicular drift measurement has not yet been evaluated.[15]

In an attempt to circumvent the anatomical variability when attempting to palpate the navicular tuberosity as well as clinical experience issues that could affect the consistency of the navicular height measurement, Williams and McClay proposed measuring the height of the dorsum of the foot at 50% of foot length and dividing by either total foot length or truncated foot length.[11] Dorsal foot height divided by either total or truncated foot length had the highest ICC values of the seven measurements they evaluated.[11] Additionally, Williams and McClay assessed dorsal foot height in 10% and 90% weight bearing.[11] Several other researchers have used the dorsal height at 50% foot length divided by the truncated foot length as a way to characterize arch height and have termed the measurement as the arch height ratio or arch height index.[1]

McPoil et al.[1] proposed an easy and minimally invasive technique to assess foot posture in the clinical setting. Bony arch index, synonymous with AHR, was utilized due to its previous high levels of validity and consistency.[1] 850 subjects participated in their study, which was aimed to assess the reliability and validity of determining arch height ratio of the foot in bilateral resting and standing positions.[1] The dorsal arch height, total foot length, and the truncated foot length were used to calculate two variations of the arch height ratio, total foot length - arch height ratio (TFL-AHR) and truncated – arch height ratio (TRUN-AHR).[1] TFL-AHR is found by dividing the height of the foot at 50% of its total length by total foot length.[1] TRUN-AHR is found by dividing the height of the foot at 50% of its total length by the length of the foot from calcaneus to the base of the first metatarsal phalangeal joint.[1] Results indicated that TFL-AHR and TRUN-AHR correlate strongly and measurements assessed bilaterally have excellent intra and inter rater reliability and validity for measuring dorsal arch height and truncated foot length when subjects stand and place equal weight on both feet.[1] TRUN-AHR also eliminates the concern of foot deformities such as hallux valgus or claw toes.[1] Therefore, it was concluded that TRUN-AHR should be utilized as a way to minimize measurement technique variability.[1] However, there is currently no standardized tool used to measure TRUN-AHR or the triplanar motion involved in pronation of the foot.

Thomas Michaud, DC has created a device to measure TRUN-AHR in the clinical setting. The Arch Height Ratio Device (AHRD) and the Medial Drift Device (MDD), allow quick measurement of the height of the medial longitudinal arch and medial drift of the malleolus. The AHRD is comprised of a wooden box with a fixated ruler for measuring foot length and a mobile caliper used to measure the height of the foot at 50% of total foot length. Michaud's AHRD aims to integrate all components involved in measuring arch height ratio into one functional tool.

Though the reliability of the navicular drift has yet to be evaluated he has also created a medial drift device to measure medial malleolar displacement during pronation. Michaud created this device based on Lundberg et al.[16] demonstrating that as the rearfoot pronates, the talus shifts medially resulting in an almost parallel translation of the talus upon the calcaneus. Furthermore, Michaud believes medial malleolar drift can provide an equivalent measure to navicular drift proposed by Menz et al.[15] thus identifying pronatory tendencies during gait. The MDD is a three dimensional, polygonal sliding ruler with a hollow base that allows for manual fixation, and mobile top that articulates with the medial malleolus. This device allows for measurement of medial malleolar drift by the amount of displacement of the top portion of the device along a horizontal axis. The MDD developed by Michaud address the amount of triplanar motion, specifically the frontal plane and motions involved in pronation of the foot/ankle. However, standardized measurements with the use of these two devices have not yet been established.

This study aims to determine inter-rater and intra-rater reliability of AHR and MD measurements, using Michaud's devices.

METHODS

SUBJECTS

This study received approval from the Shenandoah University Institutional Review Board and all patients signed informed consent prior to participation in this study. The subjects were recruited via convenience sampling by an email recruitment flier sent out to Shenandoah University's Health Professions campus. Each subject filled out a subject demographic questionnaire including information such as height, weight, gender, history of previous foot pain, and whether the subject wears orthotics. Subjects were included if they were over 18 years of age and able to fully bear weight on both feet. Subjects were excluded if they had a history of foot/ankle surgery in the past 12 months, had a history of chronic ankle instability as measured by having more than 2 ankle sprains on a side, any current or reported foot/ankle pain within the past 2 months, and inability to actively dorsiflex to 0 degrees. The left and right feet of 23 subjects (18 female, 5 male) were measured with both the MDD and the AHRD.

