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RESEARCH STUDY

Relationship Between Three Static Angles of the Rearfoot and the Pattern of Rearfoot Motion During Walking

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The purpose of this study was to determine the relationship of the static angle of the rearfoot during single leg standing, relaxed standing foot posture, and subtalar joint neutral position with the pattern of rearfoot motion during walking. The authors felt that this study was important to gain a better understanding of the relationship between dynamic rearfoot motion and three static rearfoot angles which are often included in foot examination procedures. The pattern of rearfoot motion was assessed using two-dimensional video recordings for each lower extremity of 31 healthy young adult subjects with a mean age of 25.2 years. The mean path of rearfoot motion during walking crossed relaxed standing foot posture but did not cross single leg standing or subtalar neutral position. These findings suggest that the mean path of rearfoot motion during the first 60% of the walking cycle occurs between the static angles of relaxed standing foot posture and single leg standing. In addition, the static angle of the rearfoot in single leg standing may serve as a clinical indicator of the degree of maximum rearfoot eversion occurring during the walking cycle.

Key Words: *walking, rearfoot, eversion, subtalar joint*

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An understanding of the typical pattern of rearfoot motion during walking is essential for developing the rationale required for the fabrication and utilization of foot orthoses in the management of foot and ankle disorders. Foot orthoses have been described as a primary component in treatment protocols used for individuals with lower extremity dysfunction, including plantar fasciitis (9), hallux valgus (10), and metatarsalgia (8). In addition, the relationship of various static rearfoot positions to the pattern of rearfoot motion during walking would provide important information for planning an examination protocol for the foot and ankle. Clark et al have suggested that excessive eversion of the rearfoot is correlated with various injuries of the lower extremity (1). Thus, knowledge regarding the association of static rearfoot angles to the pattern of rearfoot motion would permit the development of an examination protocol that is more representative of the dynamic movement patterns of the rearfoot.

Wright et al were the first investigators to examine the pattern of rearfoot motion (12). These investigators analyzed the rotation about the axes of the subtalar joint and the ankle (talocrural) joint during walking. To measure motion occurring at these two articulations, Wright et al used two sets of potentiometers positioned in a plaster cast that were aligned to the estimated mechanical axes of the subtalar and talocrural joints (12). Individual joint motion was then recorded in two normal subjects while walking over ground. The patterns of subtalar joint motion were found to be similar for the two subjects. Prior to and at heel contact, the subtalar joint was in an inverted or supinated position. The subtalar joint then underwent the motion of eversion or pronation. Throughout the latter portion of the walking cycle to toe-off, the subtalar joint underwent the motion of inversion or supination. Their results also indicated that both subjects reached subtalar joint neutral position at approximately 70% and 65% of the respective stance phases. For their investigation, Wright et al defined neutral position as "the position of the subtalar and talocrural joints when each subject was standing relaxed with their knees fully extended, the arms at the sides, feet six inches apart, and with a comfortable amount of toeing-out" (12).

While the study conducted by Wright et al was a landmark investigation and provided the first quantitative assessment of subtalar joint motion, there were several problems with their methodology (12). The use of the plaster cast to stabilize the potentiometers on the tested extremity could have affected the subject's walking pattern. The external validity of their study is weakened significantly because they only used two male subjects. Finally, without extensive radiographic procedures, it would be extremely difficult to determine the specific subtalar joint axis for each of the subjects that they tested.

In a more recent study, McPoil and Cornwall evaluated the relationship between two static standing postures and the pattern of rearfoot motion in both feet of 50 healthy, asymptomatic subjects (7). These investigators did not directly measure subtalar joint motion as had been attempted by

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Wright et al in their study. Rather, McPoil and Cornwall measured subtalar motion indirectly by evaluating rearfoot motion, which, as they noted, is most often observed and measured clinically. Each subject was filmed using two-dimensional videography while they walked over a 12-m walkway three times for each extremity. After the walking trials were completed, the static rearfoot postures were filmed while each subject stood in their relaxed calcaneal stance position (standing in a relaxed posture) as well as in their neutral calcaneal stance position (standing with the subtalar joints in neutral position). Rearfoot motion and static position were then digitized and angles calculated for both the left and right feet. Each foot was considered as an individual structure, so 100 feet were evaluated. Based on the results of their study, McPoil and Cornwall described the typical pattern of rearfoot motion as follows: *1)* the rearfoot was slightly inverted prior to heel strike; *2)* from heel strike to foot flat, the rearfoot undergoes the motion of eversion, with the average percent time to maximum rearfoot eversion being approximately 40% of stance phase for the 100 feet; *3)* the motion of rearfoot inversion was initiated after 50% of the stance phase and continued until toe-off; and *4)* the neutral rearfoot position for the typical rearfoot motion pattern was relaxed calcaneal stance position and not neutral calcaneal stance position.

