

Effect of Ankle Dorsiflexion Range of Motion on Rearfoot Motion During Walking

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The purpose of this study was to investigate whether the amount of ankle passive dorsiflexion range of motion influences the pattern of frontal plane rearfoot motion during walking. Three-dimensional motion of the rearfoot was measured in two groups of subjects, those with ankle passive dorsiflexion range of motion less than or equal to 10°, and those with ankle passive dorsiflexion range of motion greater than 15°, while they walked along a 6.1-m walkway. The results indicated that the only statistically significant differences between the two groups were in the time to reinversion of the rearfoot and the time to heel-off. Slight-to-moderate limitation of ankle passive dorsiflexion range of motion significantly alters the timing, but not the magnitude, of frontal plane rearfoot motion during walking. (*J Am Podiatr Med Assoc* 89(6): 272-277, 1999)

One of the principal objectives of a clinical examination of the foot and ankle is to identify those factors or conditions that produce compensatory movements of the foot. It is generally thought that these compensatory movements either cause or aggravate the patient's original complaint.¹ Identification and correction of the cause or causes of the compensatory movement will allow the patient's symptoms to be reduced. One of the causal factors that has long been implicated and reported in the literature is limited ankle passive dorsiflexion range of motion.²⁻⁴

Normal passive dorsiflexion range of motion of the ankle is generally agreed to be approximately 20°.⁵⁻⁸ There is less agreement, however, regarding the amount of joint movement required for normal gait. In the earliest study on this subject, Murray and associates⁹ reported that between 8° and 10° of talocrural dorsiflexion range of motion was needed during the stance phase of normal gait. Subsequently, Stauffer et al,¹⁰ reporting on a study of five men who

wore their own street shoes while they walked, determined that 10.2° of dorsiflexion was needed during walking. A later study of 50 men walking barefoot indicated that only 4° of dorsiflexion range of motion was needed for normal walking.¹¹ On the basis of these studies, it appears that between 4° and 10° of passive dorsiflexion range of motion is required during the stance phase of normal gait. Several authors have suggested that values less than 10° constitute equinus and therefore will result in subtalar joint compensation during weightbearing. This compensation will produce abnormal pronation during gait.^{1, 12, 13}

Although the theoretical basis of equinus resulting in abnormal pronation of the subtalar joint as a compensatory motion is widely accepted, it has never been actually documented in the literature. In addition, the magnitude of the equinus deformity that would result in the abnormal compensatory pronation has not been verified. The purpose of this study was to determine whether slight-to-moderate passive dorsiflexion range of motion deficits of the ankle actually result in abnormal frontal plane rearfoot motion during walking.

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Materials and Methods

Subjects

Ankle passive dorsiflexion was measured in 106 subjects. Measurements were made while the subjects lay prone on an examination table with their knees completely extended.^{3, 5} All measurements were performed by the same investigator (T.G.M.). Subjects were selected for participation in the study on the basis of these measurements. Those individuals with passive dorsiflexion range of motion less than or equal to 10° (n = 43) were placed in a limited range of motion group, and those with passive dorsiflexion range of motion greater than 15° (n = 44) were placed in a normal range of motion group. Those with passive dorsiflexion range of motion between 10° and 15° were eliminated from the study. The study group, then, comprised 87 subjects (40 men, 47 women) between the ages of 19 and 41 years (mean, 26.4 years). The subjects had no history of congenital deformity, pain, or traumatic injury to either lower extremity for at least the 6 months preceding the start of the study. Table 1 provides demographic information on the subjects who participated in the study. This study was approved by the institutional review board at Northern Arizona University prior to the start of data collection, and all subjects provided informed written consent.

Instrumentation

The rearfoot motion of each subject was measured using the 6D-RESEARCH electromagnetic motion analysis system (Skill Technologies, Inc, Phoenix, Arizona). This system is based on the Fastrak tracking device (Polhemus, Colchester, Vermont) and uses an electromagnetic transmitter with up to four electromagnetic sensors. The transmitter as well as each sensor consists of three orthogonal coils. Near-field, low-frequency, magnetic-field vectors are generated from the transmitter, with each sensor detecting these field vectors. The detected signals are entered into a digital signal processor that computes the sensor's position and orientation relative to the transmitter. Thus the sensor creates an embedded coordinate system that is equivalent to using three markers on the surface of the body segment. The system's effective accurate range is a radius of 76 cm from the transmitter. Within this range it is accurate to within 0.8 mm and 0.15°. Although this range is too small for analysis of a full walking stride, it is sufficient for analyzing the stance phase of walking.¹⁴

