

ORIGINAL RESEARCH

THE USE OF A STATIC MEASURE TO PREDICT FOOT POSTURE AT MIDSUPPORT DURING RUNNING

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ABSTRACT

Background: The posture of the foot has been implicated as a factor in the development of running-related injuries. A static measure of foot posture, such as the longitudinal arch angle (LAA), that can be easily performed and is predictive of the posture of the foot at midsupport while running could provide valuable information to enhance the clinician's overall evaluation of the runner.

Purpose: The purpose of this study was to determine if the LAA, assessed in relaxed standing, could predict the posture of the foot at midsupport while running on a treadmill.

Study Design: Cross-sectional Study

Methods: Forty experienced runners (mean age 26.6 years) voluntarily consented to participate. Inclusion criteria included running at least 18 miles per week, previous experience running on a treadmill, no history of lower extremity congenital or traumatic deformity, or acute injury three months prior to the start of the study. Each runner had markers placed on the medial malleolus, navicular tuberosity, and medial aspect 1st metatarsal head of both feet. A high speed camera (240 Hz) was used to film both feet of each runner in standing and while running on a treadmill at their preferred speed. The LAA in standing and at mid-support while running was determined by angle formed by two lines drawn between the three markers with the navicular tuberosity serving as the apex. The LAA in midsupport was determined using the mean of the middle five running trials.

Results: The levels of intra-rater and inter-rater reliability for the dynamic LAA were excellent. The results of the t-tests indicated that mean values between the left and right foot were not significantly different for the standing or running LAA. The results of the t-tests between male and female runners were also not significantly different for standing or running LAA. The Pearson correlation between standing and running LAA for all 80 feet was $r = 0.95$ ($r^2 = 0.90$).

Conclusions: The standing LAA was found to be highly predictive of the running LAA at midsupport while running. Approximately 90% of the variance associated with foot posture at midsupport in running could be explained by the standing LAA.

Keywords: Foot posture, longitudinal arch angle, running

Level of Evidence: 4, Controlled laboratory study

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INTRODUCTION

The high incidence of lower extremity overuse or repetitive stress injuries has been well documented amongst both novice and experienced distance runners, with novice runners reporting more running-related injuries than experienced runners.¹ While the etiology of running-related overuse or repetitive stress injuries is multi-factorial, both foot mobility, especially foot pronation, as well as the static posture of the foot have long been hypothesized as potential risk factors in the development of running-related injuries.

Recent research has called into question the significance of foot mobility as a risk factor in the development of running-related injuries.^{1,2,3} Dowling et al, conducted a systematic review and reported that very limited evidence exists to support the concept that dynamic foot mobility is a risk factor in the development of running-related overuse injuries.² In one of the few prospective studies conducted to determine if increased foot mobility or pronation was a factor in the development of overuse injuries, Willems et al reported that 46 out of a group of 400 physical education students that were followed for one-year, developed exercise related lower leg pain and exhibited increased foot mobility or pronation.³ The difference in amount of rearfoot pronation, however, between the non-symptomatic group and the exercise related lower-leg pain group was only 1.7 degrees.³ In one of the few studies that has actually compared the amount of foot mobility using three-dimensional motion analysis between two groups of runners, one group classified as having a normal foot-type and the other group classified as having a pronated foot-type, McClay and Manal reported that the amount of foot mobility between the two groups was almost identical.⁴ The only difference between the two groups of runners was the position of the rearfoot at initial contact with the supporting surface. The pronated group made initial contact 8.5 degrees everted, while the normal group was 1.7 degrees inverted at initial contact. McClay and Manal concluded that the difference between these two groups of runners was not the actual amount of foot motion, but the position or posture of the foot at initial contact as well as at heel off with the pronated group in a pronated position throughout the stance

phase of running.⁴ Thus based on best available evidence, the importance of foot mobility as a risk factor for the development of running-related overuse injuries is uncertain.

