IN VIVO QUANTIFICATION OF THE FUNCTIONAL CHARACTERISTICS OF THE REARFOOT COMPLEX

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DECLARATION.

I declare that this thesis has been composed by myself and embodies the results of my own research carried out whilst studying at the University of Salford from October 1995 to February 1999. All other sources of material have been specifically acknowledged. None of the material has been used previously in application for a higher degree.

NOMENCLATURE.

trom	Total range of motion
rom	Range of motion.
FORFT	Forefoot segment
Ank/Stj	Ankle joint and sub talar joint complex
MTJ	Mid tarsal joint
RFC	Rearfoot Complex.
Order of predominance	Indicates the relative values of the ranges of motion in the frontal, transverse and sagittal body planes. The first in the order of predominance is the plane in which the largest range of motion took place, the second the plane in which the second largest range of motion took place and the third the plane in which the smallest range of motion took place.
Frt	Frontal plane
Trn	Transverse plane
Sag	Sagittal plane

ABSTRACT.

During normal weight bearing the ankle, sub talar and mid tarsal joints function as a kinematic chain and their motions are interdependent. This chain has three important characteristics. Firstly, the motion in one of the components (joints) produces motion at the other components (joints). Secondly, the three joints are interdependent because the function of each is dependent on the position and motion at the other joints. Thirdly, the pattern of motion between the joints during weight bearing motion is fixed. The aim of this investigation was to determine the functional characteristics of the combined ankle, sub talar and mid tarsal joints (the rearfoot complex).

A non invasive in vivo kinematic assessment was conducted to determine the relative rotations at the ankle/sub talar complex, the mid tarsal joint and the rearfoot complex, during weight bearing internal and external rotation of the leg in 25 subjects.

The results confirm that the rearfoot joints operate as a kinematic chain. The motion at the ankle/sub talar complex suggests that the ankle is capable of a considerable range of transverse plane motion. The axes of rotation for the mid tarsal joint described in this thesis are the first for this joint quantified from a kinematic assessment and thus supersede the theoretical axes for this joint described in the literature. The predominant motion in the overall rearfoot complex is transverse plane motion. This would suggest that the primary function of the foot is to permit transverse plane rotations of the leg and proximal structures whilst maintaining the foot in a stable position of the floor. In contrast to some of the literature, the ability of the foot to accommodate the transverse plane motion of the leg is a function of all three rearfoot joints.

CHAPTER 1

INTRODUCTION

The joints of the rearfoot, the ankle, sub talar and mid tarsal joints, are traditionally considered separately. Popular biomechanically orientated texts often describe the motion at each joint with no reference to the motion occurring at the others joints. The weight bearing movements in the rearfoot do not, however, support this approach to rearfoot mechanics. The motions at the ankle, sub talar and mid tarsal joints are coupled and the rearfoot joints function as a kinematic chain where motion in one joint is accompanied by motion in the other joints. These motions within the foot are coupled with transverse plane rotation of the leg proximally. Conversely, the transverse plane rotation of the leg during normal walking, which is an essential component of achieving the desired forward displacement of the contralateral foot, will always be accompanied by motion within foot.

The characteristics of the movements in each component of the kinematic chain and in the overall chain can be described using the range and direction of motion displayed in each cardinal body plane, the axis of rotation around which motion takes place and any changes in these during the total range of motion in the chain. Clearly, these should be derived through scientific assessment and used to develop a model of rearfoot function.

There is considerable published work that collectively is improving our understanding of rearfoot mechanics and contributing to the scientific basis upon which the model of rearfoot function is based. This literature most frequently involves an in vitro study and there are several important points regarding such experiments and the relevance of the subsequent data. To provide a realistic description of rearfoot motion akin to that in vivo the cadavers must be loaded to simulate the normal in vivo situation. Some studies, however, do not load the cadavers whilst others have used loads below those which the foot would be subjected to during normal function. The movements in a cadaver foot must be produced by a process akin to that in vivo. Some studies record the motion of the foot relative to the leg (the position of which is fixed), whereas a combination of the leg moving relative to the foot and the foot moving relative to the leg occurs during most activities. Some studies induce motion in the rearfoot by applying load to sectioned muscles or by rotating the leg in the transverse plane, whereas a combination of muscle, ligament, ground reaction forces and proximal movements produce motion during normal function. The motion through which the rearfoot moves must be similar to that through which it moves in vivo. Some studies, however, measure rearfoot kinematics during dorsiflexion and plantarflexion of the foot, internal and external rotation of the leg and inversion and eversion of the foot, whereas these occur simultaneously during normal function. Also, the sample number in cadaver studies is usually restricted to below ten, which does not represent an acceptable sample size.

The in vivo investigations in the literature have involved invasive methods to derive the necessary kinematic data. The most popular method is to implant small metal beads into the tarsal bones and to track their three dimensional position using X ray. This is clearly unacceptable given the dangers of repeated exposure to radiation. This too reduces the numbers of subjects that can be investigated.

The work presented in this thesis addresses some of these issues by recording the motion of the rearfoot kinematic chain in vivo using a non invasive method during weight bearing transverse plane rotation of the leg. The data has not only been used to describe the motion at the individual joints but also the combined function of the ankle, sub talar and mid tarsal joints and thus the kinematic chain. In vivo studies have the advantage that the rearfoot is functioning under a realistic load, the influence of active muscles and ligaments on the joint motions are included and the sample size can be increased in comparison to the cadaver based studies. This study builds on the techniques of in vitro studies and assesses the overall characteristics of the rearfoot in addition to those of its individual components.

The initial purpose of this study was to design a non invasive in vivo method which would allow the functional characteristics of the rearfoot kinematic chain to be determined. This description could be used to categorise individuals according to the functional characteristics of their rearfoot complex and investigate any relationship between each category and the incidence and type of lower limb pathology. In particular, the mechanism by which transverse plane leg rotation is accommodated by the rearfoot was of interest because of its supposed link to knee pathology.

CHAPTER 2

REVIEW OF THE REARFOOT COMPLEX

2.1 INTRODUCTION.

The rearfoot complex is a model of rearfoot function that consists of the talus, calcaneus, navicular and cuboid, and thus involves the ankle, sub talar and mid tarsal joints. The weight bearing function of these joints has been described as a kinematic chain where the movements in the individual joints are interdependent with each other. The concept of interdependency is further illustrated by the fact that the correct function of each joint is required for the rearfoot complex to perform its principal function of allowing transverse plane motion of the tibia whilst the foot remains relatively fixed on the floor. These points are discussed in more detail in section 2.3. First, however, it is necessary to review the anatomy and functional characteristics of the individual joints in the complex.

2.2 REVIEW OF THE INDIVIDUAL JOINTS IN THE REARFOOT COMPLEX.

2.2.1 THE ANKLE JOINT.

The ankle joint, or talocrural joint, is formed by the articulations between the body of the talus and the distal ends of the tibia and fibula. The joint has three sites of articulation. Laterally, the fibula base articulates with the large triangular facet which dominates the lateral side of the talar body. Medially, a smaller and comma shaped facet on the medial side of the talus articulates with the lateral aspect of the medial malleolus. Superiorly, the trochlea surface articulates with the inferior aspect of the tibia, the tibial plafond. The trochlea surface is convex from posterior to anterior and concave from medial to lateral. In addition, it is wider anteriorly than posteriorly and so has a wedged appearance.

There are multiple co-lateral ligaments of the ankle and, along with the strong syndesmosis between the fibula base and tibia, they are responsible for the frontal plane stability of the joint. Laterally there are three distinct bands; the anterior and posterior talofibular ligaments and, central to these, the calaneofibular ligament. These three ligaments restrain inversion of the talus relative to the tibia. In addition they prevent excessive anterior and posterior displacement of the talus relative to the tibia.

Medially the co-lateral ligaments are less distinct. Although separate bands are present, the general appearance it that of a single large triangular ligament. The medial ligament is considerably stronger than the lateral ligaments. It has a single origin on the inferior aspect of the medial malleolus and an extensive insertions on the navicular (naviculotibial portion), the central aspect of the calcaneus (calcaneotibial portion), the medial aspect of the talar neck (anterior talotibial portion) and the posterior and medial aspect of the talus (posterior talotibial ligament). The medial ligament is responsible for restraining eversion of the talus relative to the tibia.

2.2.1.1 Motion at the Ankle.

The principal characteristic of ankle joint motion has been well defined. All the literature describes the predominant motion at the ankle as dorsiflexion, motion of the talus towards the anterior aspect of the tibia, and plantarflexion, motion of the talus away from the anterior aspect of the tibia. Coupled with this predominant sagittal plane motion are small degrees of frontal and transverse plane motion.

The general orientation of the ankle joint axis reflects this sagittal plane domination. Isman and Inman (1969) conducted a two dimensional analysis of the ankle joint in 46 cadaver specimens to determine the orientation of the joint axis when the talus was manually dorsiflexed and plantarflexed through its full range of motion. They consistently found the ankle joint axis slightly distal to both malleoli. The average axis was orientated 80° (SD 4°) from the long axis of the tibia and 84° (SD 7°) from the mid line of the foot. These results were in agreement with the earlier qualitative studies of Barnett and Napier (1952) and Hicks (1953) who both described the axis as being close to the malleoli. Lundberg et al (1989a) calculated ankle joint axes for 30° of plantarflexion and 30° of dorsiflexion of the foot using roentgen stereophotogrammetry. The mean ankle joint axis passed through both malleoli in the transverse plane view and was angled 7.33° relative to the transverse plane (pointing down and laterally).

Van Langelaan (1983) assessed tibiotalar motion during external rotation of the leg in 10 loaded cadavers (Figure 2.1). He reported ankle joint axes angled between 86.3° and 107.5° (mean 99°) relative to the sagittal plane and -4.6° and 25.9° (mean 11.5°) relative to the transverse plane. Lundberg et al (1989a) compared ankle joint axes determined for the motions of dorsiflexion and plantarflexion of the foot, to ankle joint axes determined for the motions of internal and external rotation of the leg. They commented that there were multiple directions of ankle axes and that the axes for dorsiflexion and plantarflexion of the foot were different from those for internal and external rotation of the leg. Like Van Langelaan (1983), Lundberg et al noted that the orientation of the ankle joint axis was different for each stage of ankle motion, suggesting that the axis was not fixed in position or orientation but was a constantly varying instantaneous axis of rotation. A previous two dimensional radiographic study had described multiple centres of rotation for the ankle (Sammarco 1973) suggesting that multiple axes existed.

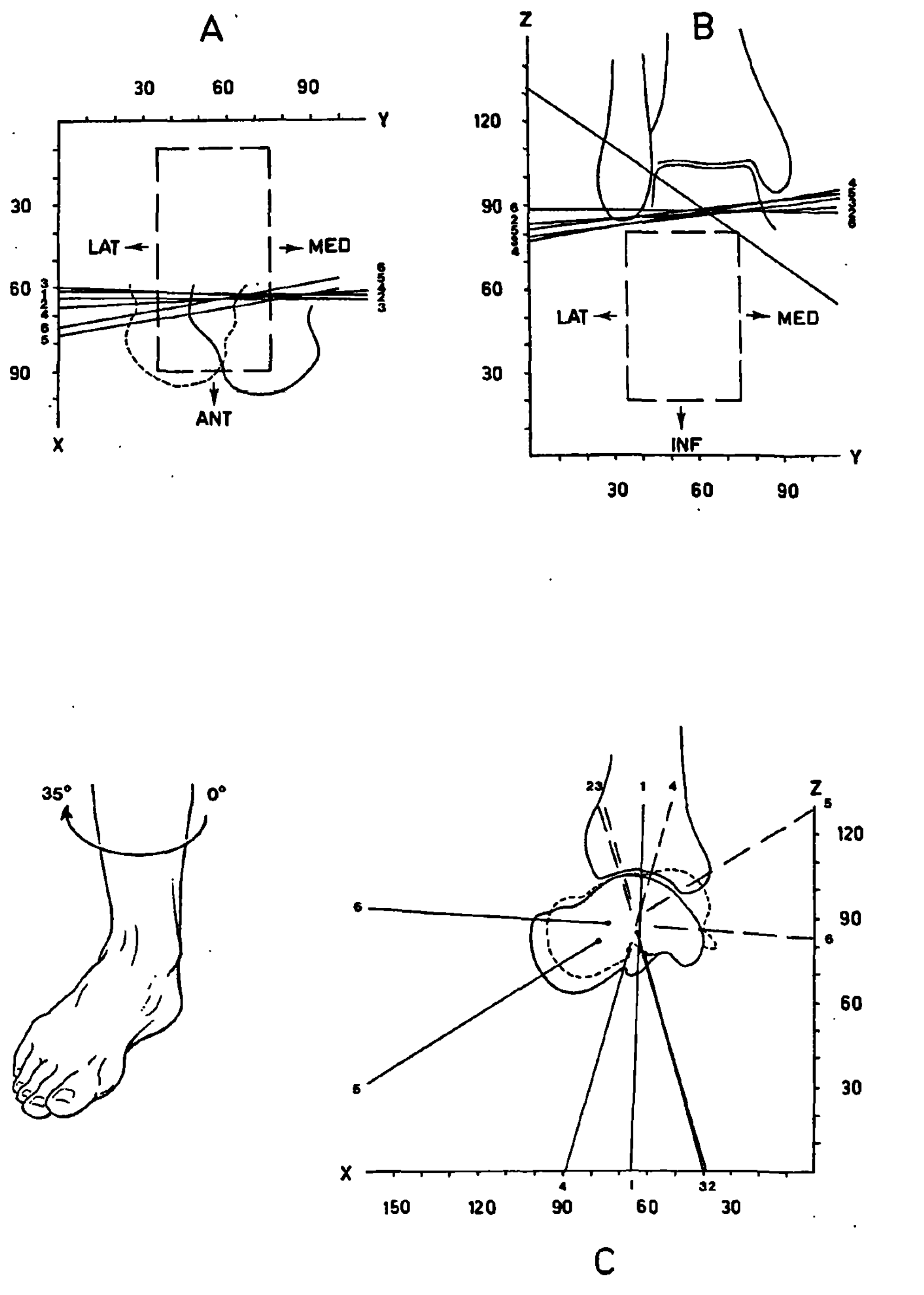


Figure 2.1

Transverse (A), frontal (B) and sagittal plane (C) views of the ankle joint axes calculated by Van Langelaan (1983) for one cadaver, during external rotation of the leg from an internally rotated position in 6 phases. Phase 1 corresponds to the first part of the external leg rotation and phase 6 to the last part.

The concept of an ankle joint axis whose orientation was not fixed during the range of motion had been suggested earlier by Barnett and Napier (1952). They described two distinct arcs on the medial facet of the talus that would produce two distinct centres of rotation during ankle motion. They deduced that during dorsiflexion the ankle axis was inclined downwards in a lateral direction and during plantarflexion the axis was inclined downward in a medial direction. The detailed analysis conducted by Van Langelaan (1983) and Siegler et al (1988) has confirmed the concept of multiple axes of rotation for the ankle joint, though neither study suggested that there were distinct axes for dorsiflexion and plantarflexion.

The ankles in Lundberg et al's (1989a) study, however, did display a pattern suggesting distinct 'dorsiflexion' and 'plantarflexion' axes when the foot was dorsiflexed and plantarflexed. Plantar flexion axes were inclined downward in a medial direction or were close to the horizontal when compared to the dorsiflexion axes, which tended to be inclined downward in a lateral direction (Figure 2.2). The angle between the dorsiflexion and plantarflexion axes when projected onto the frontal plane was, on average, 37°. In the transverse plane projection the axes were all close to the centres of the malleoli and in all projections all axes crossed each other at a central point within the talus.

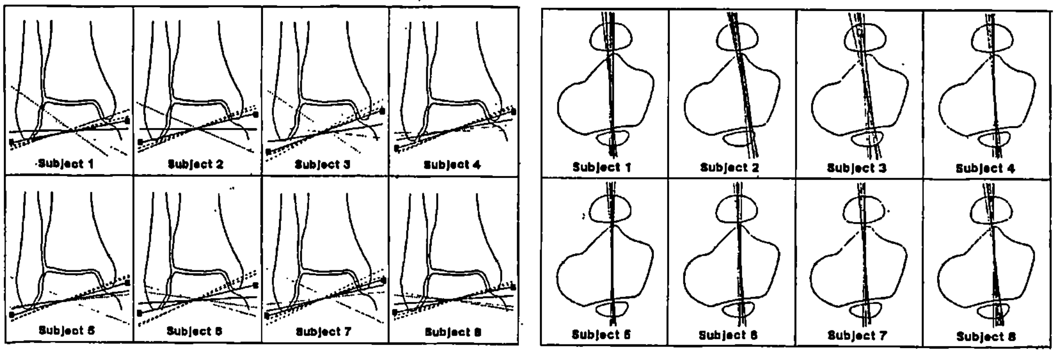


Figure 2.2

Frontal and transverse plane views of the ankle joint axes calculated by Lundberg and Svensson (1989a). In the frontal plane view the distinct laterally and downward orientated axes are the dorsiflexion axes, those orientated horizontally or downward and medially are plantarflexion axes. In the transverse plane view all axes pass through both malleoli.

It is reasonable to suggest that the ankle might possess different axes for dorsiflexion and plantarflexion of the foot because of the non spherical nature of the trochlea surface. Furthermore, McCullough and Burge (1990) found that some degree of transverse plane rotation of the talus within the ankle mortise is possible and it is reasonable, therefore, to suggest that there are different axes of rotation when the ankle is moved by dorsiflexion and plantarflexion of the foot compared to when it is moved by transverse plane rotation of the tibia. A further point on this issue is that during gait the sagittal plane motion of the ankle and the transverse plane motion of the leg take place simultaneously and thus some further axis or axes might exist.

There is some evidence of variation between individuals in the orientation of the plantarflexion/dorsiflexion ankle joint axis. Isman and Inman (1969) reported axes ranging from 68° to 88° relative to the long axis of the tibia and 69° - 99° relative to the mid line of the foot in 46 cadavers. In Lundberg et al's (1989a) sample of 8 subjects the mean angle made by the ankle axis to the transverse plane, calculated for 30° of foot plantarflexion and 30° of foot dorsiflexion, varied between -2° and 14.3°. In Van Langelaan's (1983) work, where ankle joint axes were calculated during transverse plane rotation of the tibia, the angle of the mean ankle joint axis varied between individuals by 21.2° relative to the sagittal plane and 30.8° relative to the transverse plane in 8 subjects. Significantly, despite all these individual variations the principal motion at the ankle joint was dorsiflexion and plantarflexion.

The range of motion available at the ankle joint also shows variation between individuals. This reflects not only real individual variations but also the variety of methods employed to deduce the range of motion and the choice of reference positions. Some investigators have measured motion between the talus and tibia, others the sagittal plane motion of the plantar surface of the foot relative to the leg, claiming this to be a measure of ankle joint motion. However, since both the sub talar and mid tarsal joints are capable of some sagittal plane motion, any investigator must be confident that they can stabilise both these joints during such measurements. This is questionable. The choice of measuring device also varies, some using radiographs, and others goniometers. Unfortunately no method of assessing ankle joint motion has been universally accepted. Rome (1997) illustrated the effect of using different protocols on the clinical measurement of ankle motion. Factors such as whether the subject was weight bearing or non weight bearing, sitting or standing, prone or supine and whether motion was actively or passively produced were all shown to affect clinical measurements.

Hicks (1953) measured the range of motion between the talus and tibia in 10 cadavers. He described an average total range of sagittal plane motion as 50°. Using X-rays Sammarco (1973) measured the range of motion in 21 weight bearing ankles. The total range of sagittal plane motion varied from 24° to 75°, with an average of 43°. The mean range of dorsiflexion was 21° and that of plantarflexion 23°. Lundberg et al (1989a) calculated an average of 54.1° of principally sagittal plane ankle motion when the foot was moved from 30° of plantarflexion to 30° of dorsiflexion.

2.2.2 THE SUB TALAR JOINT.

The sub talar joint is formed by the three facets on the inferior surface of the talus and three corresponding facets on the superior surface of the calcaneus. The contours of all six articular areas are complex and all are angled relative to each other. The posterior articulation is the largest and has a separate joint capsule from that of the anterior and middle articulations. The anterior and middle facets are smaller and sometimes continuous with each other. They share their joint capsule with the talonavicular joint. Separating the posterior articulation from the anterior and middle articulations is the sinus tarsi. This is a tunnel formed by the sulcus calcanei and the sulcus tali running from posterior/medial to anterior/lateral. Within the sinus tarsi is the interosseous talocalcaneal ligament that runs from inferior/lateral to superior/medial. This ligament functions to maintain the close association between talus and calcaneus during joint motion. Lateral to the sinus tarsi is the cervical ligament that runs from the dorsal superior aspect of the calcaneus to the inferior/lateral aspect of the talar neck. The cervical ligament tightens during supination of the foot.

2.2.2.1 Motion at the Sub Talar Joint.

Sub talar joint motion is a complex tri-planal motion described as pronation, a combination of eversion, abduction and dorsiflexion, and supination, a combination of inversion, adduction and plantarflexion. During closed chain sub talar joint supination the talus abducts, dorsiflexes and everts relative to the calcaneus. During closed chain sub talar joint pronation the talus adducts, plantarflexes and inverts relative to the calcaneus.

Motion at the sub talar joint takes place around an axis that is angled relative to all three cardinal body planes. The specific orientation of the sub talar joint axis has been extensively investigated. In 1966 Root et al modified Manter's (1941) earlier experimental set up in an attempt to determine the orientation of the sub talar joint axis in 22 amputated feet. Pins of adjustable length were inserted into the body of the talus and the plane of motion of the pins was identified using a flat surface. The flat surface was then placed within a box whose sides represented the cardinal body planes and the angle of the axis relative to these planes determined. This assumed that the axis for the total range of sub talar joint motion was perpendicular to the plane of motion. The results confirmed the data of previous investigators (Elftman and Manter 1938, Manter 1941, Hicks 1953). The investigators described an average axis making an angle of 17° to the sagittal plane, range of 8° to 29° (SD 2.23) and an angle of 41° to the transverse plane, range of 22° to 55° (SD 8.36). These are now the accepted figures for the angulation of the sub talar joint axis relative to the cardinal body planes and form the basis of the current model of sub talar joint function. Subsequent investigations have confirmed that these figures are generally correct (Isman and Inman 1969, Van Langelaan 1983, Benick 1985, Engsberg 1987, Lundberg and Svensson1993).

All the literature describing the motion at the sub talar joint highlights individual variation in the orientation of the sub talar joint axis. Isman and Inmans' (1969) work involving 47 cadavers revealed marked individual variations in the orientation of the sub talar joint axis. The angle of the axis to the sagittal plane varied by 43° and the angle of the axis to the transverse plane by 48° within the sample. Van Langelaan (1983) found the angulation of the axis to the sagittal plane to vary between 5.4° and 32.3°, mean 23.5°, and the angulation of the axis to the transverse plane to vary between 23.2° and 56.4°, mean 41.9°, in his sample of ten cadavers. Like Van Langelaan (1983), Lundberg and Svensson (1993) analysed the motion of metal beads implanted in the bones of the tarsus and leg using X-rays. The specific axis orientation for each individual was not documented, but the authors commented that variation between subjects was considerable. Work by Manter (1941) and Engsberg (1987) has documented similar results.

If, as the literature suggests, the orientation of the axis varies between individuals, two sub talar joints whose axes are at opposite ends of the range of orientations will possess very different functional characteristics. For example, with regard to the transverse plane orientation of the axis, as the angle between the transverse plane and the axis increases the range of transverse plane sub talar joint motion per degree of sub talar joint motion will increase and the range of frontal plane sub talar joint motion will decrease. The reverse is the case when the axis makes a smaller angle to the transverse plane. A sub talar joint with an axis angled 16° from the sagittal plane and 20° from the transverse plane, for example, would display 9.0° of eversion, 3.4° of abduction and 2.6° of dorsiflexion for 10° of pronation around the axis. However, if the transverse plane orientation was 65°, 10° of sub talar joint pronation would produce 4.1° of eversion, 9.1° of abduction, and 1.2° of dorsiflexion. The present model of sub talar joint function, which is based on the averaged sub talar axis, might not be suitable in such instances because the two sub talar joints would function differently to each other and to a sub talar joint with the average axis. The variation in sagittal plane orientation might not produce such significant changes in sub talar joint function. The range of angles relative to the sagittal plane (5.4° – 47°) means that the angle is rarely more than 45°. Consequently, with regard to the angulation of the axis to the sagittal plane, the predominant motion will be frontal plane motion for almost all the population and two sub talar joints with axes at opposite ends of the range will retain more similar characteristics of motion. That is not to infer, however, that the change in sagittal plane angulation is of no significance.

The degree of individual variation in axis orientation quoted in the literature (Figure 2.3) would suggest that the use of an average sub talar joint axis to represent a population may not be satisfactory, since a proportion of the population will possess a sub talar joint axis whose orientation differs significantly from the average. Furthermore, such wide variation could result in significantly different rearfoot movements and consequently different foot and lower limb pathologies being associated with different sub talar joint axis orientations. Root et al (1966) stated,

> " the range of variance in the direction of the axis of the sub talar joint motion should have considerable clinical significance".

A further complication in the model of sub talar joint function is the fact that the orientation and position of the sub talar joint axis has been found to change throughout the range of joint motion. Van Langelaan (1983) calculated the orientation of the sub talar joint axis at various stages of supinatory motion in 10 cadavers. The sub talar joint axes he deduced changed orientation during the range of motion, tending to move from a low pitch and medial orientation in pronation, to a high pitch and forward orientation in supination. When the axes for each stage of supination were superimposed on each other they formed a bundle of axes. The angle between the first and last axes in a bundle was also variable between individuals, ranging from 4.4° to 24.8° in the case of the sagittal plane orientation and 2.8° to 26.3° in the case of the transverse plane orientation. The axis was consistently angled closer to the sagittal plane and further from the transverse plane as the sub talar joint supinated. Thus, not only does the axis change orientation during the range of motion, the extent to which its orientation changes in variable between individuals (Figure 2.4).

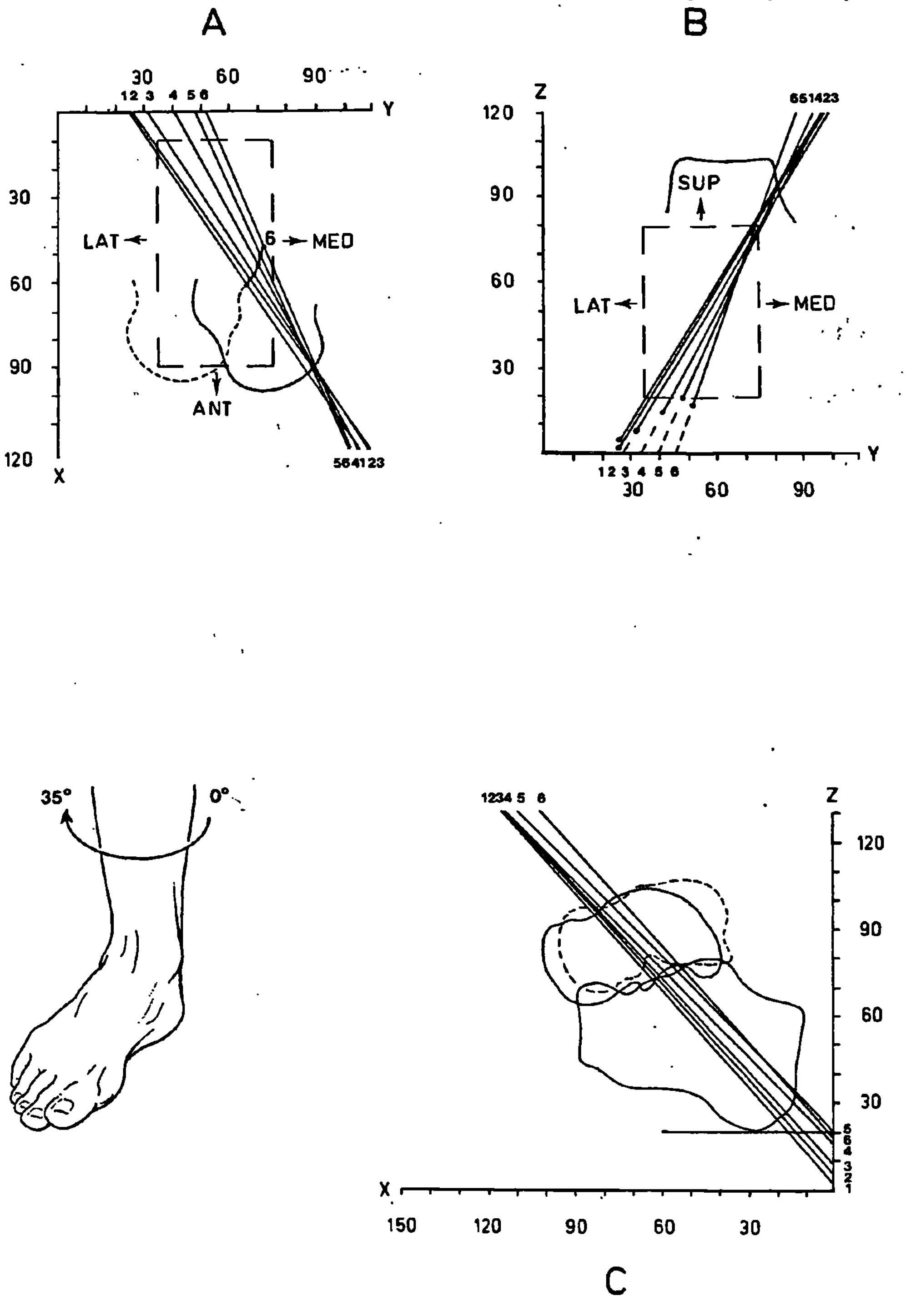


Figure 2.4

Transverse (A), frontal (B) and sagittal plane (C) views of the sub talar joint axes calculated by Van Langelaan (1983) for one cadaver, during external rotation of the leg from an internally rotated position. Phase 1 is the initial external rotation, phase 6 is the last phase near the maximum externally rotated position.

Benick (1985), using the same equipment as Van Langelaan (1983), and later Lundberg and Svensson (1993) have documented similar results. Siegler et al (1988), who also analysed motion of the talus and calcaneus in cadavers, also stated that the sub talar axis was not a fixed axis of rotation though they did not state the specific orientations of the joint axes. Considering the variable orientations of the sub talar joint axis during its range of motion, and the changes in the functional characteristics of the joint this reflects, it might not be appropriate to use a single joint axis orientation to represent an individual. Certainly, calculating the orientation of the sub talar joint axis from the total range of sub talar motion may not reflect the axis around which the joint rotates during gait, since only a proportion of the full range is used during gait. Determining the portion of sub talar motion used during gait and calculating an axis of rotation for this part of the total range of motion would enable a more relevant axis orientation to be calculated.

The range of motion at the sub talar joint is usually assessed by measuring the range of supination and pronation separately. The so-called neutral position of the sub talar joint is used as a reference position from which the respective ranges of motion can be measured. This position is said to be the point of maximum joint congruency and can be found by a number of palpation methods (Cook et al 1988). However, the poor inter observer reliability for the determination of the neutral position puts into question the validity of subsequent measurements and makes comparisons between different studies difficult (Ball and Johnson 1993, Pierrynowski et al 1996). Despite this there is general agreement that there is more supination than pronation at the sub talar joint. The ratio of these motions is traditionally said to be 2:1 although clinically this is often found not to be the case.

The total ranges of sub talar joint motion quoted show some variation between authors. Hicks (1953) reported 24° of sub talar motion from 10 cadaver specimens. Van Langelaan (1983) recorded a minimum of 15.5° and a maximum of 30°, average 23.6°, during external rotation of the leg from an internally rotated position. Ball and Johnson (1993) measured the frontal plane angle between the heel and leg and reported a mean total range of motion of 37.3°, range 28° - 48° (SD 5.4°) in 25 prone subjects.

Care must be taken when interpreting some investigators' results because what may be described as sub talar joint motion may in fact only be the frontal body plane component of sub talar joint motion, or even the frontal plane component of the ankle and sub talar joints. Strictly speaking, sub talar joint motion is that which takes place around the sub talar joint axis. Since the axis is angled relative to each cardinal body plane, the range of motion cannot be observed from any single cardinal body plane. Further problems may arise because not every foot has the same predominant motion. Thus, if one foot has less frontal plane motion than another it is not correct to assume that the range of sub talar joint motion is less in that foot. Measuring frontal plane sub talar motion in isolation does not describe sub talar joint function adequately (Engsberg et al 1988). Also, sub talar joint function is that between the talus and the calcaneus and, since the talus cannot be assessed clinically, most methods of measuring sub talar motion assume the talus to be immobilised in the ankle mortice. This is questionable (McCullough and Burge 1980, Ahl et al 1987) and variable depending upon an examiner's ability to stabilise the ankle joint. In addition, Ball and Johnson (1993) have shown that the protocol for measurements of sub talar motion is very important. They illustrated that the position of a subject (prone, sitting or kneeling), the method of producing passive sub talar joint motion (either moving the heel or the whole foot) and whether the motion was actively produced by the subject all have significant effects on the measured range of motion. As with measures of ankle joint motion, no method of measuring sub talar joint motion has received universal acceptance.

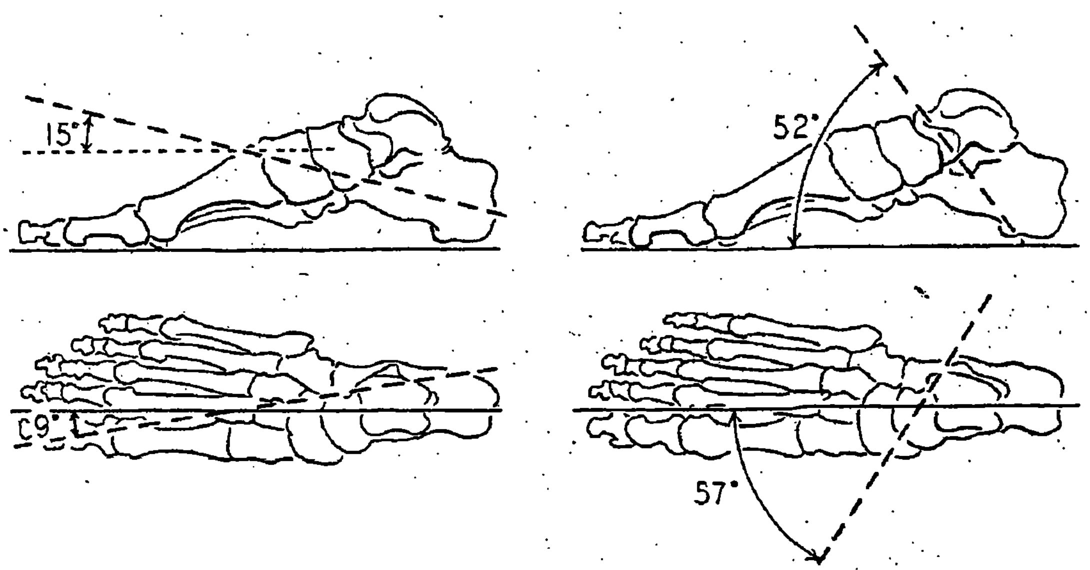
2.2.3 THE MID TARSAL JOINT.

The mid tarsal joint is a conceptual functional unit comprising the calcaneocuboid and talonavicular joints. The calcaneocuboid joint is formed by the articulation between the anterior surface of the calcaneus proximally and the posterior surface of the cuboid distally. The posterior surface of the cuboid is concave from medial to lateral and convex from superior to inferior. The talonavicular joint is formed by the anterior surface of the talus head proximally, and the posterior surface of the navicular distally. The posterior surface of the navicular is concave, both in a medial/lateral and superior/inferior directions. The smooth talar head is convex in both medial/lateral and superior/inferior directions. The navicular and cuboid are joined by a fibrous joint that allows little movement of either bone in relation to the other and thus are considered to be one unit.

2.2.3.1 Motion at the Mid Tarsal Joint.

The current model of mid tarsal joint motion is based on two separate conceptual axes of rotation around which motion takes place synchronously. Manter (1941) described the oblique axis of the mid tarsal joint, which was angled 52° from the transverse plane and 57° from the sagittal plane (Figure 2.5). Motion around the axis produces combined plantarflexion, inversion and adduction (supination) and dorsiflexion, eversion and abduction (pronation). In a foot with this axis, 10° of pronation would produce 7.9° of abduction, 5.1° of dorsiflexion and 3.4° of eversion. This was consistent with similar descriptions of this axis in earlier work (Elftman and Manter 1938, Fick 1911 - cited by Manter 1941).

The second conceptual axis at the mid tarsal joint is the longitudinal axis. Manter (1941) described its position as 15° from the transverse plane and 9° from the sagittal plane (Figure 2.5). Motion around the average axis would produce 9.5° of eversion, 2.6° of abduction and 1.5° of dorsiflexion for every 10° of pronation. Since this early work few other investigations appear in the literature concerning the motion at the conceptual oblique and longitudinal axes of the mid tarsal joint. The model based on these axes has however been accepted regardless of the apparent lack of evidence concerning the function of the joint in relation to these conceptual axes.



Longitudinal axis

Oblique axis

Figure 2.5

Orientation of the conceptual longitudinal and oblique mid tarsal joint axes (from Manter 1941).

Huson (1991) believed that the talonavicular and calcaneocuboid joints were sufficiently independent to question the existence of a single functional unit such as the mid tarsal joint. He used Van Langelaan's (1983) results to justify his argument. Van Langelaan described a mean talonavicular axis angled 14.1° to the sagittal plane and 38.5° to the transverse plane. The mean calcaneocuboid axis was angled 2.7° to the sagittal plane and 51.9° to the transverse plane. These results show that the calcaneocuboid and talonavicular joints had different axes of rotation. Also, Van Langelaan described relative motion between the cuboid and navicular of between 3.9° and 9.9° (mean 6.8°) during external rotation of the leg from an internally rotated position. Thus, the navicular and cuboid are not rigidly fixed relative to each other. It is clear from these results that within any pronation or supination around the conceptual mid tarsal joint axes the cuboid and navicular undergo some motion relative to each other. However, the conceptual mid tarsal joint provides a model that describes the principal motions of the navicular and cuboid relative to the calcaneus and talus. The principal motions of the navicular and cuboid are always in the same direction and some degree of relative motion between the cuboid and navicular in a direction other than that of the principal motion does not contradict the concept of a single functional mid tarsal joint.

Furthermore, the axes Van Langelaan (1983) determined for the separate talonavicular and calcaneocuboid joints reflect the conceptual mid tarsal joint axes. As a generalisation, the individual joint axes have the sagittal plane orientation of the conceptual longitudinal mid tarsal joint axis and the transverse plane orientation of the conceptual oblique mid tarsal joint axis (Figure 2.6 and Figure 2.7). From this we can clearly see where the motions at the conceptual oblique and longitudinal mid tarsal joint axes originate. We can also conclude from the actual rotation axes that the two joints undergo very similar motions and, since they always take place in the same direction and have strong anatomical linkage, can be considered a single functional unit. Thus, Huson's (1991) suggestion that the talonavicular and calcaneocuboid joints must be considered separately can be rejected.

