©Journal of Sports Science and Medicine (2005) **4,** 332-341
http://www.jssm.org

Young investigator
Research article

AN INVESTIGATION OF A REFERENCE POSTURE USED IN DETERMINING REARFOOT KINEMATICS FOR BOTH HEALTHY AND PATELLOFEMORAL PAIN SYNDROME INDIVIDUALS

Pazit Levinger ✉ and Wendy Gilleard

Southern Cross University, NSW Australia

Received: 05 January 2005 / Accepted: 19 May 2005 / Published (online): 01 September 2005

ABSTRACT
The choice of a reference posture is important when investigating rearfoot motion in clinical populations. The reference posture used may affect the magnitude of the peak angles and therefore may not enable comparison of the rearfoot kinematics across different populations. This study examined the relationship between the rearfoot frontal plane pattern of motion and three reference postures during the stance phase of walking in healthy and patellofemoral pain syndrome (PFPS) subjects. The three reference postures investigated were: Relaxed Standing posture, subtalar joint neutral position (STJN) and when the calcaneus and the lower leg were vertically aligned (Vertical Alignment). The rearfoot inversion/eversion during the stance phase was measured in 14 healthy subjects and 13 subjects with diagnosed PFPS using three dimensional motion analysis with the three different reference postures. The graphs of rearfoot inversion/eversion motion were overlaid with the angle at the rearfoot in the static posture and any intersection between the static angle and rearfoot motion was noted. An ANOVA showed significant differences in static posture between the groups for Relaxed Standing ($p = 0.01$), and STJN ($p = 0.02$). For both groups, with Relaxed Standing as a reference posture, the mean rearfoot pattern of motion did not intersect the Relaxed Standing static angle during the stance phase. The use of Vertical Alignment reference posture, however, showed an intersection of this reference posture through the rearfoot pattern of motion. The use of the Vertical Alignment reference posture also generated a typical rearfoot motion pattern for both groups and therefore it may be an appropriate reference posture for both healthy and PFPS individuals.

KEY WORDS: Vertical alignment, subtalar joint neutral position, rearfoot motion, reference posture.

INTRODUCTION

The rearfoot motion measurement relative to the lower leg during walking reported in the literature is affected by the reference posture used by the investigators. Using a different reference posture may influence the absolute peak magnitude of the rearfoot motion as well as the rearfoot angle at heel strike (Cornwall and McPoil, 1999). The common reference postures used in the literature are Relaxed Standing (Cornwall and McPoil, 1999; Hunt et al., 2001b; Leardini et al., 1999; McPoil and Cornwall, 1994; Scott and Winter, 1991; Wright et al., 1964), positioning of subtalar joint in neutral (STJN)

(Pierrynowski and Smith, 1996) and when the posterior calcaneus is vertical to the posterior lower leg (Vertical Alignment) (Donatelli et al., 1999; Liu et al., 1997; McClay and Manal, 1998; Moseley et al., 1996).

The Relaxed Standing posture was used as a reference posture by Wright et al (1964) who showed that the subtalar joint was in the same position at mid stance and during relaxed standing. Support for Wright et al results was given by McPoil and Cornwall (1994) who showed that the angle of the rearfoot during the Relaxed Standing posture intersected graphically through the stance phase rearfoot pattern of motion. The angle of the rearfoot in Relaxed Standing posture intersected with the rearfoot motion pattern at the beginning of stance at approximately 5% - 10% and at the termination of stance at approximately 63% (McPoil and Cornwall, 1994; 1996a; Wright et al., 1964). It was suggested therefore that investigators should use the Relaxed Standing posture of the calcaneus as this posture represents a subtalar neutral position which occurs during typical rearfoot motion while walking (McPoil and Cornwall, 1994; 1996b; Pierrynowski and Smith, 1996; Wright et al., 1964).

Pierrynowski and Smith (1996) reported that when using STJN as a zero reference posture for the gait cycle, the rearfoot angle in STJN did not intersect through the rearfoot pattern motion during the stance phase. The STJN angle, however, did intersect with the rearfoot pattern motion during the swing phase. They therefore concluded that STJN should not be used as a reference posture for measuring rearfoot motion in healthy subjects.

The Vertical Alignment method for use in determining rearfoot patterns of motion has not been similarly investigated. The concept of vertical alignment between the posterior rearfoot and lower leg was thought to represent the “ideal” physical relationship of bony segments (Lee, 2001; Root et al., 1977). Root et al (1977) suggested that the “ideal foot” should be when the subtalar joint neutral position is aligned or vertical with the vertical bisection line of the distal lower leg. This reference posture will also enable normalisation to the same zero reference posture for the rearfoot relative to the tibia in the frontal plane, thus, enabling inter-group comparison. Further research, however, is needed to examine the relationship of the rearfoot pattern of motion during stance phase and the rearfoot angle in this posture when using the Vertical Alignment as a reference posture.