For the present study, the electromagnetic trans-

Table 1. Demographic Information on the Subjects Participating in the Study

Characteristic	Limited Group (n = 43)	Normal Group (n = 44)	Total (N = 87)
Sex			
Male	21	19	40
Female	22	25	47
Mean age (years)	26.7 (4.8)	26.1 (5.0)	26.4 (4.9)
Mean height (cm)	171.3 (7.4)	169.7 (7.9)	170.5 (7.6)
Mean weight (kg)	72.5 (13.0)	69.4 (14.0)	70.7 (13.8)
Mean passive dorsiflexion range of motion (°)	9.6 (1.1)	19.4 (4.1)	13.9 (5.3)

Note: Values in parentheses are SD.

mitter was positioned at a height of 96 cm at the mid-way point of a 6.1-m raised walkway. The walkway was raised to a height of 76 cm to avoid any possible distortion of the electromagnetic fields caused by metal reinforcement in the laboratory's concrete floor (Fig. 1). Two electromagnetic sensors were used to collect angular position data for the lower leg and calcaneus during walking. The sampling rate for the two sensors was 60 Hz. The frontal plane rear-foot angle was calculated using a joint coordinate system as defined by Grood and Suntay.¹⁵ The angle of the rearfoot was defined as the displacement between the tibial and calcaneal sensors about the y-axis in the foot or leg coordinate system rather than the laboratory coordinate system. The resultant angle was smoothed using a 6-Hz low-pass Butterworth digital filter. Figure 2 illustrates the definition of the angle measured in this study and the position of the sensors on the subject.

To record the temporal occurrences of heel strike, foot flat, heel-off, and toe-off, three force-sensing switches were secured to the plantar surface of each subject's heel, first metatarsal head, and hallux with adhesive tape. The signal produced by each switch was recorded and synchronized with the kinematic data.

Procedure

Following the recording of the subject's height and weight, two small (2.8 × 2.3 cm) electromagnetic sensors were attached to the right lower extremity with double-sided adhesive tape. Sensors were placed on

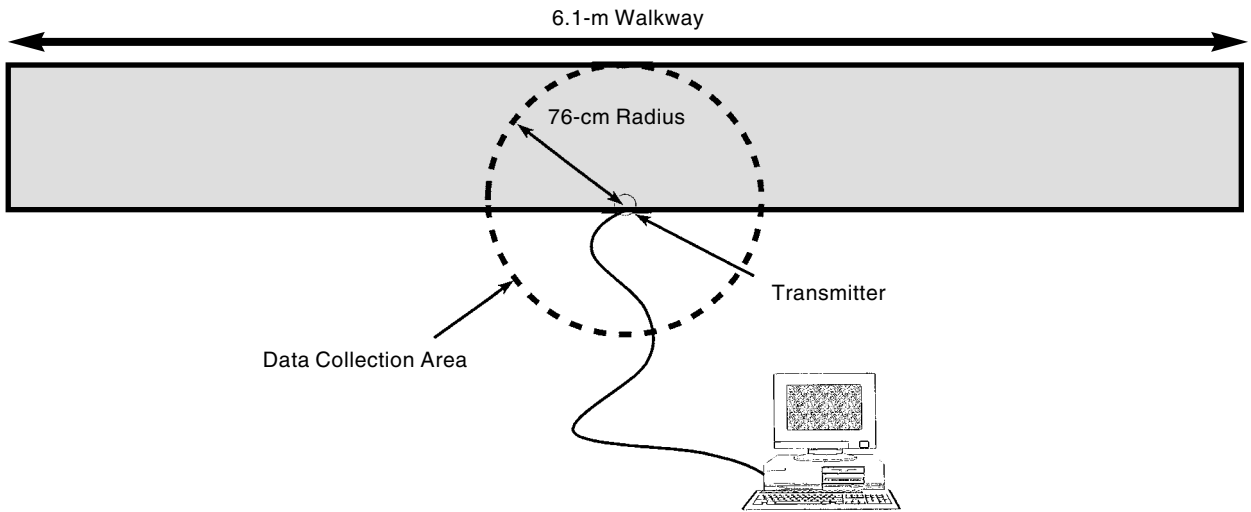


Figure 1. Schematic representation of the experimental setup used to collect kinematic data on the lower leg and calcaneus during walking.

the anterior tibial tubercle and the posterior calcaneus (Fig. 2). These locations were selected because of minimal presence of soft tissue and thus the reduced possibility of sensor-skin movement during walking. The sensors and foot switches were connected to a microcomputer for data collection by means of a 30-foot serial cable. The subject first stood relaxed with the knees extended and feet positioned parallel to the plane of motion while the orientation of each sensor relative to the laboratory reference frame was initialized to zero. This position was used as the reference point for all angular measure-

ments. After the sensors were initialized, each subject walked along the walkway at a self-selected speed. A total of five consecutive walking trials were recorded for each subject. Orientation data relative to a global reference frame for each of the electromagnetic sensors were stored in the microcomputer for further analysis. Any questionable trials were repeated.