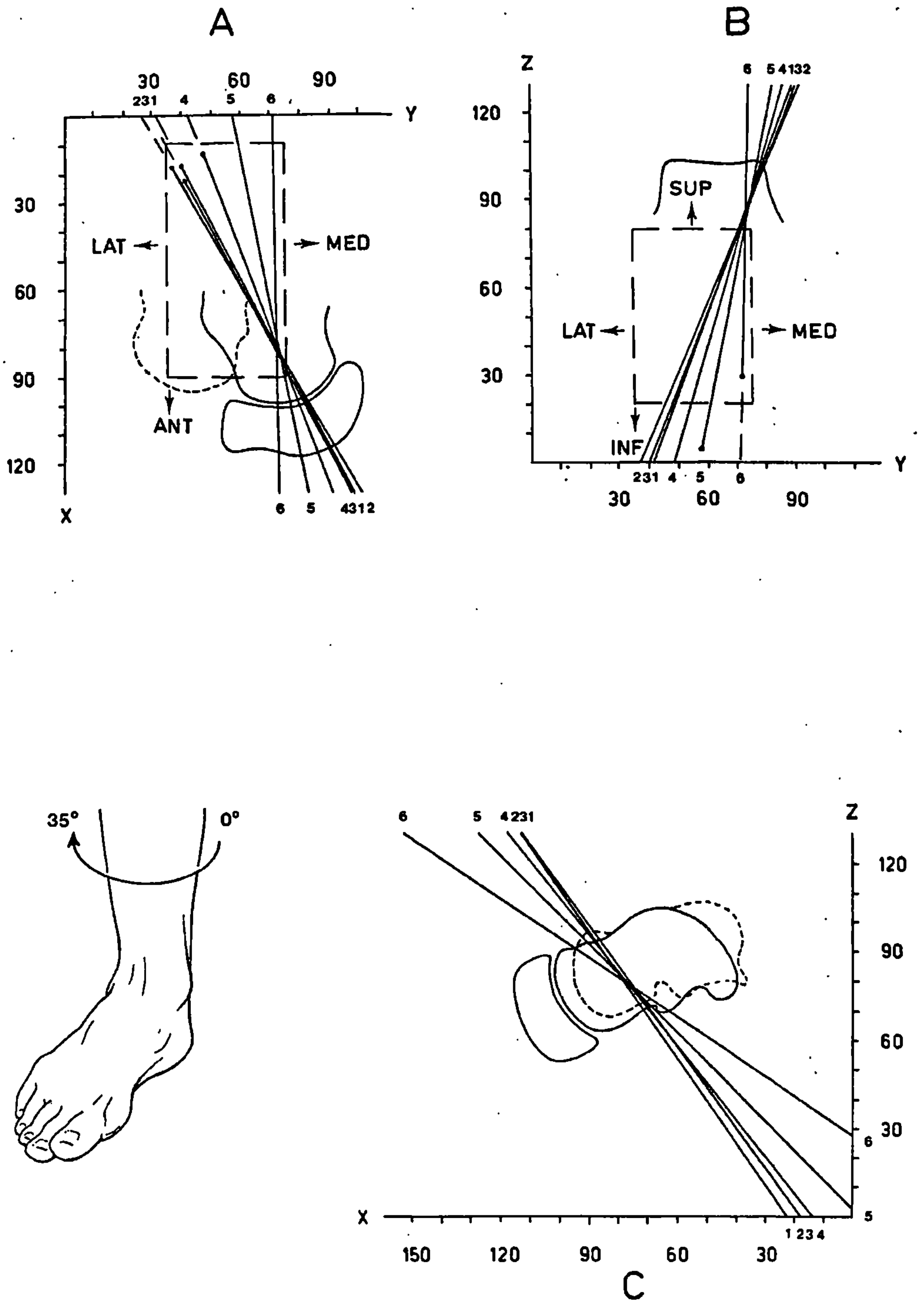


Figure 2.6

Transverse (A), frontal (B) and sagittal plane (C) views of the talonavicular joint axes calculated by Van Langelaan (1983). All axes calculated during the stepped external rotation of the leg from an internally rotated position. Phase 1 is the initial internally rotated position, phase 6 the last phase near the maximum external rotation.

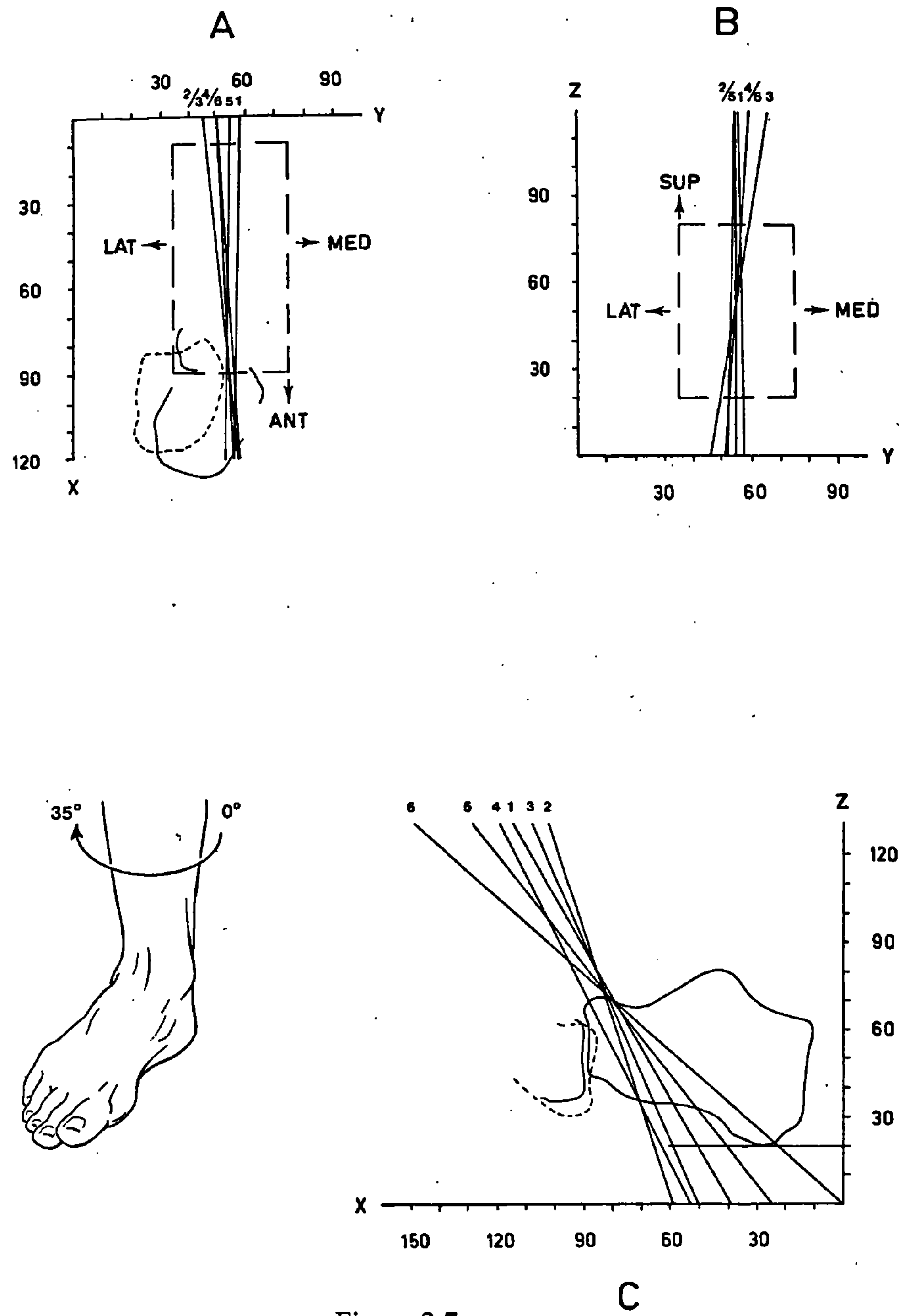


Figure 2.7

Transverse (A), frontal (B) and sagittal plane (C) views of the calcaneocuboid joint axes calculated by Van Langelaan (1983). All axes calculated during the stepped external rotation of the leg from an internally rotated position. Phase 1 is the initial external rotation, phase 6 the last phase near the maximum externally rotated position.

The range of motion available at the mid tarsal joint has not been conclusively determined. Hicks (1953) is the only author to quantify the motion around the separate oblique and longitudinal axes, although his experiments were conducted using unloaded cadavers and methodology not fully explained. Around the oblique axis he measured a total range of motion of 22° and around the longitudinal axis he measured 8° of motion. Van Langelaan (1983) described a mean of 43.1° of talonavicular motion (range 29.9° to 50.7°) and a mean of 15.8° of calcaneocuboid motion (range 8.8° to 25.3°) during external rotation of the weight bearing leg from an internally rotated position. This motion occurred around the longitudinally orientated axes in figures 2.6 and 2.7. During 30° of external leg rotation Lundberg and Svensson (1993) measured a total of 23° of talonavicular motion around similarly orientated axes. It is difficult to interpret the results of the latter two authors' work in relation to Hick's earlier work. The primitive methodology employed by Hick, and the lack of weight bearing tests, means that the work by Van Langelaan (1983) and Lundberg and Svensson (1993) is the best quantitative indicator of mid tarsal joint motion documented to date.

A further point must be considered when assessing the range of motion at the mid tarsal joint: the total range of motion at the mid tarsal joint is variable and depends upon the position of the sub talar joint. The mid tarsal joint is described as locked when it is fully pronated around both the oblique and longitudinal axes. The point at which the mid tarsal joint becomes locked changes as the sub talar joint pronates and supinates. As the sub talar joint pronates the range of mid tarsal joint pronation increases. Thus, as the sub talar joint pronates the locked position is found with the forefoot in an increasingly everted position relative to the rearfoot. As the sub talar joint supinates the range of mid tarsal joint pronation decreases and the locked position is found with the forefoot in an increasingly inverted position relative to the rearfoot. Philips (1983) quantified the change in the locked position of the mid tarsal joint. He found an exponential increase in the range of forefoot eversion relative to the rearfoot with increasing sub talar pronation.

Elftman (1960) suggested that the locking mechanism at the mid tarsal joint was a consequence of changes in the position of the individual talonavicular and calcaneocuboid joint axes. He suggested that when the sub talar joint pronated, the axes of the talonavicular and calcaneocuboid joints converged to produce motion in similar planes. This would allow a greater freedom of mid tarsal joint motion. In contrast, sub talar supination would increase the angle between the two joint axes and result in conflicting talonavicular and calcaneocuboid motions. In this instance there would be less mid tarsal joint motion available since the conflicting motions would reduce the freedom of mid tarsal joint motion. Elftman used what appear to be approximate bisections of the talar head and calcaneal facet of the calcaneocuboid joint to describe the joint axes. This is a fundamental flaw in Elfman's theory because he uses conceptual axes of rotation. The actual axes of rotation of the talonavicular and calcaneocuboid joints determined by Van Langelaan (1983) and Lundberg and Svensson (1993) (talonavicular only) are not orientated obliquely across the talar head and calcaneal facet. Furthermore, Elfman states that the orientation of the axes of the individual joints become more similar as the sub talar joint pronates. Van Langelaan, and Lundberg and Svensson's results both contradict this. The axes of the individual joints are more similar when the sub talar joint is supinated and become relatively dissimilar in pronation. From this it is possible to conclude that the convergence of the talonavicular and calcaneocuboid axes, or the increasing similarity of talonavicular and calcaneocuboid motions, is not the factor producing the locking and unlocking of the mid tarsal joint. In fact, because the individual talonavicular and calcaneocuboid joint axes are relatively similar throughout the range of sub talar pronation and supination, the direction of motion at the individual joints might not be factor in the locking mechanism.

Possible explanations for the locking mechanism include tightening of the soft tissues around the mid tarsal joint. When the sub talar joint supinates the talus everts but the navicular inverts. Consequently, the joint capsule that they share will undergo a twist in the frontal plane which one would expect to increase the tension in the capsule and potentially restrict talonavicular motion. If the locking mechanism is osseous in nature it is more likely to originate at the calcaneocuboid joint, since the relatively smooth contours of the talar head could not realistically provide any osseous restraint to motion. At the calcaneocuboid joint the medial extension of the cuboid is positioned under the superior extension on the calcaneal facet. It is conceivable that when the sub talar joint pronates and the calcaneus everts, the change in the frontal plane position of the calcaneal facet releases the medial extension on the cuboid facet, facilitating a superior sliding motion of the cuboid on the calcaneal facet, with a subsequent increase in the range of calcaneocuboid, and thus mid tarsal joint, pronation. The locking mechanism of the mid tarsal joint requires further investigation.

2.3 THE REARFOOT COMPLEX.

2.3.1 REARFOOT COMPLEX MOTION.

The primary function of the rearfoot complex during normal walking is to allow transverse plane rotation of the tibia to take place whilst the foot is in contact with the ground. The transverse plane tibial rotation is an integral part of more proximal transverse plane rotations which allow the swinging limb to move forwards of the weight bearing limb, initiate the next step and thus maintain the forward motion of the body during ambulation. Motion in the rearfoot complex is driven by transverse plane leg rotation which, by moving the talus, forces the calcaneus, navicular and cuboid to articulate. The resulting rearfoot complex motion is described as pronation (combined dorsiflexion, abduction and eversion) and supination (combined plantarflexion, adduction and inversion) although the motion at the individual ankle, sub talar and mid tarsal joints is different.

During closed chain rearfoot complex pronation the talus adducts, plantarflexes and inverts relative to the calcaneus. The calcaneus everts, abducts and dorsiflexes relative to the talus. This sub talar pronation and ankle plantarflexion distribute forces medially under the forefoot, which, it is assumed, abducts and dorsiflexes the mid tarsal joint around its oblique axis and inverts the mid tarsal joint around its longitudinal axis. During closed chain rearfoot complex supination the talus abducts, dorsiflexes and everts relative to the calcaneus. The calcaneus plantarflexes, adducts and inverts relative to the talus. Weight is shifted laterally under the foot producing a pronatory and locking moment around the mid tarsal joint axes. The mid tarsal joint undergoes relative supination around both its axes in response to the dorsiflexion of the talus and relative plantarflexion of the calcaneus.

2.3.2 RATIONALE FOR THE REARFOOT COMPLEX.

The concept of a model of rearfoot function which is based on motion resulting from three separate articulations differs from the current rearfoot model which considers the motion at the ankle, sub talar and mid tarsal joints separately and often concentrates solely on the function of the sub talar joint. It is necessary, therefore, to justify this concept prior to accepting and investigating the model. The rationale for the rearfoot complex model is that:

- all three rearfoot joints are required for the rearfoot to perform its primary function of allowing the essential rotations of proximal structures in the transverse plane to take place whilst the foot is weight bearing on the floor;
- the motions in the complex are interdependent, meaning that the correct function of each joint is dependant on the correct function of the other two joints;
- the pattern of interdependent motion between the joints is fixed and thus will always be the same.

There is considerable evidence to substantiate these statements.

2.3.2.1 All three rearfoot joints are required for the rearfoot to perform its primary function of allowing the essential rotations of proximal structures in the transverse plane to take place whilst the foot is weight bearing on the floor.

The mechanism which allows the tibia and other proximal structures to rotate in the transverse plane whilst allowing the foot to remain in a fixed position on the floor requires the correct function of all three rearfoot joints. Importantly, for each joint, correct function is dependent upon the position and motions of the other two joints in the complex. Thus, the joints are functionally interdependent. For example, the adduction, plantarflexion and inversion motions of the talus during internal leg rotation are inseparable. Thus, the contributions of the ankle (plantarflexion component) and sub talar joints (adduction, plantarflexion and inversion components) to leg rotation are inseparable. Furthermore, since preventing motion at one of these joints will decrease the motion available in the other, neither the ankle nor the sub talar joint alone could permit the degree of transverse plane leg rotation seen during gait. The contribution of the mid tarsal joint to leg rotation has been described by Sanner (1986). He noted that the leg continued to internally rotate even when sub talar pronation (indicated by movement of the heel) had ceased. He attributed this to pronation around the mid tarsal joint oblique axis. Lundberg et al's (1989c) results confirm the contribution of the mid tarsal joint. He observed only 1.2° of sub talar motion during the initial stages of externally rotating a leg from a 20° internally rotated position. Though some of this motion may have occurred at the ankle, the mid tarsal joint too must have contributed to the range of leg rotation available. However, since mid tarsal joint function is dependent upon the position of the ankle and sub talar joints, it too cannot permit the degree of transverse plane leg rotation required during gait. Clearly then, neither the motion at the ankle, sub talar nor mid tarsal joint is solely responsible for the conversion of leg rotation into rearfoot motion.

2.3.2.2 The motions in the complex are interdependent, meaning that the correct function of each joint is dependent on the correct function of the other two joints.

The interdependent motions in the complex can be illustrated by considering the interactions between the individual joints in the rearfoot complex and thus how the function of one joint can influence that of another. Motion at the sub talar joint influences that at the mid tarsal joint. The plantarflexion of the talus and relative dorsiflexion of the calcaneus during weight bearing sub talar pronation lowers the navicular, everts the mid tarsal joint, distributes pressure medially under the forefoot and consequently creates a supinatory moment, due to the ground reaction force, around the longitudinal axis and a pronatory moment around the oblique axis. Sub talar joint pronation also unlocks the mid tarsal joint increasing its range of pronation and allowing joint to pronate around the oblique axis. This also forces the mid tarsal joint to supinate around the longitudinal axis. In contrast sub talar joint supination inverts the mid tarsal joint, creates a pronatory moment at the longitudinal axis due to the ground reaction force and reduces the range of mid tarsal joint pronation (Philips 1983).

Motion around the mid tarsal joint oblique axis is able to influence sub talar joint motion. Weight bearing pronation at the mid tarsal joint oblique axis cannot take place unless the talar head moves plantarly and so pronates the sub talar joint. Conversely, supinating the mid tarsal joint around the oblique axis moves the talar head dorsally and supinates the sub talar joint.

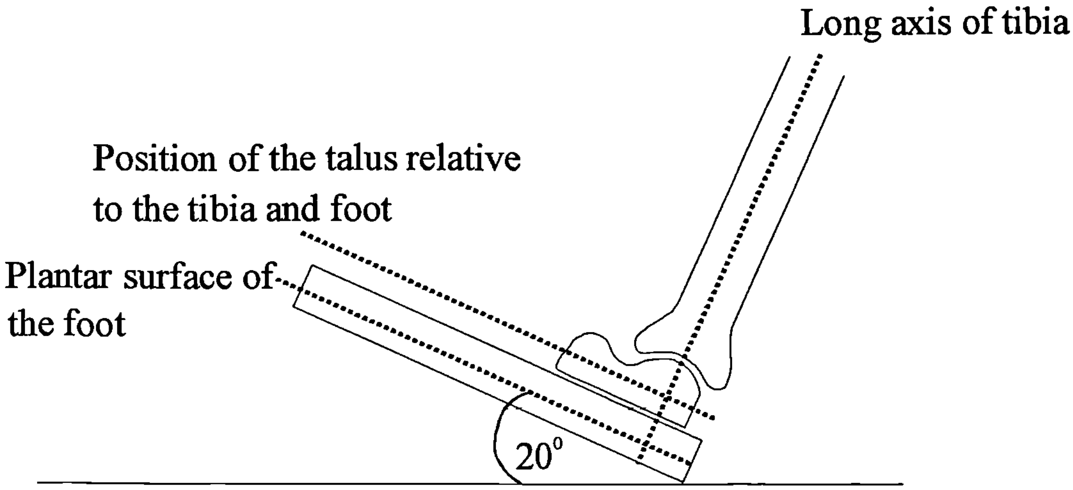
The locked or unlocked status of the mid tarsal joint also has some effect on sub talar joint function. In its locked position the mid tarsal joint is unable to provide any eversion of the forefoot, which might be required when walking on uneven terrain for example. The rigidity of the locked mid tarsal joint allows the eversion moment to be referred back to the sub talar joint. The necessary eversion will be provided here if the range of sub talar motion is sufficient. In its unlocked position the mid tarsal joint contributes to the range of internal rotation of the talus and calcaneus, which in turn increases the range of internal tibial rotation. This is an important role because it increases the range of transverse plane motion in the rearfoot and reduces the torsional stresses that would otherwise be placed on the ankle and sub talar joints.

Clearly, the sub talar and mid tarsal joints have considerable influence on each other's function and the two joints are wholly interdependent. The function of the ankle joint, however, is not wholly dependent on the positions and motions of the other joints involved in the rearfoot complex. The function of the ankle joint is interdependent with the function of the sub talar and mid tarsal joints because it is influenced by their function. However, since the ankle is able to undergo additional motion that is independent of sub talar and mid tarsal joint function, it may also be considered as independent of the rearfoot complex. For example, during closed chain rearfoot complex pronation the plantar flexion of the talus occurs at the ankle. This increases the functional range of ankle dorsiflexion. In addition, because adduction of the talus is accompanied by internal rotation of the leg the ankle joint axis also internally rotates. Subsequent ankle joint motion will display a greater proportion of sagittal plane motion because the ankle axis makes a greater angle to the sagittal plane. Closed chain sub talar joint supination will have the opposite effect and reduce both the functional range of ankle dorsiflexion and the proportion of sagittal plane motion occurring at the ankle. However, motion may also take place at the ankle without pronating or supinating the rearfoot complex, by forward or backward motion of the tibia, which does not force the talus to move. Thus, the ankle has two mechanisms of operation. In one mechanism it is interdependent with the rearfoot complex (because the talus moves relative to the tibia as the rearfoot complex articulates). In the second mechanism the ankle is independent of the rearfoot complex (because the tibia is moving relative to the talus for which the rearfoot complex does not have to articulate). The ability of the ankle joint to operate independently of the rearfoot complex should not lessen the significance of the ankle joints contribution to rearfoot function, however, since loss of ankle motion will disrupt both sub talar and mid tarsal joint functions.

The interplay between the interdependent and independent functions of the ankle joint is evident during normal ambulation. Between the periods of heel strike and forefoot loading the whole foot plantarflexes relative to the leg and the rearfoot complex pronates. The talus will plantarflex in order to lower the forefoot onto the ground. However, as a component of the rearfoot complex pronation the talus will undergo additional plantarflexion relative to the tibia to allow the sub talar joint to pronate and the mid tarsal joint to unlock. Thus, if the angle between the tibia and the plantar surface of the foot increases from 90° at heel strike to 110° at forefoot loading (so the ankle appears to have plantarflexed by 20°), the talus will in fact have plantarflexed by 20° independently of the rearfoot complex, plus an additional number of degrees as a component of rearfoot complex pronation (Figure 2.8). Clearly, the two mechanisms by which the ankle joint operates act synchronously during gait.

If the relationship between the sub talar and mid tarsal joints is described as two way (i.e. in the normal rearfoot complex both joints influence and can be influenced by the function of the other), the relationship of these joints with the ankle is comparatively one way, because the talus, and therefore the ankle, is influenced by their function but the ankle is unable to have any effect on sub talar and mid tarsal joint function.

The foot at heel strike.



The foot at forefoot loading.

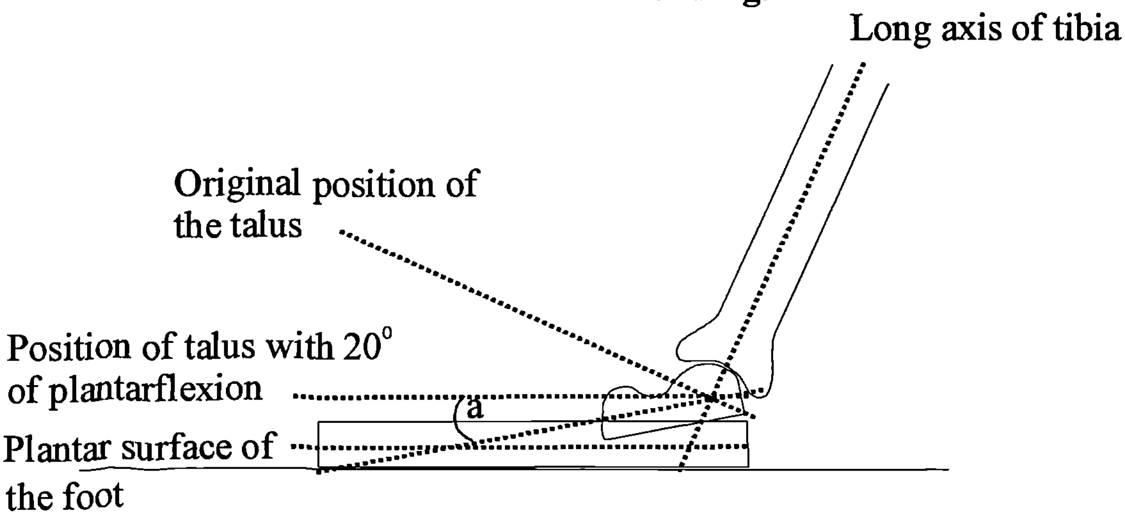


Figure 2.8

a = the angle of talar plantarflexion as a component of rearfoot complex pronation. The actual position of the talus is $20^0 + a^0$ plantarflexed.

Clearly, the motions of the individual joints in the rearfoot are interdependent. Huson described the rearfoot joints as a closed kinematic chain, which implies that motion in one part of the rearfoot produces or influences motions in the rest of the rearfoot. This concept fits well with the influence that the function of the ankle, sub talar or mid tarsal joints have on each other. The fact that motion in one joint, or one part of the kinematic chain, produces motion in the rest of the rearfoot was illustrated by Van Langelaan (1983). He assessed the motion of the individual bones in the rearfoot of 10 cadavers during external rotation of the leg from an internally rotated position. All three rearfoot joints moved throughout the range of leg rotation. No joint remained in a fixed position whilst the others in the complex moved. Thus, motion in one of the joints is always accompanied by motion in the other joints, which is consistent with the kinematic chain concept.

2.3.2.3 The pattern of interdependent motion between the joints is fixed.

A further characteristic of a closed kinematic chain, with which Huson (1991) likened the rearfoot, is that the pattern of motion, under given constraints, occurs in a fixed pattern. In the case of rearfoot complex function the constraint is that the foot is load bearing. Given this constraint, the pattern of motion between the rearfoot joints is fixed. Benick (1985) assessed the motion of the individual rearfoot bones during transverse plane rotations of two cadaver legs. He found the motions of the bones were almost identical during external leg rotation and internal leg rotation (Figure 2.9 and Figure 2.10). He also assessed the effect of vertical loading and the speed of leg rotation on the tarsal movements. Neither had a significant effect.

Benick compared the pattern of tarsal motions during phased rotation of the leg (in approximately 10° steps) and continuous rotation of the leg. Here too, no significant difference was found between the tarsal movements. Thus, the pattern of motion is independent of the direction of motion, speed of motion, vertical segmental loading and the method by which motion is induced. The pattern of motion, therefore, at the individual ankle, sub talar and mid tarsal joints is fixed during rotation of the leg.

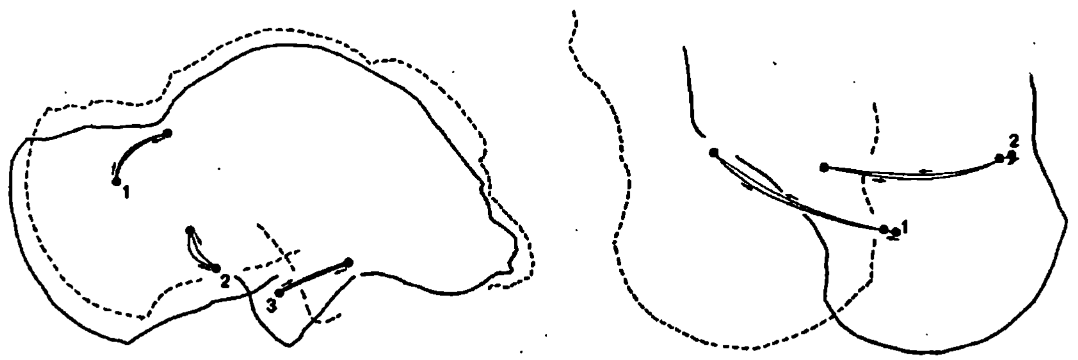


Figure 2.9

The motion of a single metal bead in the calcaneus, the path of the bead during external leg rotation (rearfoot complex supination) is almost identical to that during internal leg rotation (rearfoot complex pronation). From Benick (1985).

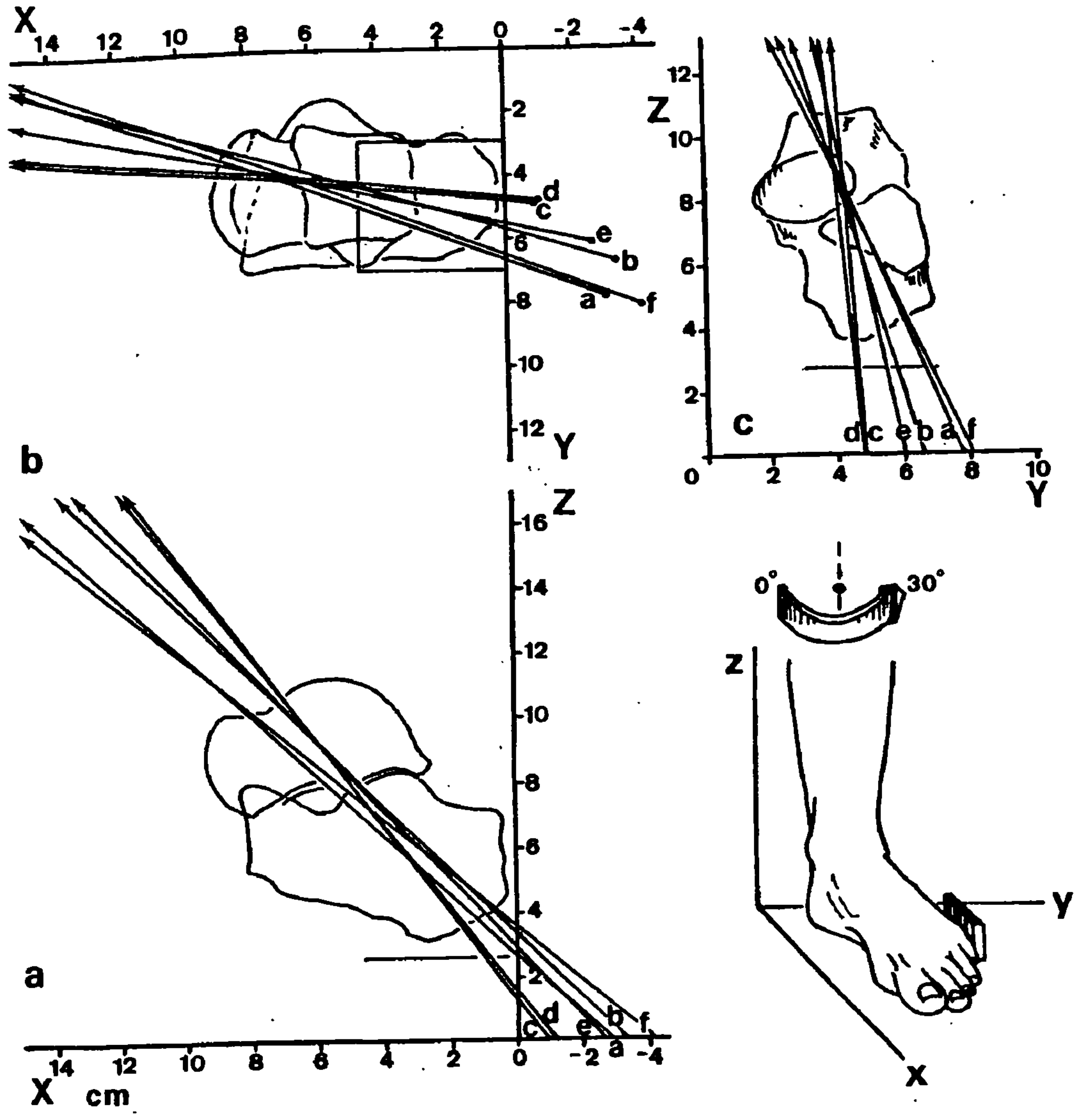


Figure 2.10

Talocalcaneal joint axes calculated by Benick (1985). Axes a, b and c are calculated during external rotation of the leg from and internally rotated position. Axes e, f and g are calculated during internal rotation of the leg from an externally rotated position. The axes for the rotations in two different directions are almost identical.

Since each joint must rotate for the rearfoot to perform its primary function, all joint rotations are interdependent and the three rearfoot joints will always undergo the same rotations during internal and external rotation of the leg, it is reasonable to suggest that the three joints could be considered as a whole and not individually. These characteristics of the motion at the ankle, sub talar and mid tarsal joints provide a sound scientific basis for the concept of the rearfoot complex. Furthermore, the rearfoot complex provides a model of rearfoot function that supersedes the current model, because it considers the contribution of the three joints in the function of the rearfoot collectively and not individually.

2.3.3 DEVELOPING A CONCEPTUAL MODEL OF THE REARFOOT COMPLEX.

The literature review thus far depicts the rearfoot complex as a kinematic chain in which transverse plane rotation of the leg drives the rotations at the ankle, sub talar and mid tarsal joints, to produce the pronation and supination of the rearfoot complex. When adopting the kinematic chain concept Van Langelaan (1983) termed the transverse plane rotation of the leg as the input rotation to the kinematic chain. Thus, in a conceptual model of the rearfoot complex transverse plane leg rotation is the single input rotation which produces a fixed pattern of rotations in the three joints, and which must therefore produce an output rotation.

The fact that during gait, and in the rearfoot complex model, transverse plane leg rotation is the principal rotation driving rearfoot complex motion becomes clear when the inability of sagittal and frontal plane leg motion to drive the rearfoot complex is considered. The sagittal plane motion of the leg required during gait is accommodated at the ankle joint, independent of the rearfoot complex, and thus cannot drive the rearfoot complex into motion. Very little frontal plane motion is required during gait since only small medial/lateral shifts in the position of the body mass are required. The necessary medial/lateral shift of the body mass is produced principally by frontal plane motion at the hip. Thus, there is little frontal plane motion of the leg and thus little rotation which could drive the rearfoot complex although the rearfoot complex must accommodate the frontal plane angulation of the leg relative to the floor.

In contrast, the ability of proximal transverse plane rotations to drive rearfoot complex motion and the importance of the transverse plane motion capabilities in the foot, can be illustrated when the principal function of motion in the transverse plane during gait is considered. The transverse plane rotation of the pelvis, femur and tibia, take place to allow the non weight bearing limb to move from behind to in front of the weight bearing limb, thus allowing forward progression of the body. This is only possible if the weight bearing limb has a stable base of support which accommodates the necessary transverse plane motion of the proximal segments. If the foot could not perform this function the foot would need to rotate relative to the floor, generating significant frictional forces on the plantar surface of the foot, and losing the stable base of support. The foot thus serves as a support base but also a pivot point for the body's transverse plane rotations. Thus, as the non weight bearing limb is moved from behind to in front of the weight bearing limb, the pelvis, femur and tibia all rotate in the transverse plane and the foot must accommodate (and is thus driven into rotation) the total range of proximal transverse plane rotations.

This ensures that foot strike of the non weight bearing limb occurs sufficiently far forward to maintain the desired distance of travel for each step. The foot does not have such a relationship with the frontal and sagittal plane rotations of the lower limb, further confirming that the rearfoot complex input rotation, or driving rotation, is principally transverse plane rotation of the leg.

The preceding discussion has established that the principal rotational movement driving rearfoot complex motion is transverse plane rotation of the leg, as opposed to sagittal or frontal plane motion of the leg. This input rotation to the rearfoot complex will force the ankle, sub talar and mid tarsal joints to rotate in a fixed pattern and produce an output rotation from this kinematic chain. Here we have the beginnings of a conceptual model of the rearfoot complex. Transverse plane rotation of the leg serves as the input rotation to the kinematic chain. This chain has three links, or three points of further rotation (the ankle, sub talar and mid tarsal joints), which, when driven by the input rotation, produce the output rotation. In such a model, for a given input rotation the output rotation will always be the same because the rotations in the kinematic chain are fixed (see section 2.3.3.2). Thus, the relationship between the input and output rotation provides information about the nature, or characteristics, of the kinematic chain. Since the literature review has highlighted that the characteristics of the three rearfoot joints, in particular the sub talar joint, are variable between individuals, it is not necessarily the case that the relationship between the input and output rotations will be the same for every individual in the population.

The output rotation of the rearfoot complex has not yet been defined. It is usual to use the motion of the distal segment relative to the proximal segment as a basis for describing the characteristics of a joint, or complex of joints. Thus, the motion of the femur relative to the pelvis defines the characteristics of the hip. Similarly, the rotation of the tibia relative to the femur describes the characteristics of the knee. Thus, for the rearfoot complex, the rotation of the most distal segment relative to the proximal segment describes its characteristics. In the conceptual model developed thus far, the distal segment is the output rotation of the rearfoot complex and the proximal segment the input rotation to the rearfoot complex. The proximal segment can be defined as the leg and the distal segment as the navicular and cuboid. Hence, for a given transverse plane rotation of the leg (input rotation) we will observe a given rotation of the cuboid and navicular (output rotation) relative to the tibia, which results from the combined rotations of the ankle, sub talar and mid tarsal joints. The plane of motion of the output rotation is complex and depends on the functional characteristics of the rearfoot complex, and the changes in these characteristics during the range of rearfoot complex motion. Thus, the relationship between the transverse plane rotation of the leg and the resultant rotation of the navicular and cuboid describes the characteristics of the rearfoot complex.

All the necessary components of the conceptual model for the rearfoot complex are now defined. We have the input rotation, the closed kinematic chain and the output rotation defined. The model, therefore, comprises an input rotation which drives the motion of a kinematic chain, which has three points of articulation and whose pattern of rotation is fixed, resulting in an output rotation. The relationship between the input and output rotation for an individual is fixed, since the components and pattern of rotation in the kinematic chain is fixed. However, the literature suggests that the characteristics of the individual components of the kinematic chain are not fixed between individuals. Thus, if the components of the kinematic chain vary the relationship between the input and output rotation is likely to vary in a similar manner and therefore not be the same for every individual.

If a method could be developed to determine the relationship between the input and output rotations of the rearfoot complex, the functional characteristics of the rearfoot complex could be described. Also, the suggestion that there exists individual variation in the functional characteristics of the rearfoot complex could also be investigated.

2.3.4 PREVIOUS ATTEMPTS TO QUANTIFY THE FUNCTIONAL CHARACTERISTICS OF THE REARFOOT COMPLEX.

The functional characteristics of the rearfoot complex describe the type of motion the complex displays, in terms of the proportion of motion displayed in each cardinal body plane, the direction of motion in these three planes, the orientation of the axis around which the rotations take place and the pattern of any changes in these. The rearfoot complex has not previously been considered as a kinematic chain with a specific input and output rotations that represent the characteristics of the complex, as described in section 2.3.3. Thus, any previous attempts to assess the functional characteristics of the rearfoot complex by other authors do not correspond to the model presented here.

Downing et al (1978) was the first investigator to measure the motion resultant of the combined ankle, sub talar and mid tarsal joints and thus attempt to describe the functional characteristics of the rearfoot complex. The investigators measured the rearfoot complex motion in the cardinal body planes and determined an axis of rotation for the rearfoot complex. This axis was said to be the axis around which the motion resultant of the three individual joints took place. The axis represents the functional characteristics of the entire complex because its orientation is determined by the motion resultant of the motion at the three individual joints. This concept is ideal for representing the characteristics of several joints combined, because it gives a single measure as opposed to a separate measure for each joint which would require more complex interpretation.

Downing et al (1978) measured the range of transverse plane rearfoot complex motion using the rotation of the tibia relative to the floor as indicated by a pin extending anteriorly from the tibia. Frontal plane rearfoot complex motion was measured using the angle between the posterior surface of the calcaneus and the floor. The sagittal plane rearfoot complex motion was measured using the angle between the floor and a line from the navicular tuberosity and the medial malleolus. Angular measures in each plane were taken with the rearfoot maximally supinated, with the sub talar joint in its neutral position and with the rearfoot maximally pronated. The authors described a mean composite rearfoot complex axis (for the total range of rearfoot complex motion) angled 18° to the sagittal plane and 51° relative to the transverse plane from a sample of 42 individuals (72 feet). The angle of the composite axis relative to the sagittal plane varied from 7° to 42° within the sample and the angle to the transverse plane from 32° to 62°. In addition to an axis calculated from the total range of rearfoot complex motion, axes were also determined for the separate movements from maximum supination to sub talar neutral and from neutral to maximum pronation. The average supinatory axis (for the motion between maximum supination and sub talar joint neutral) was angled 39° from the transverse plane and 16° from the sagittal plane. The average pronation axis (for the motion between sub talar joint neutral and maximum pronation) was angled 65° from the transverse plane and 27° from the sagittal plane. Thus, the functional characteristics of the rearfoot complex during supination included a predominance of frontal plane motion. In contrast, the functional characteristics of the rearfoot complex during pronation included a predominance of transverse plane motion. Clearly, a further functional characteristic of the complex is that the functional characteristics change during its range of motion.

In principle Downing et al's (1978) method should be highly satisfactory since the measurements are simple to take, do not require expensive apparatus and are non invasive. However, there are serious sources of error in the measurement protocol which retract from the validity of Downing et al's work. Firstly, the method used to measure the range of frontal plane rearfoot complex motion is flawed. The investigators used the angle between the heel and the floor for this angular measure. This angle will alter as the rearfoot complex pronates and supinates because the heel inverts and everts during these motions. However, the angle of the heel relative to the floor can also be altered if the leg moves relative to the floor in the frontal plane, which it may do so without rearfoot complex motion. This is clearly the case in the investigators work (Figure 2.11). Thus, the frontal plane measures were invalid and the results probably incorporate more frontal plane rearfoot complex motion than actually took place. Also, any frontal plane motion occurring at the mid tarsal joint would not be reflected in the frontal plane motion of the heel. Consequently, the frontal plane measurements only indicate the ankle/sub talar component of frontal plane rearfoot complex motion, but even then are invalid since they relate to the floor and not the leg.