The use of an appropriate reference posture for investigating the rearfoot motion in a clinical population with foot and lower leg pathology may be important in order to correctly display atypical motion during ambulation. Using the Relaxed Standing posture as the typical subtalar neutral position in subjects with abnormalities of the lower leg and foot, such as excessive pronation, may eliminate the appearance of compensation in the rearfoot during walking. The suggested use of the Relaxed Standing posture as a neutral posture has only been investigated for a healthy population (McPoil and Cornwall, 1994). It is possible that for subjects with foot and knee pathology the use of another reference posture may be more applicable. Further research is needed to investigate the most suitable reference posture for subjects with lower leg and foot pathologies in order to enable comparison of rearfoot kinematics across healthy and clinical populations.

Abnormal subtalar joint motion particularly has been suggested to lead to patellofemoral pain syndrome (PFPS) (Tiberio, 1987). Excessive rearfoot eversion may lead to abnormal knee internal rotation which may possibly translate to greater stresses on the knee structures and may also alter patella tracking, (Donatelli, 1987; Tiberio, 1987) however studies to date have been inconclusive. As such, investigating the use of different reference postures in this clinical population may reveal differences in the rearfoot kinematics in further studies.

Although previous studies investigated the Relaxed Standing and the STJN as reference postures, the test retest reliability of the reference postures was not addressed (Cornwall and McPoil, 1999; Hunt et al., 2001b; Leardini et al., 1999; McPoil and Cornwall, 1994; Pierrynowski and Smith, 1996; Wright et al., 1964). Investigation of the test retest reliability of kinematic gait measurements is well documented, (Carson et al., 2001; Ferber et al., 2002; Kadaba et al., 1989), however, little attention has been given to the influence of the reliability of the reference posture on foot kinematics.

The purpose of this study was to examine the effect of three reference postures: Relaxed Standing posture, STJN and Vertical Alignment on the rearfoot frontal plane pattern of motion during the stance phase of walking in healthy and PFPS subjects. Additionally, the test retest reliability of the Relaxed Standing and STJN reference postures was investigated. The null hypothesis was that regardless of the reference posture used no difference would be found for both groups in the rearfoot frontal plane pattern of motion.

METHODS

Fourteen females with no history of congenital or traumatic deformity to their lower extremity (knee or foot) with a mean age 25.9 (7.8) years, weight 61.3

(7.6) kg and height 1.66 (0.07) m were recruited as the control group. Thirteen females with diagnosed PFPS with a mean age, weight and height of 38.4 (10.1) years, 70.6 (18.2) kg and 1.66 (0.06) m formed the clinical group. The PFPS subjects either had not received treatment prior to testing or treatment was not recent to the testing and the subjects were still symptomatic. The subjects from both groups were physically active and participated in similar sporting recreational activities for a mean of 3.0hr for the PFPS and 4.1hr for the control group per week. PFPS subjects had unilateral symptoms as diagnosed by an independent physiotherapist on their right knee for at least 1.5 years (mean of 11 years; range 1.5-30 years). The diagnosis of PFPS was based on the complaint of retropatellar pain that was provoked during weight bearing activities such as running, squatting, kneeling, ascending stairs and descending stairs as well as after prolonged sitting (Fulkerson, 1997; McConnell, 1986) and a physical examination. The physical examination also included tests for exclusion of other conditions, such as, knee joint malfunction (Magee, 2002) and observation of biomechanical malalignment (Magee, 2002). Subjects with traumatic injury in the patellofemoral joint, patellar tendonitis (jumper's knee), previous surgery, ligaments and meniscus disorders, severe knee deformities, such as, genu valgum/genu varum, severe foot deformities, such as, pes cavus and pes planus or hallux valgus (Magee, 2002) were also excluded from the study. Ten subjects from the control group were tested on two occasions, one week apart, in order to investigate the test retest reliability of the Relaxed Standing and STJN reference postures. Subjects were recruited by advertisements placed around the university campus. Prior to participation, all subjects were informed about the nature of the study and signed an informed consent, which was approved by the Human Ethics Committee of Southern Cross University (ECN-02-101).

With the subject prone and their foot (to be measured) hanging 15-20 cm over the end of the table, the examiner bisected the posterior lower leg and the posterior calcaneus using Sliding Calipers (Elveru et al., 1988b; Wooden, 1990). Inversion/ eversion motion of the rearfoot relative to the tibia was investigated by attaching external retro-reflective markers to a tibia shell (Manal et al., 2000) and the calcaneus. An individual tibia shell (20.5cm x 9 cm, 0.08kg), made of heated polyform material, (Rolyan), similar to Manal et al (2000), was located at the lateral distal one third of the shank length while the subject was sitting with the tibia perpendicular to the floor. Sports tape was placed around the shank over the shell in order to maintain the position of the tibia shell. The rearfoot segment was defined by three 6-mm diameter external markers on the calcaneus. Two markers were placed on a line on the posterior aspect of the calcaneus, which bisected the heel in the frontal plane, one marker on the upper ridge and the second on the lower ridge. A third marker was positioned on the lateral aspect of the calcaneus, approximately mid point between markers one and two (McClay and Manal, 1998) (Figure 1). All the foot markers were attached directly to the calcaneus during weight bearing (resting standing) to decrease the error between skin marker and skeletal location (Maslen and Ackland, 1994). Four 1.2-cm diameter reflective markers were attached to the shell similar in position to Manal et al (2000). The first marker was located 30% of the shank length proximal to the lateral malleolus. Then the three markers remaining were positioned with a 20% of the shank length being the vertical and horizontal spacing between the four markers in lateral and anterior positions (Manal et al., 2000) (Figure 1).