While the findings of the McClay and Manal study was one of the first to highlight the importance of considering foot posture in runners, a recent systematic review by Carvalho et al, has reported that both high-arch and low-arch foot postures are associated with running-related injuries.⁵ Although this systematic review did not include a meta-analysis and effect-size estimates, it substantiates the work of other researchers who have reported that a low-arch or pronated foot type is a risk factor for the development of various types of running-related injuries including medial tibial stress syndrome (MTSS) and plantar fasciitis. Yates & White conducted a prospective study to determine the incidence of MTSS in military recruits during basic training and used the Foot Posture Index (FPI) to classify foot posture.⁶ These authors reported that the recruits who developed MTSS had a more pronated foot posture and that identifying those individuals with a pronated foot type prior to the start of training might reduce the incidence of MTSS. Pohl et al compared 25 female runners with a history of plantar fasciitis in comparison to an age-matched control group and reported that the runners with a history of plantar fasciitis had a more low-arch or pronated foot posture.⁷ Williams et al assessed 20 high-arched and 20 low-arched runners to determine if difference existed in the injury patterns between the two groups of runners.⁸ They reported that the high-arched runners had a greater incidence of ankle and bony injuries while the low-arched runners demonstrated more knee and soft tissue injuries.

The posture of the foot is usually described as being a high (pes cavus) arch or a low (pes planus) arch or pronated foot posture and is typically assessed by measuring the medial longitudinal arch of the foot. One of the most common measures described in the literature to assess the medial longitudinal arch is the Longitudinal Arch Angle (LAA) which was first described by Dahle et al.⁹ Dahle et al used the LAA to visually and subjectively assess the medial longitudinal arch posture in 55 athletes. Although they did not attempt to objectively measure the LAA,

they did report a substantial degree of within-rater reliability using visual assessment of the LAA.⁹ Jonsson and Gross objectively assessed the LAA in 63 healthy Navy recruits as part of a study that evaluated the within-rater and interrater reliability of lower-extremity and foot skeletal measurements. They reported that the mean LAA for this group of subjects was 141.6° and that the LAA had high levels of intra- and inter-rater reliability.¹⁰ McPoil and Cornwall were the first to determine if the LAA measured in relaxed standing position could predict the LAA at midsupport during running.¹¹ They assessed 17 experienced runners who averaged running 32 miles per week and reported that the static LAA was highly predictive, explaining 84% of the posture of the foot at or near midsupport during running. While the results of this study supported the inclusion of the LAA as part of the physical examination of the runner, the video recordings in this study were obtained during over-ground running.¹¹ While it could be argued that over-ground running is the preferred method for video recording, a treadmill is typically utilized in most clinical settings to perform a running gait analysis. Thus, the findings reported by McPoil and Cornwall may not be clinically applicable.¹¹ In a more recent study, Langley et al replicated the study by McPoil and Cornwall to determine if the LAA measured in a relaxed standing position could predict the LAA at discrete points during running, including midsupport.¹² In addition, they also attempted to determine if the static LAA could predict the motion of the medial longitudinal arch. Similar to the findings of McPoil and Cornwall, they reported that the static LAA could explain 86% of the posture of the foot at or near midsupport during running. These authors also reported that no significant relationship was found between the static LAA and motion of the medial longitudinal arch. However, in light of the limited evidence to support the importance of foot mobility as a risk factor for the development of running-related overuse injuries this finding would not diminish the importance of the LAA as a predictor of foot posture during running. While Langley et al did utilize a treadmill for data collection and indicated that the 15 physical active males in their study ran two to three times a week, they provided no information on the number of miles the subjects ran per week. In addition,

they used a highly sophisticated, three-dimensional motion analysis system that required multiple cameras. Thus, the applicability of their findings in the typical clinical setting that utilizes a treadmill and single camera would be limited.¹²