Even though the methodology used for recording rearfoot motion was not the same, the results of the McPoil and Cornwall study were in agreement with the previous findings of Wright et al in that the static angle of the rearfoot that occurs when the individual is in the relaxed standing foot posture does appear to be their neutral rearfoot position during walking. Neutral rearfoot position, according to McPoil and Cornwall, indicates the static rearfoot angle to which dynamic rearfoot motion is referenced during the stance phase of walking.

While previous investigations have examined the relationship between the pattern of rearfoot motion and the static angles of the rearfoot when the individual is positioned in relaxed stance and subtalar neutral position, Hunt has noted the importance of considering the static angle of the rearfoot when the individual is standing on a single leg (4). Hunt states that the angle of the lower leg to the calcaneus is a significant measurement since the weight shift that occurs with single leg standing represents the functional lower leg position that occurs during walking (4). Hunt further recommends that the measurement of the lower leg and its relationship to the calcaneus in single leg standing should be included in the examination of the lower extremity and foot (4). To date, no study has actually examined the relationship between the static angle of the rearfoot in single leg standing and the typical pattern of rearfoot motion during walking.

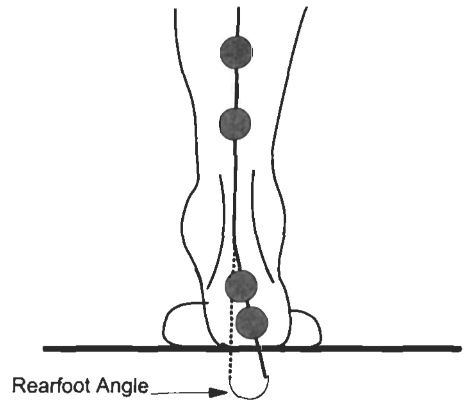

FIGURE 1. *Illustration of the bisection lines used to calculate the rearfoot angle.*

The purpose of this descriptive study was to determine the relationship between the pattern of rearfoot motion during walking to the static angle of the rearfoot as measured in single leg standing, relaxed standing foot posture, and subtalar joint neutral position. For this study, both the dynamic and static rearfoot angles were defined as the angle formed by one line bisecting the reflective markers positioned on the lower leg, and a second line bisecting the reflective markers positioned on the calcaneus (Figure 1). The research hypothesis for this study was that the pattern of rearfoot motion during walking would intersect the angle of the rearfoot in relaxed standing foot posture but would not intersect the rearfoot angle in single leg standing or subtalar joint neutral position.

METHODS

Subjects

Thirty-one young adults, 18 women and 13 men, were selected to serve as subjects for this study. Volunteers with a history of congenital or traumatic deformity to either lower extremity, a history of foot pain, or a traumatic injury to the ankle or foot 12 months prior to the start of data collection were excluded from the list of possible subjects. Furthermore, subjects determined by a visual examination to have severe foot deformities, such as pes cavus, pes planus, or hallux abducto valgus, were also excluded from selection. The mean age of the 31 subjects was 25.6 years with a standard deviation of 4.2 years. The testing procedures were approved by the Institutional Review Board at Northern Arizona University, Flagstaff, AZ, and all subjects signed an informed consent form prior to participation.

FIGURE 2. *The subject positioned in double-limb support for videotaping of the static rearfoot angles relaxed standing posture and subtalar joint neutral position.*

FIGURE 4. *The subject positioned in single limb standing for the videotaping of the static rearfoot angle in single leg standing.*

Equipment

A super VHS video camcorder filming at a speed of 60 fields per second was used to record two-dimensional rearfoot motion. The video recordings of rearfoot motion were digitized using the Peak Performance Technologies (Peak Performance Technologies, Englewood, CO) automated digitization software. Prior to filming, the camera was calibrated using a known linear distance in the field of view to correct for any lens aberrations that might affect movement measurements. Finally, the accuracy of our filming and digitizing procedures were assessed by filming a series of known angular measurements. The results of this test showed a difference of less than .5° between all of the calculated and actual measurements obtained.