Figure 1. Marker set on the calcaneus and on the tibia shell.

Four video cameras (Panasonic WV-CL830/G colour CCTV) were used to record the external markers for each reference postures and during the stance phase of walking gait at 50 Hz with a shutter speed of 1/2000s. Prior to each test session the data collection area was calibrated and defined using a 16-point calibration object. Direct Linear Transformation (DLT) was used to obtain 3D coordinate data from multiple 2D views. An error of less than 0.5% of the three-dimensional DLT percent object space calibration was considered acceptable (Peak Performance Technologies, Peak Motus, version 7, user manual). Walking took place on a 10m walkway, which had an embedded force platform (sampling frequency of 1000Hz , Kistler, type 9287) centrally placed which was used to define the stance phase.

Prior to the walking trials, three different reference standing postures used for further calculation of the stance phase kinematic data were initially recorded for two seconds including: Relaxed Standing posture, STJN and Vertical Alignment. Relaxed Standing posture was defined as when the subject stood relaxed in a comfortable position. Positioning the subtalar joint in neutral during standing for STJN was done as described by McPoil and Brocato (1985). When the head of the talus was felt equally between the lateral and medial sides, the subtalar joint was in neutral position. The third reference posture was achieved when the subjects elevated or lowered their medial longitudinal arch when standing with full knee extension. The examiner visualised when the bisection lines of the calcaneus and the lower leg become vertically aligned (Vertical Alignment) and the frontal plane alignment of the rearfoot relative to the tibia was recorded. The axis was then mathematically rotated (Hunt and Smith, 2004; Hunt et al., 2001a) through the individual's angle recorded in the frontal plane. Rotation of the rearfoot vertical axis enables normalisation to the same zero reference posture for the rearfoot relative to the tibia in the frontal plane for Vertical Alignment reference posture.

Following multiple practice trials, five acceptable walking trials in bare feet at a self selected speed were recorded. Subjects were instructed not to look down while walking but to maintain visual contact with an eye level on a marker located on the far wall to maintain natural gait. Trials were considered acceptable when the subjects' right foot landed on the force plate with no disturbances to the subjects' walking rhythm during the trials. Gait velocity was monitored during the walking session by using two light gates (Swift Performance Equipment) placed approximately six metres apart. After each trial the gait velocity was noted.

Peak Motus (version 7) software was used to capture and optimally filter (cutoff determined by Jackson knee method using a Quintic Spline processor) the 3D trajectories of each marker. The inter-segment angles were calculated according to Grood and Suntay (1983) and similar to Manal et al (2000). Using the vertical GRF, the stance phase data were time normalised such that heel strike was 0% and toe off was 100% and the data were ensemble averaged.

The mean of the five trials for each subject was used in further analysis. An ANOVA was used to assess angular differences in the Relaxed Standing and Vertical Alignment reference postures between the groups at a 0.05 level of significance. The method of determining the appropriate reference posture was similar to that used in previous studies (McPoil and Cornwall, 1994; Pierrynowski and Smith, 1996). The graphs of rearfoot inversion/ eversion motion were overlaid with the angle at the rearfoot in the static posture, and any intersection between the graphs was noted (example shown in Figure 2). Intraclass Correlation Coefficient (ICC), Percent Close Agreement (PCA) and the Standard Error of the Measurement (SEM) were used to assess test retest reliability for the Relaxed Standing and STJN static reference postures. Test retest reliability of the Vertical Alignment reference posture and differences between the groups were not calculated as the rotation of the angle resulted in a zero value in both cases.

RESULTS

For both groups, with Relaxed Standing as a reference posture, the mean rearfoot pattern of motion did not intersect the Relaxed Standing static angle during the stance phase (Figure 2A and 3A). With the STJN as a reference posture, the STJN static angle intersected the mean rearfoot motion for the control group at 14% and 85% of the stance phase although for the clinical group, there was no intersection (Figure 2B and 3B). For the Vertical Alignment reference posture the Vertical Alignment static angle intersected the rearfoot mean motion for both groups (at approximately 20% and 83% for the control group and at approximately 87% for the clinical group) as seen in Figure 2C and 3C. The rearfoot pattern of motion was in inversion most of the stance phase when the Relaxed Standing posture was used as a reference posture for both groups (Figure 2A and 3A). When using the STJN reference posture the rearfoot was in eversion most of the stance phase only for the control group (Figure 2B and 3B). For both groups however the rearfoot was in eversion for most of the stance phase when the Vertical Alignment reference posture was used as seen in Figures 2C and 3C.