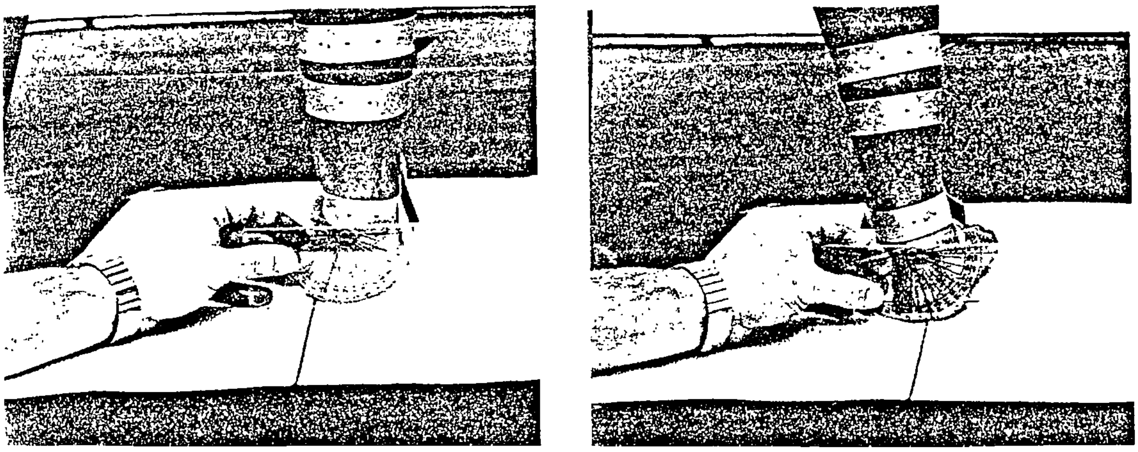


Figure 2.11

From Downing et al's 1978 paper: measuring the frontal plane rearfoot complex motion. The measurement is prone to error because the leg is able to move in the frontal plane independent of the rearfoot complex, as is clearly illustrated in the photograph

The transverse plane measure too was flawed. Using a measure of the transverse plane rotation of the tibia relative to the floor as the authors did, they assumed that the foot, or at least the forefoot, was fixed relative to the floor. They did not attempt to assess whether the forefoot moved in the transverse plane relative to the floor or attempt to provide physical constraints on the forefoot to prevent it moving in the transverse plane. Also, taking measurements of the position of a pin extending anteriorly from the tibia relative to the floor is susceptible to error if the tibia rotates in a plane other than the transverse plane. Again, the authors made no attempt to control or measure the rotation of the tibia in planes other than the transverse plane.

Finally, the measurement of sagittal plane rearfoot complex motion was also flawed. The authors attached drawing pins to the medial malleolus and navicular tuberosity to define a line which, when related to the floor, gave an angular measure of sagittal plane rearfoot complex motion. These drawing pins were held in place using rubber straps. Clearly, the tension in these straps made them liable to move relative to the skin and thus relative to the malleolus and navicular tuberosity. This is highly important since the range of sagittal plane motion recorded was very small (mean 8.7°) and even small errors such as 1° are significant as a proportion of the total range. Also, the concept that this measurement represents the sagittal plane motion in the rearfoot complex was not justified. The angle would change as the tibia was moved vertically during rearfoot complex pronation and supination, but this only indicates elevation of the tibia, not necessarily sagittal plane rearfoot complex motion.

Given the substantial errors in the experimental design of Downing et al's (1978) work, it is difficult to determine what exactly was measured and what the calculated 'rearfoot complex axis' relates to. Furthermore, Downing et al did not document any repeatability work relating to their method. The repeatability of measuring heel position in the frontal plane is known to be poor, particularly when using the sub talar joint neutral position (Freeman 1990, Menz 1995). Considering the use of two dimensionally projected lines for the transverse plane measures and the general poor quality of measurements which include pen lines drawn on paper and subsequently measured with a protractor, the results documented by Downing et al should be considered unreliable.

No other work has been published which attempts to measure the motion resultant of all three rearfoot joints. Consequently, considering the poor quality of Downing et al's work, to date there has not been a reliable description of the functional characteristics of the rearfoot complex. However, some authors have measured the ratio of transverse plane tibial rotation to frontal plane heel motion, which gives some indication of the functional characteristics of the ankle/sub talar component of the rearfoot complex. These provide some indication of what the characteristics of the rearfoot complex might be and serve as a valuable comparison to any description of the rearfoot complex.

The work of Bowden and Bowker (1995) illustrates the degree of individual variation in the functional characteristics of the ankle/sub talar component of the rearfoot complex. The authors measured the range of tibial rotation and the frontal plane motion of the leg and heel between the positions of maximum weight bearing rearfoot supination and maximum weight bearing rearfoot pronation, using a laterally wedged supporting surface to force the rearfoot to pronate. They determined the ratio of tibial rotation to rearfoot motion (Tibial Rotation/Rearfoot motion) (using the frontal plane angle between the leg and heel for the latter) in 27 subjects. The average TR/RC ratio was 1.29 but a wide range of values were evident in the 27 subjects tested (0.39 - 2.26) (Table 2.1).

Subject (Control group)	Right leg	Left leg	Subject (patellofemoral pain group)	Painful leg	Non-painful Leg
C1	1.41	1.18	I1	1.50	1.32
C2	0.84	0.66	I2	1.26	1.13
C3	2.11	2.26	I3	1.21	1.23
C4	0.66	0.39	I4	1.10	0.46
C5	0.80	0.81	I5	0.92	0.85
C6	1.18	1.96	I6	1.17	1.52
C7	1.08	1.64	I7	0.93	1.01
C8	0.97	1.47	I8	1.99	1.32
C9	1.98	1.36	I9	1.28	1.79
C10	1.39	2.02	I10	1.54	1.24
C11	1.04	1.22	I11	0.74	1.02
C12	1.21	1.2	I12	1.47	1.19
			I13	1.46	1.93
			I14	1.25	1.74
			I15	1.73	1.55

Table 2.1

Ratio of transverse plane leg rotation to frontal plane heel/leg motion in 12 pain free control subjects and 15 subjects with patello-femoral pain

Other authors have carried out similar work. Olerud and Rosendahl (1987) reported an average of 0.4° of external leg rotation per 1° of foot supination (using the frontal plane angle between the heel and leg to indicate supination) and Lundberg et al (1989b) described an average of 0.2° external tibial rotation per 1° of foot supination (also using the frontal plane heel to leg angle as an indicator of supination).

These results suggest that different individuals possess ankle/sub talar complexes with different functional characteristics as reflected in the ratio of tibial rotation to frontal plane heel to leg motion. This is not surprising considering the individual variation in the functional characteristics of the sub talar joint highlighted in section 2.1.2.1. If such individual variations were reflected in the functional characteristics of the rearfoot complex, then a rearfoot complex model based on the functional characteristics of the average rearfoot complex would be inappropriate. A proportion of the population may possess a rearfoot complex whose functional characteristics are not accurately described by the model based on an average rearfoot complex. The extent of the individual variation in the functional characteristics of the rearfoot complex may necessitate that contrasting rearfoot complexes be considered separately. This could be achieved by categorising rearfoot complexes according to their functional characteristics. The criteria for a category would ideally be a single quantitative measure of the functional characteristics of the rearfoot complex. The concept of a rearfoot complex axis, as suggested by Downing et al (1978), would meet this criterion. This single quantitative measure of the functional characteristics of the rearfoot complex would allow simple comparison between individuals. The model of rearfoot function would then comprise two or more categories and include those individuals whose rearfoot complex varies, in terms of its functional characteristics, from the average rearfoot complex. This would be a significant improvement on the present model of rearfoot function that is based on the functional characteristics of the average rearfoot and does not account for individual variation.

Since the rearfoot complex displays different functional characteristics during different stages of its range of motion, a rearfoot complex axis derived from the total range of rearfoot complex motion may not adequately describe the functional characteristics of the complex. Furthermore, the rearfoot complex rarely utilises its total range of motion dynamically and without some knowledge of which part of its total range of motion it moves through during gait it is impossible to deduce a meaningful rearfoot complex axis orientation. Thus, it is preferable to assess the functional characteristics of a rearfoot complex whilst it moves through the part of its total range of motion which is used during gait.

2.4 SUMMARY.

The rearfoot complex comprises the ankle, sub talar and mid tarsal joints. The general characteristics of the ankle and sub talar joints have been described. The ankle allows predominantly sagittal plane motion around a series of instantaneous axes of rotation. The sub talar joint also has a variable axis orientation throughout its range of motion, but also displays considerable individual variation in the orientation of this axis. The characteristics of the mid tarsal joint are poorly described in the literature. The only reliable evidence suggests a balance of frontal and transverse plane motion.

The concept of the rearfoot complex as a model of rearfoot function has been validated on the basis that: the correct function of each joint is needed for the rearfoot to perform its primary function; the rotations in the rearfoot complex are interdependent; and the pattern of rotation between the joints is fixed. A conceptual model to describe the function of the rearfoot complex has been developed. This describes the rotations in the ankle, sub talar and mid tarsal joints as a closed kinematic chain, driven by transverse plane leg rotation, and producing an output rotation in the form of navicular and cuboid motion.

With regard to the conceptual model developed in section 2.3.3, there has been no attempt to quantify the functional characteristics of the rearfoot complex reported in the literature. Related literature suggests that the functional characteristics of the rearfoot complex may vary between individuals, which would not be surprising given the individual variation in the three components of the complex. If it exists, the individual variation should be described in the model of rearfoot complex function. This would be a further improvement on the current model of rearfoot function. The axis of rotation for the rearfoot complex could be used as a single quantitative measure of the functional characteristics. Using the conceptual rearfoot complex model developed here, this axis is the axis around which the navicular and cuboid rotate relative to the tibia and is thus the axis around which the combined rotations at the ankle, sub talar and mid tarsal joints take place.

CHAPTER 3

AIM OF INVESTIGATION AND METHODOLOGY

3.1 AIM OF INVESTIGATION.

In chapter 2 a model of rearfoot function was described which incorporates all three rearfoot joints and is based on the weight bearing functional characteristics of the combined joints. The model assumes that transverse plane rotation of the leg is the input rotation to a kinematic chain, which comprises the ankle, sub talar and mid tarsal joints, and that this produces an output rotation in the form of navicular and cuboid motion.

The aim of this investigation is to quantify in vivo the functional characteristics of the rearfoot complex using non invasive techniques. It will thus involve quantifying the functional characteristics of the combined ankle, sub talar and mid tarsal joints, ankle/sub talar complex and the mid tarsal joint. Quantifying the characteristics of the composite function of the three rearfoot joints will provide a description of the proposed model of rearfoot function. Describing the characteristics of the ankle/sub talar complex and mid tarsal joint will explain how the characteristics of the composite function of the three rearfoot joints are derived. The functional characteristics can be defined as the range of motion in each cardinal body plane displayed by the joint, the axis around which joint rotations take place and the changes in these characteristics.

This assessment of rearfoot function will build on the methods used in the literature reviewed in chapter 2 in that it will:

i. be a three dimensional in vivo assessment;

ii. be a non invasive assessment;

iii. involve an assessment of the rearfoot during continuous motion, as opposed to the assessment of rearfoot motion in increments;

iv. consider the part of the total range of rearfoot motion that is used during gait;

v. describe the functional characteristics of the combined three rearfoot joints;

vi. describe the contribution of the ankle/sub talar complex and mid tarsal joints to the characteristics of the rearfoot complex;

vii. enable a single quantitative measure of the functional characteristics of the rearfoot complex and its components to be determined (rearfoot complex axis).

The advantage of describing the composite characteristics of the three rearfoot joints is that it is not necessary to assess the function of the individual joints, but only to measure their combined motion. This approach avoids many of the problems associated with not being able to isolate joints individually because the talus is not accessible and the palpation of bony landmarks for each joint is difficult. Also, even if it were possible to assess the function of each joint individually, their combined function would still have to be estimated as opposed to measured. Finally, assessment of each joint individually is only possible using cadavers or invasive techniques in vivo, which are clearly undesirable. In contrast, assessment of the combined function of the three rearfoot joints can be achieved using non invasive in vivo techniques and does not require the individual joints to be identified.

3.2 METHODOLOGY.

3.2.1 OVERVIEW OF METHODOLOGY.

It is proposed that the motion of the leg and the motion of the navicular and cuboid be assessed during static, weight bearing rearfoot complex pronation and supination using a camera based three dimensional motion analysis system to track the position of reflective markers attached to each segment. The rotation of the navicular and cuboid relative to the leg will serve as a description of the functional characteristics of the rearfoot complex since these are the input and output rotations of the rearfoot kinematic chain. In addition, the three dimensional motion of the heel will be assessed. This will provide data to describe the ankle/sub talar complex (motion of heel relative to leg) and the mid tarsal joint (navicular and cuboid relative to the heel). It will allow the relationship between the ankle/sub talar complex and the mid tarsal joint components of the rearfoot complex and the function of the entire complex to be investigated. This will provide a measure of the functional characteristics of the rearfoot complex, and also provide a description of the contribution of these two components to the characteristics of the composite function of the three rearfoot joints.

In accordance with the proposed model of the rearfoot complex, the motion of the leg, which is the input rotation to the rearfoot complex, must be mechanically constrained to transverse plane motion. The subjects must perform internal and external rotations of the leg to produce pronation and supination of the rearfoot complex. In line with accepted methods of kinematic analysis, the leg, the heel and the navicular and cuboid will be defined using position data describing the motion of three points on their surface relative to a global co-ordinate system, and through the definition of local co-ordinate systems for each segment. The absolute rotations (angular motion with respect to the global co-ordinate system) and relative rotations (angular motion with respect to another segment) of the segments will be calculated using Euler angles. This component of the investigation is the **static rearfoot complex assessment.**

The rotations in the three cardinal body planes will be incorporated into the trigonometric equations used by Downing et al (1978) to compute the orientation of an axis of rotation for the absolute and relative rotations of the different segments. This will provide a single measure to quantify the functional characteristics of the rearfoot complex and each of its components.

Finally, to ensure that the part of the range of rearfoot complex motion that is used during gait is assessed within the static assessment data, the part of the total range of rearfoot complex motion through which the segments move during gait is to be identified within the data from the static rearfoot complex assessment. This will be achieved by assessing the range of rearfoot complex motion during gait and is the basis of the **dynamic rearfoot complex assessment**. A detailed description of the investigation now follows.

3.2.2 DATA COLLECTION.

Twenty five subjects with no history of lower limb fractures, previous ligament injuries or other pathology affecting the musculoskeletal system were recruited from the population at Salford University. All 25 under went both the static and dynamic rearfoot complex assessments. Since the methodology involved in the static assessment was unique and untested in vivo, the static rearfoot complex assessment was repeated on 4 of the 25 subjects (8 limbs in total). These two males and two females completed a second series of static assessments at least 1 week after the first static assessment (range 1 week – 4 weeks).

Standard subject parameters were also taken; age, height and weight, and are listed in table 3.1.

Subject number	sex	age	height (cm)	weight (kg)	Data used left	Data used right
1	m	36	172.0	71.8	yes	yes
2	m	27	184.5	78.0	yes	yes*
3	m	23	192.5	87.2	yes	yes
4	f	34	169.0	61.6	yes	yes
5	m	21	178.0	65.0	yes	yes
6	m	22	176.5	79.8	yes	no
7	f	28	168.0	71.4	yes	yes
8	f	21	154.0	53.4	yes	yes
9	f	44	159.0	53.6	yes	yes
10	m	22	181.5	94.6	yes	yes
11	f	24	161.0	59.2	yes	yes
12	f	22	163.5	63.2	yes	yes
13	f	23	152.0	54.2	yes	yes
14	m	22	167.5	66.6	yes	yes
15	f	21	158.0	58.0	yes	yes
16	m	25	178.0	76.0	yes	yes
17	m	34	169.0	82.0	yes	yes
18	f	27	177.5	77.0	yes	yes
19	f	26	165.0	59.8	yes	yes
20	f	28	160.0	60.0	yes	yes
21	m	21	177.5	42.2	yes	yes
22	m	41	167.0	58.2	yes	yes
23	f	21	161.0	50.4	yes	no
24	f	21	154.5	72.8	yes	yes
25	m	27	163.5	60.4	yes	yes
MEAN	/	26.4	168.4	66.3	/	/
Female	13	26.2	161.7	61.1	/	/
Male	12	26.8	175.6	71.8	/	/
total	25	/	/	/	25	23
total	/	/	/	/	48	

Table 3.1

Table gives details of the 25 subjects used in this study. The right limb data of subjects 6 and 23 was excluded because no valid reference position could be determined due to lost data files. * = the data from the dynamic assessment were judged invalid (see section 4.2) but data from static assessment were valid.

3.2.2.1 Static rearfoot complex assessment.

3.2.2.1.1 Experimental rig.

It was necessary to design and build a device that allowed the leg to rotate in the transverse plane, but constrained its motion in the frontal and sagittal planes. This ensured that the input rotation to the rearfoot complex during the assessment was solely transverse plane rotation of the leg, as described in the rearfoot complex model. This aspect of the investigation was very similar to the experiments carried out by Van Langelaan (1983) and Benick (1985) and consequently their experimental protocols were examined. These two authors used the same piece of experimental equipment. They built a mechanical rig which allowed the foot of a below knee cadaver specimen to be placed with the plantar surface of the foot in contact with the ground and the ankle at approximately 90° i.e. tibia was vertical. The transverse plane motion of the leg was induced by electrical motors that turned a mechanical ring. The mechanical ring was mounted on bearings that constrained its rotation to the transverse plane and the tibia was fixed to the inner surface of the mechanical ring using screws. The transverse plane motion of the forefoot of the cadavers was constrained using a metal bar on the lateral side of the forefoot. Using this rig the investigators had been able to constrain the input rotation to the rearfoot complex to transverse plane tibial rotation.

A similar rig was designed for this investigation. This consisted of a horizontally orientated platform mounted above a wooden board (0.8m x 1m) using three steel supports. The height of the platform from the board was adjustable between 15cm and 40 cm. Within the platform a ring was mounted on three bearings, restricting rotation of the ring to a plane parallel to the supporting surface (Figure 3.1).

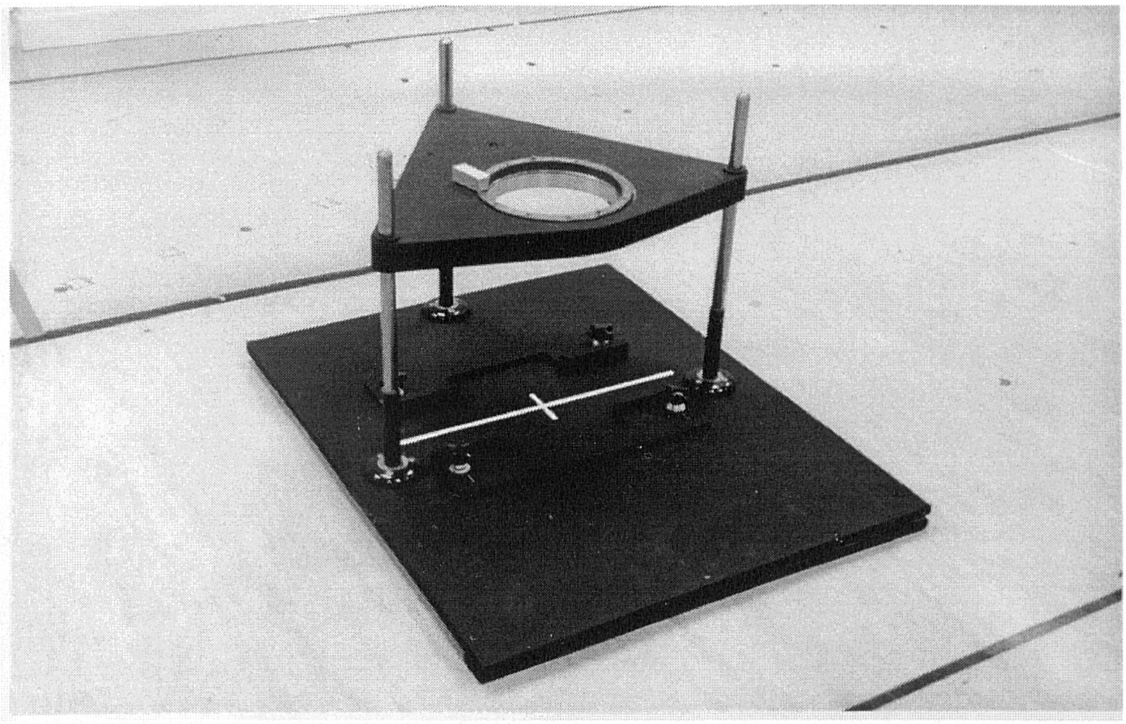


Figure 3.1

Experimental rig used in the static rearfoot complex assessment. It comprises a steel platform mounted parallel to the supporting surface on three steel poles. Mounted within the platform on three bearings is a ring that rotates in a plane parallel to the supporting surface.

The mechanical ring mounted in the platform was 20cm in diameter. This rig allowed a subject to stand on the board with one leg inside the ring and the other adjacent to it in a normal stance position. The motion of the leg in the frontal and sagittal planes was restrained by packing the space between the inner surface of the ring and the leg with blocks of plastozote (Figure 3.2).

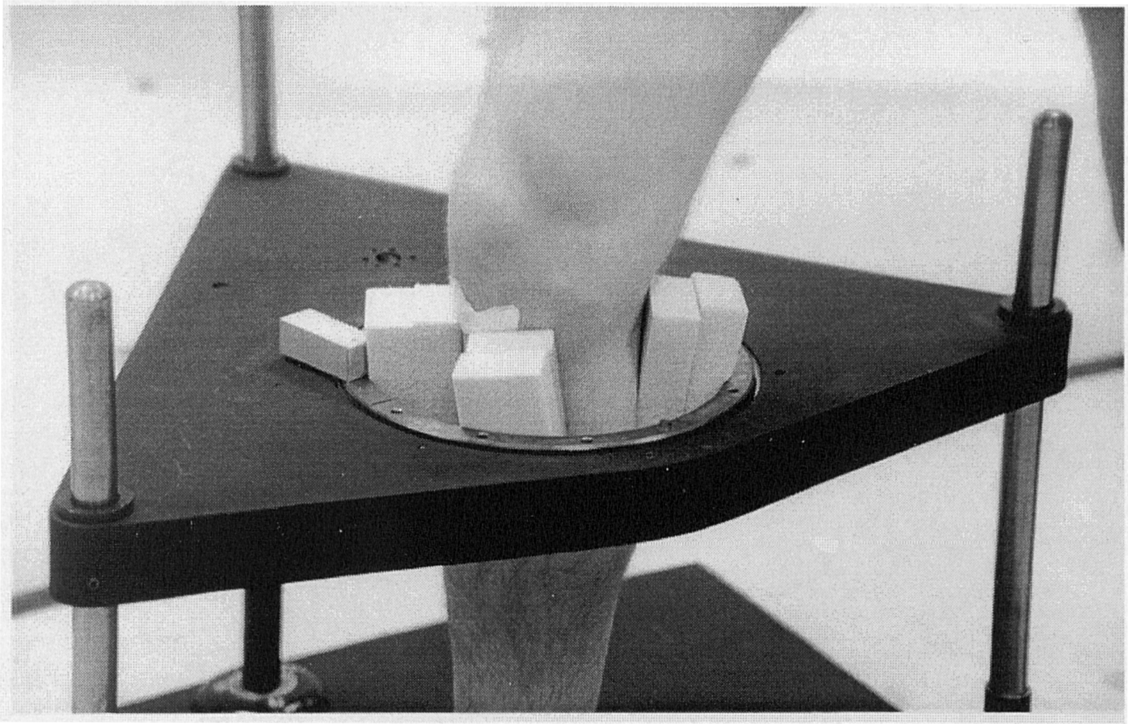


Figure 3.2

Packing the space between the leg and the ring with plastozote blocks restricted movement of the leg relative to the rotating ring.

Since the subjects were to induce rearfoot complex motion by rotation of the leg in the transverse plane, it was important that the axis of rotation of the leg was aligned as close as possible to the axis of rotation of the rotating ring. This would allow the leg to move in a manner as natural as possible. The centre of rotation of the ring was determined by first projecting the inner surface of the ring onto the surface of the wooden board using a plumb line. By taking the perpendicular of several lines intersecting the projection of the inner ring at two points, the centre of rotation of the ring relative to the wooden board was determined. The general position of the axis of rotation of the leg during Van Langelaan's (1983) study was consistently positioned slightly posterior to the posterior surface of the tibia in the sagittal plane view and centrally placed relative to the tibia in the frontal plane view. In vivo, this position is slightly posterior to the medial malleolus in the sagittal plane view and slightly medial of the centre of the posterior surface of the leg in the frontal plane view. Thus, to align the rotation axes of the leg and the axis of rotation of the mechanical ring, the foot was positioned so that in a sagittal plane view the medial malleolus was slightly anterior to the centre of rotation of the rotating ring, and the centre of the posterior surface of the leg was slightly lateral of the centre of rotation of the rotating ring (Figure 3.3 and Figure 3.4). These positions were assessed visually and maintained during the experiments by the plastozote blocks.

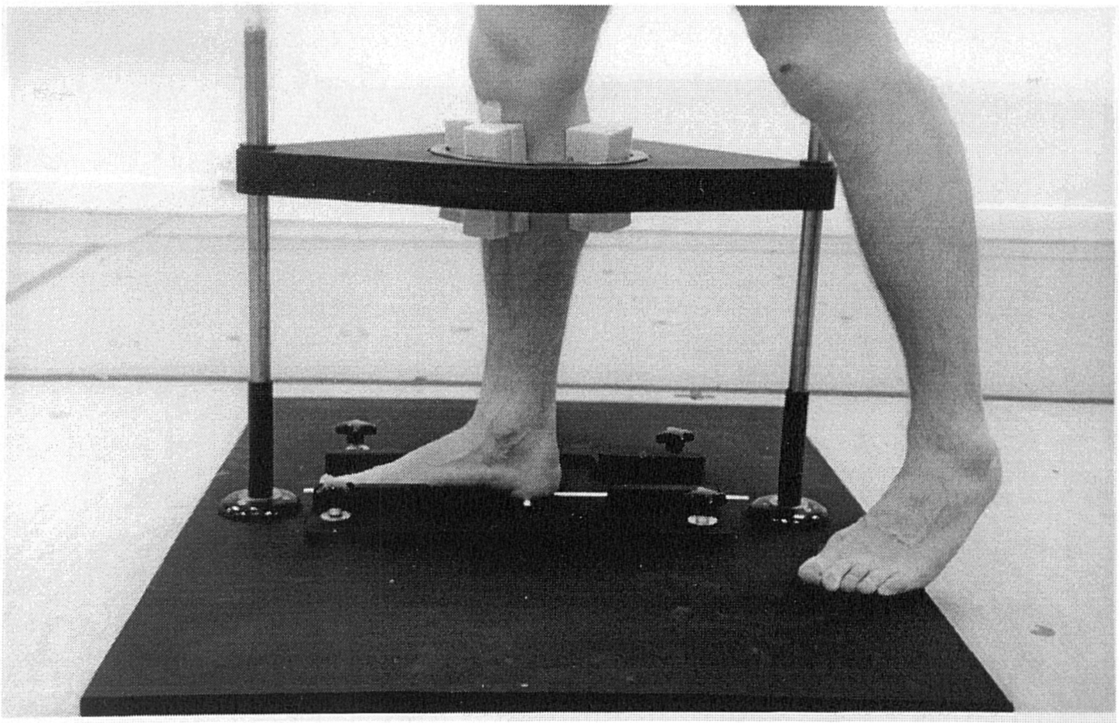


Figure 3.3

The sagittal plane alignment of the leg and foot relative to the centre of rotation of the ring, indicated by the cross hair (partially obscured under heel) on the wooden board.

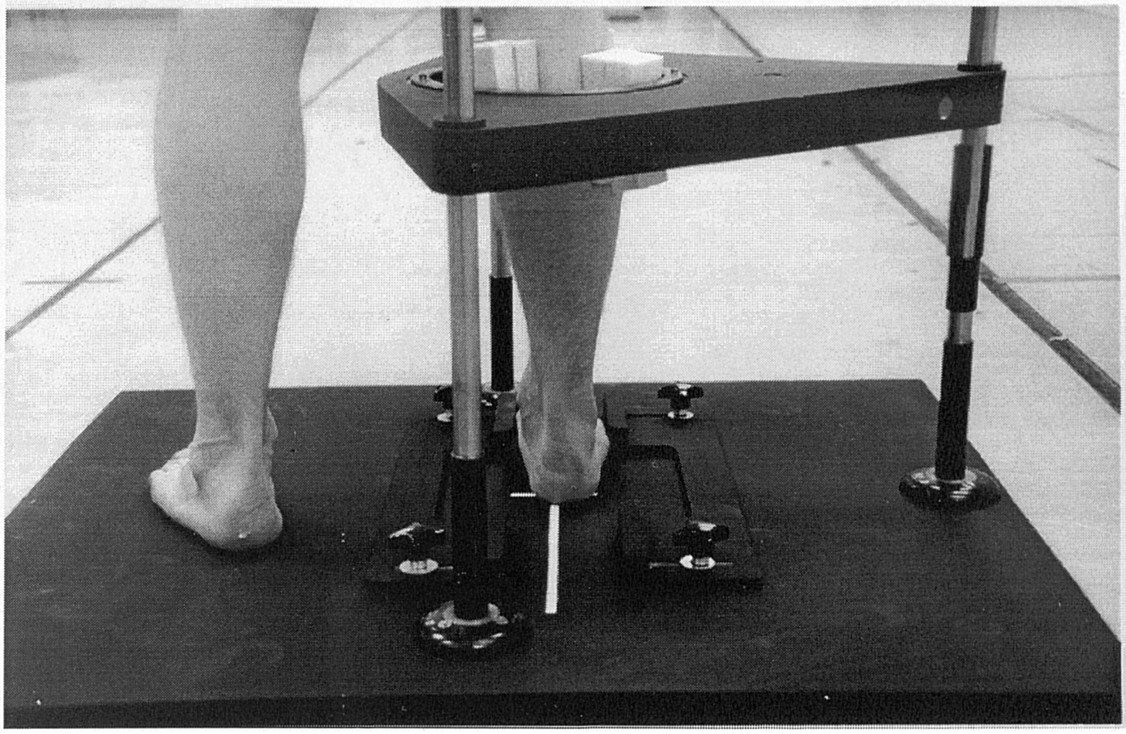


Figure 3.4

Frontal plane alignment of the foot and leg relative to the centre of rotation of the ring, indicated by the cross hair (partially obscured under heel) on the wooden board.

It was also important that the position of the foot on the board was such that the rotation angles subsequently calculated related to the anatomical planes of the foot. The angular rotations of all the segments were calculated relative to the x, y and z axes of the global co-ordinate system (Figure 3.5).

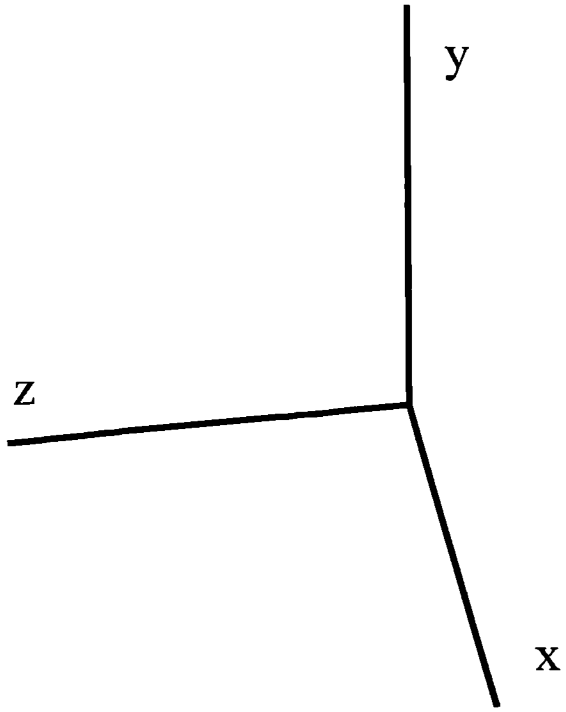


Figure 3.5

Global co-ordinate system used in this investigation.
x axis = anterior/posterior axis, y axis = vertical axis, z axis = medial/lateral axis).

For these angular rotations to have anatomical bearing, the anatomical cardinal body planes must align with those of the global co-ordinate system. An accepted method of achieving this alignment is to align the x axis of the global co-ordinate system (anterior/posterior axis) with a line from the centre of the plantar surface of the heel through the second metatarsal head (Figure 3.6). This aligns the anatomical sagittal plane with the plane defined by the x and y axes of the global co-ordinate system. This in turn aligns the anatomical frontal plane with the plane defined by the z and y axes of the global co-ordinate system. The anatomical transverse plane automatically aligns with the plane defined by the x and z axes of the global co-ordinate system since both are perpendicular to the other two planes.

To ensure that the foot remained in the correct position during the assessment, two adjustable boards, which prevented the forefoot from slipping in the transverse plane, were attached to the wooden base. This maintained the alignment of the plane defined by the x and y axes of the global co-ordinate system with the line from the centre of the plantar surface of the heel through the second metatarsal head, which is used to define the sagittal plane of the anatomical system (Figure 3.6).

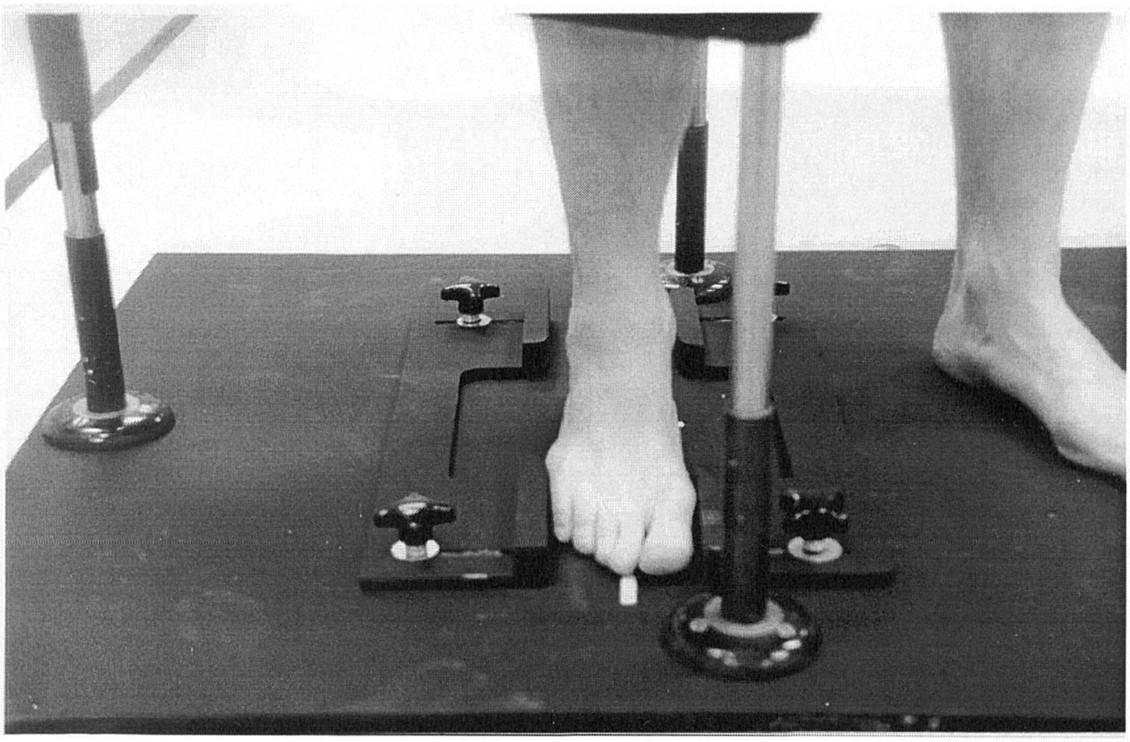


Figure 3.6

Two wooden boards were used to prevent the forefoot slipping in the transverse plane and thus maintain the alignment of the anatomical planes and the global co-ordinate system.

3.2.2.1.2 Describing the motion of the navicular and cuboid, the heel and the leg.

As with any two rigid body segments, the motion of the navicular and cuboid relative to the leg can be assessed if the positions of three points on each segment are known. Position data for three points on the surface of each segment can be derived from an image based motion capture system if the three points are identified with reflective markers. Subsequently, local co-ordinate systems for each segment can be defined using the three known points and the angular motion of the segment described.

This approach clearly assumes that the navicular and cuboid are a single rigid segment. Whilst, strictly speaking, this is not the case, the reason why they can be considered rigid has been explained in section 2.1.3.1. Briefly, this is because the two bones are firmly bound together with ligaments and during rearfoot complex motion the two bones always move in the same direction as each other. Thus when the talonavicular joint pronates so too does the calcaneocuboid joint and vica versa for supination.

A number of practical problems exist in defining this distal segment of the rearfoot complex. The positions of three points can be identified with reflective markers and these can be used to describe the motion of the segment. However, the nature of camera based motion analysis systems that detect and track the position of such markers requires that the markers be sufficiently spaced to allow clear definition of the three separate points. Also, the markers themselves must be of a reasonable size to achieve accurate determination of the positions. Due to the size of the navicular and cuboid, the size of reflective markers which can be attached to them and the spacing of markers is significantly restricted. However, it is generally considered that the navicular and cuboid together with the cunieforms and middle three metatarsals are a rigid unit.

Whilst without doubt there is some relative movement between these bones, their general motion is, like that of the navicular and cuboid, principally in the same direction and anatomically they too are tightly bound together. When the navicular and cuboid, and thus mid tarsal joint, supinates, the metatarsals too supinate. Incorporating the metatarsals into the rigid body model of the distal segment of the rearfoot complex increases the surface area over which three points describing the position of the segment can be identified. This makes the process of identifying the position of the individual markers much easier for the motion analysis system. The distal segment of the rearfoot complex model was therefore extended to include the cunieforms and the middle three metatarsals, which is in effect a segment comprising the forefoot.

In addition to achieving reasonable size and spacing of markers, where possible markers should be physically displaced away from the segment. This increases the amount by which the markers physically move. The greater the displacement of the marker away from the segment, the greater the physical movement of the marker and the more accurate the description of the path of motion and the angle of rotation subsequently calculated (Panjabi and Goel 1982).

To define the forefoot segment with three markers that were sufficiently spaced, were of reasonable size and were projected away from the segment, a molded platform was designed for attachment to the forefoot segment. The platform was made from Hexalite mouldable plastic material, moulded to the navicular/cuboid and second metatarsal area of the forefoot segment. Attached to this platform were three 40mm plastic wands projecting dorsally. Each wand had a 15mm diameter reflective marker attached to its tip (Figure 3.7).

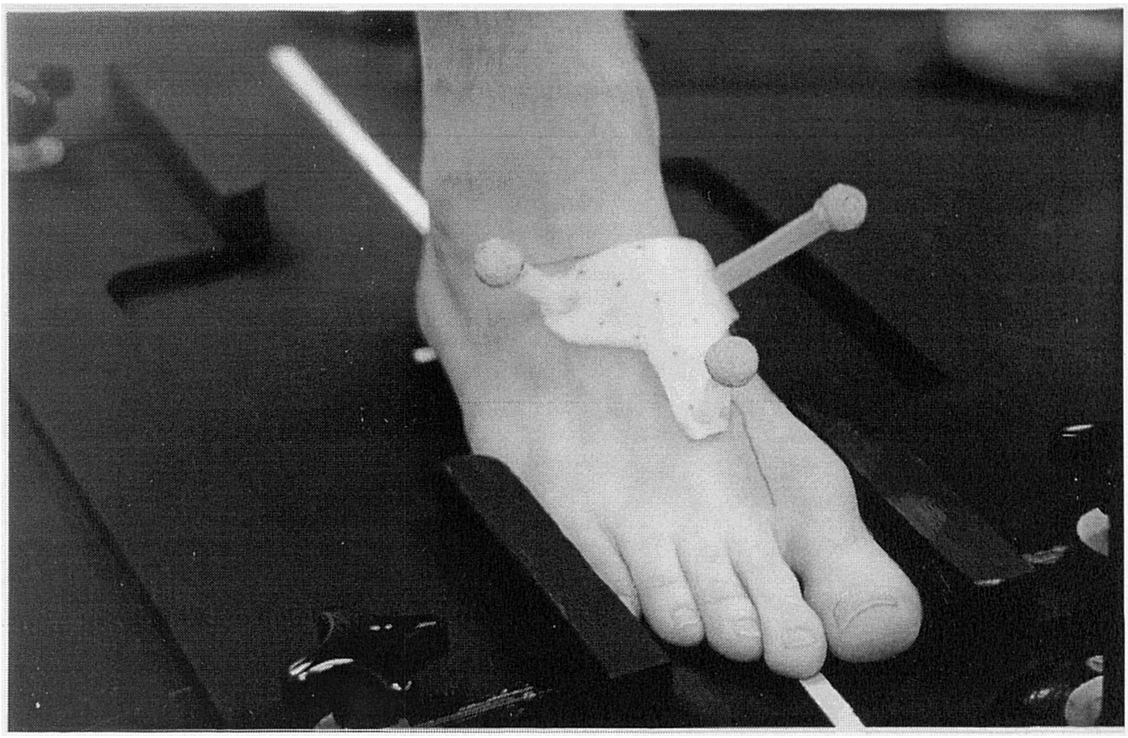


Figure 3.7

Hexalite platform used to project and space three markers on the forefoot segment. Proximal aspect of the platform was mounted on the navicular and cuboid and the forward extension over the second metatarsal shaft.