Data Analysis

Type (2,1) intraclass correlation coefficients were used to assess between-trial reliability of the dura-

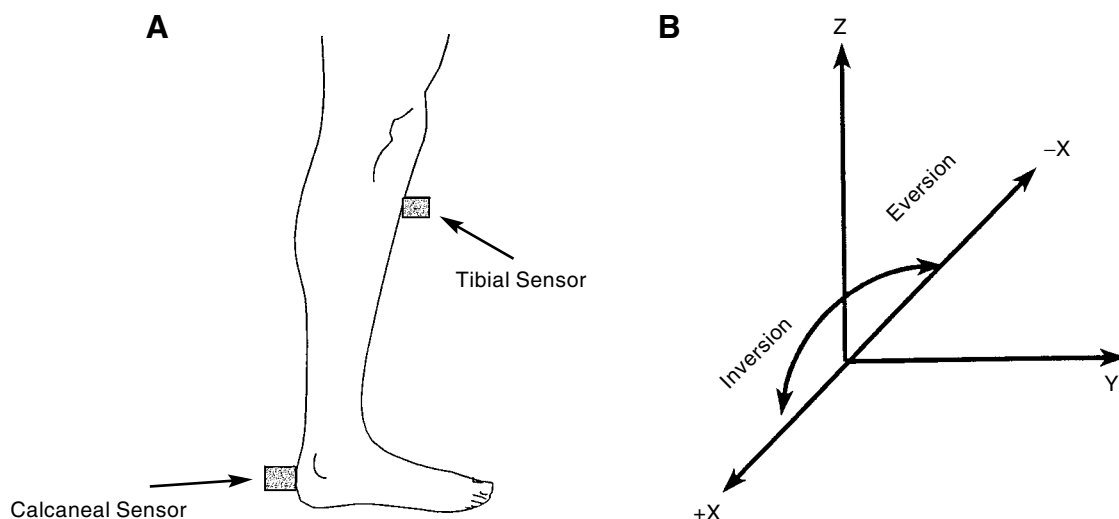


Figure 2. A, Sensor placement; B, the definition of the kinematic data measurement.

tion of each subject's stance phase.¹⁶ Between-trial consistency of the motion patterns obtained by the electromagnetic system was estimated using the average standard deviation, the average standard error of the mean, and the average coefficient of multiple correlation values for all subjects.^{17,18}

In addition to descriptive statistics, the variables of stance phase duration, time to heel-off, angle at heel strike, maximum angle, time to maximum angle, and time to reinversion were compared between the two groups using independent *t*-tests. Time to reinversion was defined as the point at which the rearfoot inversion/eversion curve crossed the zero point from negative to positive values. An alpha level of .05 was used for all tests of statistical significance.

Results

The intraclass correlation coefficient for stance phase duration was found to be 0.910. According to the classification system proposed by Landis and Koch,¹⁹ this is considered "almost perfect." Between-trial reliability for the remaining dependent variables measured in this study has been documented previously in the literature using a similar protocol.^{20,21} Reliability of the motion patterns was assessed by the mean standard deviation and standard error of the mean values, which were found to be 2.3° and 0.25°, respectively. The mean coefficient of multiple correlation values indicating between-trial variability of the dorsiflexion/plantarflexion and inversion/eversion motion patterns were found to be 0.963 (± 0.038) and 0.914 (± 0.058), respectively. On the basis of these values, the authors believe that there was adequate between-trial consistency for the angular displacements measured.

Figure 3 shows the frontal plane rearfoot angles during the stance phase of gait for each group of subjects tested. The mean values for the dependent variables measured, as well as the results of the *t*-tests, are presented in Table 2. As can be seen, only the values for the time to reinversion and the time to heel-off were found to be significantly different between the two experimental groups ($P < .05$). Subjects in the limited group reinverted 6.2 percentage points sooner and had heel-off 2.8 percentage points sooner than did those in the normal group. During walking, the study subjects, regardless of their group assignment, dorsiflexed 6.9° ($\pm 3.9^\circ$) from the relaxed standing position during the stance phase of walking.