Procedures

Each subject was first asked to lie prone so that the lower one-third of their leg and calcaneus could be bisected bilaterally using a felt-tip pen. All bisections were performed by the same investigator (TGM). Once the bisection lines were completed, the subject was instructed to practice walking over a 10-m walkway for 15–20 minutes. The subject was told not to look down at the walkway while practicing and was constantly observed by the investigators during the practice period. Gait velocity was monitored during the practice walking session by means of two-timing lights positioned 4.87 m apart. Once the subject's between-trial stance phase durations were consistent (variation of 30 msec or less for 10 consecutive practice trials), four reflective markers were positioned bilaterally with two-way tape to the end points of the previously drawn bisection lines on the lower leg and calcaneus (Figure 2). The subject was then asked to walk barefoot over the walkway so that rearfoot motion could be videotaped for three separate trials at the midpoint of the walkway for each lower extremity (Figure 3). To prevent camera distortion, each lower extremity was filmed individually. Thus, each subject was required to walk six times. The video camcorder was positioned 5 m from the midpoint of the walkway and at a vertical height of 28 cm from the floor. During video data collection, stance phase durations were continuously monitored. Those trials in which the stance phase duration varied by more than 30 msec were repeated.

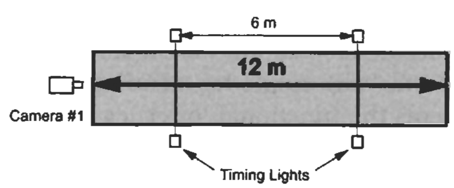

FIGURE 3. *Illustration of the position of the video camera and timing lights in relation to the walkway.*

Upon completion of the walking trials, each subject was asked to stand in double-limb support at the midpoint of the walkway and static video data of the reflective markers were recorded while the subject was positioned *1)* in their relaxed standing foot posture (Figure 2) and *2)* while standing in subtalar joint neutral position. The method described by McPoil and Brocato, in which palpation was used to place the medial and lateral aspects of the talar head in congruence with the navicular by having subjects elevate or lower their medial longitudinal arch during standing, was used to position the subtalar joint in neutral (6). All subtalar joint neutral position placements were performed by the same investigator (TGM).

Once completed, the subject was then asked to assume a single leg standing position (Figure 4). To ensure that the subject accomplished the one-leg stand by shifting the pelvis laterally over the support leg, the subject was asked to repeat the lateral pelvic shift several times while being observed by the same investigator (TGM). To prevent extrinsic muscle use to maintain body balance during the recording of one-leg standing, subjects were allowed to place their hands on a chair for stability.

Data Analysis

The video recordings of the three trials of rearfoot motion for each lower extremity were digitized using the Peak Performance software. Recognizing the problems associated with two-dimensional analysis of the rearfoot, each trial was digitized for the period starting six video fields prior to heel strike and ending 5–10 video fields after the first indication of heel-off. Thus, only the initial 60% of the rearfoot motion pattern during walking was analyzed. This limitation on the digitization of the two-dimensional video recordings was considered necessary to minimize distortion of the reflective markers placed on the lower leg and calcaneus, secondary to external rotation of the lower leg which occurs rapidly after the heel begins to leave the ground (3). Furthermore, Cornwall and McPoil have demonstrated that there are minimal differences between two-dimensional and three-dimensional recording of rearfoot motion as long as the analysis of the two-dimensional rearfoot motion does not extend beyond 60% of the stance phase of walking (2). The static video recordings of single leg standing, relaxed standing foot posture, and subtalar joint neutral position were also digitized.

A software program was written to connect the four digitized reflective markers and create bisection lines. The software then calculated the vertex formed by the two lines and the relative degrees of movement between the lower leg and calcaneus. The following variables were calculated from the resulting rearfoot motion data for each trial analyzed: stance phase duration, maximum rearfoot eversion, time to maximum rearfoot eversion, time to heel-off, and the rearfoot angle at heel strike.