The definition of the heel was achieved using a similar technique. A heel cup was made by moulding a piece of Hexalite to a heel and three 40mm wands were attached to the cup. The three wands were projected posteriorly, medially and laterally and 15mm markers were attached to the tips of the wands. This achieved the necessary spacing and projection of markers (Figure 3.8). The heel cup was secured to the heel using double sided sticking tape.

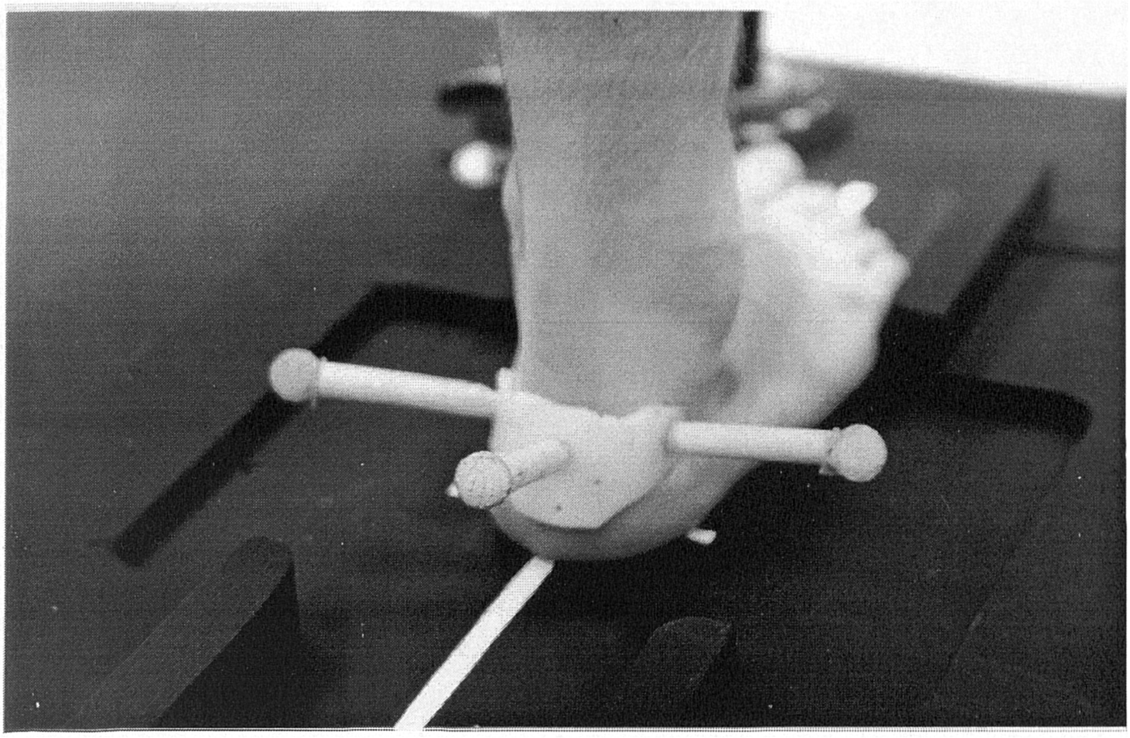


Figure 3.8

Hexalite heel cup used to mount three markers on the heel.

The definition of the leg was similar to that of the heel. The three markers were spaced and projected away from the segment by attaching them to the ends of three 80mm wands which were attached to a piece of Hexalite moulded to the shape of the posterior calf. The attachment on which the markers were mounted was positioned in the distal half of the leg because the platform of the mechanical rig obscured the top of the leg in the view of the motion analysis system cameras. The markers were projected posteriorly, medially and laterally (Figure 3.9) and the attachment secured on the leg using elasticated velcro straps.

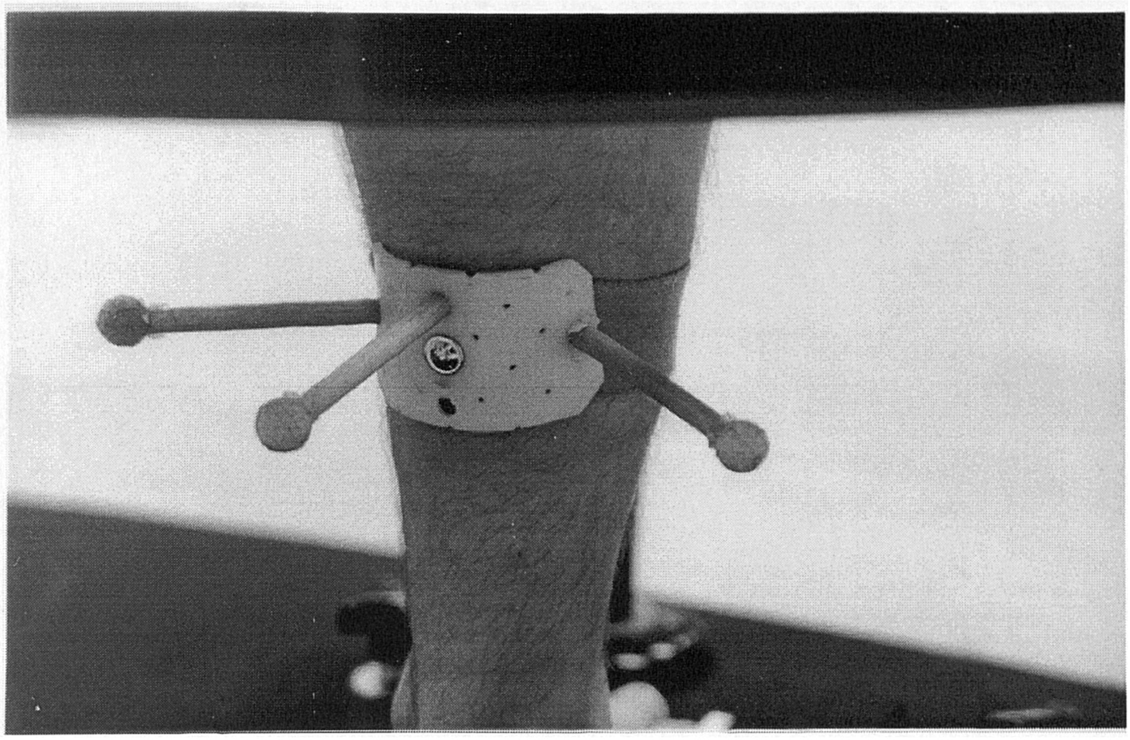


Figure 3.9

Markers attached to the leg via a Hexalite platform and elasticated strapping held in place with Velcro.

3.2.2.1.3 Three dimensional motion analysis system.

An infra-red motion analysis system (MacReflex) with four cameras was used to track the positions of the 15mm markers attached to the leg, heel and forefoot segments at a sampling frequency of 50Hz.

The cameras were set up in a near symmetrical set up around the experimental rig (Figure 3.10). Two cameras were in front of the rig and two behind the rig. This enabled the experiments for the left and right limbs to be carried out without the experimental rig or cameras being moved.

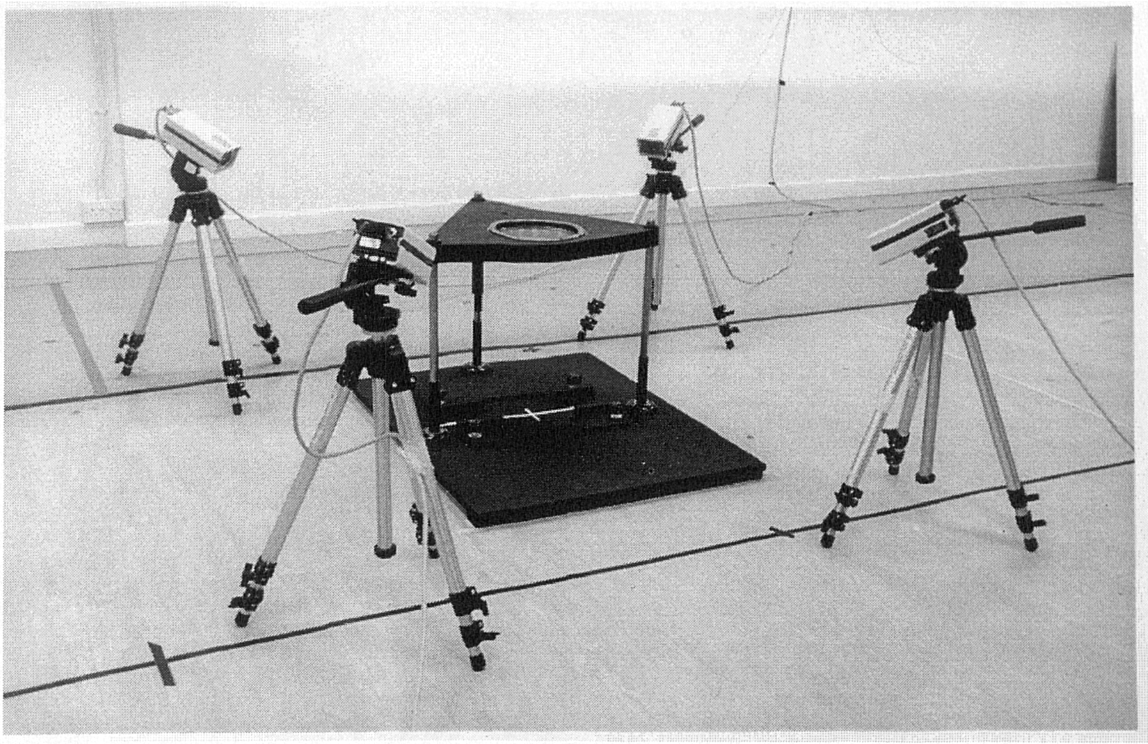


Figure 3.10

Arrangement of the four MacReflex cameras used in the static rearfoot complex assessment around the experimental rig.

The arrangement of the cameras was determined by two factors. Firstly, the markers attached to the leg, heel and forefoot needed to be seen by at least two cameras during the experiments in order for their three dimensional position to be determined. The position of the cameras in respect of this factor was deduced by trial and error. Secondly, the position of the cameras relative to the calibration frame used to define the global co-ordinate system is important since this influences the quality of the calibration and the accuracy of subsequent measurements.

The motion analysis system was calibrated using a 9 marker calibration frame. The measurement volume of the frame was 55cm x 26cm x 30cm (length x height x width) and the markers were 20mm in diameter. The frame defined the position of the global co-ordinate system within the field of view of the cameras. The origin of the global co-ordinate system was defined by the central marker, which was placed over the centre of rotation of the rotating ring when projected on to the wooden board. This ensured that the movements of the markers attached to both the left and right limbs took place within the calibrated volume. (Figure 3.11)

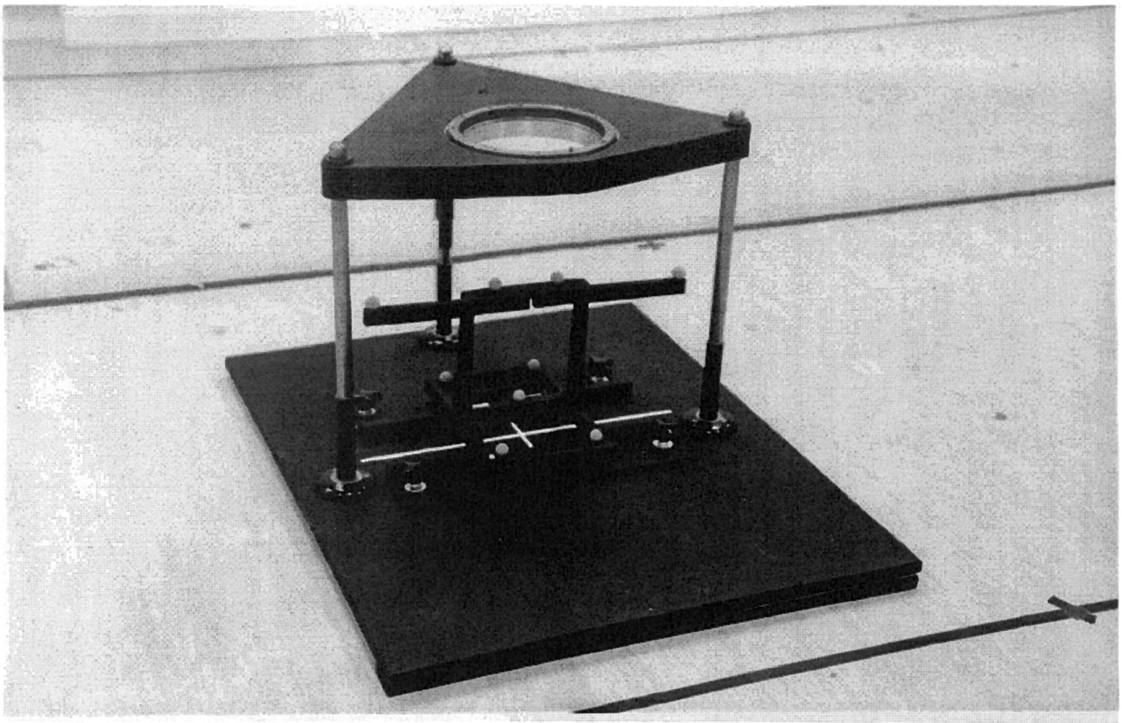


Figure 3.11

The 9 marker calibration frame used to define the global co-ordinate system in the static rearfoot complex assessment. The frame was positioned so that the origin of the global co-ordinate system (the most central marker) was over the centre of rotation of the ring (the cross hair on the wooden board), ensuring that all motion took place within the calibrated volume.

3.2.2.1.4 Performance of the motion analysis system.

A previous assessment of the accuracy of measurements made with the MacReflex system had reported average angular errors of 0.3° over sixty three different static and dynamic tests, and using two different camera configurations (Nester and Bowker 1999). These tests were performed using five MacReflex cameras and a calibration frame of volume 190cm x100cm x 100cm (length x height x width). The work illustrated the excellent accuracy of measurements made with the MacReflex system, but highlighted that a difference in camera arrangement can influence the repeatability of measurements without influencing the accuracy or precision of measurements. Since the camera arrangement to be used in this study involved only four cameras and these were arranged differently than in the previous work, the performance of the MacReflex system was tested.

The principal aim of the tests was to assess the repeatability of measurements, since it was this variable that was affected by changing camera arrangement in the previous study, although accuracy and precision measures (actual measurement error and standard deviation) were also calculated.

Static and dynamic tests were conducted using two 15mm markers mounted 100mm apart on a steel pin that was 30cm in length. Ten consecutive five second recordings were made with the markers stationary in the centre of the calibrated area. Two dynamic recordings were then made during which the pin was moved through the calibrated volume in a figure of eight formation. Each dynamic recording lasted fifteen seconds.

The mean distance between the two markers was calculated for each of the static and dynamic tests (tables 3.2 and 3.3). The mean measurement error was excellent at 0.24mm in the static tests and 0.11mm in the dynamic tests. Also, the standard deviations indicate that measurements do not vary considerably during a recording, although there are occasional significant deviations from the mean value of the measurement. Figure 3.12 presents typical results from the tests. These significant deviations are always due to one or two data points having values significantly different than the rest and it would be expected that appropriate filtering of the data would remove these values. These occasional data points are believed to result from the markers passing behind the metal structures of the experimental rig, obscuring the view which the cameras have of the markers.

Clearly, the accuracy and precision of the measurements taken using the cameras in this arrangement is acceptable. The variation in the distance measured between the ten static tests is an indicator of the repeatability of system measurements, the principal performance parameter under investigation. The distance measured varied by only 0.04mm between the ten static tests, illustrating that repeatability of measurements is acceptable using this camera arrangement.

Trial	Mean distance (mm)	SD
Dynamic1	100.12	0.53
Dynamic2	100.10	0.25
MEAN	100.11	0.39

Table 3.2

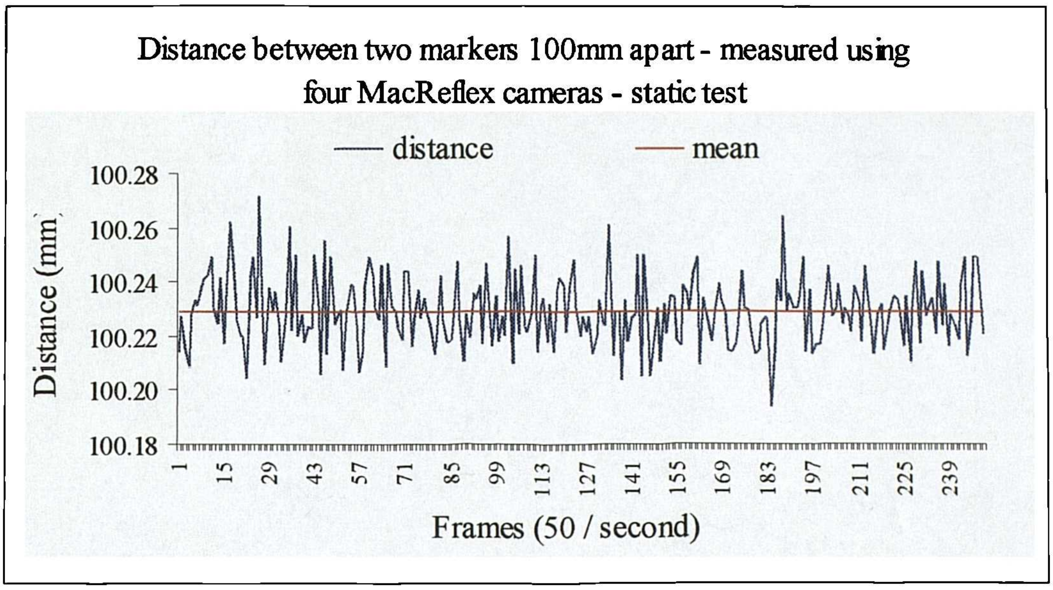
The mean distance between two markers during two fifteen second dynamic recordings with four MacReflex cameras. Actual distance was 100mm.

Trial	Mean Distance (mm)	SD
Static 1	100.23	0.01
Static 2	100.27	0.22
Static 3	100.26	0.21
Static 4	100.25	0.16
Static 5	100.23	0.08
Static 6	100.25	0.18
Static 7	100.23	0.09
Static 8	100.24	0.12
Static 9	100.25	0.15
Static 10	100.24	0.12
Mean	100.24	0.13
Minimum	100.23	0.01
Maximum	100.27	0.22
Range	0.04	0.21

Table 3.3

The mean distance between two markers during 10 five second static recordings with four MacReflex cameras. Actual distance was 100mm.

Graph A



Graph B

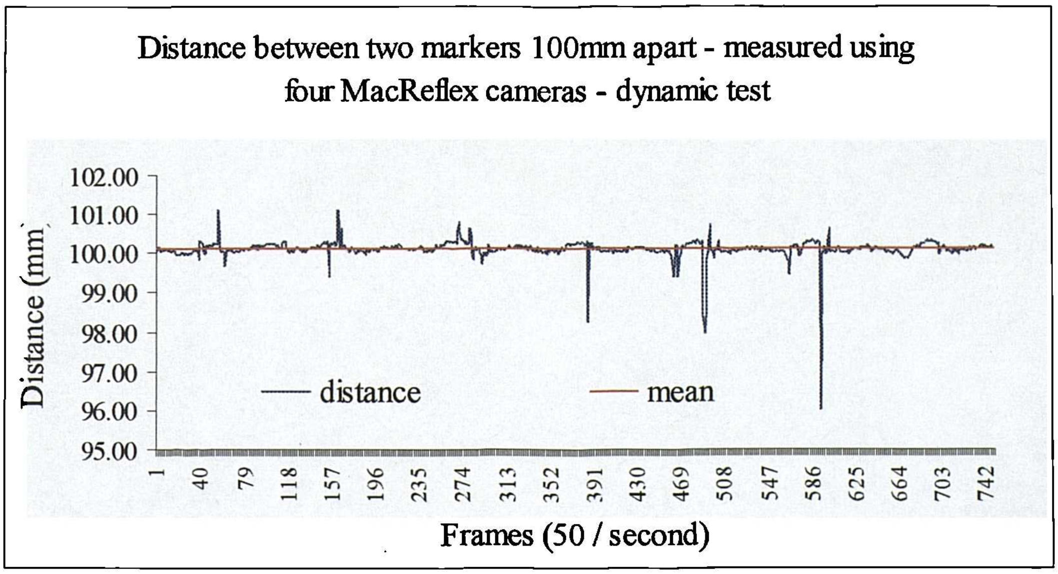


Figure 3.12

Graphs illustrate the variations in the distance between two markers measured using four MacReflex cameras. Graph A is an example of one of the static tests, Graph B is an example of one of the dynamic tests.

These tests confirm that the particular arrangement of cameras used in this investigation and the use of a smaller calibration frame have not compromised the accuracy, precision or stability of the MacReflex system. Overall, the system is capable of measurements sufficiently reliable for the intended use.

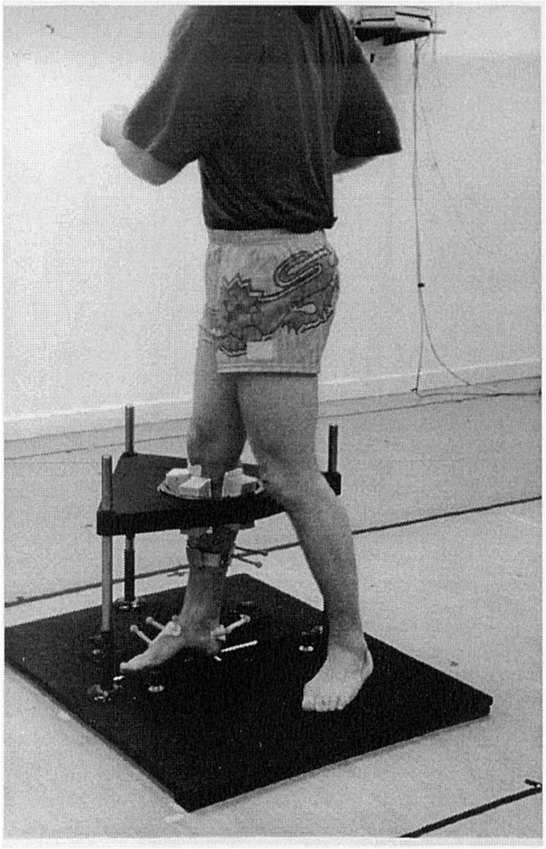
3.2.2.1.5 Experimental procedure for the static rearfoot complex assessment.

The wooden board, experimental rig and four MacReflex cameras were set out as in figure 3.10 and the MacReflex system calibrated. The subject was instructed to stand with one limb placed inside the mechanical ring of the rig and the other adjacent to it on the wooden platform. The foot of the limb inside the ring was aligned with the centre of rotation of the rig and in the anatomical position, as described in section 3.2.2.1.1, whilst the subject stood in their relaxed standing position. The boards on either side of the forefoot were then moved up to the medial and lateral sides of the forefoot and secured in position. The subject was asked to confirm that their foot was secure between the two boards.

The forefoot, heel and leg marker sets were attached as described in section 3.2.2.1.2. To ensure that each marker could be seen by at least two cameras a test recording was taken. This also provided an opportunity for the subject to practice the rotational movements that were to be performed. The subject was told to rotate their pelvis in an outward direction and rotate their foot outwards so that they were stood on the outside (lateral) border of their foot. This was the position from which the motion sequence to be completed during each test started (figure 3.13). They were then instructed to rotate their pelvis and the entire lower limb inwards as far as was pain free. This produced internal leg rotation and rearfoot complex pronation (figure 3.14). The subjects then rotated their limb outwards until they returned to the start position. The investigator demonstrated the movements to assist in the explanation. Subjects were given eight seconds to perform this movement but were instructed to move at the pace most comfortable to them.

Once the markers were in the correct place the leg was secured into the ring using plastozote blocks. Four sets of blocks were placed around the leg. One set on the anterior and lateral aspect, one on the anterior and medial aspect, another on the posterior and lateral aspect and the fourth on the posterior and medial aspect (Figure 3.2).

The subject was then asked to practice the rotational movements of the limb again to ensure that they were comfortable in their posture and were able to exploit a sufficient range of motion of the limb and foot. A sufficient range of motion was characterised by: in the start position the foot being supinated to the extent that the first metatarsal was non weight bearing; the subject forcibly achieving maximum internal limb rotation by rotation of proximal structures and without obvious muscular effort in the foot and leg; and the original start position being reached again at the end of the movement.



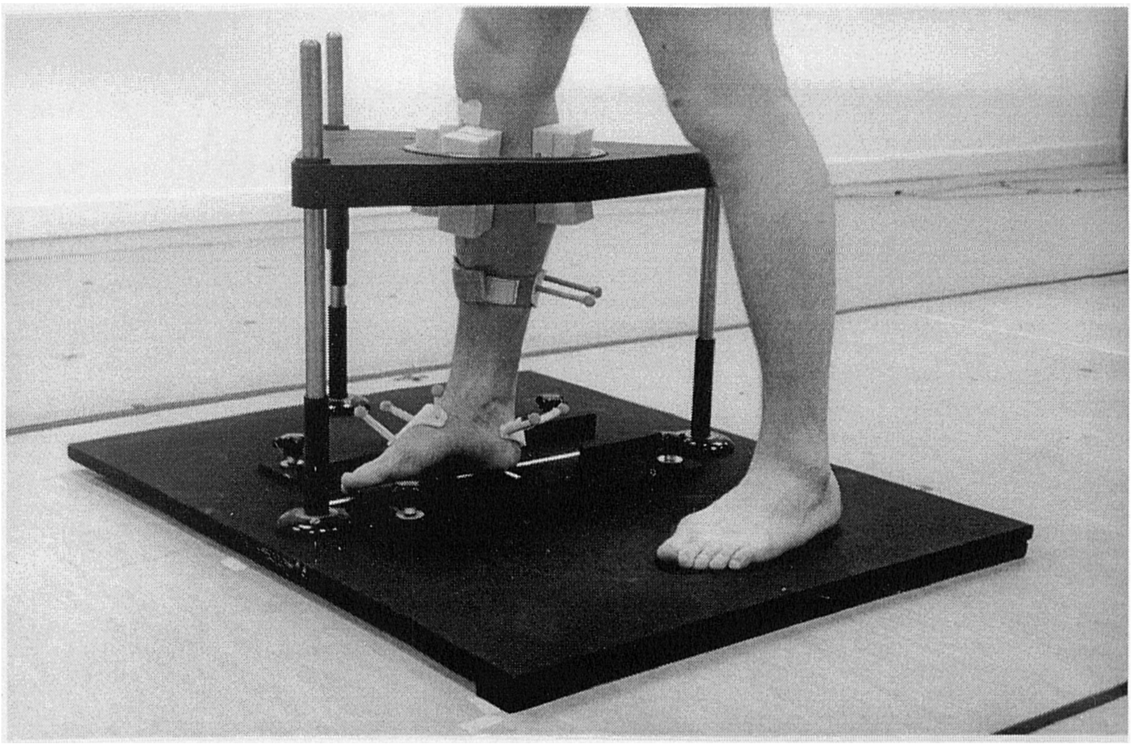


Figure 3.13

Typical position of a subject at the start of the motion sequence. The limb is externally rotated, the rearfoot supinated and the first metatarsal none weight bearing.

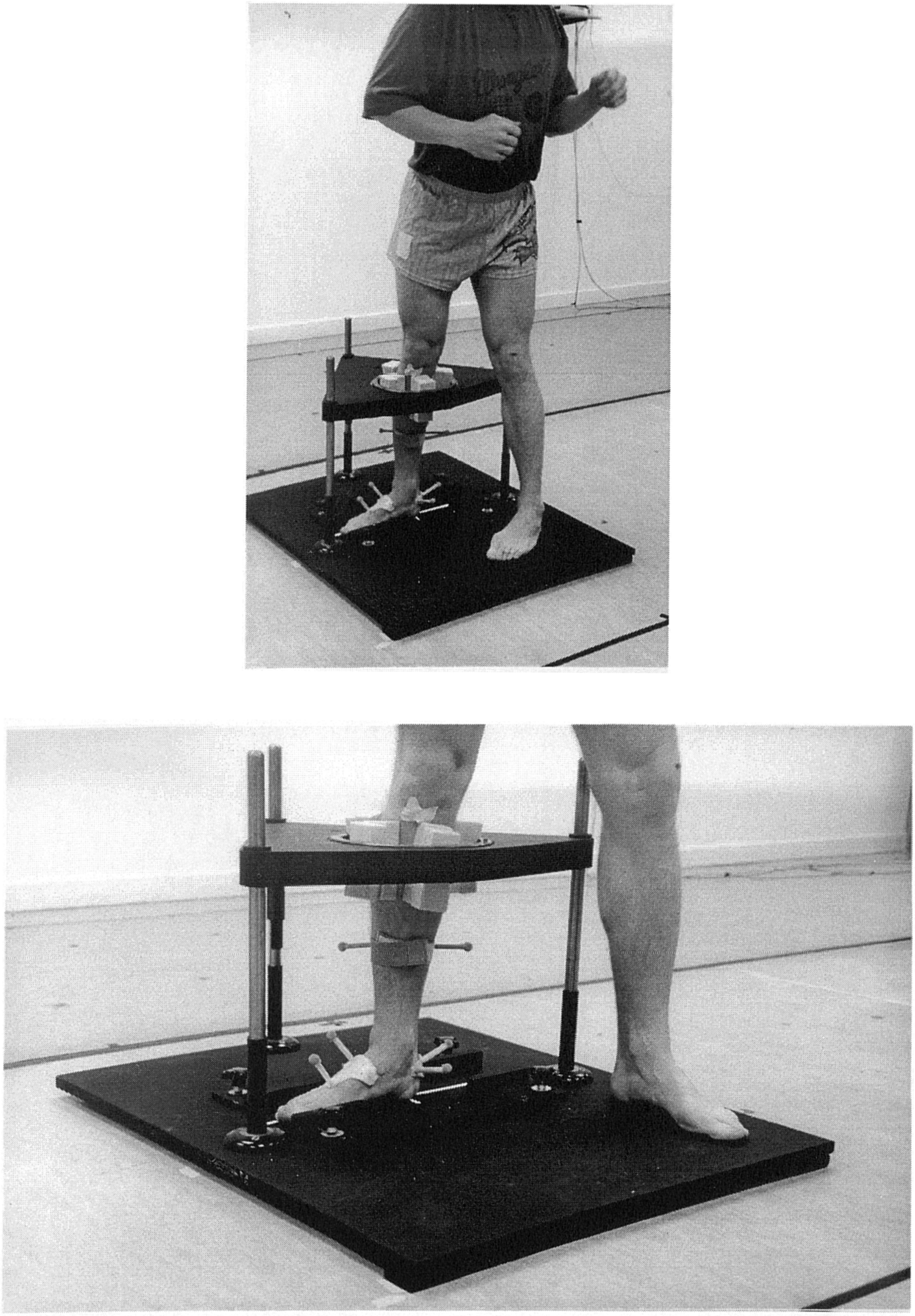


Figure 3.14

Typical position of a subject at the mid point of the motion sequence. The limb is maximally internally rotated and the rearfoot pronated.

Once the subject was comfortable in their posture and able to exploit a sufficient range of limb and foot motion the experimental test recordings were made. Ten recordings of the subject performing the motion sequence were taken consecutively. A single reference recording was then taken. During this two second recording the subject stood in their relaxed standing position (Figure 3.15). The position of the body in this stance is determined by the body's anatomy, body weight, ground reaction and muscular forces, which interact to produce a stable posture. These factors are relatively constant and consequently so too is the relaxed standing position. This is in contrast to alternative reference positions, such as the sub talar joint neutral position, which require palpation, manipulation and subjective positioning of joints, and have been shown to be unreliable (Ball and Johnson 1993, Pierrynowski et al 1996).

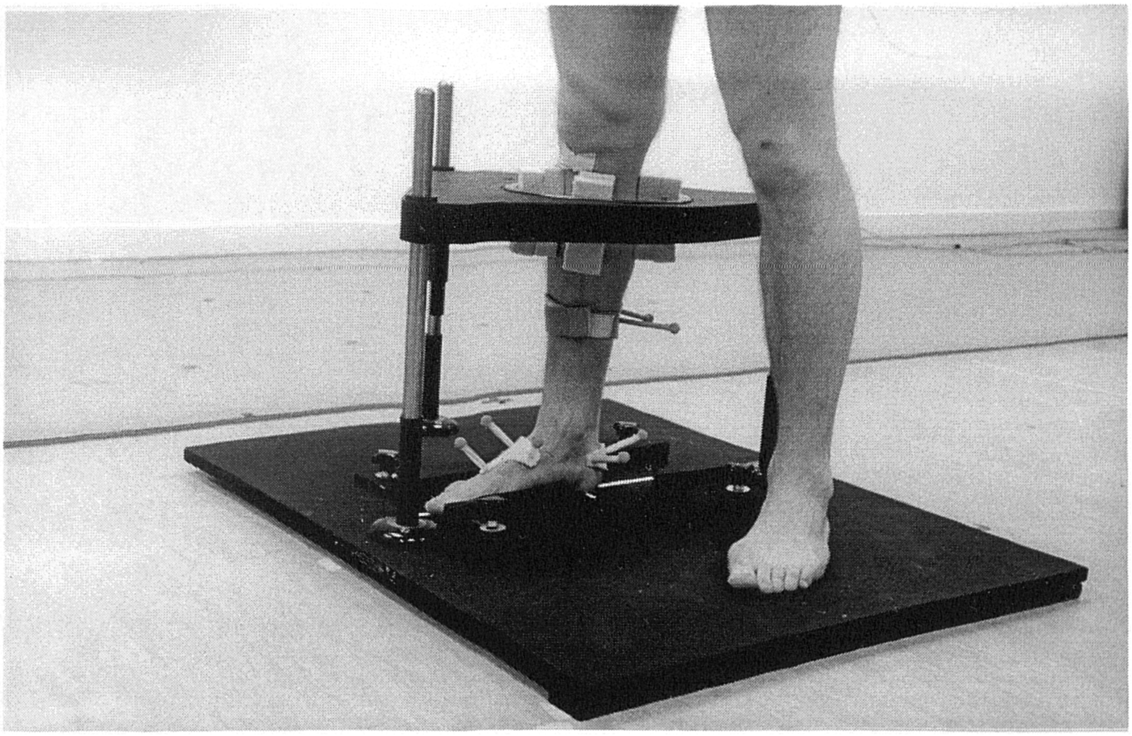


Figure 3.15

Typical position of a subject in the relaxed standing position during the static rearfoot complex assessment.

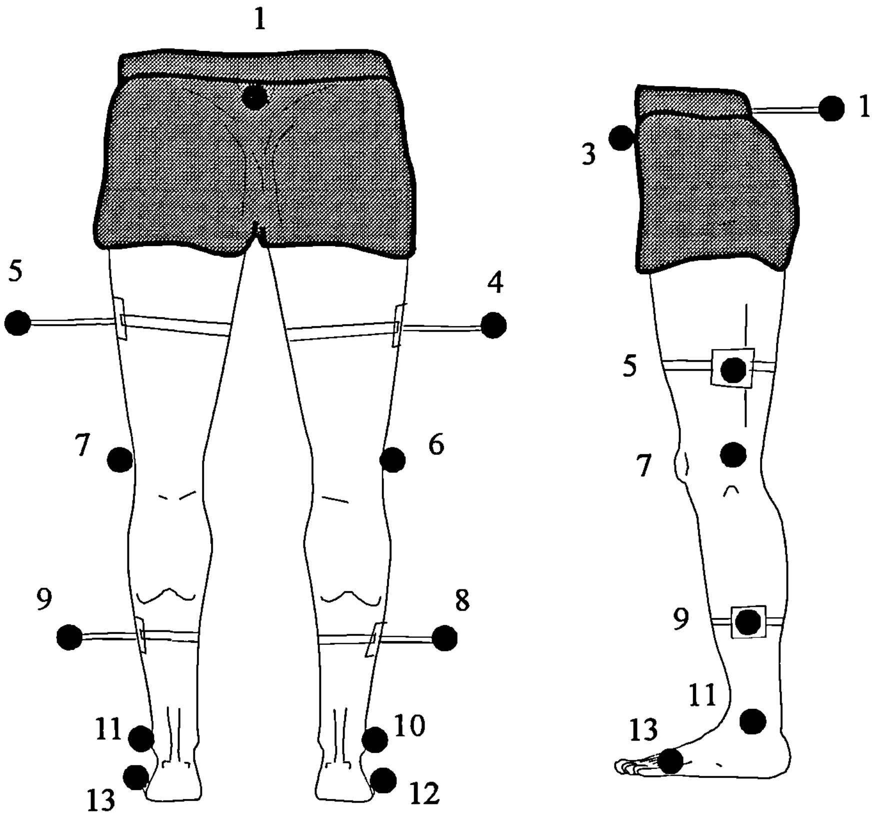
This entire procedure was then repeated for the other leg. Within the sample of 25 subjects the order in which the limbs were tested was randomised.

3.2.2.2 Dynamic rearfoot complex assessment.

The aim of the dynamic rearfoot complex assessment was to measure the range of rearfoot complex motion during gait relative to the same reference position that was used during the static assessment. If the dynamic and static assessments of the rearfoot complex use the same reference position, then the motion relative to this position in one assessment can be related to the motion relative to this position in the other assessment. This would allow the part of the total range of rearfoot complex motion that was used during gait to be identified within the total range of motion measured during the static assessment.

Since rearfoot complex motion is coupled with transverse plane leg rotation, the pattern of internal and external rotation of the leg relative to the foot indicates the pattern of rearfoot complex motion. When the leg internally rotates the rearfoot complex is pronating, when the leg externally rotates the rearfoot complex is supinating. The transverse plane rotation of the leg relative to the foot can be measured as the angle between a position vector from the centre of the ankle joint and the fifth metatarsal head, and a local co-ordinate system of the leg (Kadaba et al 1990). The transverse plane position of the foot (the entire segment) in the static assessment is fixed and its position can be represented by the global co-ordinate system. The rotation of the leg relative to the foot in the dynamic assessment, defined as a local co-ordinate system and a position vector respectively, is therefore the same as the rotation of the leg relative to the global co-ordinate system (absolute leg rotation angle) in the static assessment.

A 13 marker system, based on that described by Kadaba et al (1990) (Figure 3.16), was used to define the pelvis and femur of both limbs as local co-ordinate systems, and the leg and the foot of both limbs as local co-ordinate systems and a position vector respectively. This full lower limb system was used because of restrictions imposed by the data processing software.



1 - sacral	6 - right knee	10 - right ankle
2 - right ASIS	7 - left knee	11 - left ankle
3 - left ASIS	8 - right shank	12 - right 5th metatarsal
4 - right thigh	9 - left shank	13 - left 5th metatarsal
5 - left thigh		

Figure 3.16

The 13 marker set up used in the dynamic rearfoot complex assessment. The marker positions are based on a similar marker set up described by Kadaba et al (1990).

A five camera MacReflex motion analysis system was used to capture the motion of the 13 markers attached to the lower limb at a sampling frequency of 50Hz. The cameras were arranged as in figure 3.17. The MacReflex system was calibrated using a nine marker calibration frame of volume 190cm x 100cm x 100cm (length x height x width). The accuracy of the system in this set up has been tested previously and averaged 0.3° (Nester and Bowker 1999).

