

The Relationship between Plantar Loading and Rearfoot Motion during Walking

Kristine Nielsen

Faculty Sponsor: Thomas W. Kernozek, Ph.D., Physical Therapy Department

ABSTRACT

Fifty college students participated in research that examined the relationship between plantar loading and rearfoot motion during walking. Plantar loading data was gathered using the EMED SF pressure platform sampling at 70 Hz that lay flush within a 10 meter walkway. While maintaining a constant speed of 1.5 m/s, participants were asked to contact their right foot on pressure platform while maintaining a natural stride. Data from two dimensional motion (video based) was collected by measuring the motion of passive markers on the calcaneus and lower leg of participants during walking at 60 Hz. Plantar loading variables from the pressure platform had a poor relationship with all of the rearfoot motion measurements during walking. Therefore, the amount of rearfoot motion may be independent of plantar loading patterns.

INTRODUCTION

The foot is thought to function best, and injuries are less likely to result, when the subtalar joint is in a neutral position. Failure to maintain this neutral position results either in pronation, represented as calcaneal eversion, or supination, represented as calcaneal inversion, of the foot (Hamill et al, 1995). Some pronation is normal for the weight-bearing foot, but excessive or prolonged pronation is associated with increased stresses being applied to the foot (James et al, 1978). Common problems thought to be related to over pronation include lower limb stress fractures, shin splints, lower back pain, hip pain and knee pain (Halbach, 1981).

The amount of pronation can be determined by measuring the rearfoot angles. Rearfoot angles are calculated using the absolute angles of the leg and the calcaneus in the frontal plane. Two markers are placed on the back of the leg to define the longitudinal axis of the leg. Another two markers are placed on the calcaneus to define the longitudinal axis of the calcaneus. These markers are used to calculate the absolute angles of the leg and heel and thus the rearfoot angle is:

$$\theta_{RF} = \theta_{leg} - \theta_{calcaneus}$$

By this calculation, a positive angle represents supination, a negative angle represents pronation, and an angle equal to zero is neutral position (Hamill et al, 1995).

Some studies have looked at different ways of measuring pronation. Halbach used the Harris mat test to show the weight-bearing pattern when performing research on cross-country runners (Halbach, 1981). The present study will examine if greater pronation relates to greater contact area and force in the medial region of the foot during walking. If this is true, can pronation be determined by using a pressure platform?

METHOD

Participants

Fifty healthy college students enrolled at University Wisconsin- La Crosse volunteered as participants.

Materials

Plantar loading data was gathered using the EMED SF pressure distribution measurement system (70 Hz) that lay flush with a 10 meter walkway. A photoelectric timing system was used to verify that walking speed in the middle 1 meter of the walkway was within 1.5 m/s \pm 5% for each trial. Two dimensional rearfoot motion was used to measure the motion of reflective markers on the calcaneus and lower leg of the participants during walking (video 60 Hz). A Panasonic AG450 video camera was located approximately 8 meters away from the pressure platform at one end of the walkway. The markers from the video were smoothed using a Butterworth digital filter (6 Hz).

Procedure

The data was collected during a single session of approximately 20-30 minutes in length. Before the data collection occurred, participants were familiarized with the equipment and testing procedure. Participants were then asked to remove their shoes and socks. Four reflective markers, indicating the longitudinal axes of the leg and calcaneus, were placed on the back of their right leg.

Static measurements were recorded by having the participant stand naturally with the right foot only on the pressure platform. Additional static measurements were taken by having both feet on the pressure platform while standing naturally. For both of these measurements, data was collected using the pressure platform and rearfoot motion analysis. Rearfoot motion analysis consisted of measurements obtained from video of the participant's leg. Video from the rear was taken during walking and static trials.

Once static measurements were recorded, the participant was instructed to practice walking at a speed of 1.5 m/s on the 10 meter walkway. A photoelectric timing system provided the participants feedback on their speed. While maintaining this constant speed, they were also instructed to land their right foot in the center of the pressure plate when they came to it on the walkway. This all had to be done while maintaining a natural walking stride. Once the participants had established this task, data was recorded. A total of 5 walking trials were recorded for each participant.

RESULTS

Plantar pressure data was processed by dividing the length of the plantar surface into thirds. Arch index was defined by taking the middle third and dividing it by the sum of total plantar surface area (Cavanagh et al, 1987). Medial lateral force index or medial lateral area index was calculated ratio of the total force or contact area medial and lateral to the center of pressure. This ratio of force and area determined if there was greater force or contact area on the medial or lateral portion of the plantar surface during walking.