The rearfoot motion pattern of each subject's extremity was calculated by first normalizing the data with respect to their stance phase duration and then averaging across trials. The mean rearfoot motion pattern for the initial 60% of stance phase for all 62 feet was also determined in a similar manner.

Statistical Analysis

To determine between-trial reliability of the stance phase durations and the rearfoot motion variables for each subject, type 2,1 intraclass correlation coefficients (ICCs) were calculated on the three trials for each of the 62 feet (11). Means and standard deviations were calculated for all of the variables as well as relaxed standing foot posture, subtalar joint neutral position, and single leg standing. Finally, Pearson product moment correlations were computed to determine the relationship of relaxed standing foot posture, subtalar joint neutral position, and single leg standing with the maximum rearfoot eversion angle.

RESULTS

The mean stance phase duration for all 62 feet was 0.653 seconds with a standard deviation of 0.058 seconds. The means and standard deviations for all other variables are listed in the Table. The resulting ICCs were .99 for stance phase duration, .98 for maximum rearfoot eversion, .68 for time to maximum rearfoot eversion, .96 for time to heel-off, and .97 for heel strike angle. The means and standard deviations for the three static rearfoot angles and the angle of maximum rearfoot eversion are listed in the Table. The mean pattern of rearfoot motion for the first 60% of stance phase as well as the mean angles for relaxed standing foot posture, subtalar joint neutral position, and single leg standing for the 62 feet are plotted in Figure 5. The results of the correlation coefficients, calculated to determine the degree of association between maximum rearfoot eversion and the three static rearfoot angles, are listed in the Table.

	$\bar{X}$	SD	Correlation Coefficients
Relaxed standing foot posture	3.7°	3.6°	.83
Subtalar joint neutral position	1.2°	3.7°	.58
Single leg standing	7.2°	3.0°	.81
Maximum rearfoot eversion	6.3°	3.2°	

TABLE. *Means, standard deviations, as well as correlation coefficients, indicating the degree of association between maximum rearfoot eversion and the three static rearfoot angles.*

DISCUSSION

The first issue in analyzing the results of this study is the between-trial reliability of the stance phase durations. Variations in walking cadence between the three trials for each foot could have affected the averaged rearfoot motion pattern. Based on the ICCs reported, the authors felt that the protocol used in this investigation was effective in maintaining consistency in the stance phase durations for each subject's foot. The second issue of concern is the between-trial reliability of maximum rearfoot eversion, time to maximum rearfoot eversion, time to heel-off, and heel strike angle. Inconsistencies in these four dynamic motion variables could indicate experimental error caused by the digitization of the video data or extreme variability of the rearfoot motion patterns. The characterizations of the ICCs for the four variables, which ranged from .98 to .68, would be considered substantial to almost perfect according to the criteria established by Landis and Koch (5). Based on these results, the authors believe that the level of experimental error