The results of the Pearson correlations between each of the dependent variables and passive dorsiflexion range of motion are shown in Table 3. As can be seen, time to maximum angle and time to reinver-

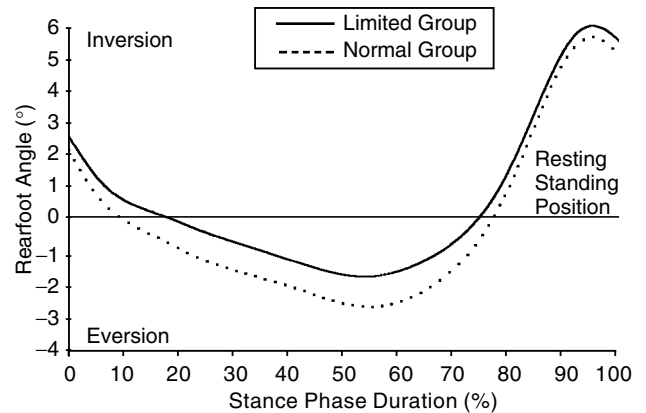


Figure 3. Mean rearfoot motion for the limited and normal passive dorsiflexion range of motion groups.

Table 2. Comparison of Mean Values for the Dependent Variables Between the Two Experimental Groups

Variable	Limited Group	Normal Group
Stance phase duration (msec)	658 (47)	671 (60)
Time to heel-off (%)	53.4 (10.9)	56.2 ^a (7.2)
Angle at heel strike (°)	2.4 (2.2)	2.0 (2.4)
Maximum angle (°)	-2.3 (0.5)	-2.5 (0.5)
Time to maximum angle (%)	48.5 (1.4)	53.9 (1.4)
Time to reinversion (%)	73.1 (1.6)	79.3 ^a (1.1)

Note: Negative values for the rearfoot angles denote eversion. Values in parentheses are SD.

^a $P < .05$.

Table 3. Pearson Correlation Coefficients for the Dependent Variables and Passive Dorsiflexion Range of Motion

Variable	Passive Dorsiflexion Range of Motion
Stance phase duration	0.107
Time to heel-off	0.116
Angle at heel strike	-0.046
Maximum angle	0.088
Time to maximum angle	0.222 ^a
Time to reinversion	0.241 ^a

^a $P < .05$.

sion were the only variables that were significantly correlated with passive dorsiflexion range of motion ($P < .05$). Although the correlations are significant, they are small, with a coefficient of determination (r^2) of .05 and .06, respectively.

Discussion

The values obtained in the present study for dorsiflexion during stance are not in agreement with the findings of any of the studies previously reported in the literature. The mean value in this study is greater than that reported by Jordan et al,¹¹ but less than those reported by Murray et al⁹ and Stauffer et al.¹⁰ The most likely cause of this discrepancy is the reference point used for defining neutral dorsiflexion. The present study used each subject's resting standing posture as the reference point rather than an absolute zero angle. Because of this difference in reference points, it is extremely difficult to compare the results of this study with those of previous studies. On the basis of this study, it appears that approximately 7° of dorsiflexion from the resting standing position is needed.

More important, the results of this study indicate that a mild-to-moderate loss of passive dorsiflexion range of motion has little or no effect on the frontal plane function of the rearfoot during the stance phase of walking. Such findings are in disagreement with several authors who indicated that passive dorsiflexion range of motion less than 10° would result in excessive subtalar joint pronation during walking.^{1, 12, 13} Instead, it appears that compensation for mild equinus conditions takes the form of changes in timing rather than magnitude. This is seen by the significantly earlier reinversion of the rearfoot during walking and the significantly earlier heel-off time in those subjects with reduced passive dorsiflexion range of motion. This is further supported by the significant ($P < .05$), albeit small, correlations between passive dorsiflexion range of motion and the timing variables (Table 2). It is, however, possible that alteration of the magnitude of frontal plane rearfoot function during walking would be seen with greater range-of-motion deficits than those investigated in this study. It is possible that passive dorsiflexion range of motion of between 8° and 10° is essentially normal. The criteria used in the present study for classifying people with limited motion may have contributed to the lack of significant frontal plane rearfoot kinematic findings. Further research should be conducted using subjects with passive dorsiflexion range of motion values less than 5° in order to see what effect, if any, a more significant limitation has on rearfoot motion. Other

areas for future research on the consequences of equinus deformity should include the effect on sagittal and transverse plane kinematics and kinetics. Future studies should also focus on areas other than the rearfoot; the effect of limited dorsiflexion on the midfoot and forefoot should also be investigated.

Summary

Reduced passive dorsiflexion range of motion has been cited in the literature as a cause of altered frontal plane rearfoot motion during gait. The results of this study indicate that passive dorsiflexion range of motion values between 5° and 10° result in no significant change in magnitude of frontal plane rearfoot kinematics during the stance phase of gait. There is an alteration in the timing of reinversion of the rearfoot and when heel-off occurs. Greater range-of-motion deficits, however, may result in altered function and therefore should be evaluated by the clinician during a physical examination. The results of the current study indicate that passive dorsiflexion range of motion values between 5° and 10° do not significantly alter a person's frontal plane rearfoot function during walking.

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