PROCEDURES

1A. Medial Drift Device (MDD)

The procedures used for this device are outlined by Thomas Michaud, DC in his 2011 textbook.22 In order to measure medial drift with the MDD, the subject was first placed in STJ neutral in standing while facing the examiner, utilizing palpation to find TNJ neutral (Fig.1). The purpose of utilizing STJ neutral is based on the literature presented by Root et al. who define STJ neutral as "The neutral position when the foot is neither supinated nor pronated."24 It has been postulated by some that TNJ neutral, as compared to STJ neutral, is a more correct term for the motion contributing to the triplanar movement of the foot.22 When finding TNJ neutral, the subject was instructed to "look forward, do not look down" to prevent the subject from altering their center of gravity and

provide an inaccurate assessment by altering their malleolar position.23 The examiner then placed their palmar aspect of first digit on the medial aspect of the talar head and had the subject pronate and supinate to find the point where the talar head articulated with the navicular, this was performed bilaterally and concurrently. The MDD was then zeroed and placed on the medial malleolus of the tibia (Fig. 2). Once the device was placed with the lower portion secured on the floor adjacent to the medial malleolus, the top portion of the MDD was slid away from the medial malleolus (Fig 3).

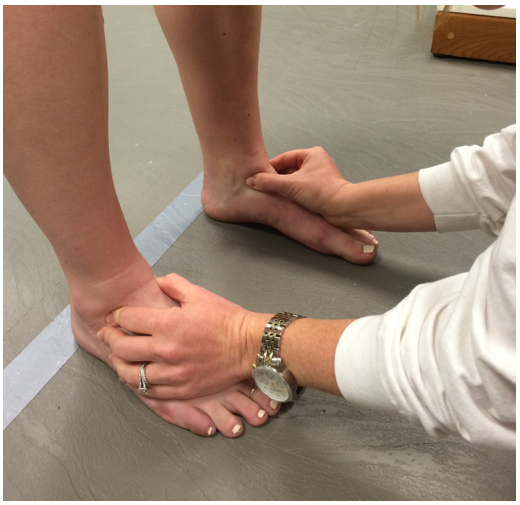

Figure 1. Examiner locates STJ neutral.

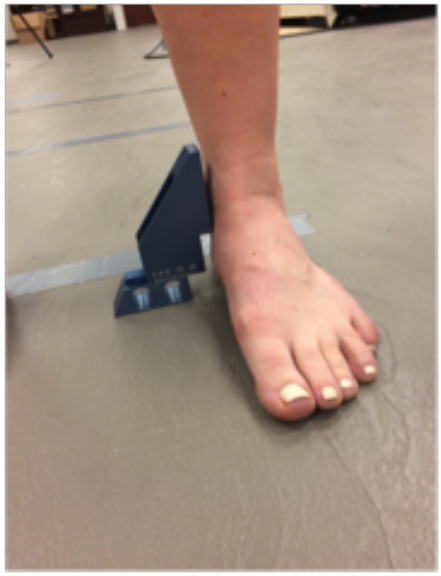

Figure 2. The device is zeroed against the medial malleolus.

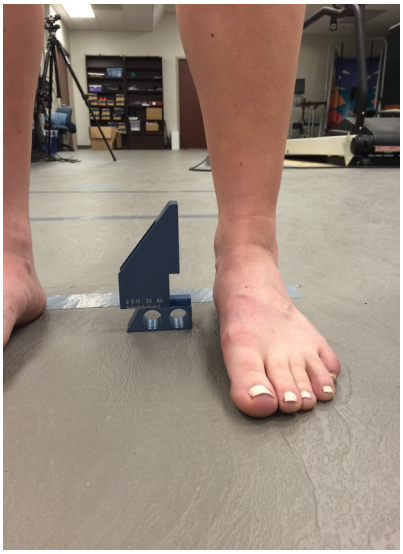

Figure 3. Device then slid away from the malleolus.

Sliding the device away from the medial malleolus allowed room for medial movement of the malleolus as the subject relaxed into their preferred foot position. The subject was then prompted manually to relax their foot by the examiner "tapping the dorsum of the foot three times" as well as providing a verbal cue of "relax completely"23 (Fig. 4). Once the subject positioned into their preferred position of relaxation, the top portion of the device was positioned to reestablish contact with the medial malleolus, and the amount of medial translation was measured in millimeters and recorded (Fig. 5). Each measurement was performed three times on each foot and repeated by all three examiners.