From plantar loading data, arch index, medial lateral force index, medial lateral area index, maximum pronation, time to maximum pronation, time to maximum pronation velocity, total rearfoot motion, and average and maximum velocity of the center of pressure were

calculated. Plantar loading and video data were also measured while standing with single limb support and double limb support. The mean and standard deviations of these calculations are listed in Table 1.

Table 1. The mean and standard deviations of calculated measurements.

	<i>Mean</i>	<i>Standard Deviation</i>
Arch Index (cm ²)	.18	6.63E-02
Medial Lateral Force Index	.92	.12
Medial Lateral Area Index	.90	.11
Maximum Pronation (degrees)	-8.08	5.16
Maximum Pronation D.L.S. (degrees)	-5.94	5.48
Maximum Pronation S.L.S. (degrees)	-3.20	4.85
Time to Max. Pronation (ms)	408.27	160.30
Time to Max. Pronation Velocity (ms)	288.42	163.59
Total Rearfoot Motion (degrees)	8.31	3.01
Average Velocity (degrees/sec)	.42	3.15E-02
Maximum Velocity (degrees/sec)	1.25	.22

Pearson correlation coefficients were performed between the rearfoot motion and plantar loading data. Descriptive statistics showing these correlations are listed in Table 2.

Table 2. The correlations between rearfoot motion and plantar loading data.

	Maximum Pronation	Maximum Pronation Velocity	Time to Max. Pronation Velocity	Total Rearfoot Motion
Arch Index*	-.22	-.16	.06	.05
Medial Lateral Force Index*	.14	.12	-.19	.03
Medial Lateral Area Index*	.23	-.02	-.15	.26
Maximum Pronation*	1.00	.28	-.76	.15
Maximum Pronation (D.L.S.)**	.75	.09	-.51	.19
Maximum Pronation (S.L.S.)**	.68	.15	-.42	.10
Time to Max. Pronation	-.84	.12	.85	-.48
Time to Max. Pronation Velocity	-.76	.11	1.00	-.31
Total Rearfoot Motion	.15	-.62	-.31	1.00
Average Velocity	-.16	-.08	.10	-.10
Maximum Velocity	.31	.11	-.22	.04

* Dynamic Measurements

** Static Measurements

The results of this study show that arch index, medial lateral force index, medial lateral area index, maximum velocity of the center of pressure correlated poorly with maximum pronation and total rearfoot motion ($r = -.22$ - $.31$). The correlation between maximum velocity of the center of pressure and maximum pronation was $r = .31$. Kinematic variables such as maximum pronation during static single limb stance (S.L.S.) and maximum pronation during static double limb stance (D.L.S.) had correlations of $.68$ and $.75$ with dynamic maximum pronation during walking, respectively. A poor relationship was found between the total rearfoot motion with maximum pronation during single limb stance, $r = .10$, and total rearfoot motion with maximum pronation during double limb stance, $r = .19$. Time to maximum pronation

tion and time to maximum pronation velocity correlated negatively with maximum pronation ($r = -.76$ and $-.84$ respectively). Also, the time to maximum pronation and time to maximum pronation velocity correlated negatively with total rearfoot motion ($r = -.31$ and $r = -.48$ respectively).

DISCUSSION

The purpose of this study was to determine if greater pronation relates to greater contact area and force in the arch region of the foot during walking. The plantar loading variables from the pressure platform had a poor relationship with all of the rearfoot motion measurements during walking. These poor correlations indicate that the amount of rearfoot motion may be independent of plantar loading patterns.

Since this is one of the first studies to relate pronation to contact area and force in the medial area of the foot during walking, our results are hard to compare to other studies. The means from the rearfoot motion data, however, can be compared to other studies. A study by Kernozek et al. found the mean maximum pronation to be -9.63° during running. The current study has a mean maximum pronation of -8.08° during walking. This difference in measurement between the two studies may be expected since there is typically less pronation during walking. Likewise, Kernozek et al.'s mean total rearfoot motion (10.09°) and mean arch index ($.23 \text{ cm}^2$) are similar to the current studies findings of 8.31° and $.18 \text{ cm}^2$, respectively (Kernozek et al, 1990). Subotnick reported that normal maximum pronation during gait is approximately 6° from subtalar neutral, with a maximum of $9.4^\circ \pm 3.5^\circ$ (Subotnick, 1975). He reported that hyperpronation may be defined as pronation in excess of 13° .

The static measurements of maximum pronation during single limb stance (.68) and double limb stance (.75) correlated much higher with maximum pronation than did the dynamic plantar loading measurements. These dynamic plantar loading measurements included arch index (-.22), medial lateral force index (.14), and medial lateral area index (.23). This illustrates that static rearfoot measurements may be a better indicator of pronation than dynamic plantar loading measurements.

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