Based on current evidence, it would appear to be important for the clinician examining a runner with a repetitive-stress injury to be aware of the posture of the foot during the stance phase of running especially at the point where the foot is most pronated and the greatest amount of arch deformation would most likely occur. Several researchers have reported that the most pronated posture of the foot occurs at or near midsupport during running.^{4,12,13} As such, a static measure of foot posture that can be easily performed and is predictive of the posture of the foot at or near midsupport while running could provide valuable information to enhance the clinician's overall evaluation of the runner. McPoil and Hunt, in describing a tissue stress model as a basis for the management of foot and ankle problems, noted that an important role of foot orthoses is to control soft tissue stress.¹⁴ Static foot posture measurements that are predictive of foot posture during stance phase in running could also assist the clinician to determine if a foot orthosis prescribed for the runner has modified or changed the posture of the foot from relaxed standing position. Thus, the purpose of this study was to determine if the LAA, assessed in a relaxed standing position, could predict the posture of the foot at or near midsupport while running on a treadmill. To enhance the clinical applicability of the findings, a single low-cost high-speed camera to capture the running images as well as free-access video analysis software program was utilized. Based on previous research, it was hypothesized that LAA measured in a relaxed standing position would be highly predictive of foot posture at midsupport while running.

METHODS

Participant Characteristics

Forty experienced runners (16 men and 24 women) voluntarily consented to participate in this study. The mean age of the 40 runners was 26.6 years, with a range of 18 to 40 years. Participants were recruited from the Regis University population as well as the

greater Denver, Colorado, metropolitan area through community advertisements and public information sessions. All runners selected for the study met the following inclusion criteria: (1) between the ages of 18 to 40 years; (2) ran at least 18 miles per week for one-year prior to participation in the study; (3) had experience running on a treadmill; (4) no previous history of lower extremity congenital or traumatic deformity or previous surgery that resulted in altered bony alignment; and (5) no acute injury during the three months prior to the start of the study that led to inability to run at least three consecutive days during that time. The Institutional Review Board of Regis University approved the study protocol and all participants provided written informed consent prior to participation in the study.

Procedures

Upon arrival to the testing center, each participant's height, weight, and blood pressure were recorded. Next, each participant was asked to stand on an elevated platform, march in place for at least five seconds, and then stop in a comfortable relaxed standing position with their weight distributed equally on both feet. While the participant stood in this position with both arms at the side and looking straight ahead, the Foot Posture Index (FPI) was performed.¹⁵ The FPI is a measure of an individual's resting standing foot posture, and it is composed of six items: talar head palpation, curves above and below the lateral malleoli, calcaneal angle, talonavicular bulge, medial longitudinal arch congruence, and forefoot abduction/adduction. Each item of the FPI is scored on a 5-point scale from -2 to +2, with a sum total of all items ranging from -12 to +12. Negative values represent a supinated posture, and positive values represent a pronated posture. The FPI was performed on all of the participants by the same investigator. Following completion of the FPI, each participant was asked to begin running without shoes on a treadmill for at least five minutes so that they could acclimate to the treadmill (Model Mercury S, Woodway USA Inc., Waukesha, WI 53186) as well as determine their preferred running speed for testing. Once the preferred running speed was selected and the participant indicate they were acclimated to the treadmill, the participant was asked to assume a relaxed standing position with equal weight placed on both



Figure 1. Placement of markers on the most prominent point of the medial malleolus, the most prominent point of the medial aspect of the first metatarsal head, and the navicular tuberosity for the determination of the Longitudinal Arch Angle (LAA).

lower extremities so that following bony landmarks were identified using palpation and marked using a water soluble ink pen on the left and right feet at the navicular tuberosity, the most prominent point of the medial malleolus, and the most prominent point of the medial aspect of the first metatarsal head. Black markers that were one centimeter in diameter were then attached to each ink mark using double-sided adhesive tape (Figure 1). Each participant was then asked to stand in the middle of the treadmill and place his or her feet six inches apart. To record data for the right foot, the participant was asked to first slide the left foot backward to just behind the right heel. The participant was then instructed to maintain the right leg perpendicular to the floor and place equal weight on both feet while video data was recorded for static standing. Once the relaxed standing position (StandLAA) was recorded, the participant was then asked to start running on the treadmill at his or her pre-selected running speed. Once the participant indicated they were in their typical running pattern, they continued to run at his or her preferred speed for five minutes while video data was recorded. Once the video recording was completed for the right foot, the same procedure was repeated