A one way ANOVA showed no significant difference in the average velocity between the groups ($p = 0.288$) with mean 1.36 $ms^{-1} \pm 0.10$ for the control and 1.40 $ms^{-1} \pm 0.08$ for the PFPS group. Results from the ANOVA showed significant differences between the groups for Relaxed Standing ($p = 0.01$) and STJN ($p = 0.02$). For the control group the static rearfoot angle using the Relaxed Standing posture was 2.5° (3.1), and -0.7° (3.9) for STJN (Figure 2). A positive value indicated eversion and a negative value indicated inversion. For the clinical group, the static angle using the Relaxed

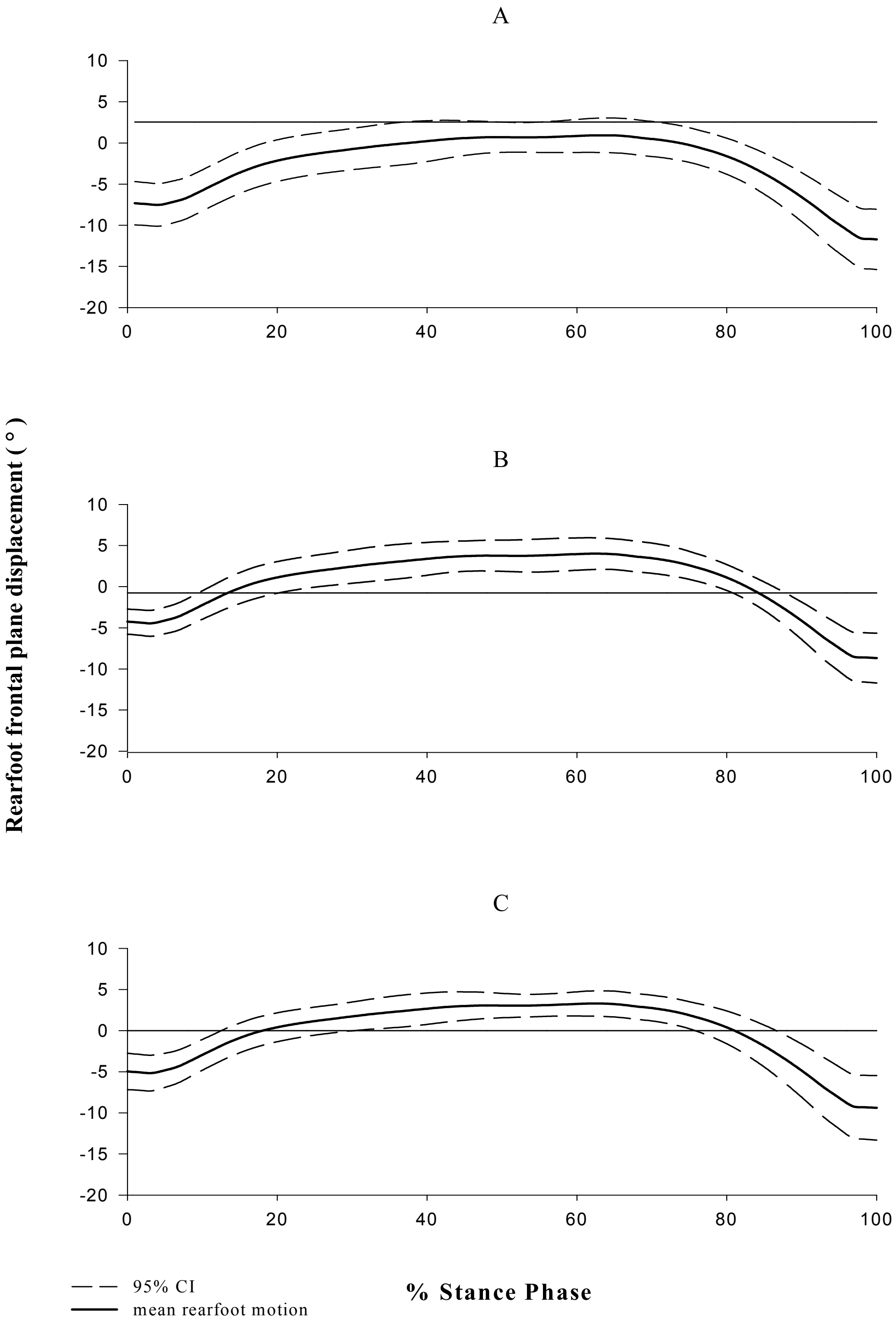

Figure 2. Mean ± 95% Confidence Intervals of rearfoot inversion/eversion of the control group during stance phase when the Relaxed Standing (A) STJN (B) and Vertical Alignment (C) were used as a reference posture. Positive values indicate eversion.

Standing posture was 7.0° (3.3), and 4.9° (4.6) for STJN (Figure 3).

The test retest reliability were ICC (3,1) = 0.32 for Relaxed Standing and ICC (3,1) = 0.10 for STJN. The PCA between tests for both Relaxed Standing and STJN showed 70% of the values were within 4° of agreement for the control group. The SEM for test retest showed values of 3.65° and 4.14° for Relaxed Standing and STJN reference postures respectively. The test-retest reliability for walking trials velocity showed ICC (3,1) = 0.71 and the PCA showed 100% of the values were within $0.1 ms^{-1}$ of agreement with Standard Error of the Measurement of $0.04\ ms^{-1}$.