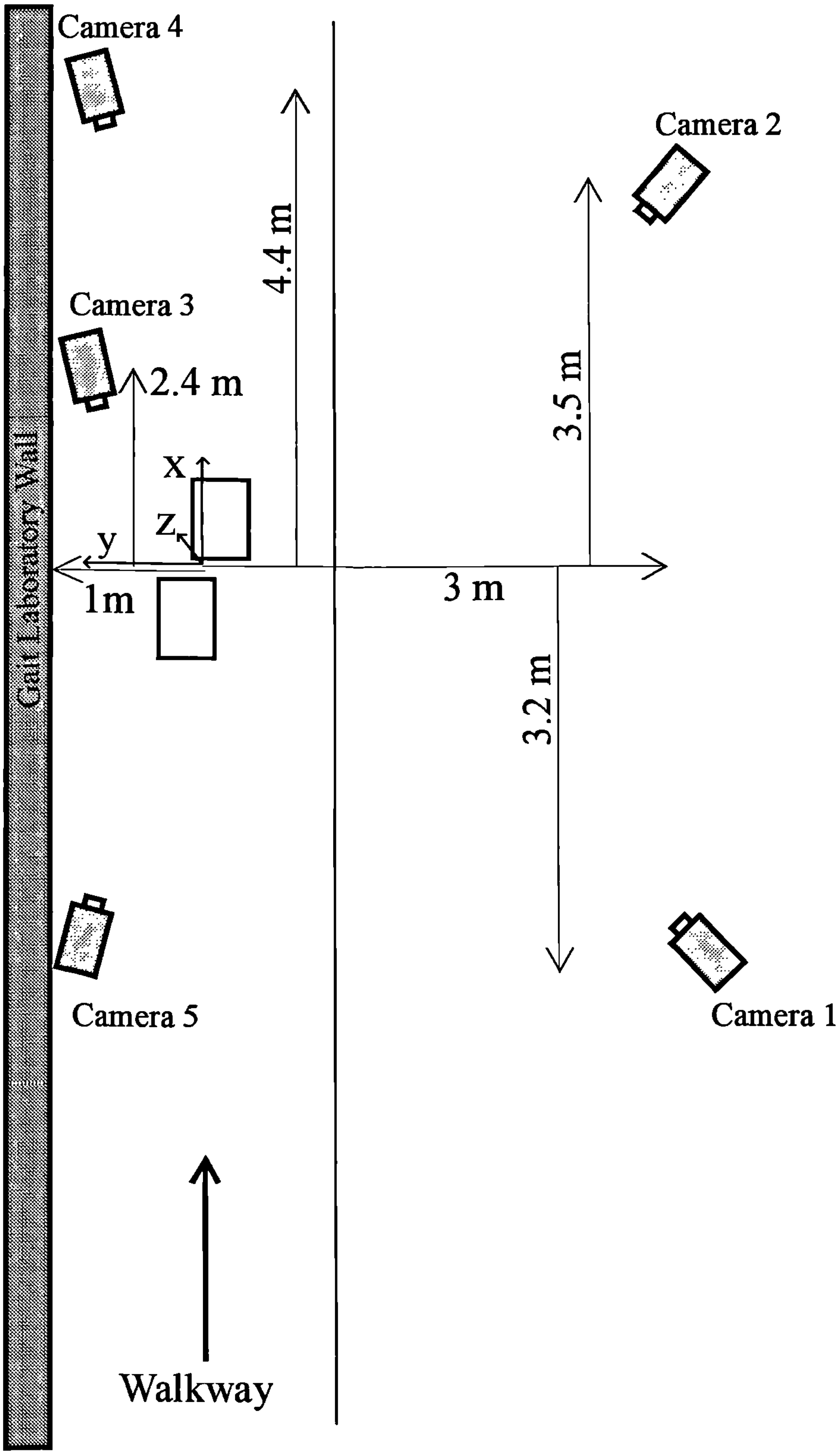


Figure 3.17

Arrangement of the five MacReflex cameras used in the dynamic rearfoot complex assessment.

3.2.2.2.1 Experimental procedure for dynamic rearfoot complex assessment.

Prior to conducting the dynamic rearfoot complex assessment the width of the knee across the femoral condyles and the width of the ankle across the malleoli were measured using sliding calipers whilst the subject was supine. All anatomical landmarks were found through manual palpation. All subjects wore shorts and T-shirt during the dynamic rearfoot complex assessment.

Eight of the thirteen 30mm markers were attached to the subject using double sided sticking tape. These were attached to the following sites on both limbs: anterior superior illiac spines; lateral femoral epicondyle; lateral malleolus; and head of the fifth metatarsal. The position of these anatomical landmarks was determined by manual palpation. The additional five markers were all mounted on 15cm wands and attached to the subject using straps. The most proximal was a wand mounted on and projecting posteriorly from the sacrum. A wand was attached to the lower one third of each thigh projecting laterally. These femoral wands were aligned in the transverse plane parallel to a line between the lateral and medial femoral epicondyles, which were found by manual palpation. A wand was attached approximately half way down each leg and aligned in the transverse plane parallel to the femoral wands.

The subject was then instructed to walk around the gait laboratory for approximately 30 seconds to ensure that none of the markers or wands were too loose or too tight. When subjects were comfortable, they were instructed to walk down the gait laboratory walkway in time to a metronome set at 108 steps per minute. This speed was chosen based on reports of normal walking speeds in the literature, which were summarised by Craik and Dutterer (1993). Walking speed needed to be controlled because it influences the kinematics of gait and without all the subjects walking at the same speed subsequent comparison of data between subjects is unreliable. Subjects had several practice walks until they could consistently walk at the desired pace and consistently walk over the two force platforms in the gait walkway. Force plate data was being collected for another piece of research work but also gave valuable information regarding the timing of heel strike. Only when the subjects could meet these criteria and were relaxed in the gait laboratory did data collection start. A minimum of ten barefoot walking trials was recorded, each starting with right foot strike of the third or fourth step and finishing five seconds later. This gave at least one gait cycle for each limb. Additional trials were recorded if the subject appeared not to be walking at the correct speed or if they appeared to be targeting the force plates. At the end of the barefoot walking trials a reference file was recorded. During this the subject stood in their relaxed standing position for two seconds.

3.2.3 DATA PROCESSING.

3.2.3.1 Calculation of angular rotations from static rearfoot complex data.

The motion data were tracked using the MacReflex software. This enables the markers to be numbered in a consistent pattern. For this investigation, markers 1-3 were those on the leg, markers 4-6 were the markers on the heel and markers 7-9 those on the forefoot. It was necessary for some parts of some of the recordings to interpolate data where marker data were missing. This was a consequence of a marker only being seen by one camera for a number of frames. The interpolation calculations are predetermined by the MacReflex software and are based on a cubic spline interpolation routine described by Nakamura (1991). The accuracy of this interpolation process has been tested using position data for markers on the lateral malleolus and anterior superior illiac spine during normal walking. The mean results are presented in figure 3.18. The results suggested that up to seven missing data points could be interpolated with a mean error of less than 2mm. When more than seven points were interpolated, the error in the marker data was less consistent, though often below 3mm. Following interpolation the raw kinematic data were smoothed using an 8th order Butterworth filter with a cut off frequency of 4Hz (Figure 3.19). The order and frequency cut off of the filter where chosen through a trial and error process and visual comparison of the smoothed and raw kinematic data. This combination provided the most appropriate smoothing of the raw kinematic data without modification of the actual motion pattern.

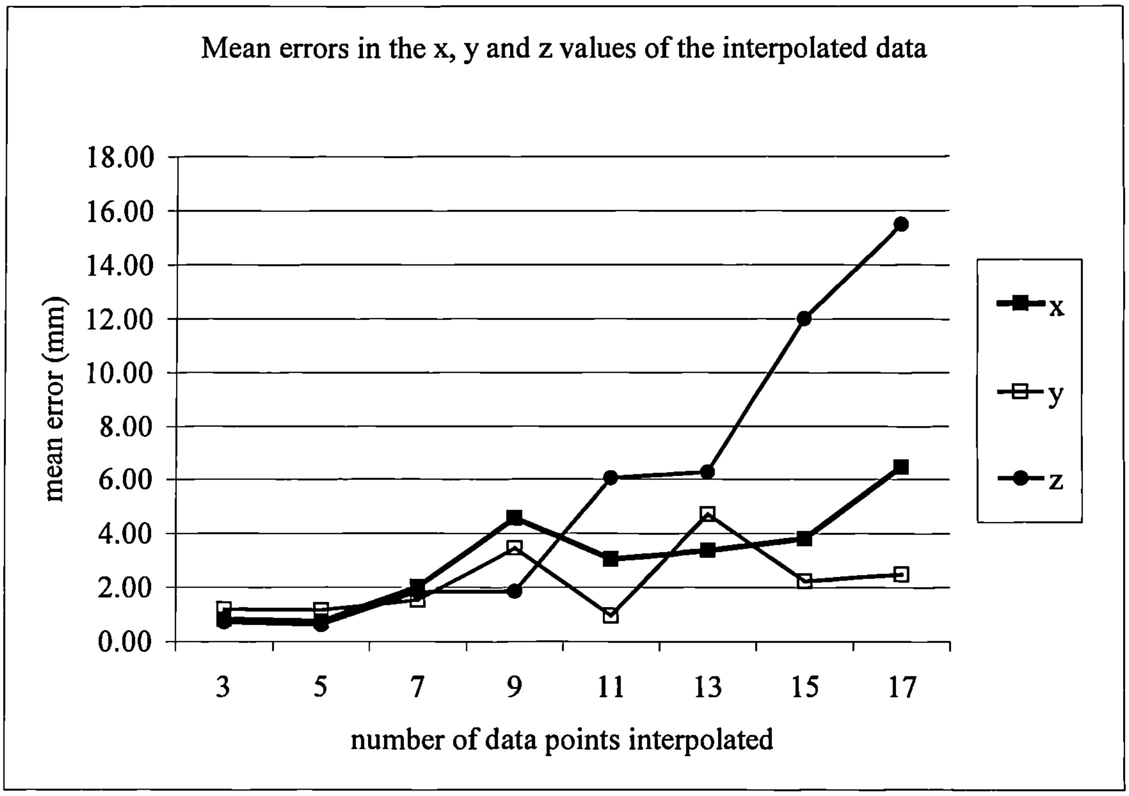


Figure 3.18

Graph illustrates the relationship between the number of motion data points interpolated and the mean error in the interpolated data compared to the actual motion data, for the x, y and z co-ordinates.

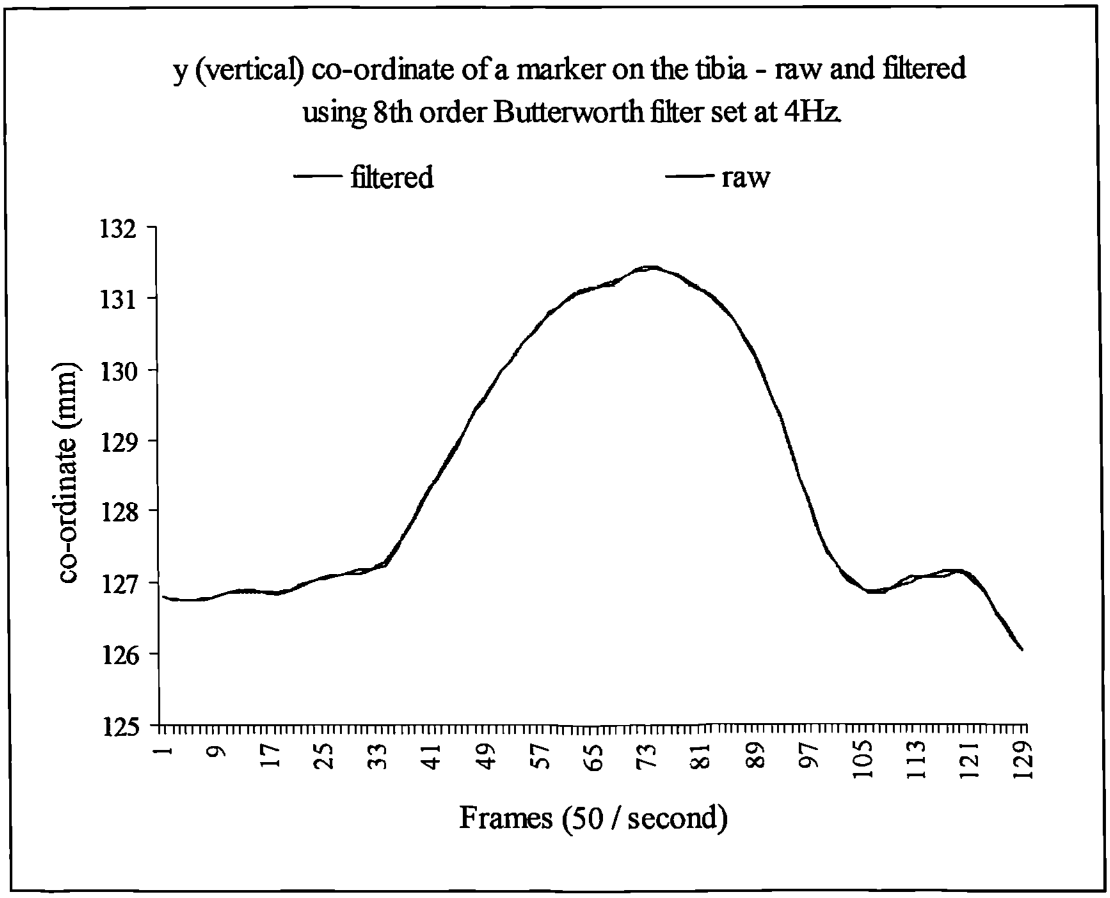


Figure 3.19

Graph of vertical co-ordinate of a marker on the leg segment, raw and filtered data (8th order Butterworth filter set at 4hz). This marker was chosen as an example because its actual physical displacement is small (approximately 5mm) and the effect of noise in the data would therefore be most evident.

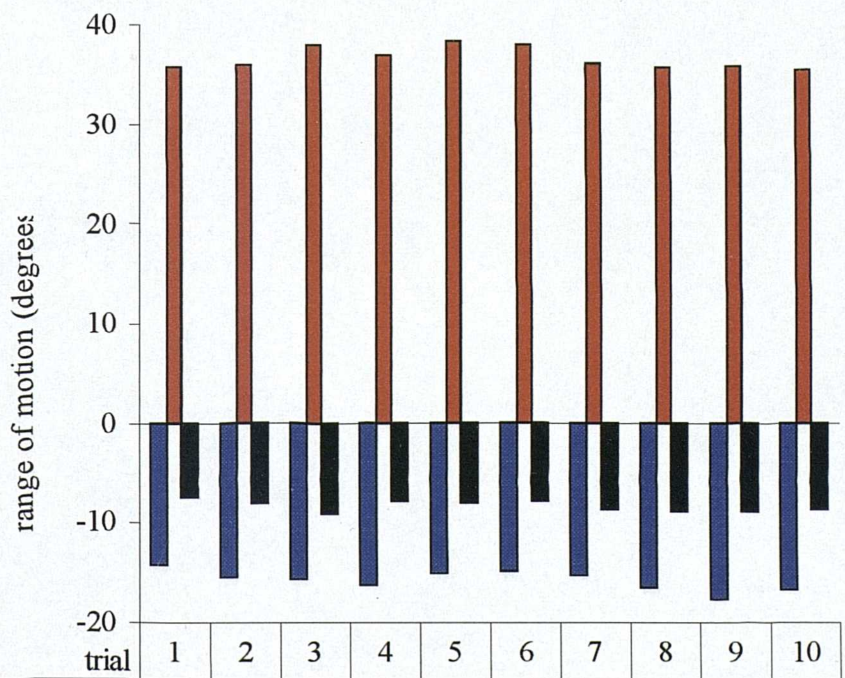
To calculate the angular rotations of the forefoot relative to the leg (rearfoot complex motion), the heel relative to the leg (ankle/sub talar complex motion), and the forefoot relative to the heel (mid tarsal joint motion) the three markers on each of the segments were used to define a local co-ordinate system for each segment. The absolute angular position of each of the segments (angular position relative to the global co-ordinate system) was deduced using Euler rotations, calculated using the conventional rotation sequence of rotation around the z axis (sagittal plane motion), the x axis (frontal plane motion) and the y axis (transverse plane motion). The angles calculated were the motion of each segment in the three orthogonal planes defined by the global co-ordinate system. The relative motion between the segments in each cardinal body plane was calculated by subtracting the angular position of the proximal segment of interest from that of the distal segment of interest. Thus, the transverse plane position of the heel relative to the leg (indicating the position of the ankle/sub talar complex) was calculated by subtracting the transverse plane angle of the leg relative to the global co-ordinate system from the transverse plane angle of the heel relative the global co-ordinate system. Since the absolute angles were the motion in the three orthogonal planes defined by the global co-ordinate system, so the relative angles were the motion in these same planes. The anatomical body planes of each subject had been aligned with these planes during the experimental procedure and so the absolute and relative angular data was motion in the sagittal, frontal and transverse cardinal body planes.

It is conventional in kinematic gait analysis to use a joint co-ordinate system to define the axes of rotation for a joint or joint complex. This approach is not appropriate for this investigation. The joint co-ordinate system approach would produce angles describing rotations that take place in planes perpendicular to the axes around which the rotations were calculated. These axes are deduced from the positions of the axes of the local co-ordinate systems that define each segment. Typically, the flexion/extension (sagittal plane motion) axis of the joint co-ordinate system is the z axis of the proximal local co-ordinate system. The internal/external (transverse plane motion) axis of the joint co-ordinate system is the y axis of the distal local co-ordinate system. The abduction/adduction (frontal plane motion) axis of the joint co-ordinate system is a floating axis whose position is the cross product of the z and y axes of the joint co-ordinate system.

In this investigation, using the joint co-ordinate system would mean that the angles of rotation for the ankle/sub talar complex would be calculated around different axes to the angles of rotation for the rearfoot complex, and different again from those of the mid tarsal joint. This would not allow the angular values of the three different relative rotations to be compared, since the angles would relate to motion in different planes. The joint co-ordinate approach is well suited to applications where the spatial orientation of segments is moving significantly, such as during gait. However, in this static assessment the spatial orientation of the segments is comparatively fixed. Since this work is investigating the functional characteristics of the ankle/sub talar complex and the mid tarsal joint, and their contribution to the functional characteristics of the overall rearfoot complex, it was imperative that the relative angular motions be comparable, and thus be calculated in the same planes.

The reference value for each of the absolute rotations (of the leg, heel and forefoot) and the three relative rotations (ankle/sub talar complex, mid tarsal joint and rearfoot complex) was calculated as the mean of the angular value from the reference trial. The reference values were then subtracted from the corresponding absolute and relative rotation values. In this way, zero degrees in the angular rotation data represented the relaxed standing position of that subject.

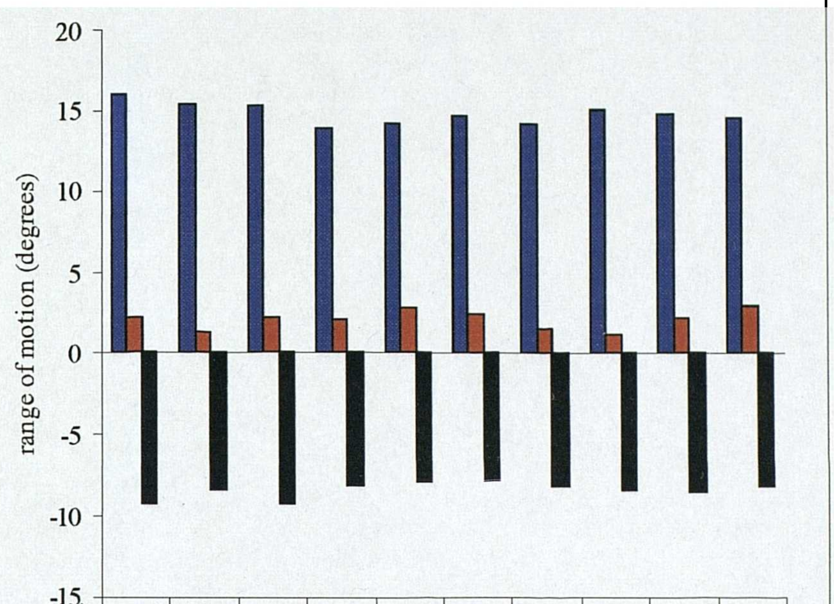
Each of the 10 trials for each limb of each subject was processed as described above. Each of the 10 trials produced absolute angular rotations for the leg, the heel and the forefoot, and relative rotations of the ankle/sub talar complex, the mid tarsal joint and the rearfoot complex. As an illustration of the variability between the 10 trials, examples are provided in figures 3.20 and 3.21.



trial	1	2	3	4	5	6	7	8	9	10
frontal	-14.2	-15.4	-15.7	-16.2	-15.1	-14.8	-15.4	-16.5	-17.8	-16.8
transverse	35.7	35.9	37.9	36.9	38.3	38.0	36.2	35.7	35.8	35.5
sagittal	-7.5	-8.1	-9.1	-7.8	-8.1	-7.9	-8.8	-8.9	-8.9	-8.7

Figure 3.20

Illustrates the variation in the range of rearfoot complex motion in the frontal, transverse and sagittal planes across ten trials.



trial	1	2	3	4	5	6	7	8	9	10
frontal	16.0	15.4	15.3	13.8	14.2	14.6	14.1	15.0	14.7	14.5
transverse	2.2	1.3	2.2	2.1	2.8	2.4	1.5	1.1	2.2	3.0
sagittal	-9.3	-8.3	-9.2	-8.1	-7.8	-7.7	-8.0	-8.3	-8.4	-8.1

Figure 3.21
Illustrates the variation in the range of forefoot motion
in the frontal, transverse and sagittal planes across ten trials.

3.2.3.2 Calculation of angular rotations from dynamic rearfoot complex data.

The motion data from the walking trials were tracked using the MacReflex software. This allowed the 13 markers to be numbered in a consistent pattern. The raw kinematic data were smoothed using a 4^{th} order Butterworth filter with the cut off frequency set at 6Hz (Winter et al 1974)

From the kinematic data the positions of the hip, knee and ankle joint centres were calculated. The hip joint centre was calculated using the position of the three pelvis markers (one on each anterior superior illiac spine and one on a sacral wand) and data from Seidel (1995) relating pelvic width and pelvic depth to the position of the hip joint centre. Pelvic width was the distance between the two markers on the anterior superior illiac spines. Pelvic depth was calculated as the distance between the mid point of the two anterior superior illiac spines and the sacral marker, minus 10cm (the length of the sacral wand). The location of the hip joint centre relative to the respective anterior superior illiac spine was 14% of pelvic width medially, 34% of pelvic depth posteriorly and 30% of pelvic width inferiorly. The knee joint centre was calculated using the position of the hip centre, the lateral knee marker, the marker on the thigh wand and a measure of knee width. The ankle joint centre was defined using the knee joint centre, the lateral malleoli marker, the leg wand marker and a measure of ankle width.

Using the knee joint centre, the marker on the leg wand and the ankle joint centre a local co-ordinate system was defined to represent the leg. The foot was defined using a single vector between the ankle joint centre and the marker on the fifth metatarsal head (Figure 3.22).

The transverse plane rotation of the leg relative to the foot was calculated as the angle between the vector and the z axis of the local co-ordinate system when projected onto the x z plane of the leg co-ordinate system. This angle was calculated for both limbs in each of the ten recorded gait trials. An average curve for each limb was then calculated for each subject, using heel strike as the first data point to normalise the data from the ten separate trials. Heel strike was determined using the force plate data recorded simultaneously with the kinematic data. Finally, the reference transverse plane angle was calculated from the reference trial and subtracted from the averaged angular data. By doing this 0° in the angle data represented the relaxed standing position of the subject.

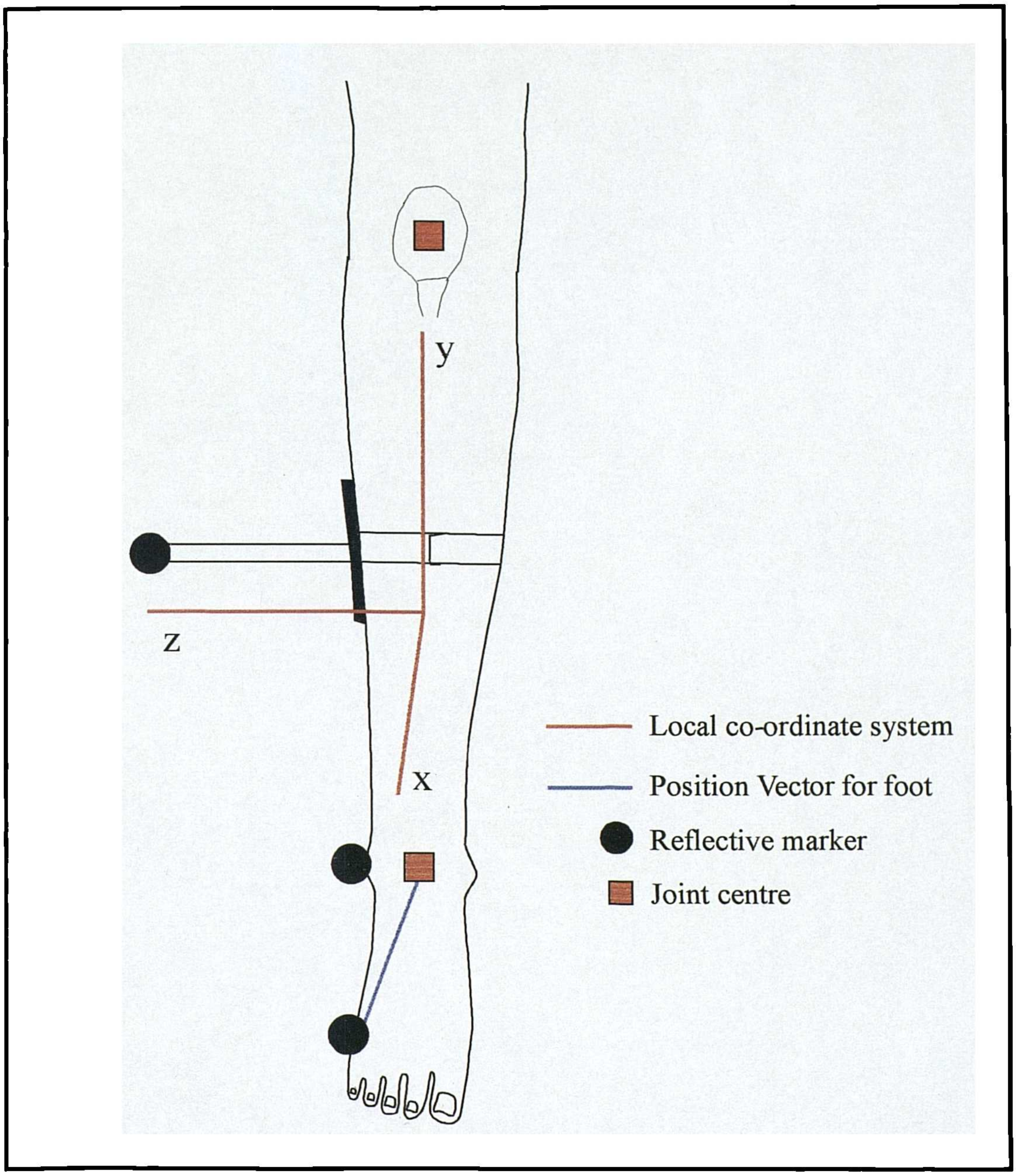


Figure 3.22

Definition of the local co-ordinate system for the leg and the position vector for the foot from the dynamic rearfoot complex data. Calculated angle was the angle between the position vector and the z axis of the local co-ordinate system when projected onto the *xz* plane of the local co-ordinate system.

3.2.4 EXTRACTION OF RELEVANT DATA FROM STATIC REARFOOT COMPLEX ASSESSMENT.

Since the literature suggests that the functional characteristics of the rearfoot joints change during the range of motion, the range of motion in each cardinal body plane was calculated for several predefined parts of the total range of motion of each of the absolute and relative rotations. The parts of the total range of motion were: the dynamic phase; the supination phase; the pronation phase; and the composite phase of motion (Figure 3.23).

The dynamic phase of motion was the part of the total range of motion used during gait. This was deduced using the dynamic rearfoot complex data (transverse plane rotation of leg relative to the foot). The transverse plane motion of the leg relative to the foot during the dynamic assessment relates to the absolute rotation of the leg during the static assessment (section 3.2.2.2). In the dynamic assessment the motion of the leg relative to the entire foot (defined as one segment using a vector between the centre of the ankle joint and the fifth metatarsal head) is calculated. This is the same as the absolute leg rotation in the static assessment because the transverse plane position of the foot is fixed and thus represented by the global co-ordinate system. Furthermore, because the static and dynamic assessments used the same reference position, the relaxed standing position, the transverse plane rotation of the leg relative to this position in the dynamic assessment can be related to the absolute transverse plane rotation of the leg relative to this position in the static assessment.

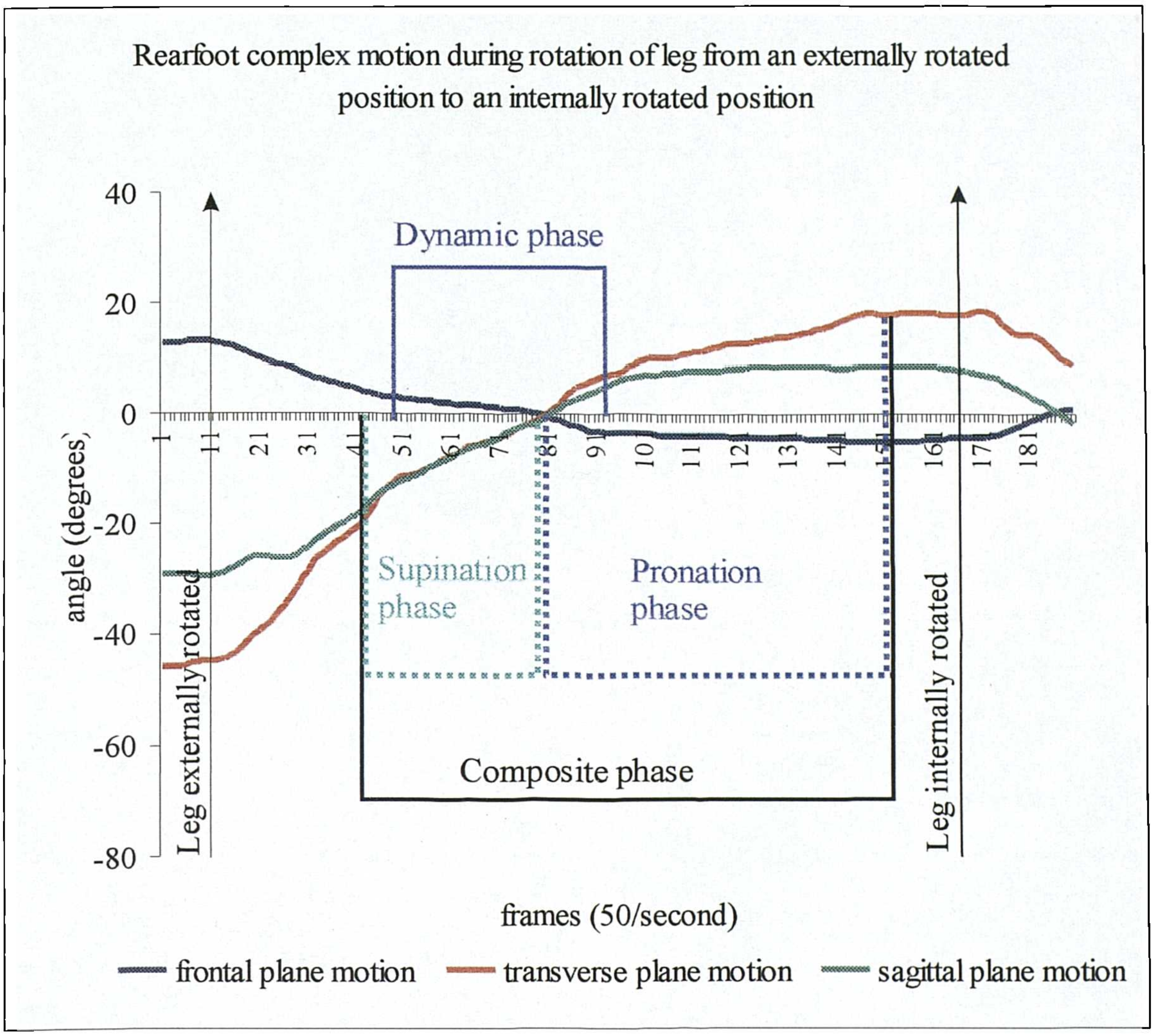


Figure 3.23

Graph illustrates the range of motion in the frontal, transverse and sagittal body planes, and the division of the total range of motion into the composite, dynamic, supination and pronation phases of motion, during rotation of the leg from an externally to an internally rotated position.

Using this relationship between the data from static and dynamic assessments, the part of the total range of motion used during gait was identified in the static rearfoot complex data (Figure 3.23).

The supination phase of motion was defined as the absolute motion of the leg from its 20° of external rotation position to 0° degrees position (relaxed standing position) to (Figure 3.23). Twenty degrees was chosen because it was the maximum range that was common to all the subjects in the sample.

The pronation phase of motion was defined as the absolute motion of the leg from its 0° position to when it was maximally internally rotated (Figure 3.23). Maximum internal rotation was chosen, as opposed to a fixed value such as 20°, because there is a definite end point to the range of motion for each individual. This is not the case for the supination range of motion because the maximum range of external leg rotation might not be achievable because of the constraints of the mechanical rig. Also, the end point of external leg rotation is far more subjective than that in the direction of internal leg rotation. Although the range of motion is different in the pronation range for each subject, the data are still comparable because the range is defined by two points that are common to all the subjects, the 0° position and the end point of the range of internal leg rotation.

Finally, the composite phase of motion was defined as the absolute motion of the leg from a position of 20° externally rotated to a position of maximum internal rotation (Figure 3.23).

The frame number of the first and last data point in each of the four phases was determined and these values used to determine the angular value in each cardinal body plane at the start and end of each of the four phases for each absolute and each relative rotation in each of the 10 trials. The range of motion in each body plane during each phase was calculated by subtraction of one angular value from the other. For example, if at the start of the supination phase the mid tarsal joint was everted by 8° and at the end was everted by 17°, the range of motion during the supination phase was 9°.

The ranges of motion in each cardinal body plane for each of the three absolute and three relative rotations were calculated for the rotation of the leg from an externally rotated position to an internally rotated position and from an internally rotated position to an externally rotated position. These values were then averaged to give an overall measure of the ranges of motion.

A summary of the different steps in this stage of the data processing is presented in figure 3.24.

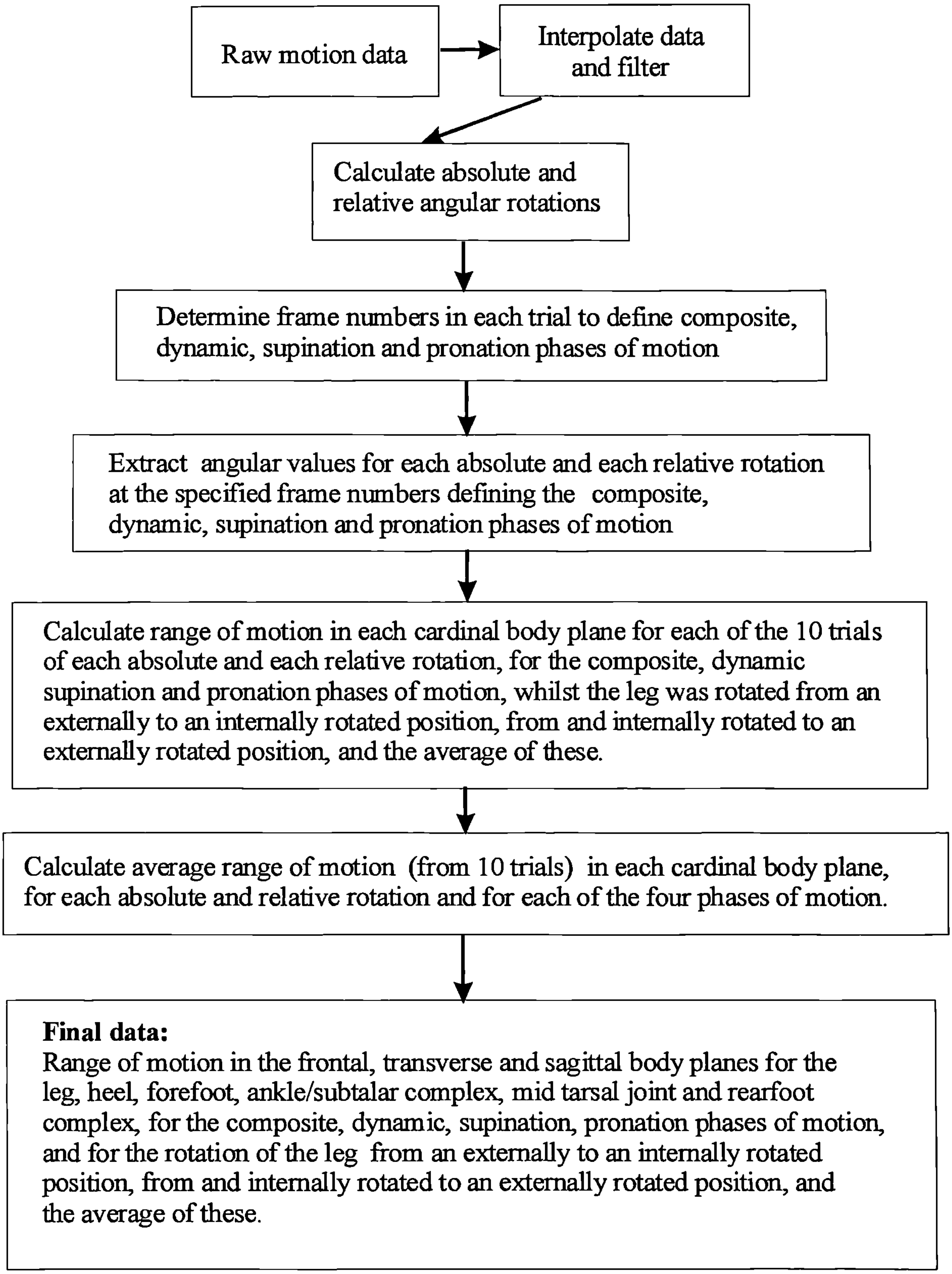


Figure 3.24

Flow diagram of the different stages of the processing of the data from the static rearfoot complex assessment.

3.2.4.1 Standardisation of angular rotations.

The angular rotations calculated to describe the motion of the segments and joints relate to the global co-ordinate system. However, since the left and right feet were orientated in different anterior/posterior directions in relation to the global co-ordinate system, the positive/negative property of the angular values was different even though the anatomical rotations were the same. For example, positive rotation around the z (medial/lateral) axis of the global co-ordinate system would indicate plantarflexion of the left heel, but dorsiflexion of the right heel. Similarly, positive rotation around the y (vertical) axis of the global co-ordinate system would indicate internal rotation of the left leg, but external rotation of the right leg. Positive rotation around the x (anterior/posterior) axis, however, would indicate eversion of both left and right heels. Unless some standardisation was imposed the two feet would be difficult to compare and comparison to the literature would be difficult.

To produce results that were standardised between the left and right limbs, all angular values were interpreted relative to a foot reference system defined for each limb. This consisted of three orthogonal axes with the +x axis orientated from proximal to distal of the foot, parallel to the x axis of the global co-ordinate system, a medial/lateral orientated +z axis that was parallel to the z axis of the global co-ordinate system and in a medial direction relative to the foot, and a vertical +y axis orientated upwards, parallel to the y axis of the global co-ordinate system (Figure 3.25).