to record both standing and running data for the left foot. Since each subject ran barefoot without shoes on the treadmill and in light of possible differences in the strike pattern when running with or without shoes, the strike pattern of each runner was recorded. For the 40 runners in this study, six (6) had a forefoot strike pattern, four (4) had a midfoot strike pattern, and 30 had a rearfoot strike pattern. The six runners with a forefoot strike pattern all lowered their heel so it was in complete contact with the surface of the treadmill prior to midsupport.

All standing and running images were recorded using a high speed camera (Model# EX FH25, Casio America Inc., Dover, NJ 07801) at a rate of 240 frames per second. To determine the reliability of different raters to consistently measure the LAA at midsupport while running, two different raters assessed the standing and running LAA images captured for the left and right feet of five randomly selected participants.

Data Analysis

The FPI foot type classifications for each participant were determined by converting raw scores using the criteria described by Redmond, with Highly Supinated = -5 to -12; Supinated = -4 to -1; Normal = 0 to +5; Pronated = +6 to +9; and Highly Pronated = +10 to +12.¹⁵ For each participant, one standing image and five running images for both the left and right foot were selected from the video recordings for analysis. The five running images for each foot were selected after three minutes from the start of the video data recording. The dynamic images used to calculate the LAA during running were captured at midsupport, which for this study was defined as the frame where the medial longitudinal arch (as indicated by the dorsum of the foot just above the marker on the navicular tuberosity) reached the most plantar position before the heel left the supporting surface. Midsupport was selected for capturing the five running images since previous studies assessing rearfoot and midfoot motion during running have reported that the maximum foot pronation occurs at or near midsupport during running. For the six images captured for each foot, a free-access video analysis software program (Kinovea, version 0.8.15, <http://www.kinovea.org>) was then used to determine the LAA by calculating the angle formed by

drawing two lines between the three markers with the navicular tuberosity as the apex of the angle (Fig. 1). For further statistical analysis, the mean of the LAA for the five running trials were averaged (RunLAA).

Statistical Analysis

To assess the reliability of the five running LAA measures for each foot, intraclass correlation coefficients were calculated to determine the consistency of one rater assessing the same group of five runner (intra-rater; ICC_{3,1}) twice as well as two raters individually assessing the same group of five runners (inter-rater; ICC_{2,1}). The level of reliability for the ICC were classified based the characterizations reported by Landis and Koch.¹⁶ These characterizations were: slight, if the correlation ranged from 0.00 to 0.20; fair, if the correlation ranged from 0.21 to 0.40; moderate, if the correlation ranged from 0.41 to 0.60; substantial, if the correlation ranged from 0.61 to 0.80; and almost perfect, if the correlation ranged from 0.81 to 1.00.

In addition to descriptive statistics, t-tests were performed to determine if there were differences between extremities and gender for the StandLAA and RunLAA measures. Pearson product coefficients were used to determine the ability of the StandLAA to predict the mean RunLAA measured at midsupport in running. All statistical analyses were performed using JMP software, Version 8 (SAS Institute Inc., Cary NC 27513). An alpha level of .05 was established for all tests of significance.

RESULTS

Demographic data for all subjects are listed in Table 1. The intra-rater reliability for the single rater assessing the LAA for the left and right feet of five runners was 0.87. The inter-rater reliability for two

Table 1. Means (standard deviations) for participant demographics.