DISCUSSION

The typical rearfoot pattern of motion shape was similar to previous reports (Cornwall and McPoil, 1999; Liu et al., 1997; McMClay and Manal, 1998;

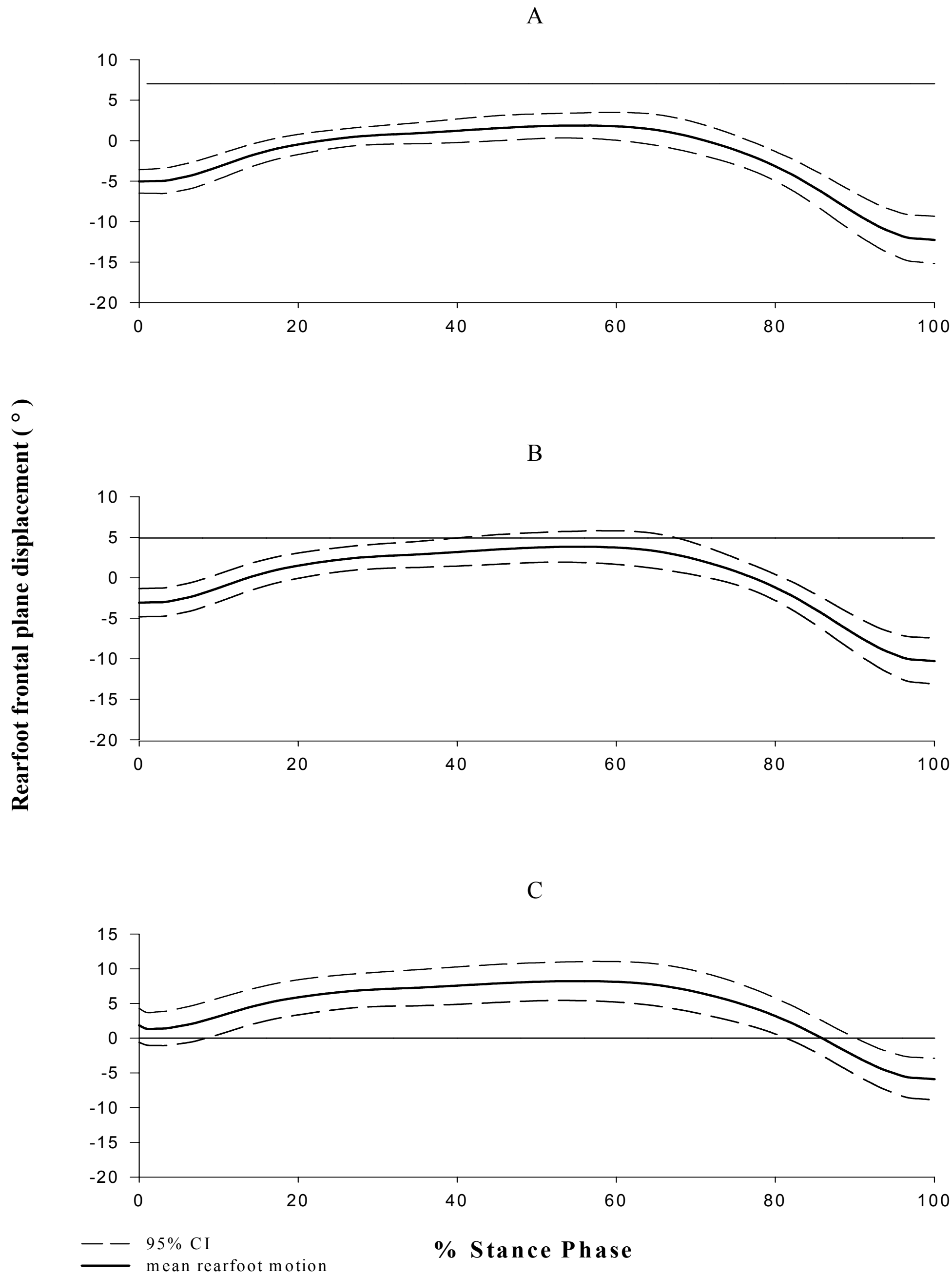

Figure 3. Mean ± 95% Confidence Intervals of rearfoot inversion/eversion of the clinical group during stance phase when the Relaxed Standing (A) STJN (B) and Vertical Alignment (C) were used as a reference posture. Positive values indicate eversion.

McPoil and Cornwall, 1994; Moseley et al., 1996; Wright et al., 1964) with differences in the magnitude of the peak angle related to the reference postures used. The use of the three reference postures resulted in shifting of the curve of the rearfoot frontal plane pattern of motion. The shift of the curve is important in identifying the magnitude of rearfoot peak motion during the stance phase. The position of the curve is also important in defining the direction of the motion. As evidenced by Figures 2 and 3, the rearfoot frontal plane of motion relative to the Relaxed Standing posture showed in both groups as remaining in an inversion displacement in most of the stance phase in contrast to previous reports (Cornwall and McPoil, 1999; Hunt et al., 2001b; Knutzen and Price, 1994; Liu et al., 1997; McClay and Manal, 1998; McPoil and Cornwall, 1994; Moseley et al., 1996; Wright et al., 1964). Differences to the literature may be the mathematical result of subjects with mildly inverted and everted foot posture in the control group and an everted foot in the PFPS group. When using the Vertical Alignment reference posture, however, the rearfoot frontal plane of motion for both groups were everted for most of the stance phase as previously reported (Cornwall and McPoil, 1999;

Hunt et al., 2001b; Knutzen and Price, 1994; Liu et al., 1997; McClay and Manal, 1998; McPoil and Cornwall, 1994; Moseley et al., 1996; Wright et al., 1964). The rearfoot motion during heel strike for the clinical group tended to be in a slight eversion which may be related to the significantly everted posture seen during Relaxed Standing. Regardless, the overall pattern of the rearfoot frontal plane motion when the Vertical Alignment reference posture used was generally similar to previous reports. Hence, in order to obtain typical rearfoot frontal plane motion, the reference posture used must be considered. The Vertical Alignment reference posture only, resulted in the previously reported rearfoot frontal plane of motion during walking for both groups.