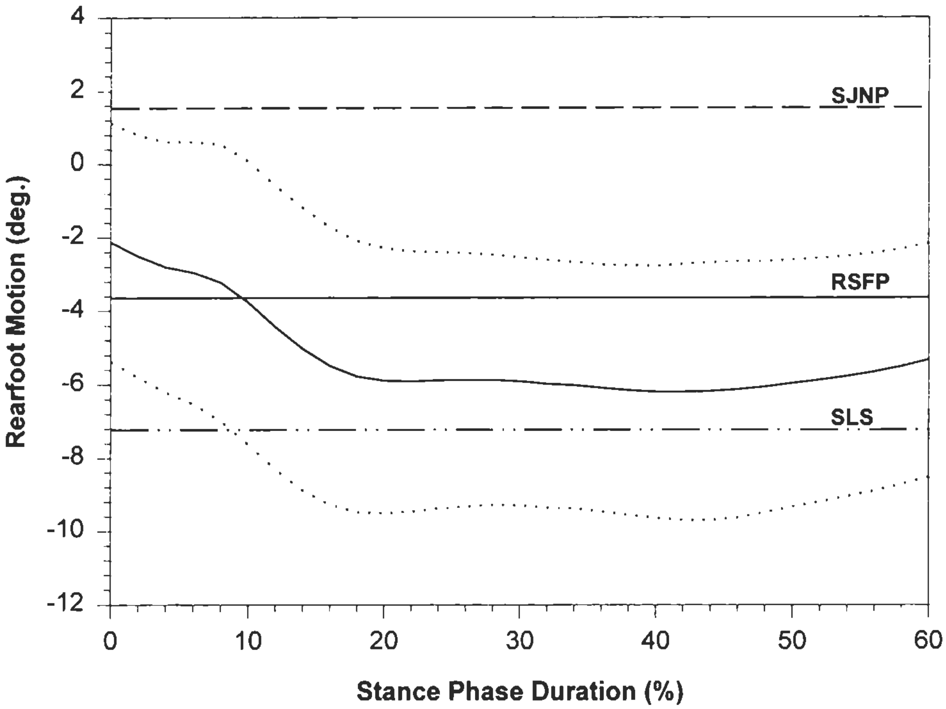

FIGURE 5. *Plot of the mean pattern of rearfoot motion as well as the mean rearfoot angles for relaxed standing foot posture (RSFP), subtalar joint neutral position (SJNP), and single leg stand (SLS) for the 62 feet. The two dashed lines represent plus or minus one standard deviation from the mean pattern of rearfoot motion.*

was minimal and further analysis of the data could be conducted to answer the proposed research question.

The purpose of this study was to determine the relationship between the pattern of rearfoot motion during walking to the static angle of the rearfoot in single leg standing, relaxed standing foot posture, and subtalar joint neutral position. The results of this investigation indicate that the mean path of rearfoot motion for the first 60% of the walking cycle did intersect the relaxed standing foot posture but did not intersect single leg standing in any of the 62 feet studied (Figure 5). In addition, the path of rearfoot motion did not intersect subtalar joint neutral position for any of the 62 feet studied. Based on these findings, the authors failed to reject the research hypothesis.

The results of this investigation are in agreement with the findings reported by McPoil and Cornwall with regard to the fact that the mean path of rearfoot motion did not pass through subtalar joint neutral position but did intersect relaxed standing foot posture (7). The fact that the mean path of rearfoot motion did not intersect single leg standing and that single leg standing has a high degree of association with the maximum pronation angle indicates that single leg standing may serve as a possible indicator of the degree of maximum rearfoot eversion occurring during the stance phase of walking. Furthermore, these findings would support the inclusion of the evaluation of the angle between the calcaneus and lower leg in single limb standing as proposed by Hunt (4).

The results of this study may also have important implications for the function of foot orthoses in the treatment of foot and ankle disorders. A major dilemma for the clinician is determining the degree of rearfoot motion control that should be provided by foot orthoses. The relationship between relaxed standing foot posture and single leg standing and the path of rearfoot motion that was demonstrated in this study may provide a criteria for the clinical estimation of rearfoot motion control, especially if further research determines that relaxed standing foot posture and single leg standing can be used as strong predictors of a patient's pattern of rearfoot motion.

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A limitation of this investigation was that the authors could not directly measure subtalar joint motion during walking. The authors, however, believe that they were able to effectively measure subtalar joint motion indirectly by evaluating rearfoot motion. It should be noted that rearfoot motion is most often observed by the clinician when assessing patients with foot problems in the clinical setting.

A second limitation which the clinician must be aware of when interpreting these results was the subject population used for this study. While the subjects selected would be representative of a population of individuals who could develop orthopaedic foot problems related to activities of daily living or recreational sports endeavors, they did not exhibit severe foot deformities which might be found in patients with systemic diseases, such as rheumatoid arthritis or geriatric patients with long term degenerative changes to their foot structure. In cases of severe foot deformity, the relationship between relaxed standing foot posture and single leg standing that was observed in the present investigation could be drastically different because of prolonged abnormal stresses to soft tissues and osseous structures within the foot.

CONCLUSIONS

The findings of this investigation indicate that the mean path of rearfoot motion during walking primarily occurs between the static angle of relaxed standing foot posture and single leg standing during the first 60% of the walking cycle. In addition, the static angle of the rearfoot in single leg standing may serve as a possible indicator of the degree of maximum pronation occurring during the walking cycle. JOSPT

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