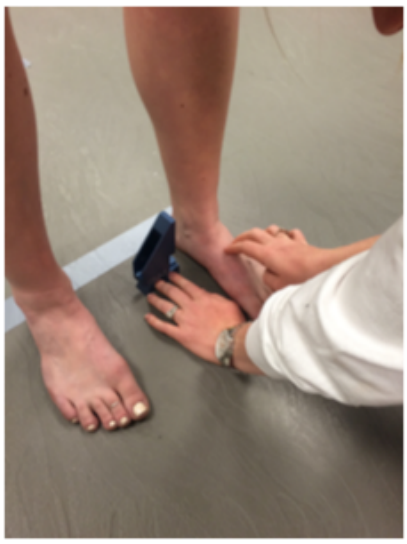

Figure 4. Dorsum of foot tapped to encourage foot relaxation.

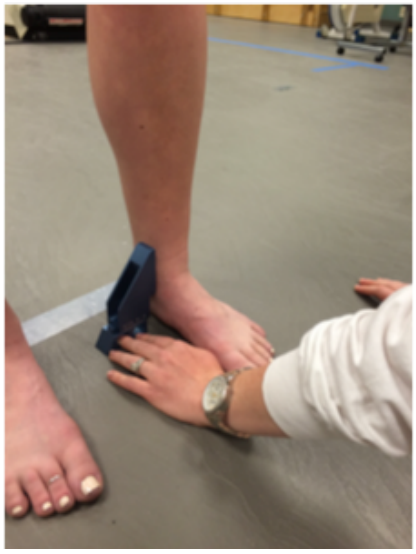

Figure 5. Amount of displacement measured.

1B. Arch Height Ratio Device (AHRD)

The procedures used for this measurement tool (see Fig. 2) are outlined in Dr. Michaud's 2011 text.22 The subject was asked to step onto the measuring tool with the back of the calcanei touching the metal backing of the device and their weight distributed evenly.23 The subject was also asked to place both the medial aspect of the forefoot and the medial aspect of the heel along the white reference line of the device to assure consistency. The length of the foot was then measured using the measuring device on the box by noting the distance from the back of the heel to the most distal aspect of the hallux (Fig. 6). The recorded length of the foot was then divided in half, at which point the height of the dorsal foot was measured using the caliper device of the measurement tool (Fig. 7).

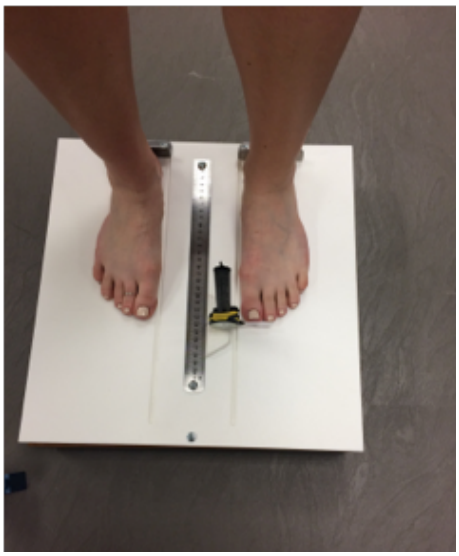

Figure 6. Length of foot measured at distal end of hallux.

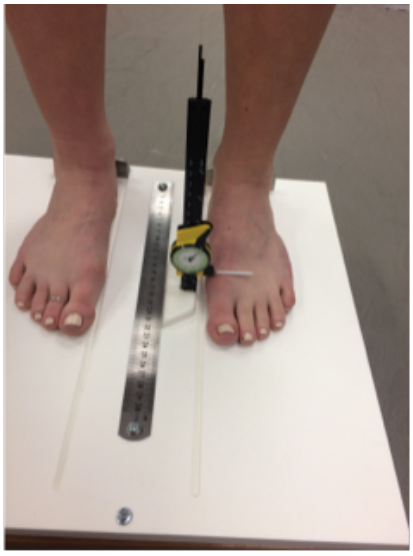

Figure 7. Height of dorsum of foot measured.

The arch height ratio was then determined by taking the dorsal arch height and dividing it by the distance from the heel of the foot to the center of the first metatarsophalangeal joint, or the truncated foot length (Fig. 8).