	Age (years)	Height (cm)	Weight (kg)	BMI (kg/cm ²)	Mileage per Week
Females (n = 24)	25.2 (6.4)	164.4 (5.6)	58.6 (5.0)	21.7 (1.8)	34.8 (14.6)
Males (n = 16)	22.8 (4.4)	179.9 (4.4)	71.8 (8.1)	22.2 (2.4)	52.7 (17.4)
All runners (n = 40)	24.3 (5.7)	170.5 (9.3)	63.9 (9.1)	21.9 (2.0)	41.9 (17.9)

Table 2. *Static and dynamic LAA descriptive statistics.*

	Mean (degrees)	Standard Deviation	95% Confidence Limits
Females (n = 24)			
Right StandLAA	144.4	6.6	141.6; 147.1
Right RunLAA	132.7	6.9	129.8; 135.7
Left StandLAA	145.0	7.6	141.8; 148.3
Left RunLAA	134.5	8.5	130.9; 138.1
Males (n = 40)			
Right StandLAA	140.9	10.3	135.4; 146.4
Right RunLAA	130.1	11.9	123.7; 136.4
Left StandLAA	142.9	8.7	138.2; 147.5
Left RunLAA	132.9	10.3	127.4; 138.4
Combined Data (n = 80)			
StandLAA	143.6	8.2	141.7; 145.4
RunLAA	132.8	9.2	130.7; 134.8
LAA= Longitudinal arch angle			

raters assessing the left and right feet of five runners was 0.96. The FPI classifications of the 80 feet of the 40 runners in this study were: highly supinated = 1; supinated = 13; normal = 41; pronated = 23, and highly pronated = 2.

Descriptive statistics for all measurements are listed in Table 2. The results of the t-tests indicated that mean values between the left and right foot were not significantly different for the StandLAA ($p = 0.288$; 95% CI: -1.0,3.4) or RunLAA ($p = 0.061$; 95% CI: -0.1,4.5). The results of the t-tests between male and female runners were not significantly different for StandLAA for the left ($p=0.432$; 95% CI: -7.6,3.3) or right foot ($p = 0.248$; 95% CI: -9.5,2.6). The results of the t-tests between male and female runners were also not significantly different for the RunLAA for the left ($p = 0.602$; 95% CI: -9.5,4.2) or right ($p=0.429$; 95% CI: -7.9,4.7) foot. Based on these findings, the StandLAA and RunLAA measures for the left and right feet were grouped together ($n = 80$ feet) for further statistical analysis. The correlation between StandLAA and RunLAA was $r = 0.95$ ($r^2 = 0.90$). The following regression equation was determined to allow the clinician to predict the RunLAA at midsupport during running using the StandLAA measured in relaxed standing:

$$RunLAA = -20.755 + 1.069 * StandLAA$$

To validate this regression equation, the predicted RunLAA value for each runner was calculated using the regression equation and compared to the actual RunLAA for each runner using a t-test. The mean

value for the “predicted” RunLAA (132.71 degrees) was compared to the mean for the “actual” RunLAA (132.78 degrees) and these means were not significantly different ($p = 0.962$), which further validates the regression equation for the prediction of the RunLAA.

DISCUSSION

The intent of this study was to determine if the LAA, assessed in relaxed standing, could predict foot posture at midsupport while running on a treadmill. Based on previous research, it was hypothesized that the LAA would be highly predictive of foot posture at midsupport while running. Prior to interpreting the results of the current study, it was important to first establish that a single as well as multiple raters could consistently measure the LAA. The consistency of a single rater (ICC) assessing five running trails for the left and right feet of five randomly selected runners on two separate days was 0.87. The inter-rater reliability (ICC) for two raters assessing five running trails for the left and right feet of five randomly selected runners was 0.96. Based on the ICC classification system proposed by Landis and Koch, both the intra-rater reliability and inter-rater reliability for the LAA would be “almost perfect”.¹⁶ On the basis of these findings, further analysis of the results was performed.

Although recent research has reported that static foot posture assessed using the FPI may not be an accurate representation of dynamic rearfoot or mid-foot mobility, it does provide important information

on the foot types of the runners who participated in the study.^{17,18} While the runners in this study were not selected based on foot type, based on the FPI classifications 51% had a normal foot type, 31% had a pronated or highly pronated foot type, and 18% had a supinated or highly supinated foot type. This varied distribution of foot types helps enhance the applicability of the findings of the current study.