Previous studies investigating the choice of reference postures reported that the Relaxed Standing posture intersected with the rearfoot pattern motion (McPoil and Cornwall, 1994) and that the STJN did not intersect the rearfoot pattern motion (Pierrynowski and Smith, 1996) which was in contrast to the present study. The results from the present study also showed that the static angle of the rearfoot, when the subtalar joint was positioned in neutral and not the rearfoot angle in Relaxed Standing intersected the rearfoot motion in the control group. It is possible that the differences in results are related to the marker set and the method of angular decomposition. In the current study, similar timing to McPoil and Cornwall (1994) and Pierrynowski and Smith (1996) of intersected points with the rearfoot motion curve were found in the control group for Vertical Alignment and STJN reference postures.

The non-intersection for the PFPS group with the Relaxed Standing and STJN angles may be a result of a significantly larger magnitude of the static rearfoot angle in the clinical group compared to the control group. The larger magnitude indicated a moderately valgus position of the calcaneus relative to the lower leg for subjects with PFP in comparison to the control group. A value of more than 6° of rearfoot eversion in Relaxed Standing also suggests that PFPS group had a moderately pronated foot (Subotnick, 1975) and is further discussed in Levinger and Gilleard (2004). The static angle of the rearfoot in Vertical Alignment posture, however, intersected the rearfoot motion when it was used as a reference posture, suggesting that the Vertical Alignment reference posture may be applicable for the clinical population in the current study. Further research is required to examine Vertical Alignment as a reference posture and its relationship to the rearfoot motion in different populations with foot abnormities. Additionally, the Vertical Alignment reference posture is also based on heel bisection similar to the other reference postures. As such, the problems associated with reliability of heel bisection and the issue of skin movement when moving from prone to standing needs further research.

The between tests reliability for the Relaxed Standing and STJN reference postures for the control group showed low reliability and SEM which was proportionally high. It was unexpected that the Relaxed Standing reference posture would show low reliability since this posture required no directed posture modification by the subjects. Standing in a comfortable position therefore may be different each time the subject is required to do so, indicating no consistent posture pattern from day to day. STJN reference posture also showed similar reliability. It is also possible that the reference postures may have been affected by the amount of toe-out and toe-in as the angle calculation used a floating anterior-posterior axis. Therefore any frontal plane variation from test to test such as toe-out and toe-in may have affected the angular values. As subjects were required to elevate and lower their arch during STJN, the toe-out position of the foot may be changed. Similarly, in Relaxed Standing the amount of toe-out was not controlled in order to allowed natural posture. Error due to skin movement in the skin-mounted markers may have existed which may have also affected the reliability of the measurements. Previous studies that reported test retest reliability for dynamic motion (Carson et al., 2001; Ferber et al., 2002; Kadaba et al., 1989) have not reported the static reference postures reliability. The lack of reported reliability for reference posture makes comparison to previous studies difficult and further research is warranted. The use of Relaxed Standing and STJN as reference postures, however, would not be recommended due to their poor test retest reliability.

Although the rearfoot dynamic motion calculated using the STJN reference posture followed the typical rearfoot motion for the control group, the reliability of positioning the subtalar joint in neutral during standing has been shown to be equivocal among researchers (Diamond et al., 1989; Freeman, 1990; Picciano et al., 1993; Pierrynowski et al., 1996; Sell et al., 1994; Smith-Oricchio and Harris, 1990). In order to place accurately and consistently the subtalar joint in neutral the examiner should have the knowledge and the experience in the method of measuring subtalar joint neutral (Diamond et al., 1989; Elveru et al., 1988b; Picciano et al., 1993; Pierrynowski et al., 1996). As a result, different values for STJN may be obtained by different examiners, and as a consequent, variation between testers may affect clinical applications and treatment (Boone et al., 1978; Elveru et al., 1988a). Additionally, when positioning the subtalar joint in neutral during standing the subject was required to actively elevate or lower their medial longitudinal arch (McPoil and Brocato, 1985) and to maintain this posture while they were videoed. It is possible that difficulty in maintaining the position during standing may also affect the accuracy of positioning the subtalar joint in neutral. Therefore the use of STJN would not be recommended. Positioning the lower leg and the rearfoot in Vertical Alignment can be observed without palpation or passive intervention by the examiner and therefore may be more applicable for rearfoot kinematics.

CONCLUSIONS

To enable comparison of the rearfoot kinematics across different populations such as healthy subjects and clinical subjects, the same reference posture should be used. According to our data for both groups the use of Vertical Alignment reference posture showed an intersection of this reference posture through the rearfoot pattern of motion as well as the published typical rearfoot pattern of motion in the frontal plane. Therefore the Vertical Alignment reference posture may be an appropriate reference posture for further study of rearfoot motion for both groups. In addition, positioning the calcaneus in a Vertical Alignment to the lower leg requires less expertise and therefore may lead to improved reliability. Further research is required to address the use of the Vertical Alignment as a reference posture due to its reliance on heel bisection.