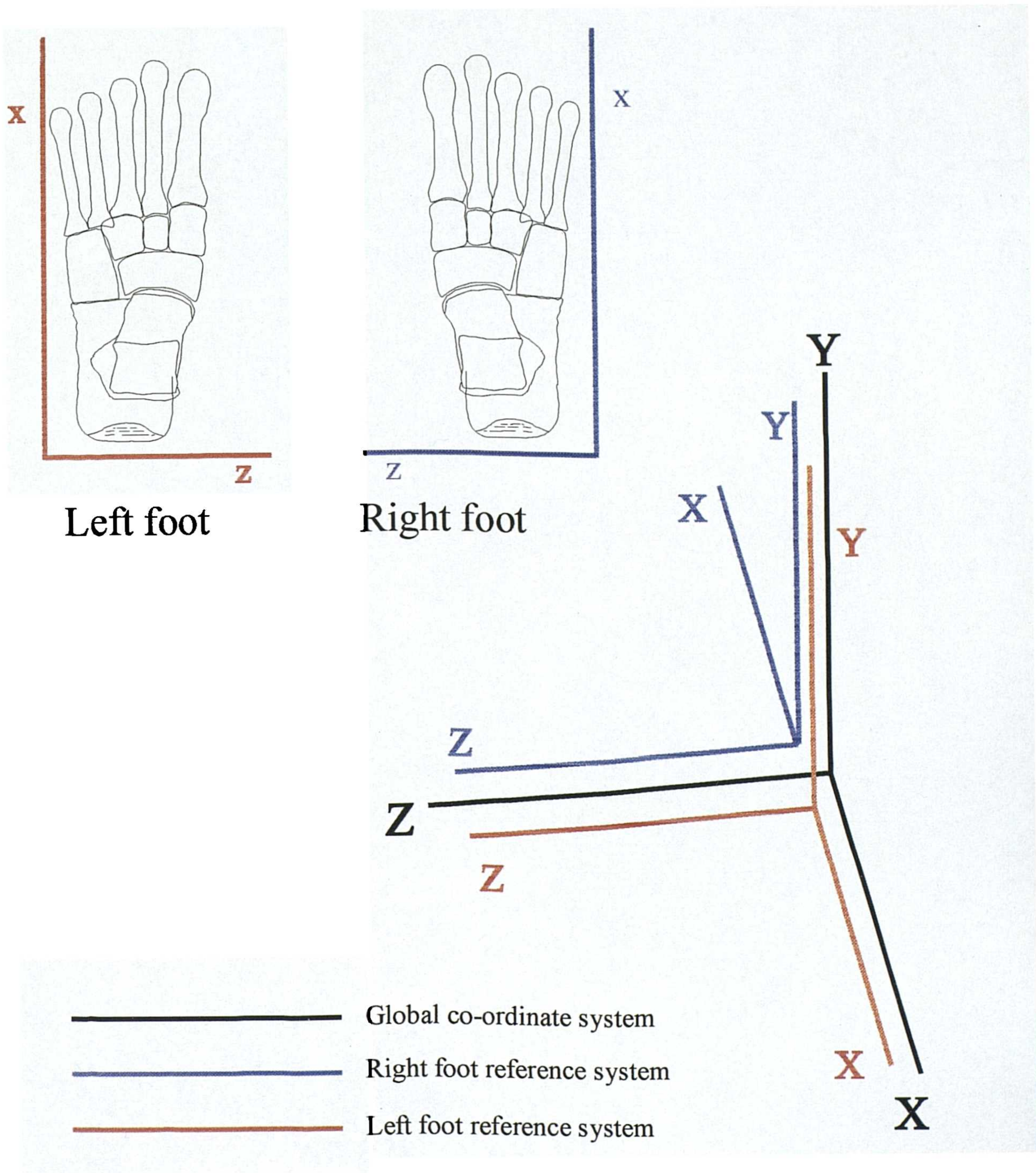


Figure 3.25

Illustrates the left and right foot reference systems relative to the global co-ordinate system and the respective feet.

To convert the angular rotation values from the global co-ordinate system to the foot reference system the following conventions applied:

For the left foot:

- Positive rotation around the x axis of the global co-ordinate system was positive rotation around the x axis of the foot reference system.
- Positive rotation around the y axis of the global co-ordinate system was positive rotation around the y axis of the foot reference system.
- Positive rotation around the z axis of the global co-ordinate system was positive rotation around the z axis of the foot reference system.

Positive rotation around the x, y and z axes of the foot reference system were eversion, abduction (external rotation) and dorsiflexion respectively.

For the right foot:

- Positive rotation around the x axis of the global co-ordinate system was positive rotation around the x axis of the foot reference system.
- Positive rotation around the y axis of the global co-ordinate system was negative rotation around the y axis of the foot reference system.
- Positive rotation around the z axis of the global co-ordinate system was negative rotation around the z axis of the foot reference system.

Positive rotation around the x, y and z axes of the foot reference system were eversion, abduction (external rotation) and dorsiflexion respectively.

By standardising the angular rotations relative to the foot reference systems, the same motion sequence in the left and right feet (the same anatomical motion) produced the same direction of motion around the axes of the foot reference system. Table 3.4 illustrates the effect of standardising the angular values.

	Anatomical motion		**Direction of rotation relative to global co-ordinate system**		**Direction of rotation relative to respective foot reference system**	
Axis of rotation	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
X	ever (+)	ever (+)	(+)	(+)	ever (+)	ever (+)
Y	abd (+)	abd (+)	(+)	(-)	abd (+)	abd (+)
Z	drflx (+)	drflx (+)	(+)	(-)	drflx (+)	drflx (+)

Table 3.4

Table 3.4 illustrates the difference in the description of the angular rotations when they are related to the global co-ordinate system and the foot reference systems. Standardising the left and right foot data ensures that the actual anatomical motions are correctly described. ever = eversion, abd = abduction, drflx = dorsiflexion, add = adduction, plflx = plantarflexion.

3.2.4.2 Data reduction.

The volume of data produced by the calculation of the angular rotations in the three cardinal body planes for 4 phases of the range of motion, for 3 segments and 3 joint complexes, during transverse plane rotation of the leg in two different directions, and the average of the rotations in two different directions, for 48 limbs, was considerable. Using the averaged data from each subject (averaged from up to 10 trials) the total number of data was 10368. The rotations in the three cardinal body planes were to be used to calculate an axis of rotation for each segment and joint complex (described in next section 3.2.5). This generates a further 6912 data, producing a total of 17280 data. Such a large volume of data were difficult to analyse and interpret. To ease data analysis, the data from the rotation of the leg from an externally rotated position to an internally rotated position, and from an internally rotated position to an externally rotated position was not used, but instead the average of these was used. Only this averaged data were used to calculate the axes of rotation of the segments and joint complexes. This reduced the volume of data by two thirds. The total number of angular rotation values was 3456 and the total number of values describing the axes of rotation subsequently calculated was 2304, producing a total of 5760 data items.

The fact that the characteristics of rearfoot motion were the same during rotation of the leg from an externally rotated position to an internally rotated position, and from an internally rotated position to an externally rotated position was confirmed by Benick (1985). This work was described in chapter 2 (section 2.3.2.3, figure 2.9 and 2.10) to validate the kinematic chain concept. Benick stated that the pattern of rotation of the individual segments in the rearfoot was identical during the rotation of the tibia in the two different directions, although the direction of motion was obviously reversed. This pattern was also illustrated in the data calculated in this investigation. The range of motion in each cardinal body plane was essentially identical during the rotation of the leg from an externally to an internally rotated position, as it was during the rotation of the leg from an internally rotated to an externally rotated position. Since this was the case, the functional characteristics could reliably be described using the data averaged from the rotation of the leg in the two directions. A case of a single subject is presented to confirm this (Table 3.5, figures 3.26 to 3.31).

SUBJ 11 LEFT	Difference between EXT to INT and INT to EXT Range of Motion (°)			Angle (°) of axis to	
	Frt	Trn	Sag	Trn	Sag
Leg	0.3	0.0	1.3	1.0	11.7
	0.3	0.2	0.5	2.2	10.8
	0.3	0.0	0.6	1.0	19.0
	0.6	0.1	0.7	1.4	8.4
Forefoot	2.1	1.1	1.2	5.6	2.0
	0.4	0.8	0.8	15.7	11.3
	0.8	0.3	0.3	2.1	0.1
	1.3	0.8	0.9	13.0	8.9
Heel	0.6	0.8	0.3	1.3	1.6
	0.0	1.2	0.4	2.4	2.3
	0.0	0.7	0.4	1.8	4.9
	0.6	0.1	0.6	2.7	19.2
Ank/Stj	0.3	0.8	1.0	1.6	40.1
	0.3	1.0	0.1	2.9	4.5
	0.3	0.7	0.2	1.9	3.5
	0.0	0.1	0.8	0.3	12.2
MTJ	2.7	0.2	1.0	4.5	2.8
	0.4	0.3	0.5	7.8	3.9
	0.8	0.4	0.1	3.5	4.2
	1.9	0.6	1.1	5.7	4.0
RFC	2.4	1.0	0.1	2.0	5.7
	0.7	0.7	0.4	3.0	2.9
	0.5	0.3	0.3	0.2	2.7
	1.9	0.7	0.2	3.3	28.5
Mean	0.7	0.5	0.6	3.6	9.0
Max	2.7	1.2	1.3	15.7	40.1
Min	0.0	0.0	0.1	0.2	0.1
Range	2.7	1.2	1.2	15.5	40.0

Table 3.5

Table details the differences in the range of motion and orientation of the axis of rotation between the rotation of the leg from an externally rotated to an internally rotated position and rotation of the leg from an internally rotated to an externally rotated position.
EXT = external rotated, INT = internally rotated.

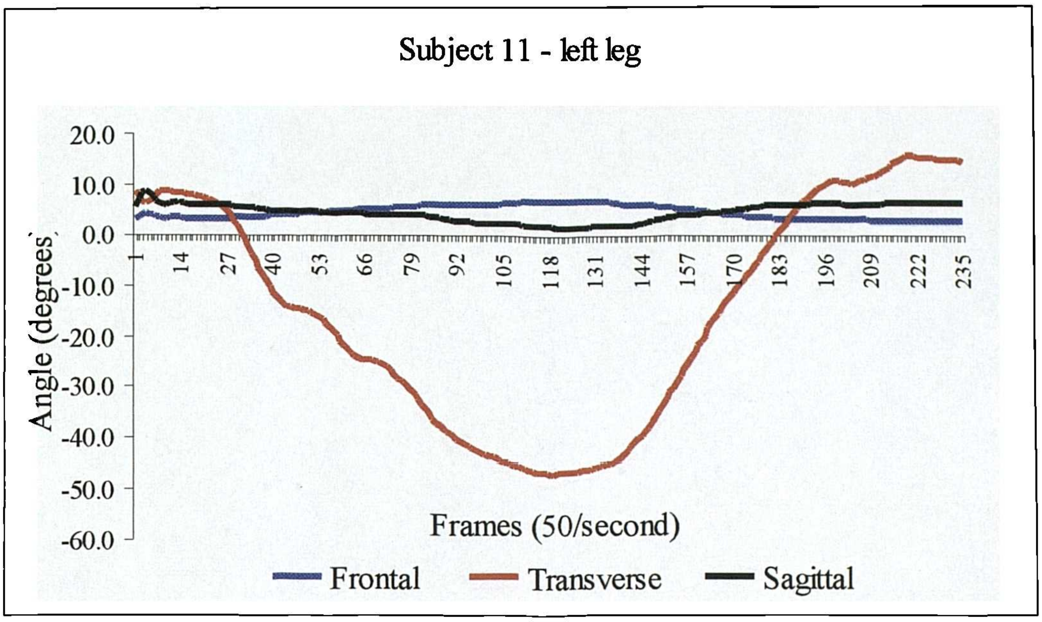


Figure 3.26

Range of leg motion in the cardinal body planes. Starts with the leg externally rotated, leg internally rotates and then returns to externally rotated position.

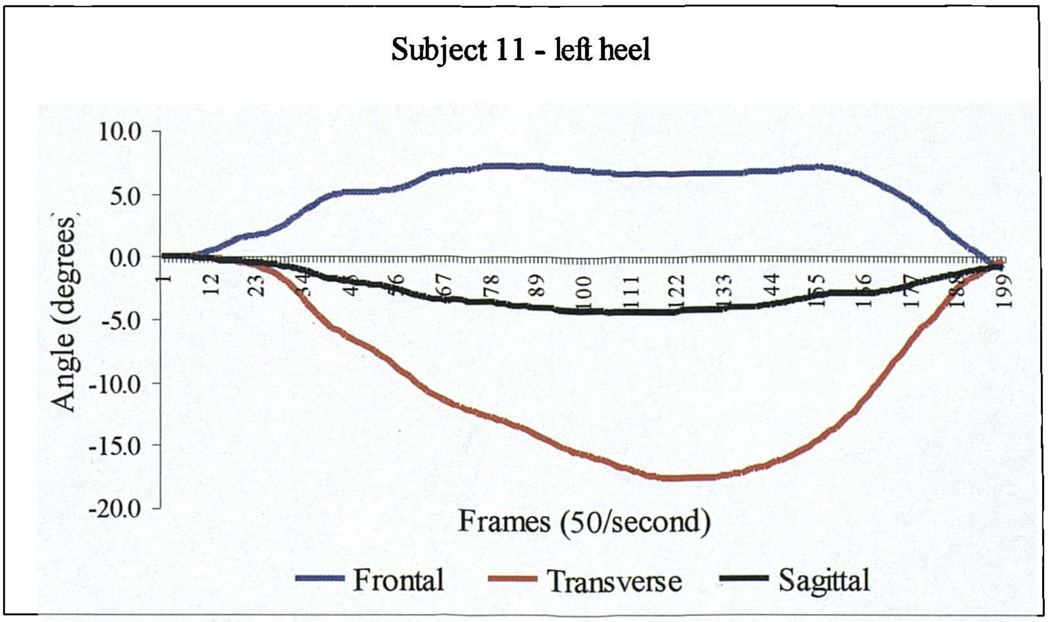


Figure 3.27

Range of heel motion in the cardinal body planes. Starts with the leg externally rotated, leg internally rotates and then returns to externally rotated position.

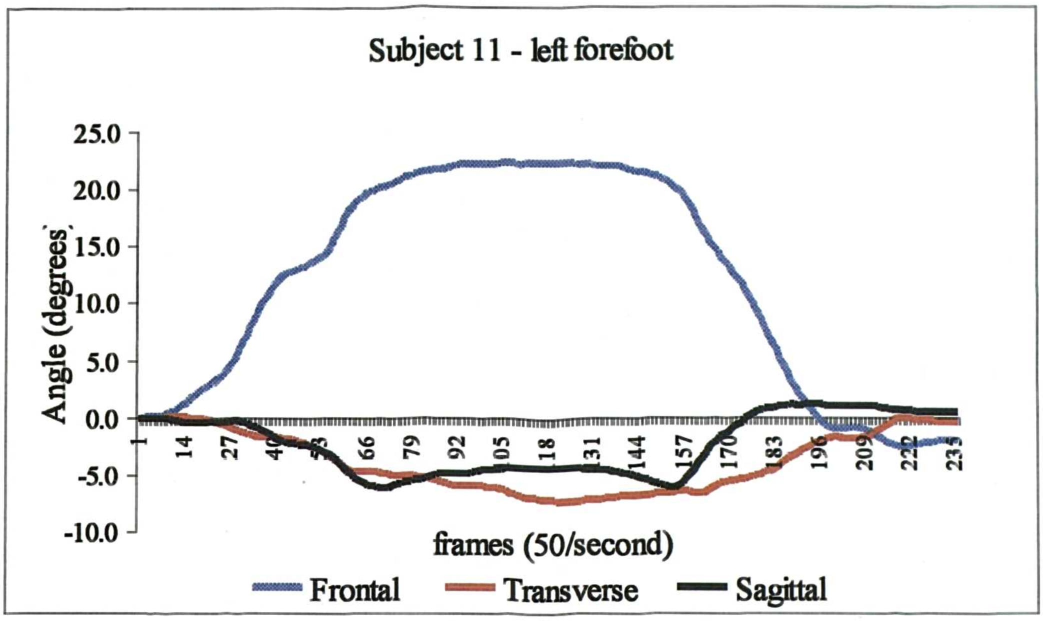


Figure 3.28

Range of forefoot motion in the cardinal body planes. Starts with the leg externally rotated, leg internally rotates and then returns to externally rotated position.

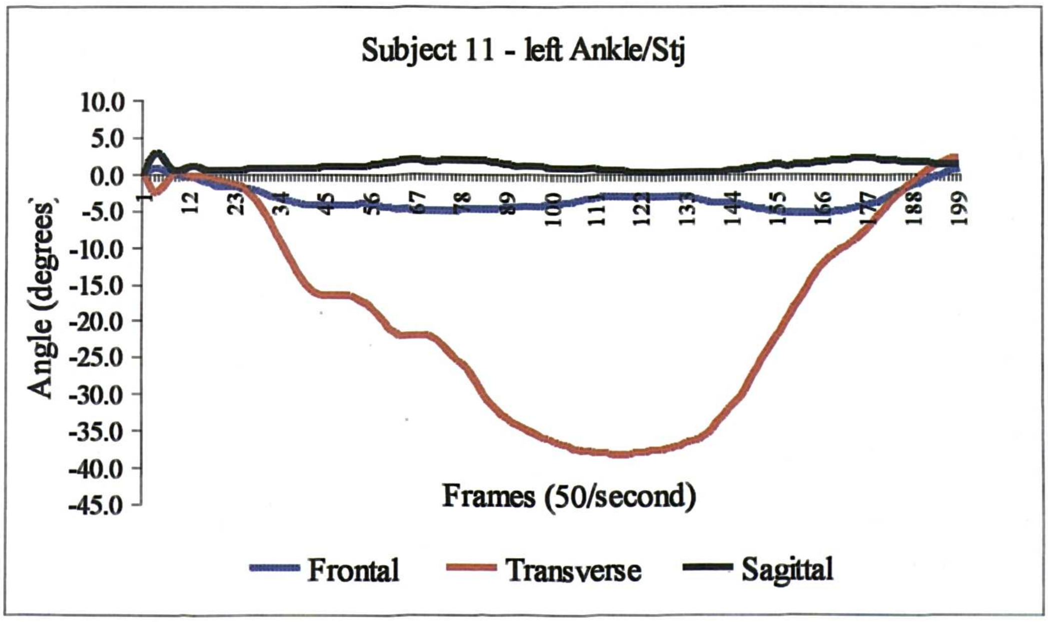


Figure 3.29

Range of ankle/sub talar complex motion in the cardinal body planes. Starts with the leg externally rotated, leg internally rotates and then returns to externally rotated position.

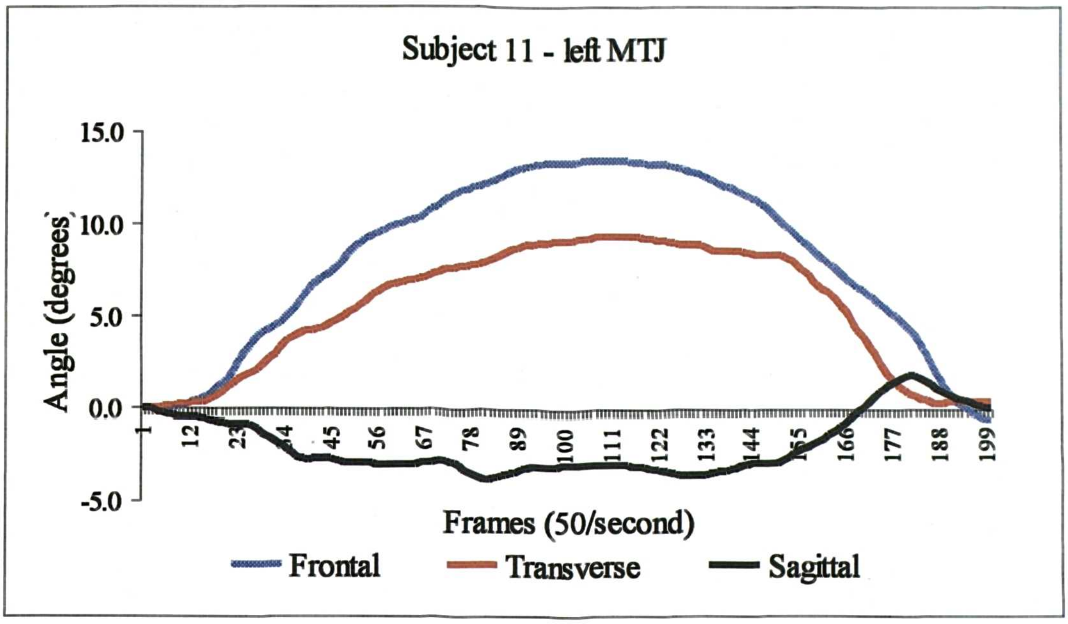


Figure 3.30

Range of mid tarsal joint motion in the cardinal body planes.

Starts with the leg externally rotated, leg internally rotates and then returns to externally rotated position.

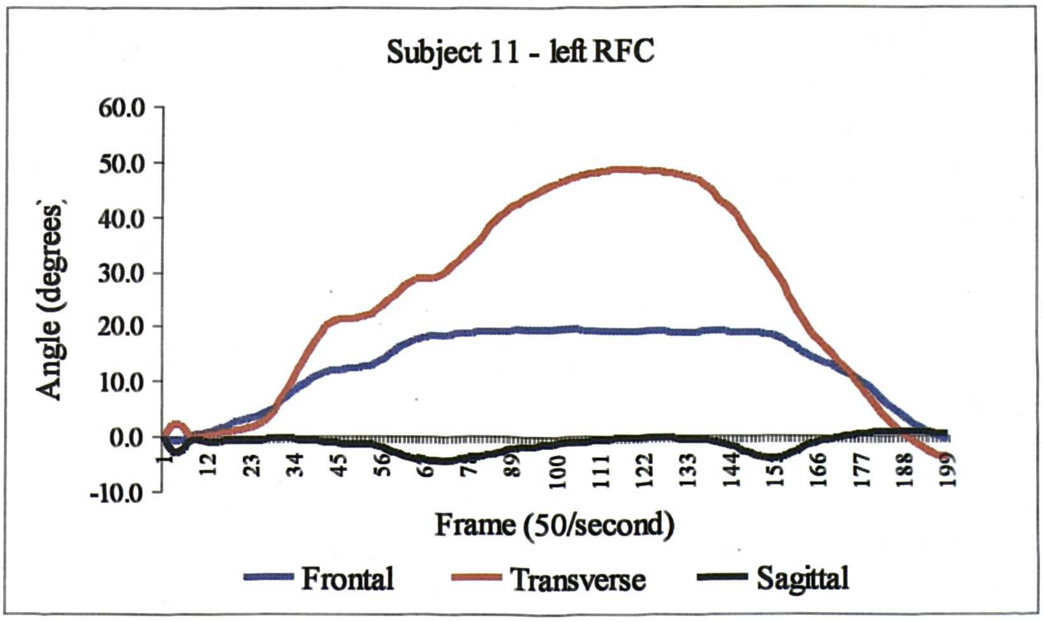


Figure 3.31

Range of rearfoot complex motion in the cardinal body planes.

Starts with the leg externally rotated, leg internally rotates and then returns to externally rotated position.

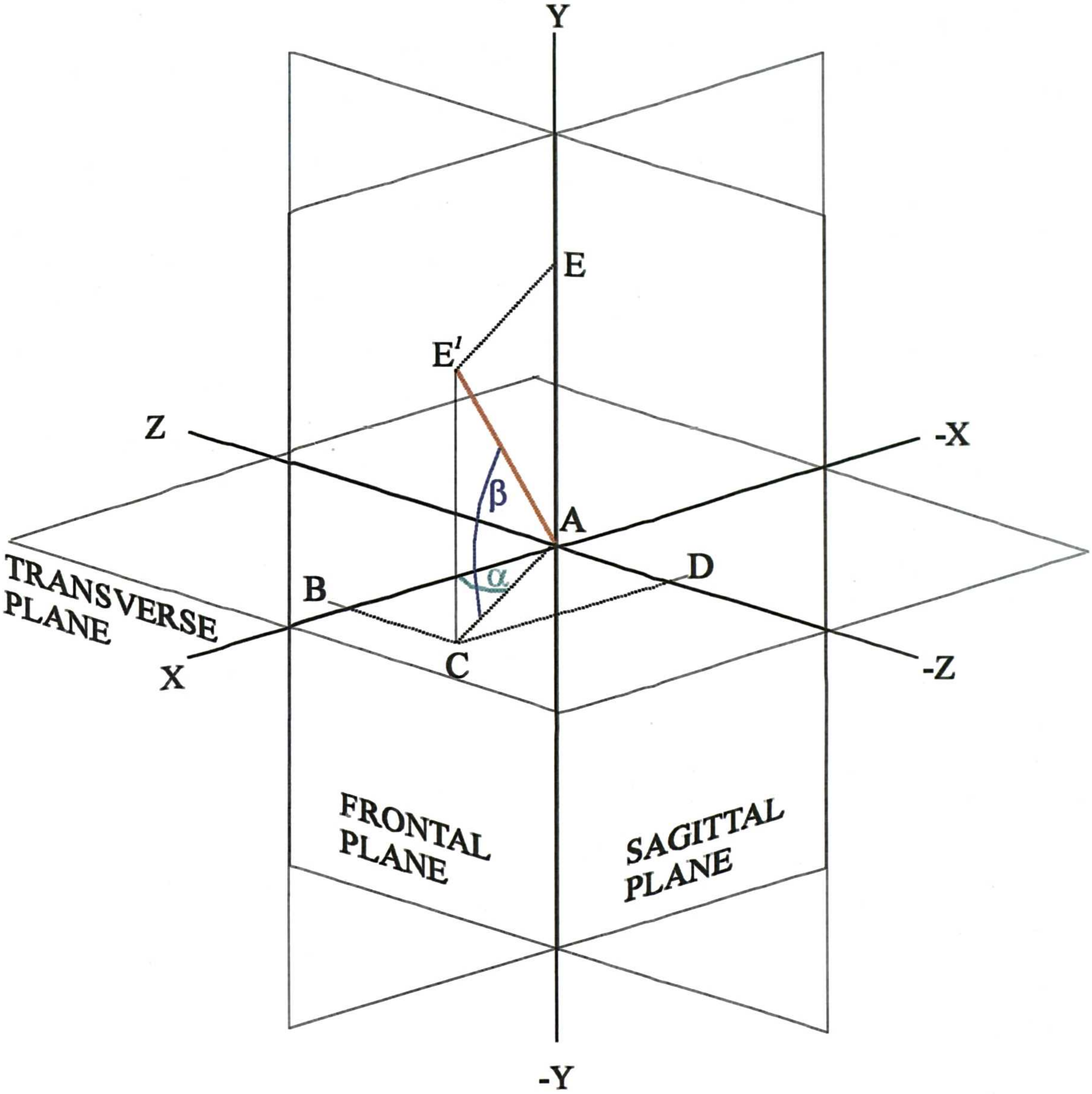
3.2.5 CALCULATION OF THE AXIS OF ROTATION FROM THE STATIC REARFOOT COMPLEX DATA.

To provide a single quantitative measure of the functional characteristics of the absolute and relative angular rotations an axis of rotation was calculated for each. The method of axis calculation was identical to that used by Downing et al (1978). This method calculates an axis of rotation relative to three orthogonal planes (cardinal body planes in this instance) using a measure of the angular rotation in each plane.

The calculation of the axis of rotation is based on the assumption that the proportion of motion displayed in the three cardinal body planes is related to the angulation of the axis around which those rotations took place relative to the cardinal body planes. For example, if a joint displays solely sagittal plane motion the axis around which this motion took place must be angled 90° to the sagittal plane, and lie in the frontal and transverse planes. Conversely, if a joint displays solely frontal plane motion the axis around which the motion took place must be angled 90° to the frontal plane and lie in the sagittal and transverse planes. This illustrates a further concept that the greater the proportion of motion displayed in any of the three planes, the greater the angle between the axis of rotation and that plane. Conversely, the smaller the proportion of motion displayed in any of the three planes, the smaller the angle between the axis of rotation and that plane. If an axis of rotation is found to make no angle to a plane then rotation around that axis will display no motion in that plane.

The rotations in each cardinal body plane take place around an axis that is perpendicular to that plane. Frontal plane motion occurs around the x axis (anterior/posterior axis) of the co-ordinate system defining the body planes, sagittal plane motion around the z axis (medial/lateral axis), and transverse plane motion around the y axis (vertical axis). Since the motion in each plane occurs around an axis of the co-ordinate system, the magnitude of angular motion in each plane can be represented by a vector directed in each of the x, y and z directions. A vector in the x direction represents motion in the frontal plane, a vector in the z direction represents motion in the sagittal plane and a vector in the y direction represents motion in the transverse plane.

Downing et al (1978) described how these three vectors could be used to construct right angled triangles with the three cardinal body planes. The vectors representing the frontal and sagittal plane motions can be used to calculate the angle of a fourth vector (representing the axis of rotation) relative to the sagittal plane when projected onto the transverse plane. This represents the angle between the axis of rotation and the sagittal plane, projected onto the transverse plane (Figure 3.32). Hereafter, this angulation is referred to as the angle of the axis of rotation to the sagittal plane. When this angle is known, the angle between the fourth vector (axis of rotation) and the transverse plane can be calculated (Figure 3.32).



AB = Vector representing motion in frontal plane

AD = Vector representing motion in the sagittal plane

AE = Vector representing motion in the transverse plane

AE′ = axis of rotation

AC = Vector representing the axis of rotation projected onto the transverse plane.

α = angle of axis to sagittal plane, β = angle of axis to transverse plane

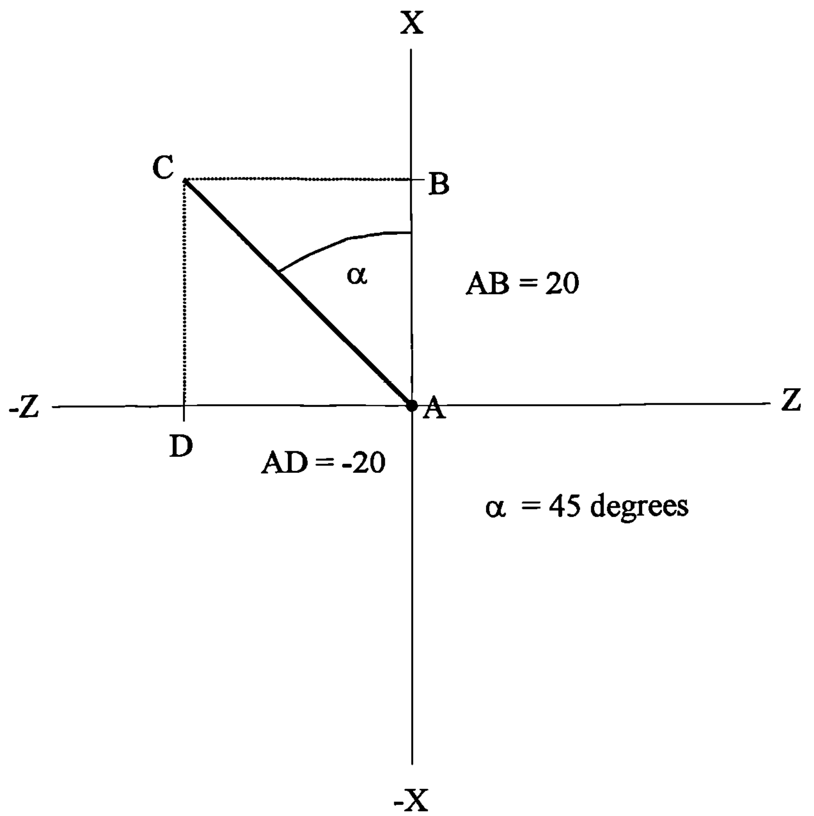
Figure 3.32

Illustration of the relationships between axes of rotation of the global co-ordinate system (X, Y and Z), the cardinal body planes (sagittal, frontal and transverse planes) and the orientation (angulation) of the axis of rotation (AE′) calculated using the range of motion in each of the three planes.

The following example is for the triplanal motion of a body segment relative to the cardinal body planes. The range of motion in the frontal plane is 20° (eversion), in the sagittal plane -20° (plantarflexion), and in the transverse plane is 30° (abduction).

Calculation of angle between the axis of rotation and the sagittal plane (refer to figure 3.33):

- Since ABC is a right angled triangle, α can be calculated using the tangent function.
- Tan α = opposite/adjacent = BC/AB = -20/20 = -1
- To find α, we need the arctangent of -1 = $\tan^{-1}(1)$ = -45.0°



AB = Vector representing the range of motion in frontal plane

AD = Vector representing the range of motion in sagittal plane

AC = Vector representing axis of rotation

α = angle between axis of rotation and sagittal plane

Figure 3.33

Illustrates calculation of the angle between axis of rotation and the sagittal plane. Axes X and Y are those of the global co-ordinate system. Vectors AB and AD represent the range of motion around these axes.

Similarly, the angle between the axis of rotation and the transverse plane can be calculated by constructing a further right angled triangle.

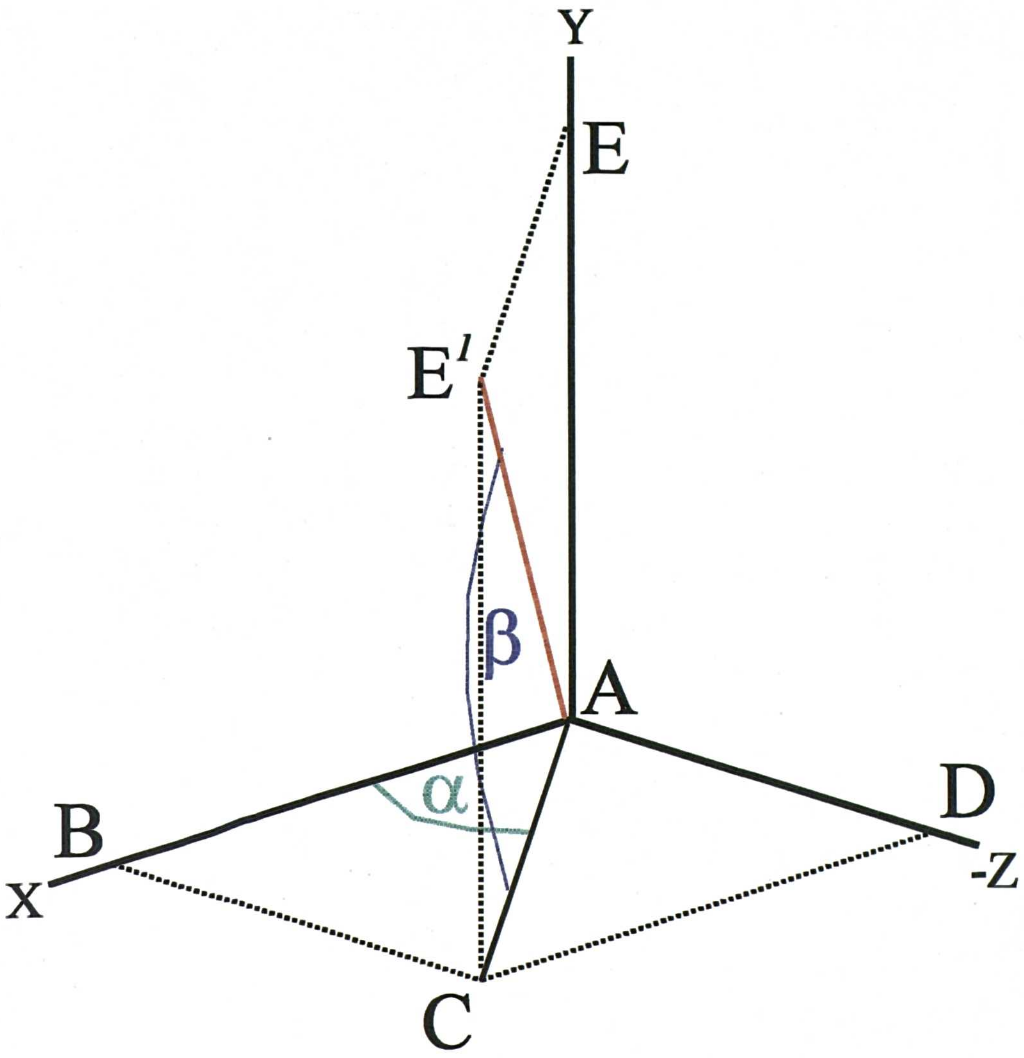
Calculation of the angle between the axis of rotation and the transverse plane (refer to figure 3.34):

- Since CAE^{1} is a right angled triangle, β can be calculated using the tangent function.
- Tan β = opposite/adjacent = CE^{1}/AC
- Since AC is the hypotenuse of the right angled triangle ABC, AC can be found by solving the following:

$$\begin{aligned} AB^2 + BC^2 &= AC^2 \\ (20)^2 + (20)^2 &= AC^2 \\ 800 &= AC^2 \\ 28.2842 &= AC \end{aligned}$$

- Since $CE^{1} = AE$, $CE^{1} = 30$
- Tan β = 30/28.2842 = 1.06
- the arctangent of 1.06 = $\tan^{-1}(1.06) = 46.7°$

In this example the axis of rotation is angled –45.0° relative to the sagittal plane and 46.7° to the transverse plane.



AB = Vector representing the range of motion in the frontal plane

AD = Vector representing the range of motion in the sagittal plane

AE = Vector representing the range of motion in the transverse plane

AE^{1} = Axis of rotation

AC = axis of rotation projected on to the transverse plane.

Figure 3.34

Illustrates the vector AB, AD and AE in relation to the global co-ordinate system X, Y and Z. AE^{1} is the axis of rotation for the motion which the vectors AB, AD and AE represent. The angle between the axis of rotation and the sagittal plane is α, the angle between the transverse plane and the axis of rotation β.

3.2.5.1 Validation of axis calculations.

Since the 'rules' governing the relationship between the proportion of motion displayed in each of three orthogonal planes and the angulation of the axis of rotation relative to these planes are known, inputting false data into the equations allows the method to be validated.

Using the method described false data were input to the equations and the angulation of the axis of rotation to the sagittal and transverse planes calculated (table 3.6). The values of 10° were chosen randomly and the total range of motion around the axis (in a plane perpendicular to it) was unknown. Due to the division component of the equations, 0° could not be input as the range of motion in a plane and 0.0001° was used to indicate no motion in that plane.

Motion in sagittal plane (known)	Motion in transverse plane (known)	Motion in frontal plane (known)	Angle of axis to sagittal plane (calculated)	Angle of axis to transverse plane (calculated)
0.0001	10	10	0.0005	44.9941
10	0.0001	10	44.9417	0.0004
10	10	0.0001	89.9877	44.9941

Table 3.6

Table details the calculated angle between the axis of rotation and sagittal and transverse planes from the false data. Systematically, the motion in each plane was considered to be zero. When this condition is true the angle between the axis of rotation and that plane should be 0°.

Clearly, and in accordance with the 'rules' governing these relationships, if there is no motion (or effectively none (0.0001°)) in the sagittal plane, the axis of rotation for the motion lies in that plane (or makes a very small angle to it (0.0005°)). If there is no motion (or effectively none (0.0001°)) in the frontal plane, the axis of rotation for the motion lies in that plane (or makes a very small angle to it (0.0123°)). If there is no motion (or effectively none (0.0001°)) in the transverse plane, the axis of rotation for the motion lies in that plane (or makes a very small angle to it (0.0004°)). Furthermore, when the motion in the transverse and frontal planes is equal, the axis lies mid way between these planes. When the motion in the sagittal and frontal planes is equal, the axis lies mid way between these planes.

The validity of these calculations can be further confirmed by reversing the calculation, so that the angulation of the axis is known and the proportion of motion in each plane is calculated (table 3.7).

trom = total range of motion

- **Range of transverse plane motion**

  = trom x *sin* (angle between transverse plane and axis of rotation)

- **Range of frontal plane motion**

  = trom x *cos* (angle between sagittal plane and axis of rotation) x *cos* (angle between transverse plane and axis of rotation)

- **Range of sagittal plane motion**

  = trom x *sin* (angle between sagittal plane and axis of rotation) x *cos* (angle between transverse plane and axis of rotation)

Motion in sagittal plane (calculated)	Motion in transverse plane (calculated)	Motion in frontal plane (calculated)	Angle of axis to sagittal plane (known)	Angle of axis to transverse plane (known)
0.00006	7.07033	7.07179	0.0005	44.9941
7.06386	0.00006	7.07825	44.9417	0.0004
7.07179	7.07033	0.00158	89.9877	44.9941

Table 3.7

Motion in sagittal, transverse and frontal planes calculated for 10 degrees of motion around an axis of rotation of known angulation to the sagittal and transverse planes.

Clearly, the axis orientations calculated through the trigonometry method produce correct results when the calculations are reversed. The motions in the frontal and transverse planes are effectively equal when the angle between the axis and these two planes is equal. The motions in the frontal and sagittal planes are effectively equal when the angle between the axis and these two planes is equal. When the axis is effectively parallel to a plane (0.0005°, 0.0004°) the motion in that plane is effectively 0° (0.00006°, 0.00158°).

The discrepancy between the range of motion values in table 3.6 and table 3.7 (10° versus 7.07°) is because the range of motion around the axis in the calculation of data in table 3.6 was unknown. Clearly, it is greater than the 10 degrees used for the calculations in table 3.7.