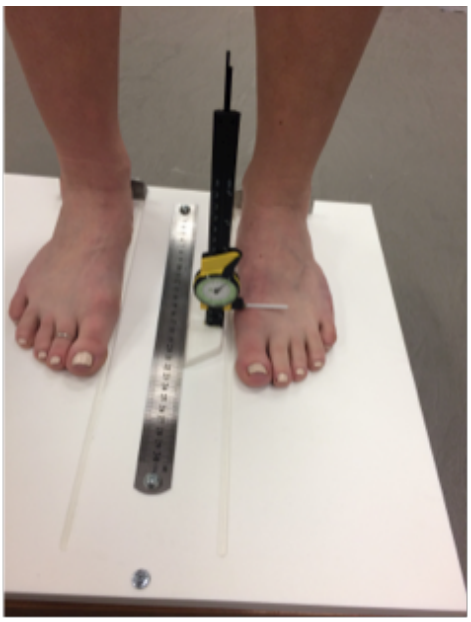

Figure 8. Truncated foot length measured.

DETERMINATION OF RELIABILITY

To determine the inter- and intra-rater reliability of these two measures, three examiners were asked to assess both arch height and medial malleolar drift on the right and left foot of each subject three times. The examiners consisted of two licensed physical therapists with a minimum of 14 years (examiner 1 had 24 years experience and examiner 2 had 14 years) experience and one second-year physical therapy student who has completed 6 credits of the musculoskeletal course curriculum including the foot and ankle, as well as a 3 credit gait and biomechanics course. Each member of the research team attended a one-hour virtual training session with Thomas Michaud, DC in order to practice and standardize methods. To determine reliability, data collection was composed of two data collection days, one week apart, in which the measurements were taken by the examiners as previously discussed. Each rater was blinded to their measures from the week before to avoid any cross over or possible bias.

RESULTS

SPSS (Version 24, IBM SPSS Statistics, Armonk, New York) was used to analyze raw data collected in this study. Intraclass correlation coefficients (ICC) were calculated to determine intrarater reliability, test retest reliability, and interrater reliability for each device. ICCs are used to demonstrate overall agreement. ICC values of <0.5 indicate poor reliability, 0.5-0.75 indicate moderate reliability, >0.75 indicate good reliability, > 0.85 indicates high potential for clinical application25. In order to address the clinical relevance of the data, for the purposes of our study, any ICC data points falling between .85-1.0 were deemed as excellent.

Both ICC single measure (ICC SM) and ICC average measure of all 3 trials (ICC AM) were calculated to determine clinical feasibility of single measure use. All calculated ICCs (SM and AM) were deemed statistically significant via their respective confidence intervals.

INTRARATER RELIABILITY

Single measure and average measure two way random ICC values were calculated for each device, examiner and foot as shown in Table 1. Statistical significance was found between all measures for each examiner for both the AHRD and the MDD. All single and average reliability measures using AHRD and MDD were found to have a high potential for clinical application, excluding the third examiner's left foot single measure (Table 1).

Table 1. Breakdown of intra-rater reliability ICCs for each rater, measure and foot.

Arch Height Ratio Device					
Rater	Foot	ICC SM	Sig	ICC AM	Sig
1	Right	0.898	<.000	0.963	<.000
	Left	0.845	<.000	0.942	<.000
2	Right	0.986	<.000	0.995	<.000
	Left	0.973	<.000	0.991	<.000
3	Right	0.92	<.000	0.972	<.000
	Left	0.772	<.000	0.91	<.000

Medial Drift Device					
Rater	Foot	ICC SM	Sig	ICC AM	Sig
1	Right	0.89	<.000	0.96	<.000
	Left	0.881	<.000	0.957	<.000
2	Right	0.923	<.000	0.973	<.000
	Left	0.932	<.000	0.976	<.000
3	Right	0.951	<.000	0.983	<.000
	Left	0.895	<.000	0.962	<.000

TEST-RETEST RELIABILITY

Test-retest reliability ICC's were calculated for each of the three examiners utilizing both devices as shown in Table 2. Right foot measures were selected to maximize efficiency of data analysis and simulate clinical feasibility. The average ICCs using AHRD for examiners 1, 2 and 3 were found to be 0.923, 0.905, and 0.918, respectively. All values were found to be statistically significant and to have a high potential for clinical application. The average measure ICCs using MDD for examiner 1 (PT), 2 (PT) and 3 (SPT) were found to be 0.808, 0.889, and 0.607, respectively. These values were deemed to be statistically significant, however, examiner 2's results were the only one determined to have a high potential for clinical application. Statistical significance was not found for any of the examiners when using MDD single measure (Table 2).