REFERENCES

Boone, D.C., Azen, S.P., Lin, C.M., Spence, C., Baron, C. and Lee, L. (1978) Reliability of goniometric measurement. *Physical Therapy* **58**, 1355-1360.

Carson, M.C., Harrington, M.E., Thompson, N., O'Connor, J.J. and Theologis, T.N. (2001) Kinematic analysis of a multi-segment foot model for research and clinical applications: a repeatability analysis. *Journal of Biomechanics* **34**, 1299-1307.

Cornwall, M.W. and McPoil, T.G. (1999) Three dimensional movement of the foot during the stance phase of walking. *Journal of American Podiatric Medical Association* **89**, 56-66.

Diamond, J.E., Mueller, M.J., Delitto, A. and Sinacore, D.R. (1989). Reliability of a diabetic foot evaluation. *Physical Therapy* **69**, 797-802.

Donatelli, R. (1987) Abnormal biomechanics of the foot and ankle. *Journal of Orthopaedic and Sports Physical Therapy* **9**, 11-16.

Donatelli, R., Wooden, M., Ekedahl, S.R., Wilks, J.S., Cooper, J. and Bush, A.J. (1999). Relationship between static and dynamic foot postures in professional players. *Journal of Orthopaedic and Sports Physical Therapy* **29**, 316-330.

Elveru, R.A., Rothstein, J.M. and Lamb, R.L. (1988a) Goniometric reliability in a clinical setting: subtalar and ankle joint measurements. *Physical Therapy* **68**, 672-677.

Elveru, R.A., Rothstein, J.M., Lamb, R.L. and Riddle, D.L. (1988b) Methods for taking subtalar joint measurements: a clinical report. *Physical therapy* **68**, 678-682.

Ferber, R., Davis, I.M., Williams III, D.S. and Laughton, C. (2002) A comparison of within and between day reliability of discrete 3D lower extremity variables in runners. *Journal of Orthopaedic Research* **20**, 1139-1145.

Freeman, A.C. (1990) A study of inter-observer and intra-observer reliability in the measurement of resting calcaneal stance position, and neutral calcaneal stance position. *Australian Podiatrist* **24**, 10-13.

Fulkerson, J.P. (1997) *Disorders of the patellofemoral joint*. 3rd Ed. Baltimore: Williams and Wilkins.

Grood, E.S. and Suntay, W.J. (1983) Joint coordinate system for the clinical description of three-dimensional motions, application to the knee. *Journal of Biomechanical Engineering* **105**, 136-144.

Hunt, A.E. and Smith, R.M. (2004) Mechanism and control of the flat versus normal foot during the stance phase of walking. *Clinical Biomechanics* **19**, 391-397.

Hunt, A.E., Smith, R.M. and Torode, M. (2001a) Extrinsic muscle activity, foot motion and ankle joint moments during the stance phase of walking. *Foot and Ankle International* **22**, 31-41.

Hunt, A.E., Smith, R.M., Torode, M. and Keenan, A. (2001b) Inter-segment foot motion and ground reaction forces over the stance phase of walking. *Clinical Biomechanics* **16**, 592-600.

Kadaba, M.P., Ramakrishnan, H.K., Wootten, M.E., Gainey, J., Gorton, G. and Cochran, G.V.B. (1989) Repeatability of kinematics, kinetic, and electromyographics data in normal adult gait. *Journal of Orthopaedic Research* **7**, 849-860.

Knutzen, K.M. and Price, A. (1994) Lower extremity static and dynamic relationships with rearfoot motion in gait. *Journal of American Podiatric Medical Association* **84**, 171-180.

Leardini, A., Benedetti, M.G., Catani, F., Simoncini, L. and Giannini, S. (1999) An anatomically based protocol for the description of foot segment kinematics during gait. *Clinical Biomechanics* **14**, 528-536.

Lee, W.E. (2001) Podiatric biomechanics: an historical appraisal and discussion of the Root model as a clinical system of approach in the present context of theoretical uncertainty. *Clinics in Podiatric Medicine and Surgery* **18**, 555-684.

Levinger, P. and Gilleard, W. (2004) An evaluation of the rearfoot posture in individuals with patellofemoral pain syndrome. *Journal of Sports Science and Medicine* **3**, 8-14.

Liu, W., Siegler, S., Hillstrom, H. and Whitney, K. (1997) Three-dimensional, six-degrees-of-freedom kinematics of the human hindfoot during the stance phase of level walking. *Human Movement Science,* **16**, 283-298.

Magee, D.J. (2002). *Orthopaedic Physical Assessment*. 4th Ed. Philadelphia, Pennsylvania: Saunders.

Manal, K., McClay, I., Stanhope, S., Richards, J. and Galinat, B. (2000). Comparison of surface mounted markers and attachments methods in estimating tibial rotations during walking: an in vivo study. *Gait and Posture* **11**, 38-45.