3.2.6 SUMMARY OF FINAL DATA CALCULATED.

The following data were calculated for each of the 48 limbs:

- The range of motion in the frontal, transverse and sagittal cardinal body planes for the absolute rotations of the leg, heel and forefoot, and the relative rotations of the ankle/sub talar complex, the mid tarsal joint and the rearfoot complex. All values were relative to the foot reference systems and angular values were averaged from the rotation of the leg from an externally rotated position to and internally rotated position and from an internally rotated position to an externally rotated position.

- These ranges of motion were calculated for the composite, dynamic, supination and pronation phases of motion.

- The relationship between the different phases of motion in each plane was further described by expressing them as a ratio.

From the ranges of frontal, transverse and sagittal plane motion the following data were calculated:

- Axes of rotation for the absolute rotations of the leg, heel and forefoot, and the relative rotations of the ankle/sub talar complex, the mid tarsal joint and the rearfoot complex, for the composite, dynamic, supination and pronation phases of motion.

CHAPTER 4

RESULTS

4.1 INTRODUCTION.

This chapter is divided into two sections. The first section details the results of the dynamic rearfoot complex assessment. This describes the transverse plane motion of the leg relative to the foot during gait for each of the 25 subjects. The second section details the results of the static rearfoot complex assessment. Only the mean numeric data (representing the whole sample of 25 subjects) from the static assessment is presented in this chapter. The numerical data from the individual subjects in listed in appendix 1.

4.2 DYNAMIC REARFOOT COMPLEX ASSESSMENT.

The mean angular data curve for a single gait cycle (calculated from both left and right limbs of all subjects) is illustrated in figure 4.1. The angular data showed a consistent pattern throughout the sample. The rearfoot complex was supinated relative to its position in relaxed standing prior to heel strike and pronated immediately after heel strike to a position more pronated than the relaxed standing position. The leg externally rotated relative to the foot (rearfoot complex supination) during the mid stance and terminal phases of stance. During swing phase the rearfoot complex initially pronated and then moved to a supinated position. The mean data was characterised by the rearfoot complex being both supinated and pronated relative to is relaxed standing position during different phases of gait.

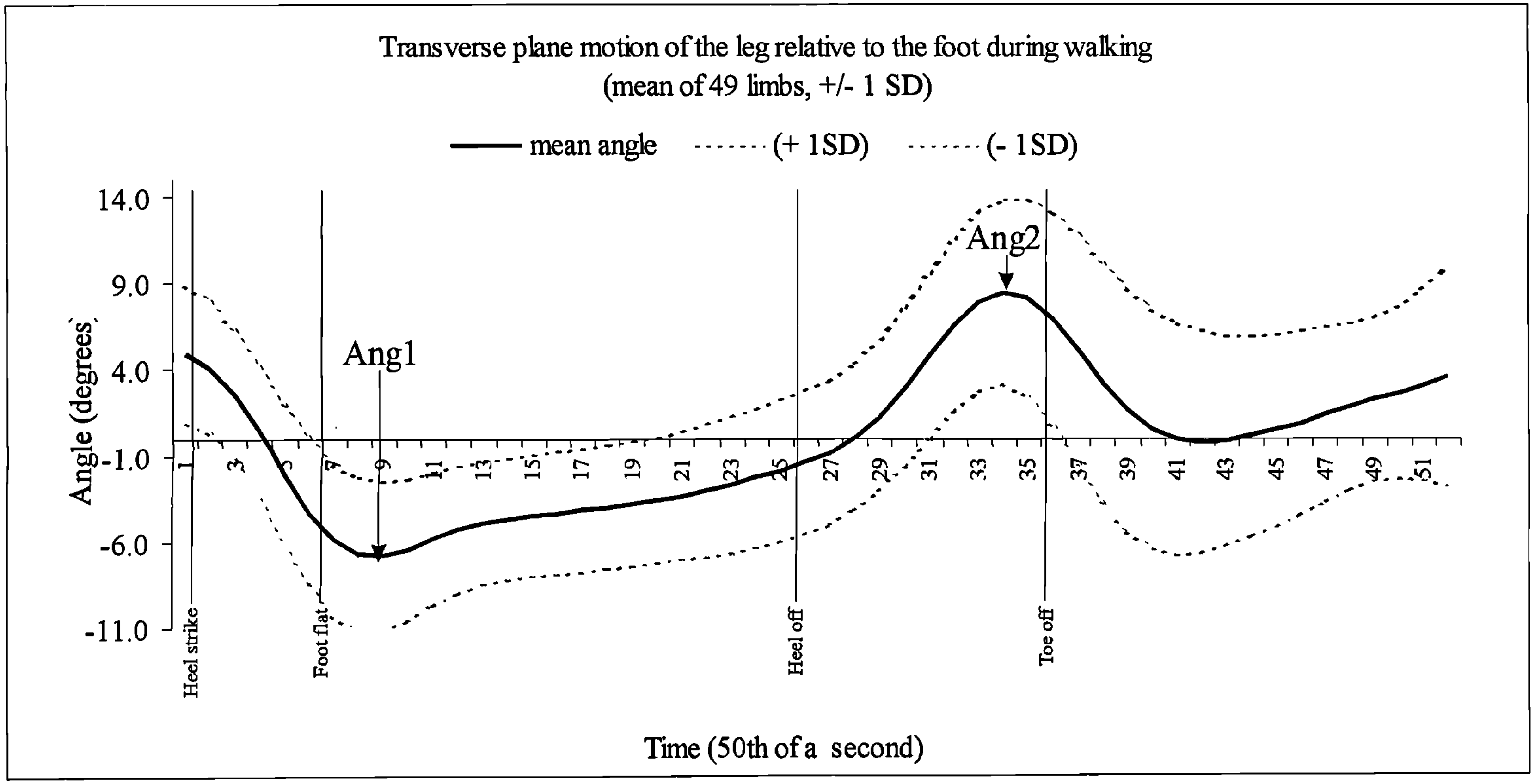


Figure 4.1

Transverse plane motion of the leg relative to the foot during 1 gait cycle. Calculated from the left and right limbs of all 25 subjects (except right limb data of subject 2). The 0 degrees line indicates the relaxed standing position. A positive angular position indicates rearfoot complex supination, a negative angular position indicates rearfoot complex pronation. See text for definition of Ang1 and Ang2.

The total range of transverse plane motion of the leg relative to the foot (which was to be used in the processing of the static rearfoot complex assessment data) was calculated as the difference between the angular value at maximum rearfoot complex pronation (Ang1) and the angular value at maximum rearfoot complex supination (Ang2) (Figure 4.1).

The Ang1 and Ang2 values and the total range of transverse plane rearfoot complex motion for each subject, are detailed in table 4.1 and illustrated in figure 4.2. For some subjects the maximum supinated position (Ang2) occurred at heel strike, not during the terminal phase of stance as the mean data suggests. This was because the rearfoot complex did not supinate past this position during the terminal phase and the maximum angular value during the terminal phase was less than that at heel strike.

	LEFT			RIGHT		
SUBJ	**Ang1**	**Ang2**	**ROM**	**Ang1**	**Ang2**	**ROM**
1	-9.2	6.0	15.2	-3.1	17.9	21.1
2	-9.6	16.1	25.7	0.0	0.0	*
3	-13.7	10.6	24.2	-5.4	12.9	18.3
4	-8.0	4.9	12.9	-5.6	12.2	17.8
5	-10.5	7.9	18.4	-2.8	18.2	21.0
6	-7.3	4.4	11.7	-5.0	10.3	15.2
7	-9.6	16.4	26.0	-6.1	18.3	24.4
8	-8.4	8.7	17.1	-1.2	16.9	18.1
9	-7.7	9.7	17.4	-3.6	14.1	17.7
10	-9.4	11.6	20.9	-2.0	14.2	16.2
11	-10.8	3.1	13.9	-7.4	2.8	10.2
12	-19.8	-1.7	18.2	-13.0	16.8	29.8
13	-13.7	1.3	15.0	-9.3	6.6	15.9
14	-5.0	9.0	13.9	-2.3	13.3	15.5
15	-7.5	8.8	16.3	-6.1	10.9	17.0
16	-7.4	7.3	14.7	-8.6	13.4	22.0
17	-7.1	10.1	17.3	-5.8	7.7	13.5
18	-3.4	13.3	16.7	-2.0	18.6	20.6
19	-8.3	5.2	13.5	-7.6	9.8	17.5
20	-6.0	5.9	12.0	-6.6	7.8	14.4
21	2.0	13.3	11.3	-0.6	11.0	11.6
22	-10.0	8.8	18.8	-5.9	14.8	20.7
23	-16.1	6.7	22.8	-10.8	13.4	24.2
24	-9.7	3.2	12.9	-7.7	9.9	17.6
25	-8.3	4.8	13.0	-6.0	8.4	14.3
Mean	-9.0	7.8	16.8	-5.6	12.5	18.1
SD	4.1	4.4	4.3	3.2	4.8	4.4
Min	-19.8	-1.7	11.3	-13.0	2.8	10.2
Max	2.0	16.4	26.0	-0.6	18.6	29.8
Range	21.8	18.0	14.7	12.5	15.8	19.7

Table 4.1

Table details the value of Ang1 and Ang2, and the total range of transverse plane motion (ROM) of the leg relative to the foot for each limb of each subject. Negative values indicate that the leg was internally rotated relative to its position at relaxed standing (rearfoot complex was pronated), and positive values indicate that the leg was externally rotated relative to its position in relaxed standing (rearfoot complex supinated). The right leg of subject 2 was excluded because it differed greatly from the general trend (see full explanation in text).

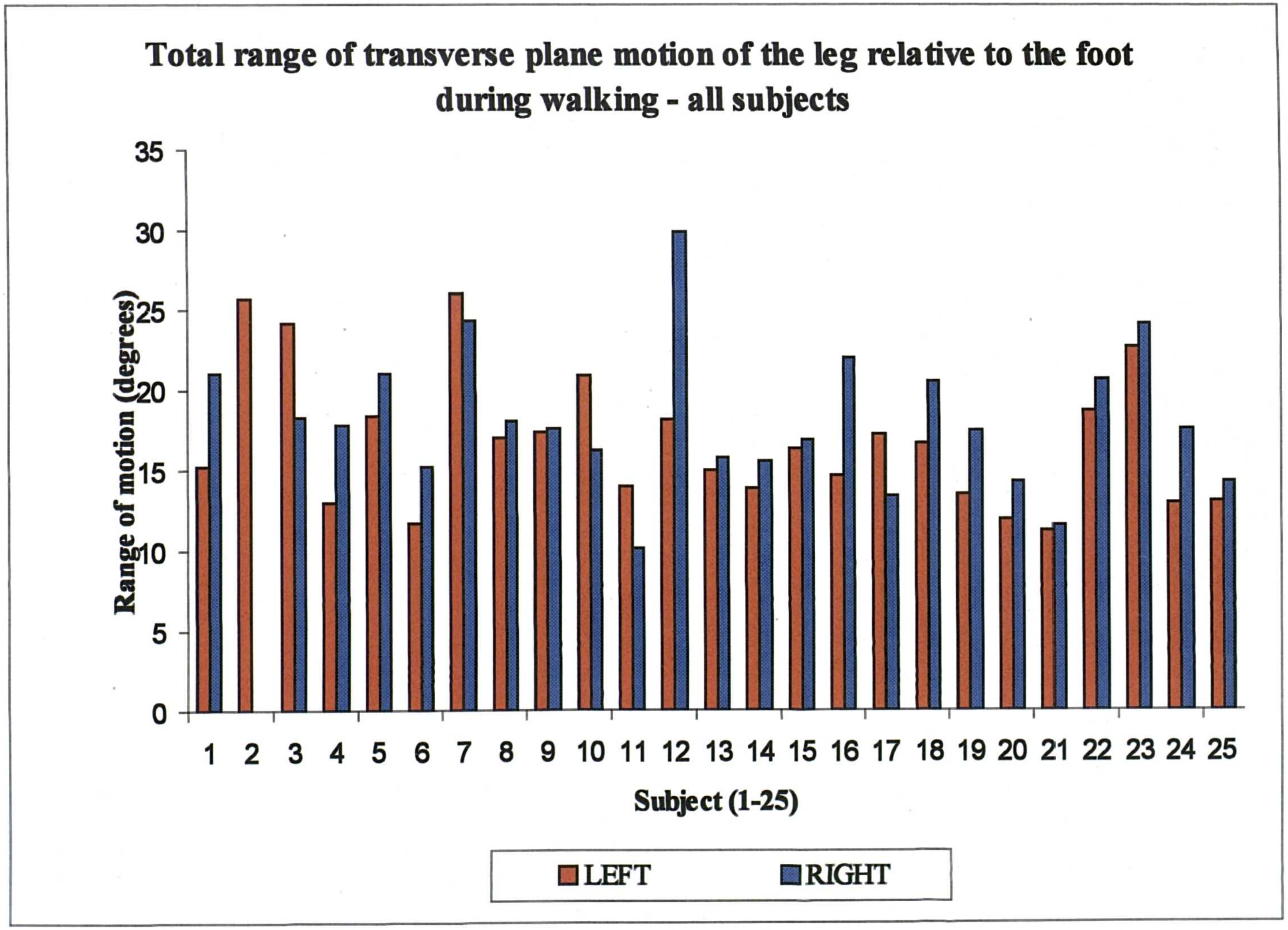


Figure 4.2

Graph illustrates the range of transverse plane motion of the leg relative to the foot for each limb of the 25 subjects.

The angular values for the right limb of subject 2 were considerably different to the rest of the sample, despite the pattern of motion being similar. The rearfoot complex was pronated relative to the relaxed standing position throughout the gait cycle. The data from this subject are presented in figure 4.3. The degree to which these data differed from the sample as a whole, and from the left limb data of subject 2, questions its validity. It is conceivable that the reference angle for the right limb of this subject was invalid. The degree of error in the reference angle required to produce such a difference could be a consequence of a reference file not being retaken after a marker had fallen off and been reattached. Since the validity of the angular values was questionable the dynamic data for the right limb of subject 2 were excluded from all further analysis.

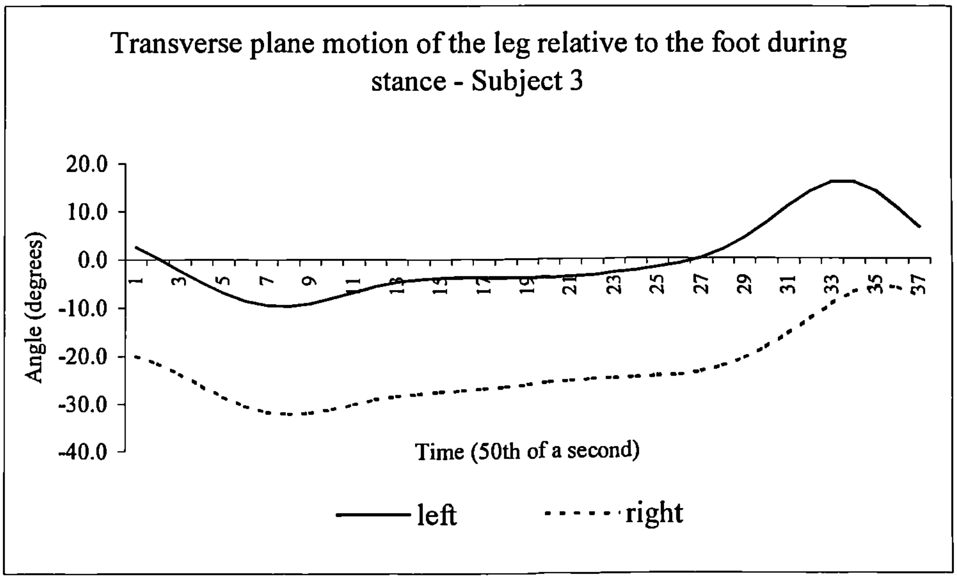


Figure 4.3

Transverse plane motion of the leg relative to the foot of the left and right limbs of subject 2. The 0 degrees line represents the relaxed standing position. The left limb data are similar to that of the rest of the sample. The right limb data are similar in terms of the pattern, but the actual angular values suggest that the foot was constantly pronated. These data are inconsistent with that of the rest of the sample and were excluded from further analysis.

4.3 STATIC REARFOOT COMPLEX ASSESSMENT.

To maintain clarity and continuity within the main text, only the mean values from the whole sample are detailed in this chapter. Tables 4.3 to 4.14 detail the mean ranges of motion in each cardinal body plane, the standard deviations of these values, the mean angulation of the axis of rotation, the ratio of the mean ranges of motion and the angulation of the axis of rotation calculated from the mean ranges of motion, for each of the absolute rotations of the leg, heel and forefoot (forft) and the relative rotations of the ankle/sub talar complex (Ank/Stj), the mid tarsal joint (MTJ) and the rearfoot complex (RFC). Each of these are listed for the four phases of the range of motion: composite (comp); dynamic (dyn); supination (supi); and pronation (pron). These are the mean values from the whole sample of 25 subjects for the left limb and 23 subjects for the right limb. The data for the right limbs of subjects 6 and 23 could not be used because there was no valid reference file.

The individual data for the ranges of motion in each of the cardinal body planes displayed by the leg, forefoot, heel, ankle/sub talar complex, mid tarsal joint and rearfoot complex of each subject during the static rearfoot complex assessment are detailed in tables A1.1 to A1.84 in appendix 1. The standard deviations of the range of motion values, the ratios of the motions in the three planes, and the axes of rotation for each of the segments and joint complexes are also detailed in these tables.

The anatomical meaning of the positive and negative properties of the angular values are described in table 4.2.

Property of range of motion	**Segment/joint complex motion during rotation of leg from an externally rotated position to an internally rotated position**			**Segment/joint complex motion during rotation of leg from an internally rotated position to an externally rotated position**		
	Frontal	Transverse	Sagittal	Frontal	Transverse	Sagittal
Positive (+ve)	eversion	external rotation	dorsi-Flexion	inversion	internal rotation	plantar-flexion
Negative (-ve)	inversion	internal rotation	plantar-flexion	eversion	external rotation	dorsi-flexion

Table 4.2

Explains the relationship between the positive and negative property of the range of motion values, and the anatomical motion of the segment/joint complex during the rotation of the leg in the two different directions. Relates to the data in tables 4.3 to 4.14 and the tables in appendix 1 and 2.

It was necessary to designate some convention because if the sign of the actual angular values calculated had been used it would produce erroneous data. For example, 12° of eversion during absolute internal rotation of the leg had a positive sign (+12°) and 10° of inversion during absolute external rotation of the leg had a negative sign (-10°). The average of these would be 0.5°, whereas the actual range of motion of interest is 11°. Thus, to produce sensible results the sign of the data during absolute external rotation of the leg was reversed. The positive and negative signs of the data in this chapter and in the appendices now refer to the coupling of motion in a particular plane. Positive frontal plane motion refers to the coupling of eversion with absolute internal rotation of the leg and inversion with absolute external rotation of the leg. Negative frontal plane motion refers to the coupling of inversion with internal rotation of the leg and eversion with external rotation of the leg.

For example, the mean left ankle/sub talar complex displayed 7.2° of frontal motion, 27.4° of transverse plane motion and –1.4° of sagittal plane motion during the composite phase. Thus, the heel everted, externally rotated and plantarflexed relative to the leg during internal rotation of the leg, and inverted, internally rotated and dorsiflexed relative to the leg during external rotation of the leg.

The angulation of the axes of rotation relative to the transverse and sagittal planes for each segment and each joint complex are illustrated in figure 4.4 to 4.9 (for composite phase of motion). These are calculated from the mean range of motion in each of the cardinal body planes, as opposed to being the mean of the axes in the sample. This practice was adopted because if the axes in the sample had different positive/negative properties the mean axis calculated might not represent the typical motion taking place. The composite phase of motion was chosen because it is an indicator of the overall functional characteristics of the segment or joint complex, and is generally more comparable to those characteristics reported in the literature. The sign convention relates to the foot reference systems described in section 3.2.4.1.

RIGHT LEG	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
comp	-0.6	-40.3	-1.0	2.0	5.9	1.3	-86.5	23.7	-88.3	57.0	1.0	62.7	1.5
dyn	-0.6	-17.7	-0.3	1.0	4.3	0.6	-86.2	16.8	-87.7	26.4	1.0	27.9	0.5
supi	-0.6	-20.3	-0.4	1.1	0.9	0.7	-86.1	8.2	-87.9	28.7	1.0	31.7	0.5
pron	0.0	-20.0	-0.6	1.3	5.7	0.8	-85.8	12.9	-88.2	89.8	1.0	8434.4	268.6

Table 4.3. Mean data for the absolute rotation of the right leg, from 23 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

RIGHT HEEL	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
comp	7.4	-13.3	-0.9	4.3	2.9	2.2	-60.4	-13.4	-60.8	-7.2	1.0	-1.8	-0.1
dyn	3.8	-5.6	-0.6	2.4	1.9	0.9	-56.3	-13.7	-55.5	-9.7	1.0	-1.5	-0.2
supi	4.5	-6.8	-0.9	1.8	1.4	0.9	-55.5	-13.6	-55.9	-11.1	1.0	-1.5	-0.2
pron	2.9	-6.5	-0.1	3.1	1.9	1.7	-64.4	0.9	-66.2	-1.0	1.0	-2.3	0.0

Table 4.4. Mean data for the absolute rotation of the right forefoot, from 23 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

RIGHT FORFT	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
comp	19.2	-3.3	4.8	7.0	2.4	2.7	-10.0	15.9	-9.4	14.1	1.0	-0.2	0.3
dyn	8.6	-0.7	2.3	4.4	1.3	1.9	-5.5	15.3	-4.6	14.7	1.0	-0.1	0.3
supi	10.7	-1.2	2.2	2.3	1.6	2.3	-6.2	12.3	-6.3	11.8	1.0	-0.1	0.2
pron	8.6	-2.1	2.6	5.5	1.5	2.3	-15.9	20.7	-13.1	16.8	1.0	-0.2	0.3

Table 4.5. Mean data for the absolute rotation of the right heel, from 23 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

RIGHT	mean Range of motion (rom)			Standard deviation (rom)			mean angle of axis to		Axis calculated from mean rom. angle of axis to		Ratio of mean rom		
Ank/Stj	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Trn	Sag	Frt	Trn	Sag
comp	8.0	27.0	0.1	5.7	4.5	2.4	73.1	-7.8	73.4	0.4	1.0	3.4	0.0
dyn	4.4	12.1	-0.3	3.2	3.1	1.2	70.7	-8.2	70.0	-4.2	1.0	2.8	-0.1
supi	5.1	13.5	-0.5	2.6	1.3	1.3	68.9	-7.3	69.1	-5.9	1.0	2.6	-0.1
pron	2.9	13.5	0.6	4.1	4.5	1.7	74.5	20.1	77.7	11.5	1.0	4.7	0.2

Table 4.6. Mean data for the rotation at the right Ankle/Sub talar complex, from 23 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

RIGHT	mean Range of motion (rom)			Standard deviation (rom)			mean angle of axis to		Axis calculated from mean rom. angle of axis to		Ratio of mean rom		
MTJ	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Trn	Sag	Frt	Trn	Sag
comp	11.9	10.0	5.8	3.8	2.3	3.6	36.3	27.4	37.1	25.9	1.0	0.8	0.5
dyn	4.8	4.8	2.9	2.4	1.8	2.1	39.7	30.3	40.7	30.9	1.0	1.0	0.6
supi	6.2	5.5	3.1	1.8	1.4	2.5	37.7	25.5	38.8	26.8	1.0	0.9	0.5
pron	5.7	4.4	2.6	3.0	1.7	3.0	33.7	28.8	35.2	24.9	1.0	0.8	0.5

Table 4.7. Mean data for the rotation at the right mid tarsal joint, from 23 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

RIGHT	mean Range of motion (rom)			Standard deviation (rom)			mean angle of axis to		Axis calculated from mean rom. angle of axis to		Ratio of mean rom		
RFC	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Trn	Sag	Frt	Trn	Sag
comp	19.9	37.0	5.8	8.2	5.6	3.3	61.0	18.3	60.7	16.3	1.0	1.9	0.3
dyn	9.2	17.0	2.6	5.1	4.3	1.9	61.5	16.5	60.6	15.6	1.0	1.8	0.3
supi	11.3	19.0	2.6	3.0	1.8	2.3	58.6	13.6	58.7	12.9	1.0	1.7	0.2
pron	8.6	17.9	3.2	6.4	5.6	2.7	62.8	24.8	62.9	20.6	1.0	2.1	0.4

Table 4.8. Mean data for the rotation at the right rearfoot complex, from 23 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

LEFT LEG	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
comp	0.7	-39.6	-0.7	1.7	5.1	1.6	-86.7	12.2	-88.5	-43.8	1.0	-55.0	-1.0
dyn	0.3	-16.8	-0.2	1.0	4.5	0.7	-86.5	16.6	-88.7	-28.8	1.0	-51.4	-0.5
supi	0.0	-20.5	-0.2	0.9	1.2	1.1	-86.5	4.4	-89.3	-84.8	1.0	-961.5	-11.1
pron	0.7	-19.1	-0.5	1.1	4.9	0.9	-85.6	-1.0	-87.5	-33.1	1.0	-27.3	-0.7

Table 4.9. Mean data for the absolute rotation of the left leg, from 25 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

LEFT HEEL	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
comp	7.9	-12.2	-2.1	3.6	2.4	1.8	-56.3	-17.8	-56.2	-15.0	1.0	-1.5	-0.3
dyn	3.5	-5.1	-1.0	2.6	1.9	1.1	-55.8	-21.6	-54.7	-15.3	1.0	-1.5	-0.3
supi	4.8	-6.3	-1.8	2.3	1.4	1.1	-51.3	-23.8	-51.1	-20.3	1.0	-1.3	-0.4
pron	3.1	-5.9	-0.3	2.7	1.7	1.0	-61.2	-0.6	-62.0	-6.3	1.0	-1.9	-0.1

Table 4.10. Mean data for the absolute rotation of the left forefoot, from 25 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

LEFT FORFT	mean *Range of motion (rom)* Frt	Trn	Sag	*Standard deviation (rom)* Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
comp	19.7	-1.0	5.3	6.0	2.9	2.8	-3.2	15.8	-2.9	15.1	1.0	-0.1	0.3
dyn	8.3	-0.1	2.7	4.4	1.5	1.8	-2.6	18.5	-0.4	17.9	1.0	0.0	0.3
supi	11.0	-0.4	2.3	2.9	2.0	2.0	-1.5	11.6	-1.9	11.9	1.0	0.0	0.2
pron	8.7	-0.7	3.0	4.6	1.5	1.8	-6.2	21.1	-4.2	19.1	1.0	-0.1	0.3

Table 4.11. Mean data for the absolute rotation of the left heel, from 25 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

LEFT Ank/Stj	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
comp	7.2	27.4	-1.4	4.7	4.0	2.2	74.3	-7.6	75.1	-11.2	1.0	3.8	-0.2
dyn	3.2	11.7	-0.8	3.1	3.1	1.2	73.3	-10.0	74.5	-13.7	1.0	3.7	-0.2
supi	4.8	14.2	-1.5	2.8	1.3	1.5	69.9	-15.7	70.5	-17.9	1.0	3.0	-0.3
pron	2.4	13.3	0.1	3.5	3.8	1.1	75.3	0.9	79.7	2.7	1.0	5.5	0.0

Table 4.12. Mean data for the rotation at the left Ankle/sub talar joint, from 25 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

LEFT MTJ	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
comp	11.8	11.2	7.5	3.7	2.7	2.9	38.5	32.9	38.7	32.2	1.0	0.9	0.6
dyn	4.8	5.1	3.6	2.2	2.4	2.1	38.6	37.0	40.2	37.2	1.0	1.1	0.8
supi	6.2	6.0	4.1	2.2	2.0	2.2	38.5	32.5	39.0	33.4	1.0	1.0	0.7
pron	5.6	5.2	3.4	2.3	1.7	1.9	37.5	32.5	38.3	30.9	1.0	0.9	0.6

Table 4.13. Mean data for the rotation at the left mid tarsal joint, from 25 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

LEFT RFC	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
comp	19.0	38.6	6.0	7.0	5.1	2.8	62.9	18.9	62.7	17.6	1.0	2.0	0.3
dyn	7.9	16.8	2.9	4.7	5.1	1.7	63.7	22.3	63.3	19.8	1.0	2.1	0.4
supi	11.0	20.2	2.5	3.4	2.0	2.2	60.7	13.2	60.8	13.1	1.0	1.8	0.2
pron	8.0	18.4	3.5	5.2	4.6	1.7	64.9	30.1	64.6	23.4	1.0	2.3	0.4

Table 4.14. Mean data for the rotation at the left rearfoot complex, from 25 limbs. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane

The Leg

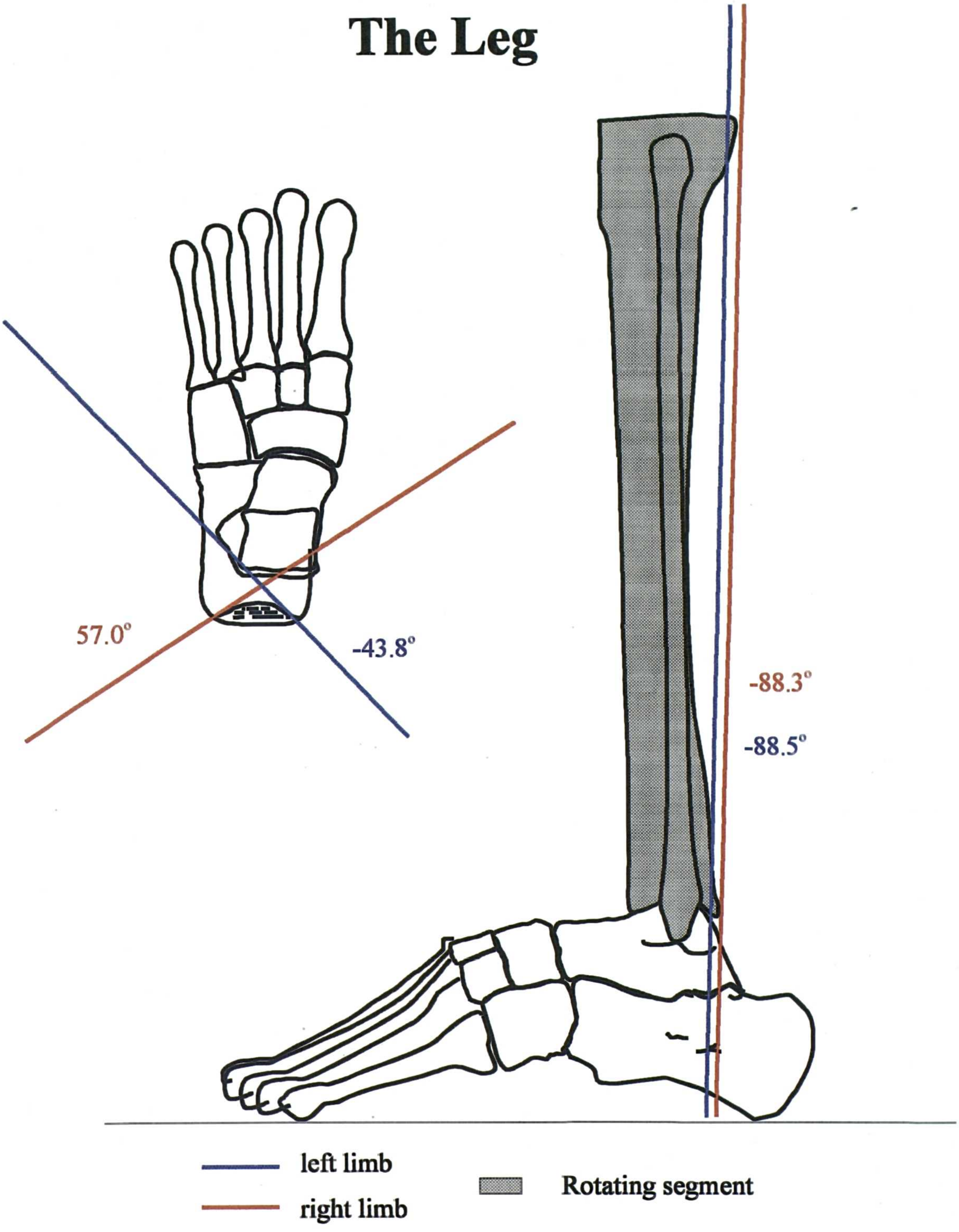


Figure 4.4

Mean axis of rotation of the left and right leg, projected on transverse and sagittal plane images of a left foot (calculated from mean range of motion in 3 cardinal body planes). Angles relate to the angulation of the axis to the sagittal and transverse planes. Anatomical position was not calculated, and is assumed from work by Van Langelaan (1983) and Benick (1983).

The Heel

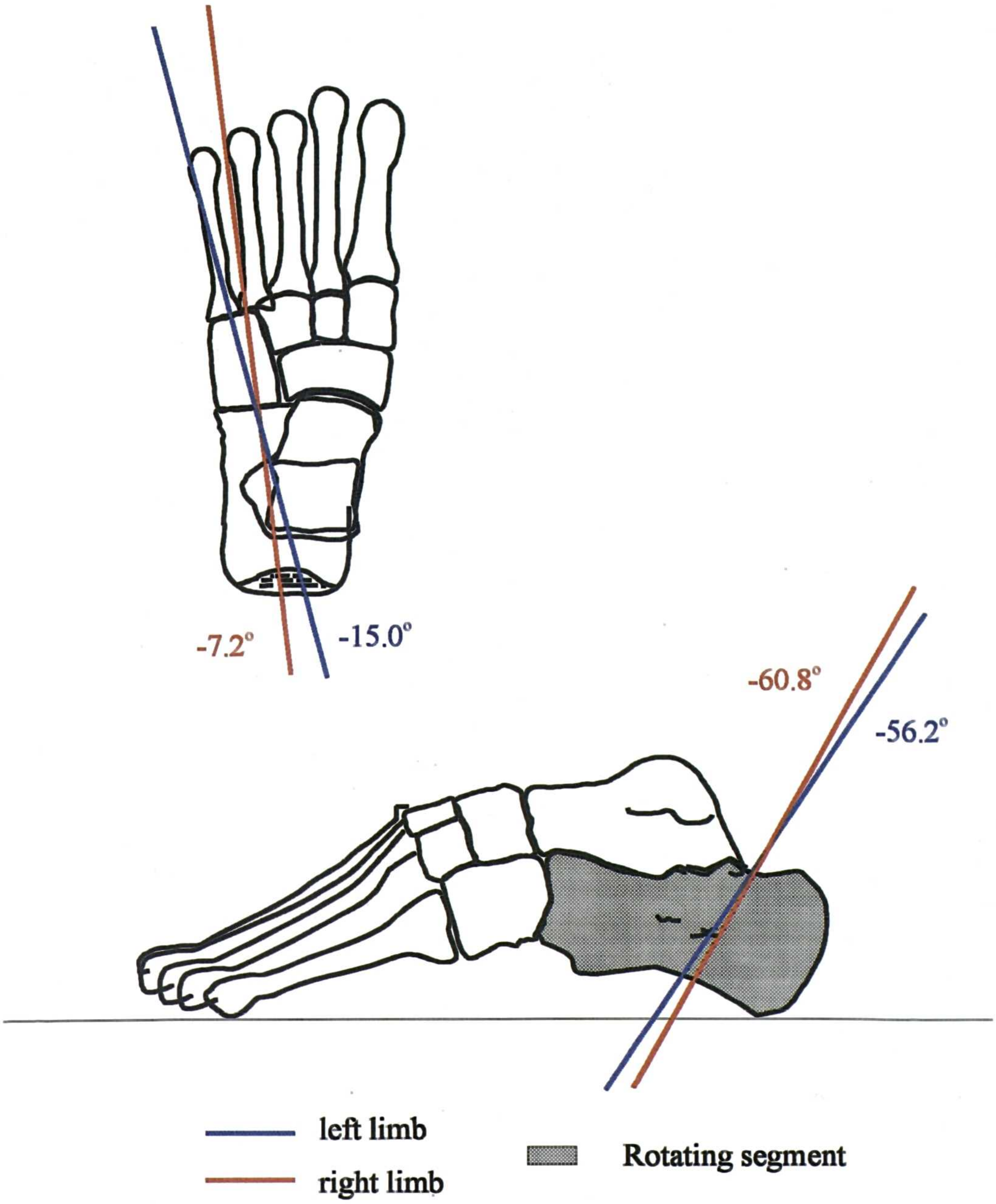


Figure 4.5

Mean axis of rotation of the left and right heel, projected on transverse and sagittal plane images of a left foot (calculated from mean range of motion in 3 cardinal body planes). Angles relate to the angulation of the axis to the sagittal and transverse planes. Anatomical position was not calculated, and is assumed from work by Van Langelaan (1983) and Benick (1983).

The Forefoot

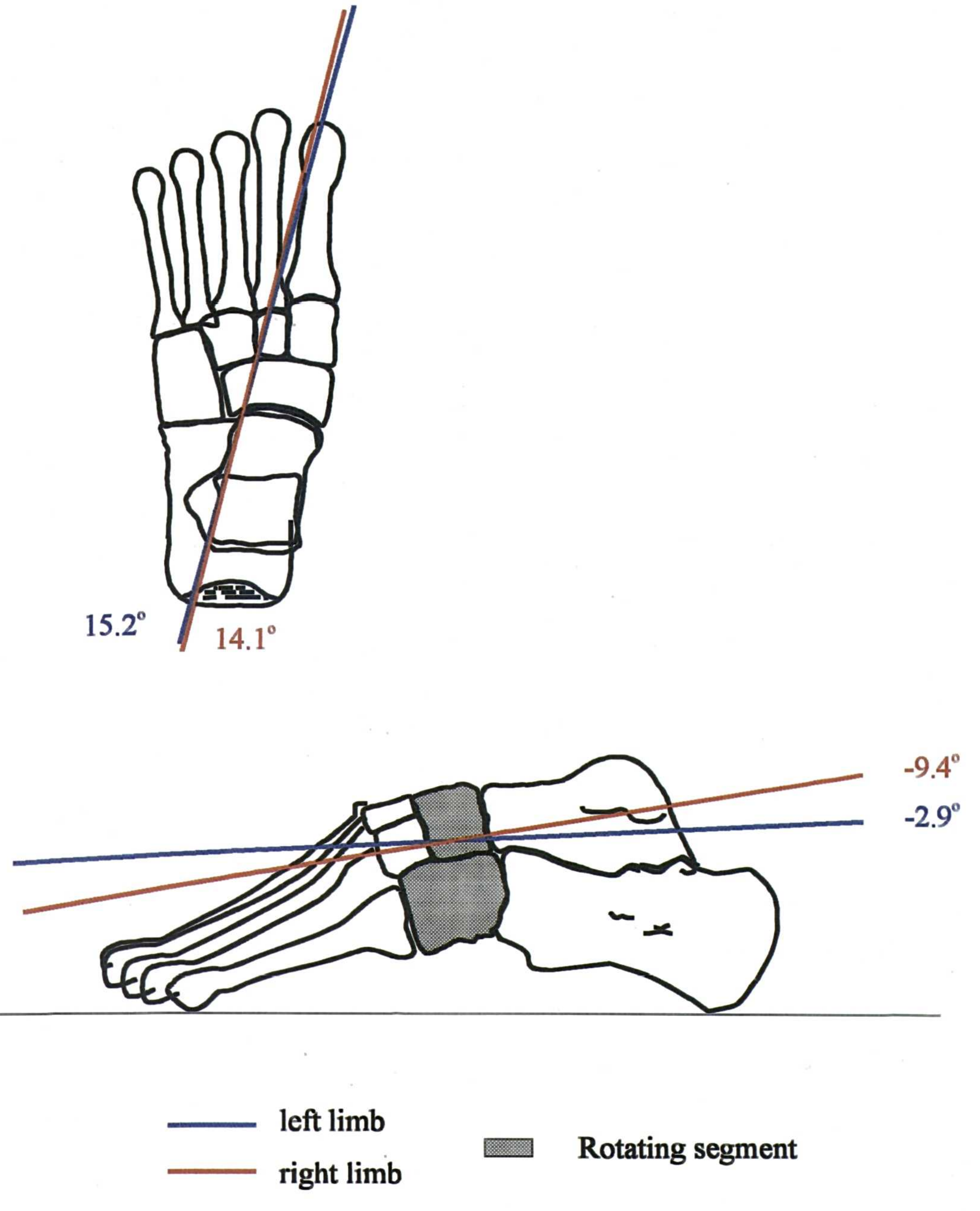


Figure 4.6

Mean axis of rotation of the left and right forefoot, projected on transverse and sagittal plane images of a left foot (calculated from mean range of motion in 3 cardinal body planes). Angles relate to the angulation of the axis to the sagittal and transverse planes. Anatomical position was not calculated, and is assumed from work by Van Langelaan (1983), Benick (1983).