Table 2. Breakdown of test-retest reliability ICCs for each rater, and device.

Arch Height Ratio Device					
Rater	Foot	ICC SM	Sig	ICC AM	Sig
1	Right	0.856	<.000	0.923	<.000
2	Right	0.826	<.000	0.905	<.000
3	Right	0.849	<.000	0.918	<.000
Medial Drift Device					
Rater	Foot	ICC SM	Sig	ICC AM	Sig
1	Right	0.678	<.000	0.808	<.000
2	Right	0.8	<.000	0.889	<.000
3	Right	0.436	<.000	0.607	<.000

INTERRATER RELIABILITY

Interrater reliability ICC's were calculated for each of the three examiners utilizing both devices as shown in Table 3. Right foot measures were selected to maximize efficiency of data analysis and simulate clinical feasibility across all examiners. Average measure ICC's between all examiners using AHRD was found to be 0.919 and 0.776 using MDD. Single measure ICC's between all examiners using AHRD was 0.791 and 0.536 using MDD. All values were found to be statistically significant, however only the AM ICC for AHRD yielded a high potential for clinical application (Table 3). These results indicate there was significant reliability between all examiners using the AHRD, and not the MDD.

Table 3. Breakdown of inter-relater reliability ICCs for each device.

Arch Height Ratio Device					
Rater	Foot	ICC SM	Sig	ICC AM	Sig
1,2,3	Right	0.791	< .000	0.919	< .000
Medial Drift Device					
Rater	Foot	ICC SM	Sig	ICC AM	Sig
1,2,3	Right	0.536	< .000	0.776	< .000

DISCUSSION

INTERPRETATION OF RESULTS

For measurements of both the AHRD and MDD, reliability coefficients range from poor to good. This study found the AHRD to have good reliability test-retest and interrater measures. The reliability of the MDD ranged from poor to moderate in test-retest and interrater measures. For both devices, intra-rater reliability was found to have a high potential for clinical applicability.

These differences in reliability may be attributed to the methods used to obtain each measure. The AHRD is comprised of several objective measurements of the foot, whereas the MDD requires the examiner to identify STJN. Sell et al supports the utilization of finding STJN in a weight bearing position as a reliable measure7. Conversely, Pierynowski et al states that a seated position is more effective for finding STJN18. Due to the inconsistent findings in the literature5,7,17,18,20, STJN is often considered a highly subjective measure. Discrepancies in interrater and test-retest reliability may have been impacted by the clinical experience of the examiner, as examiner 3 was the physical therapy student. McLaughlin et al. demonstrated that inexperienced examiners can be reliable when measuring foot posture28; however, no such study has been performed using the devices in this current study. Additionally, an observable trend of lower reliability in the intrarater measures was noted between right and left feet. It is speculated that this trend may be influenced by the hand dominance of the examiners; however, this was not explored in the current study. No literature was found to support or deny these speculations when addressing foot postures. While literature has been found to support the effects of hand dominance on dexterity26, a correlation cannot be drawn to this current study's findings.

While both devices have been found to be reliable, certain stipulations should be considered when recommending them for clinical use. The data show that both devices were more reliable when utilizing an average of three measures as compared to a single measure. Therefore, it is recommended that when utilizing these devices in clinical practice, clinicians should document the averaged measures of the device as opposed to single measures. While both the interrater and intrarater reliability of the AHRD was determined to have a high potential for clinical application when using averaged measures, only the intrarater reliability for the MDD device was found to have a high potential for clinical applicability. Therefore it is recommended that when utilizing the MDD, keeping the same examiner (regardless of experience level) throughout the evaluation process may lead to more consistent results.