Maslen, B.A. and Ackland, T.R. (1994) Radiographic study of skin displacement errors in the foot and ankle during standing. *Clinical Biomechanics* **9**, 291-296.

McClay, I. and Manal, K. (1998) A comparison of three-dimensional lower extremity kinematics during running between excessive pronators and normals. *Clinical Biomechanics* **13**, 195-203.

McConnell, J. (1986) The management of chondromalacia patellae: a long term solution. *The Australian Journal of Physiotherapy* **32**, 215-223.

McPoil, T.G. and Brocato, R.S. (1985) The foot and ankle: biomechanical evaluation and treatment. In: J*Orthopaedic and Sports Physical Therapy 2*. Eds: Gould III, A and Davies, G.J. St. Louis, Missouri: The C.V Mosby Company. 313-341.

McPoil, T.G. and Cornwall, M.W. (1994) Relationship between neutral subtalar joint position and pattern of rearfoot motion during walking. *Foot and Ankle* **15**, 141-145.

McPoil, T.G. and Cornwall, M.W. (1996a) The relationship between static lower extremity measurements and rearfoot motion during walking. *Journal of Orthopaedic and Sports Physical Therapy* **24**, 309-314.

McPoil, T.G. and Cornwall, M.W. (1996b) Relationship between three static angles of the rearfoot and the pattern of rearfoot motion during walking. *Journal of Orthopaedic and Sports Physical Therapy* **23**, 370-375.

Moseley, L., Smith, R. and Gant, R. (1996) Three dimensional kinematics of the rearfoot during the stance phase of walking in normal young adult males. *Clinical Biomechanics* **11**, 39-45.

Picciano, A., Rowlands, M.S. and Worrell, T. (1993) Reliability of open and closed kinetic chain subtalar joint neutral positions and navicular drop test. *Journal of Orthopaedic and Sports Physical Therapy* **18**, 553-558.

Pierrynowski, M.R. and Smith, S.B. (1996) Rearfoot inversion/eversion during gait relative to the subtalar joint neutral position. *Foot and Ankle International* **17**, 406-412.

Pierrynowski, M.R., Smith, S.B. and Mlynarczyk, J.H. (1996) Proficiency of foot care specialists to place the rearfoot at subtalar neutral. *Journal of American Podiatric Medical Association* **86**, 217-223.

Root, M.L., Orien, W.P. and Weed, J.H. (1977) *Normal and abnormal function of foot: Clinical biomechanics*. Los Angeles: Clinical Biomechanics Corporation.

Scott, S.H. and Winter, D.A. (1991) Talocrural and talocalcaneal joint kinematics and kinetics during the stance phase of walking. *Journal of Biomechanics* **24**, 743-752.

Sell, K.E., Verity, T.M., Worrell, T.W., Pease, B.J. and Wigglesworth, J. (1994) Two measurement techniques for assessing subtalar joint position: a reliability study. *Journal of Orthopaedic and Sports Physical Therapy* **19**, 162-167.

Smith-Oricchio, K. and Harris, B.N. (1990) Interrater reliability of subtalar neutral, calcaneal inversion and eversion. *Journal of Orthopaedic and Sports Physical Therapy* **12**, 10-15.

Subotnick, S.I. (1975) *Podiatric Sport Medicine*. New York: Futura Publishing Company.

Tiberio, D. (1987) The effect of excessive subtalar joint pronation on patellofemoral mechanics: a theoretical model. *Journal of Orthopaedic and Sports Physical Therapy* **9**, 160-165.

Wooden, M.J. (1990) Biomechanical evaluation for functional orthotics. In: *The biomechanics of the foot and ankle.* Ed: Donatelli, R. Philadelphia: F.A David Company. 131-147.

Wright, D.G., Desai, S.M. and Henderson, W.H. (1964) Action of the subtalar and ankle joint complex during the stance phase of walking. *Journal of Bone Joint Surgery* **46**, 361-382.

AUTHORS BIOGRAPHY

Pazit LEVINGER

Employment

PhD student in the School of Exercise Science and Sport Management, Southern Cross University, Australia.

Degree

BEd

Research interests

Gait analysis and the biomechanics of knee and foot injuries in clinical populations.

E-mail: pazit_levinger@yahoo.com.au

Wendy GILLEARD

Employment

Senior Lecturer in Biomechanics, School of Exercise Science and Sport Management, Southern Cross University , Australia.

Degree

PhD

Research interests

gait and posture analysis as well as biomechanical adaptations to increased mass and dimensions such as occur in pregnancy and obesity.

E-mail: wgillear@scu.edu.au

KEY POINTS

- The use of the three reference postures resulted in shifting of the curve of the rearfoot frontal plane pattern of motion. The shift of the curve is important in identifying the magnitude of rearfoot peak motion during the stance phase.
- The use of Vertical Alignment reference posture only, generated a typical rearfoot motion pattern for both groups and therefore it may be an appropriate reference posture for both healthy and PFPS individuals
- The use of Relaxed Standing and STJN as reference postures would not be recommended due to their poor test retest reliability.

✉ **Pazit Levinger**
Rehabilitation Sciences Research Centre, School of Physiotherapy. University of Melbourne, Royal Talbot Rehabilitation Centre. 1 Yarra Boulevard Kew 3101, Australia.