The results of the Pearson correlation coefficients indicate that the StandLAA obtained in resting standing posture was highly predictive of the RunLAA measured at midsupport while running explaining approximately 90% of the variance. Based on this high degree of association, the regression equation described in the Results section can be used to predict the RunLAA at midsupport in running by inserting the StandLAA value measured in relaxed standing. As a result of this finding, the hypothesis that the StandLAA measured in relaxed standing would be highly predictive of RunLAA at midsupport while running was confirmed. It would also appear, based on these findings that the measurement of the StandLAA in resting standing would be a valuable addition to the physical examination of the individual with a running-related overuse injury. In addition, as previously noted the use of the StandLAA could also assist the clinician to determine if foot orthoses prescribed for the runner have modified or changed the position of the foot from relaxed standing posture. By measuring the change in the LAA with the runner standing on the orthosis, because of the close relationship (high degree of association) between the StandLAA and RunLAA demonstrated in this study, the clinician could assume that the posture of the foot at midsupport in running would also be changed thereby reducing the level of tissue stress. Of course, further research would be required to substantiate this hypothesis.

The findings of the current study are in close agreement with the previous research by McPoil and Cornwall who reported that the static LAA was highly predictive of the dynamic LAA in midsupport while running with a correlation of $r = 0.920$ ($r^2 = 0.846$).¹² In the current study, the mean value for the StandLAA was 143.6 degrees. This is in close agreement to the mean values for the relaxed standing LAA reported by Jonson and Gross¹⁰ (141.6 degrees;

$n = 63$) and McPoil and Cornwall¹⁹ (139.4 degrees; $n = 100$). In the current study, the magnitude of the change between the StandLAA and the RunLAA was 10.8 degrees. This measure of the deformation of the medial longitudinal arch between relaxed standing and midsupport of running is almost identical to the 9.7 degree change previously reported by McPoil and Cornwall.¹¹

As was noted in the introduction, to enhance the clinical applicability of the findings of the current study, a single low-cost high-speed camera to capture the running images while running on a treadmill was utilized. In addition, a free-access video analysis software program was used to analyze the standing and running images. Several researchers have reported on the validity of using a treadmill for running analysis with the major concern being the alteration of the runner's pattern of lower extremity movement as well as ground reaction forces. In one of the only studies to compare overground versus treadmill running kinematics and kinetics using a force-transducer instrumented treadmill, Riley et al reported that a treadmill-based analysis of running mechanics can be generalized to overground running mechanics, provided the running speed on the treadmill is similar to individuals overground running speed.²⁰

Another limitation of the current study was the use of a single high-speed camera to capture sagittal plane (2-dimensional) movement of the medial aspect of the foot during running. While previous studies have discussed the issues associated with attempts to use two-dimensional motion analysis to assess rearfoot movement in running, Areblad et al reported that the use of two-dimensional techniques to assess angular values in the sagittal plane during running are similar to values obtained using three-dimensional motion analysis techniques.²¹ This is important since three-dimensional motion analysis that utilizes sophisticated equipment and software is not available in most clinical settings. Thus, the clinician can have confidence in using a single high-speed camera to record the LAA in the sagittal plane during running if they desire to assess the LAA using a treadmill.

CONCLUSION

While the etiology of running-related overuse injuries have been shown to be multifactorial, foot

posture has been implicated as a factor in several studies. Thus, it would appear to be important for the clinician examining a runner with a repetitive-stress injury to include an assessment of static foot posture. The use of a static measurement that can be reliably performed and accurately predict foot posture during running would be of value to the practitioner. The results of this study substantiate the use of the LAA, measured in relaxed standing, to predict the LAA at or near midsupport during running on a treadmill. The clinician can use the regression formula provided in this paper to understand how foot posture, when measured in relaxed standing, can change during running to enhance their physical examination findings.

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