POTENTIAL SOURCES OF ERROR

A potential source of error in this study may be examiner fatigue and discomfort. The devices were designed to be used in a clinical setting for quick assessment of medial malleolar drift or arch height ratio. However, throughout the span of data collection the large numbers of measurements taken over a prolonged period of time lead to verbalized examiner mental and physical fatigue. Examiner discomfort was also verbalized throughout data collection. The nature of the study and the tools themselves required a majority of data collection to be spent on the floor and in uncomfortable postures. This may have affected the consistency of the measurements taken. To decrease examiner discomfort and maximize ease of utilization of the devices, the second day of data collection was taken in a different room from the initial day of data collection. In this room, examiners were able to place the subjects on a platform for more optimal examiner body positioning. The differing environments could have affected the re-test reliability from one day to another.

STUDY LIMITATIONS

The population of this study consisted of asymptomatic, healthy young adults. Factors such as pain, injury, edema, and surgery could affect the reliability of the measurement tools. Therefore, the results of this study should only be considered accurate when applied to a nonpathologic population.

While exploring examiner experience was not a specific purpose of this study, it is factor that could have played a role in the results as demonstrated by the current data. By having two licensed physical therapists and one student physical therapist as examiners, there is potential that clinical experience could have influenced the results of this study. A key component in utilizing the MDD was the ability to find STJN, which is a skill whose accuracy could be affected by experience.

Lastly, examiner familiarity with the devices was not explored in this study. While there was a difference in clinical experience of the examiners, there was also a differing level of familiarity with the devices between clinicians. The lead examiner had had previous experience using the devices, while both the other licensed physical therapist and the student physical therapist had no previous experience using the device prior to beginning the study.

INDICATIONS FOR FURTHER RESEARCH

Measurement of foot posture has been a dilemma for researchers and clinicians for a number of years. Although attempts have been made, a "gold standard" measure for medial drift has yet to be determined. Navicular drop and navicular drift measurements, while widely used, have been proven to be only moderately reliable in previous literature and thus are not ideal comparisons for potential validity comparison for the MDD27. A vital component for the validation and consistency of the MDD measurement is the effectiveness of finding STJN. Reports vary on the reliability and effectiveness of measuring STJN5,7,18,20, therefore it could be argued that this needs to be explored in further depth as it relates to our current study. The potential for validation of the AHRD is more

grounded in the literature. Research has shown truncated foot length as a valid measure of arch height and could therefore potentially be used for comparison28.

While not statistically significant, there was a difference in intrarater reliability measures throughout the examiners between right and left foot measures. An investigation of hand-dominance of future examiners could potentially lead to an explanation of this phenomenon. All of the examiners in the current study were right hand dominant; repeating the study with solely left-handed examiners could perhaps result in findings related to hand-dominance and reliability of measures.

CONCLUSION

The two novel devices examined in this study have been shown to have excellent intra-rater reliability on healthy asymptomatic subjects. The AHRD had good single measure interrater reliability, and had excellent averaged measure interrater reliability. The MDD had poor to moderate single measure interrater reliability, and moderate to good averaged measure interrater reliability. These results support the potential implementation of both devices in clinical use. Clinicians may use these devices in clinical settings with an understanding of the device's potential sources of error. It is recommended that clinicians use an average of three measures to increase the reliability of each device. Additional research is warranted to explore and refine the techniques associated with the tools, as well as to add to the current body of literature supporting the credibility of foot posture measurement tools.

References:

1. McPoil TG, Cornwall MW. The relationship between static lower extremity measurements and rearfoot motion during walking. *J Orthop Sports Phys Ther.* 1996;24(5):309-314.
2. Cornwall M W, McPoil TG: Reducing two-dimensional rearfoot motion variability during walking. *J Am Podiatr Med* ASSOC 83:394-397, 7 993.
3. Clarke TE, Frederick EC, Hamill CL: The effects of shoe design parameters on rearfoot control in running. *Med Sci Sports Exerc* 15:376-38 1, 1 983.
4. Halbach J: Pronated foot disorders. *Athl Train* 16:53-55, 1981.
5. Root ML, Orien WP, Weed JH: Clinical Biomechanics: Normal and abnormal function of the foot (Volume 2), pp 7 75-1 79. Los Angeles: Clinical Biomechanics Corp., 1977.
6. Subotnick SI: Variations in angles of gait. *Phys Sportsmed* 7:110- 114, 1979.
7. Sell KE, Verity TM, Worrell TW, Pease BJ, Wigglesworth J. Two measurement techniques for assessing subtalar joint position: a reliability study. *J Orthop Sports Phys Ther*. 1994;19(3):162-167.
8. Root M, Orien W, Weed J. Biomechanical evaluation of the foot. Los Angeles: Clinical Biomechanics Corporation. 1971.
9. Winter DA. A.B.C. (Anatomy, Biomechanics and Control) of Balance During Standing and Walking. Waterloo Biomechanics, Waterloo, Ontario, Canada, 1995.
10. Kirby KA. Foot and Lower Extremity Biomechanics: A ten year collection of precision intricast newsletters. Precision Intricast, Payson, AZ, 1997.
11. Williams DS, McClay IS. Measurements used to characterize the foot and the medial longitudinal arch: Reliability and validity. *PHYS THER*. 2000;80(9):864-871.
12. Cornwall MW, McPoil TG, Lebec M, Vicenzino B, Wilson J. Reliability of the modified foot posture index. *J Am Podiatr Med Assoc.* 2008;98(1):7-13.
13. Hegedus EJ, Cook C, Fiander C, Wright A. Measures of arch height and their relationship to pain and dysfunction in people with lower limb impairments. *Physiother Res Int*. 2010;15(3):160-166.

14. Weiner-Ogilvie S, Rome K. The reliability of three techniques for measuring foot position. *J Am Podiatr Med* Assoc. 1998;88(8):381-386.
15. Menz HB. Alternative techniques for the clinical assessment of foot pronation. *J Am Podiatr Med Assoc.* 1998;88(3):119-129.
16. Lundberg A, Svensson OK, Bylund C, Goldie I, Selvik G. Kinematics of the Ankle/Foot Complex—Part 2: Pronation and Supination. *Foot Ankle Int.* 1989;9(5):248-253.
17. McPoil T, Cornwall MW. Relationship Between Neutral Subtalar Joint Position and Pattern of Rearfoot Motion During Walking. *Foot Ankle Int*. 1994;15(3):141-145. doi:10.1177/107110079401500309.
18. Pierrynowski, MR, Smith, SB. Effect of patient position on the consistency of placing the rearfoot at subtalar neutral. *J Am Podiatr Med Assoc.* 1997:87:399-406
19. Picciano AM, Rowlands MS, Worrell T. Reliability of open and closed kinetic chain subtalar joint neutral positions and navicular drop test. *J Orthop Sports Phys Ther.* 1993;18(4):553-558.
20. Sobel E, Levitz S. Reappraisal of the negative impression cast and the subtalar joint neutral position. *J Am Podiatr Med Assoc.* 1997;87(1):32-33. doi:10.7547/87507315-87-1-32.
21. Smith-Oricchio K, Harris BA. Interrater reliability of subtalar neutral, calcaneal inversion and eversion. *J Orthop Sports Phys Ther*. 1990;12(1):10-15.
22. (1) Michaud T.C. Human Locomotion: The conservative management of gait-related disorders. Newton Biomechanics; 2011. https://books.google.com/books?id=ZfXLMgEACAAJ.
23. (2) Michaud T.C. Discussion and methods of clinical use of medial drift device and arch height ratio device. 2016.
24. (3) Root M. Biomechanical Examination Of The Foot. Los Angeles: Clinical Biomechanics Corp; 1971.
25. (1) Portney LG, Watkins MP. Foundations of Clinical Research: Applications to Practice. Upper Saddle River, NJ: Pearson/Prentice Hall; 2009.
26. Michimata A, Kondo T, Suzukamo Y, Chiba M, Izumi S-I. The Manual Function Test: Norms for 20- to 90-Year-Olds and Effects of Age, Gender, and Hand Dominance on Dexterity. Tohoku *J Exp Med.* 2008;214(3):257-267. doi:10.1620/tjem.214.257.
27. Vinicombe A, Raspovic A, Menz HB. Reliability of navicular displacement measurement as a clinical indicator of foot posture. *J Am Podiatr Med Assoc*. 2001; 9(5): 262-268.
28. McPoil TG, Cornwall MW, Vicenzino B, et al. Effect of using truncated versus total foot length to calculate the arch height ratio. The Foot. 2008;18(4):220-227. doi:10.1016/j.foot.2008.06.002.
29. McLaughlin P, Vaughan B, Shanahan J, Martin J, Linger G. Inexperienced examiners and the Foot Posture Index: A reliability study. *Manual Therapy*. doi:10.1016/j.math.2016.06.009