The Ankle/Sub Talar Complex

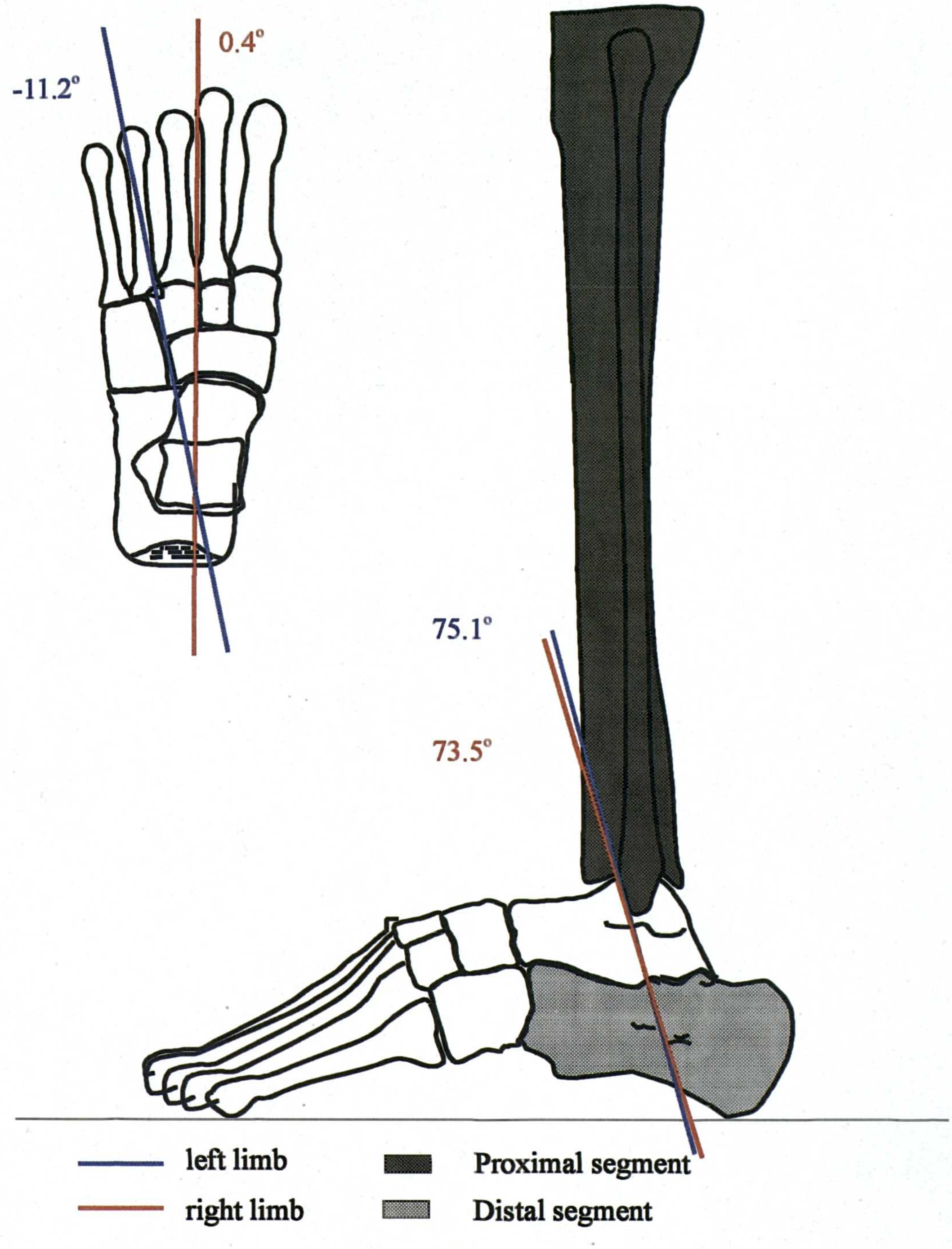


Figure 4.7

Mean axis of rotation of the left and right ankle/sub talar complex, projected on transverse and sagittal plane images of a left foot (calculated from mean range of motion in 3 cardinal body planes). Angles relate to the angulation of the axis to the sagittal and transverse planes. Anatomical position was not calculated, and is assumed from work by Van Langelaan (1983) and Benick (1983). See section 5.3.5.5 for explanation of differeces between left and right.

The Mid Tarsal Joint

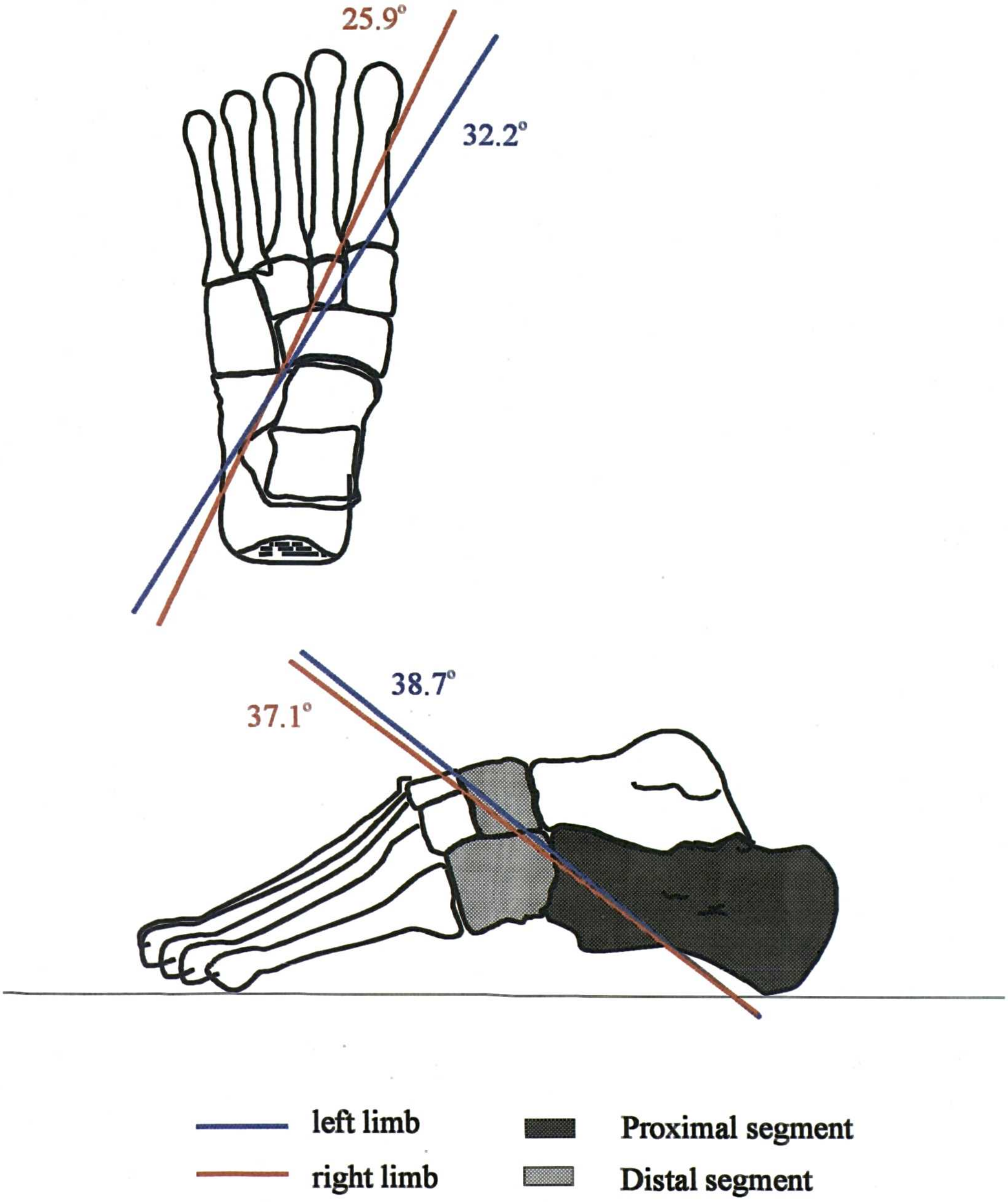


Figure 4.8

Mean axis of rotation of the left and right mid tarsal joint, projected on transverse and sagittal plane images of a left foot (calculated from mean range of motion in 3 cardinal body planes). Angles relate to the angulation of the axis to the sagittal and transverse planes. Anatomical position was not calculated, and is assumed from work by Van Langelaan (1983), Benick (1983) and Lundberg and Svensson (1993).

The Rearfoot Complex

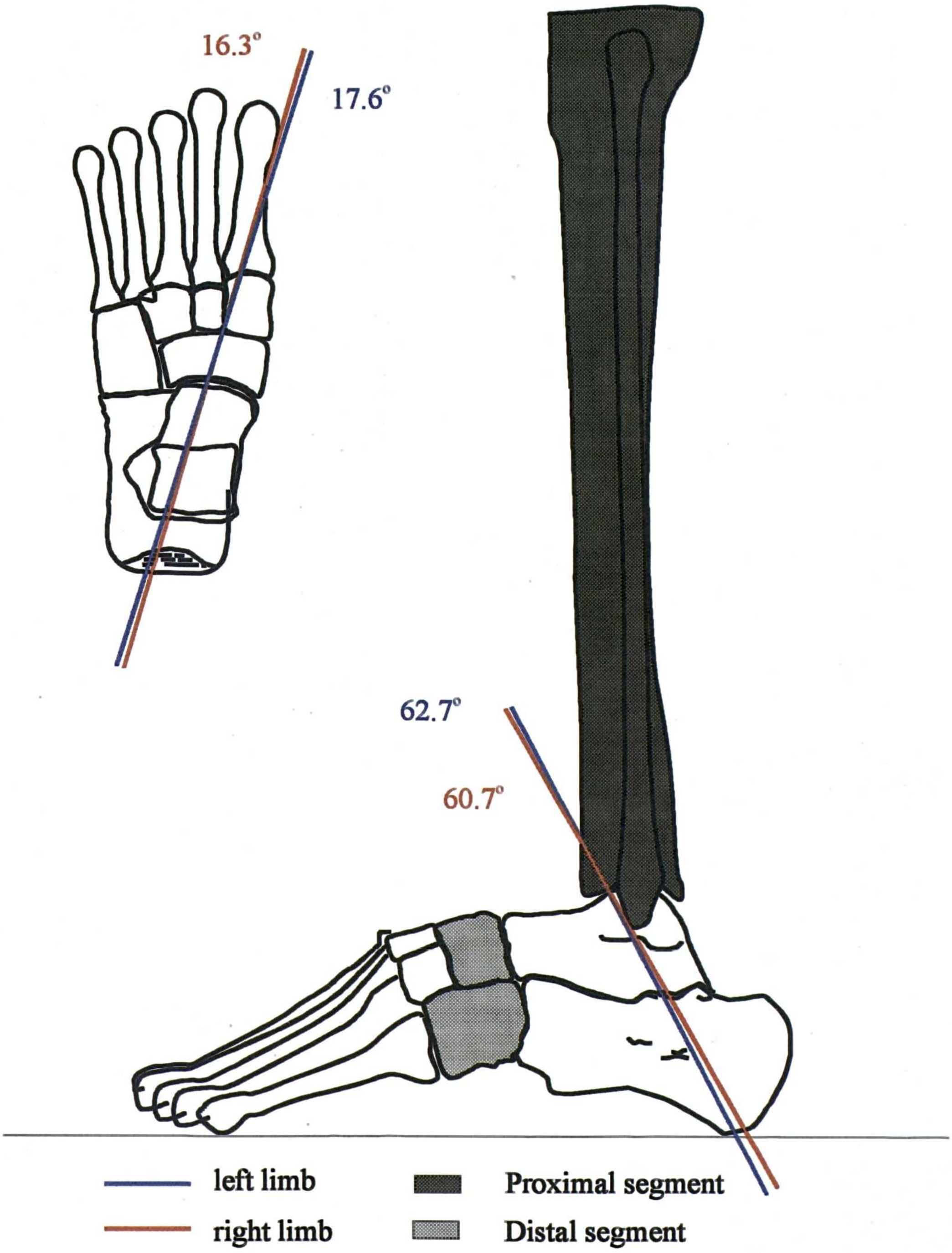


Figure 4.9

Mean axis of rotation of the left and right rearfoot complex, projected on transverse and sagittal plane images of a left foot (calculated from mean range of motion in 3 cardinal body planes). Angles relate to the angulation of the axis to the sagittal and transverse planes. Anatomical position was not calculated, and is assumed from work by Van Langelaan (1983) and Benick (1983).

The range of motion in each cardinal body plane during the composite range of motion for each segment and joint complex and for each individual subject is illustrated graphically in figure 4.10 to 4.15. This represents all the composite range of motion data detailed in appendix 1.

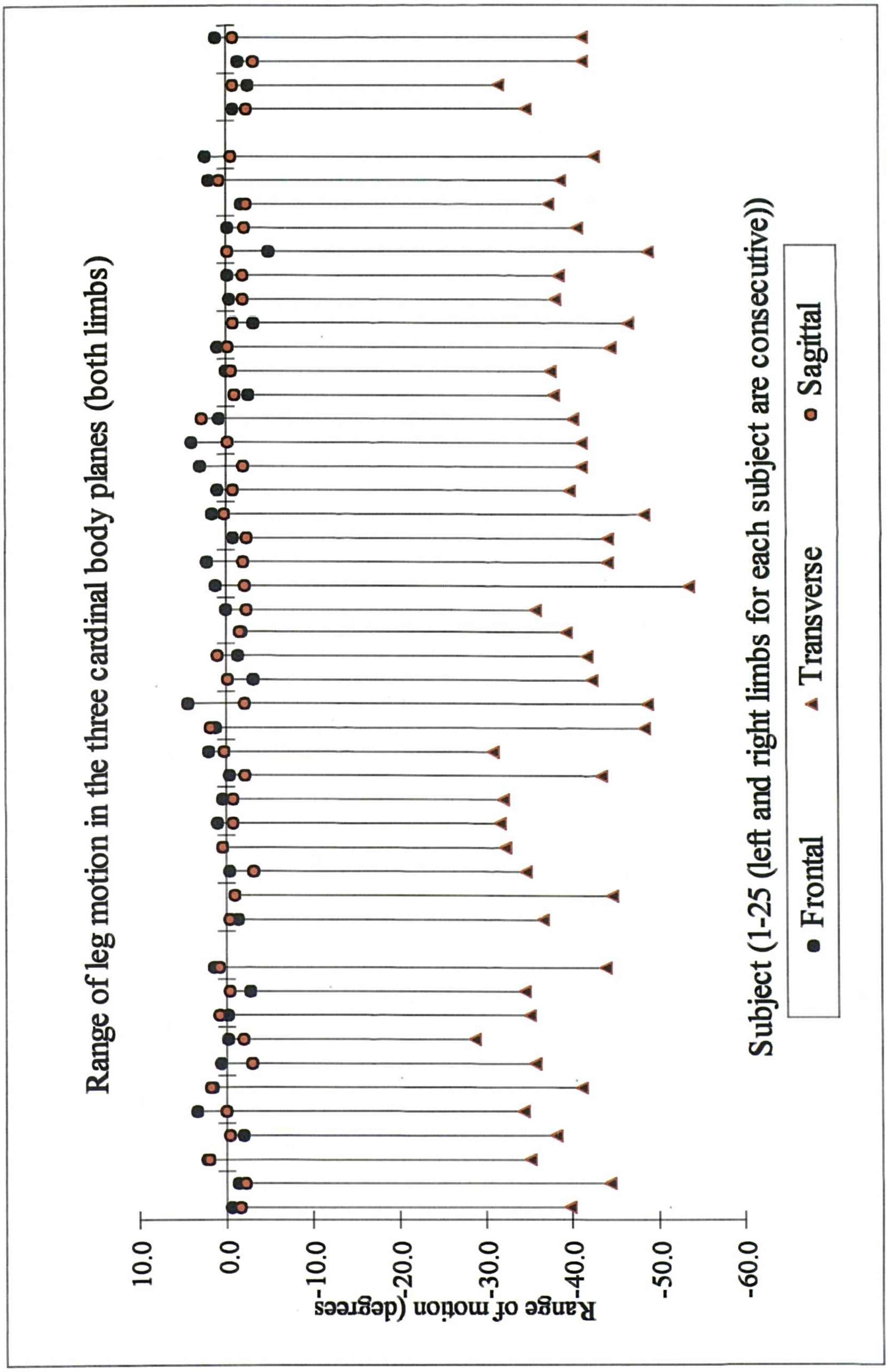


Figure 4.10

Range of motion of the leg in the frontal, transverse and sagittal body planes during the composite range of motion - all subjects.

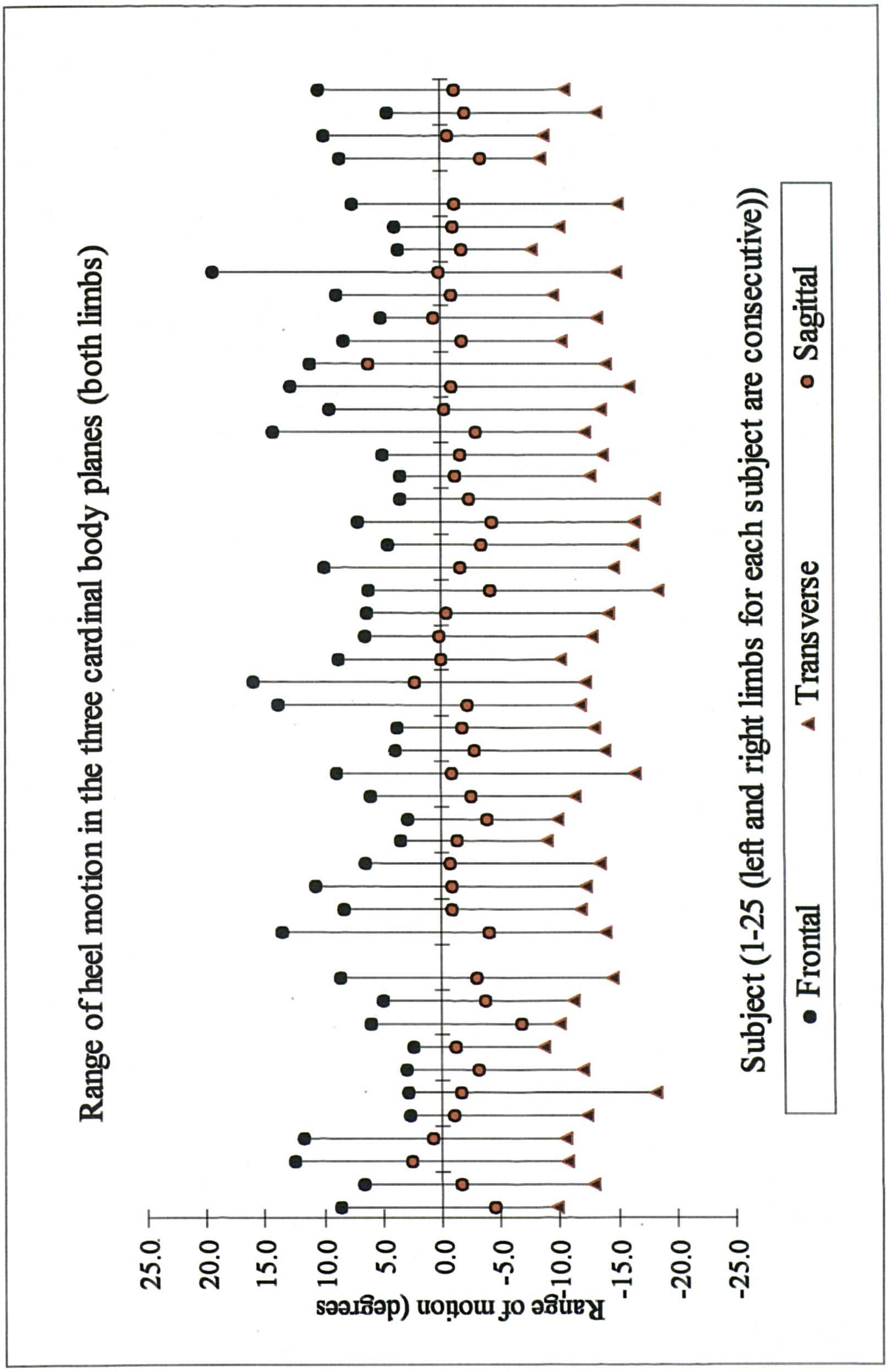


Figure 4.11

Range of motion of the heel in the frontal, transverse and sagittal body planes during the composite range of motion - all subjects.

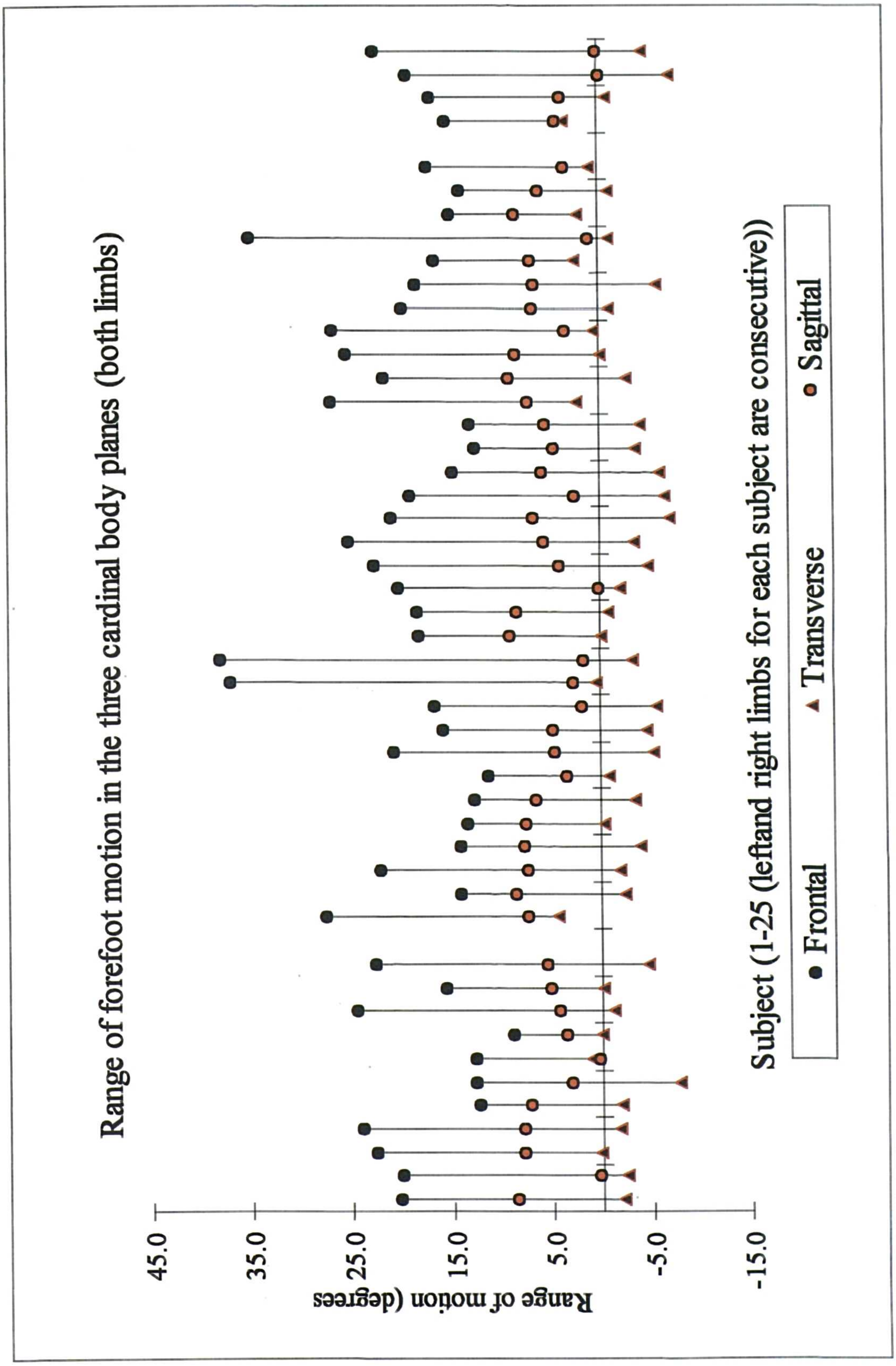


Figure 4.12

Range of motion of the forefoot in the frontal, transverse and sagital body planes during the composite range of motion - all subjects.

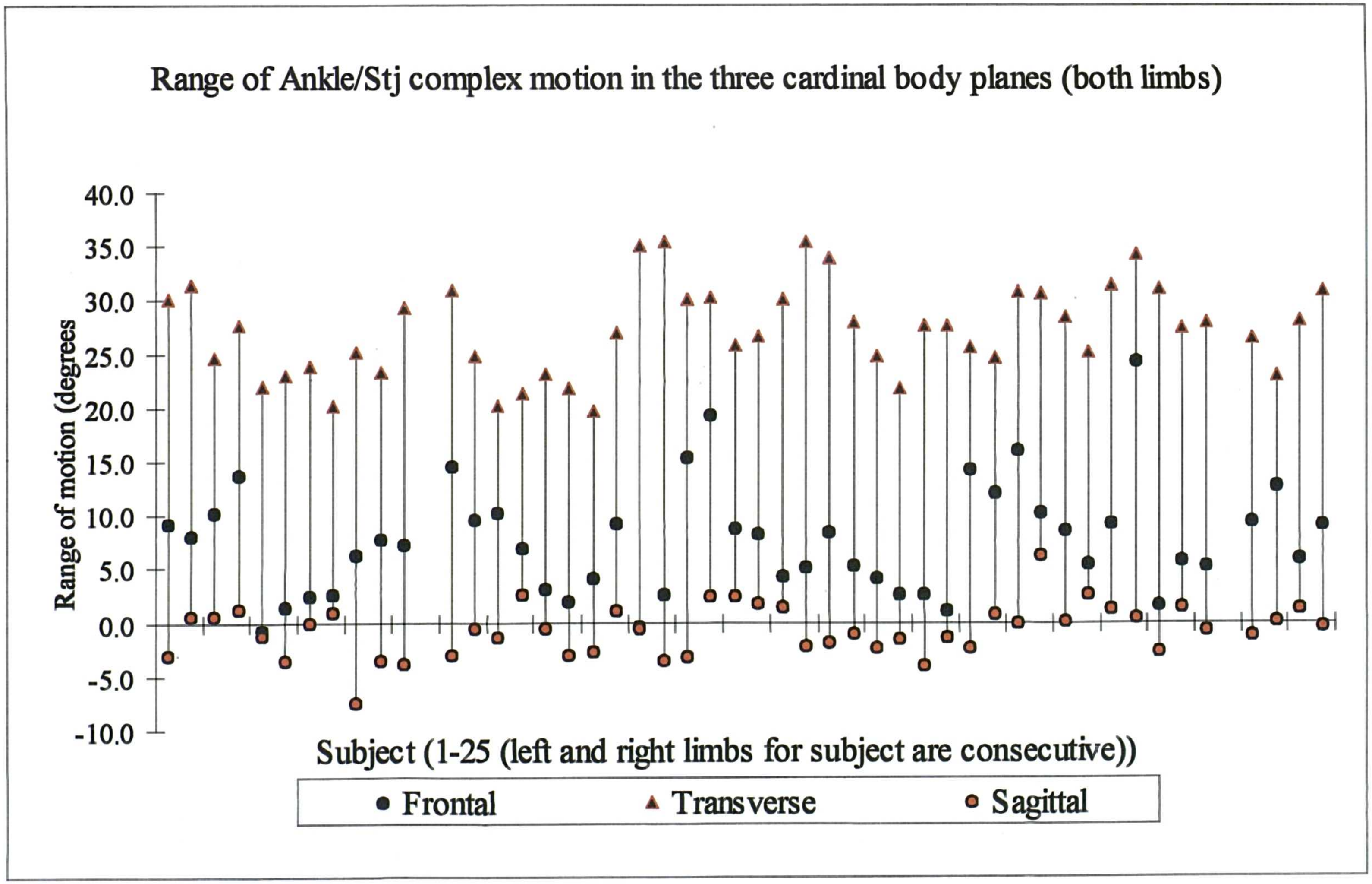


Figure 4.13
Range of motion of the ankle/sub talar complex in the frontal, transverse and sagittal body planes during the composite range of motion - all subjects.

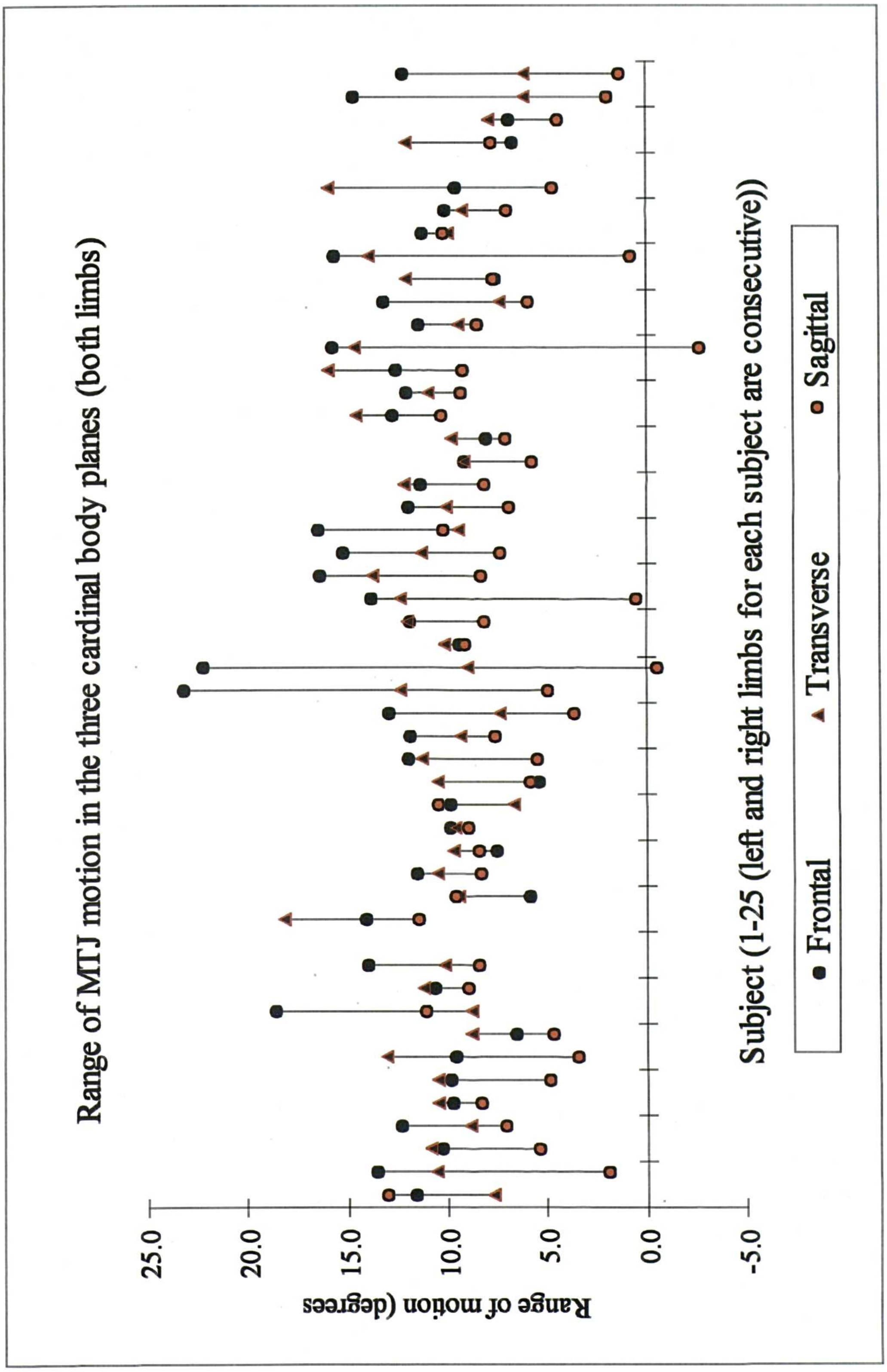


Figure 4.14

Range of motion of the mid tarsal joint in the frontal, transverse and sagittal body planes during the composite range of motion - all subjects.

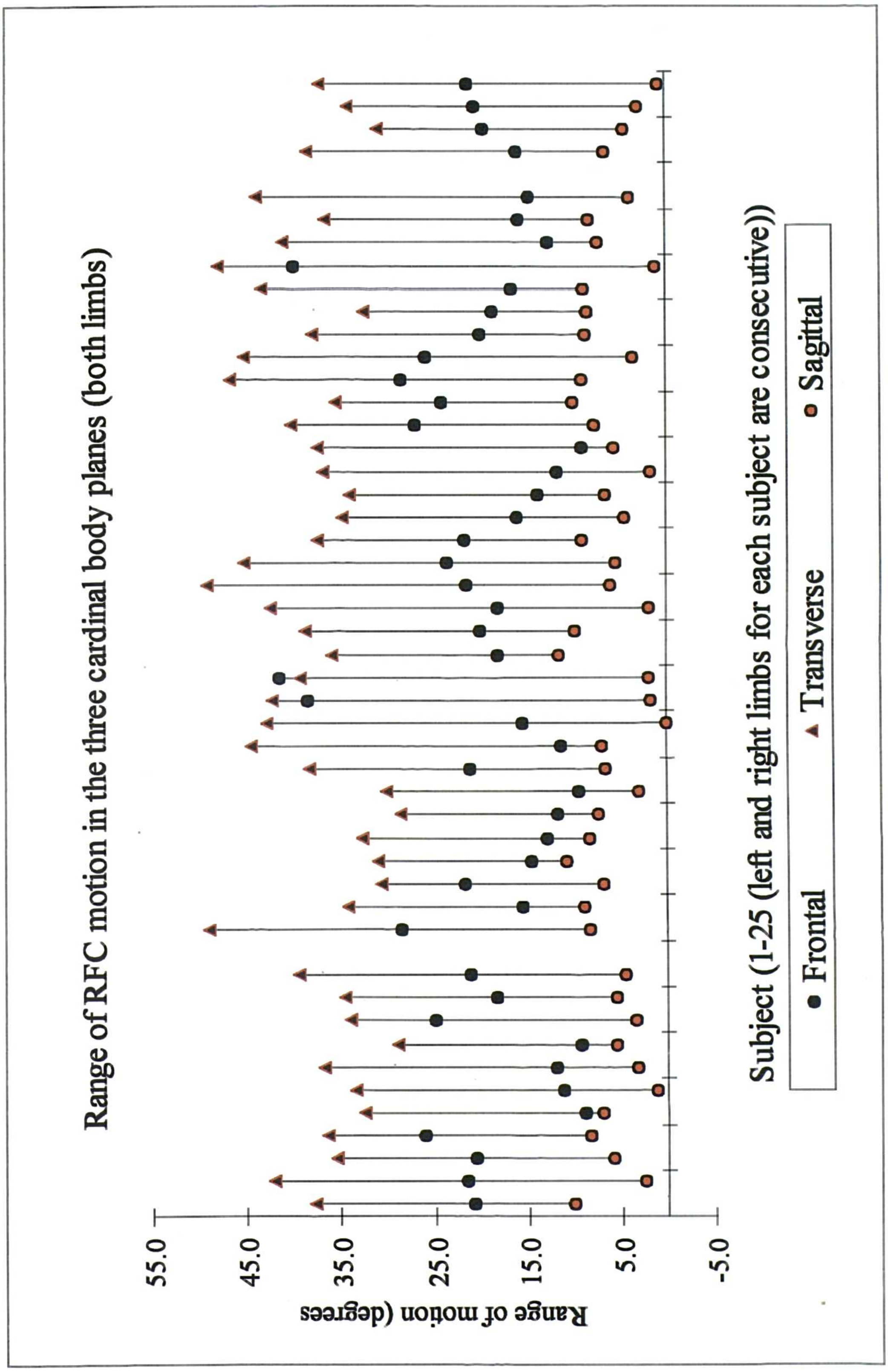


Figure 4.15

Range of motion of the rearfoot complex in the frontal, transverse and sagittal body planes during the composite range of motion - all subjects.

The angulation of the axis of rotation for the composite range of motion for each segment and joint complex and for each individual subject is illustrated graphically in figure 4.16 to 4.21. This illustrates all the axis of rotation data for the composite range of motion detailed in appendix 1.

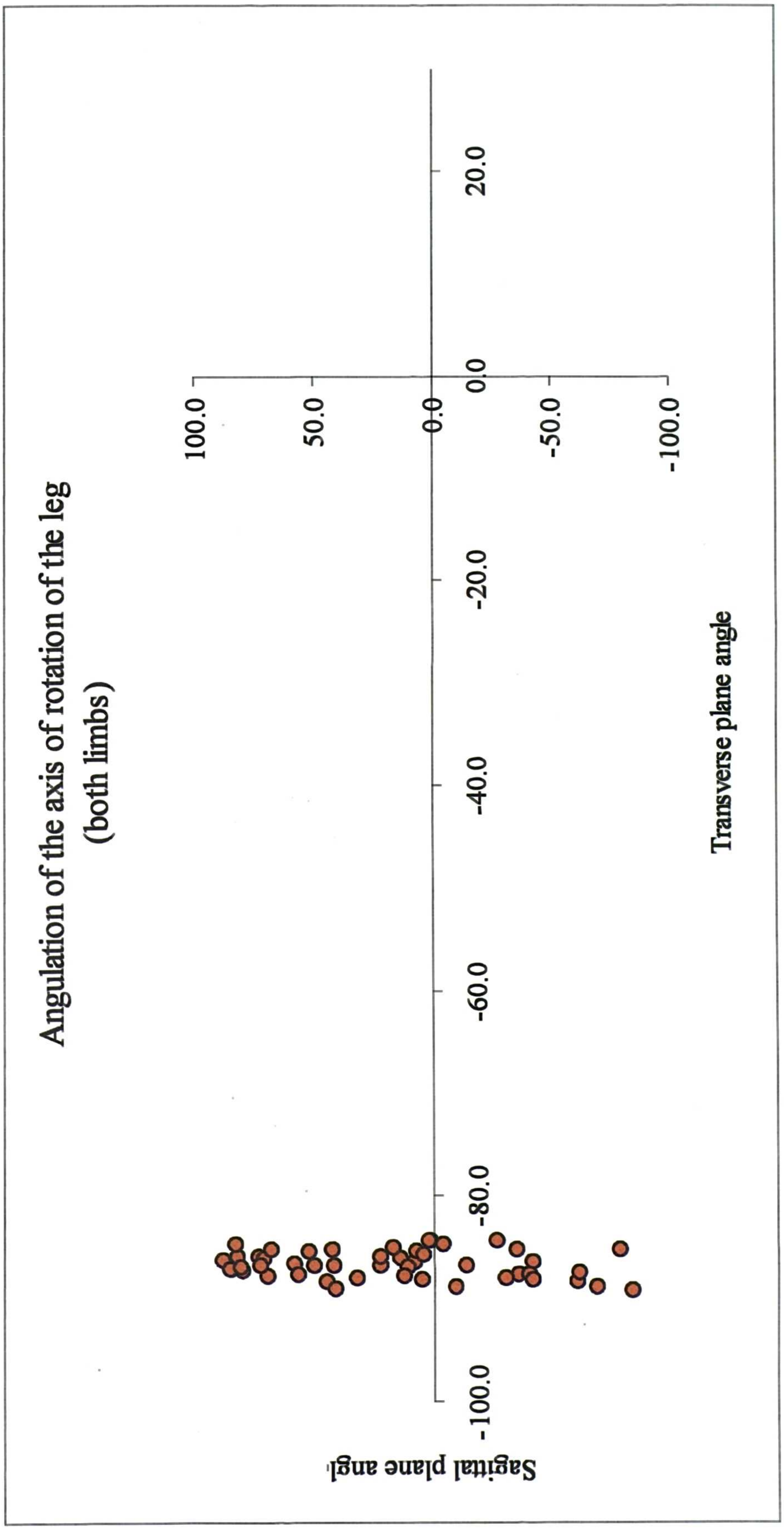


Figure 4.16

Angulation of the axis of rotation of the leg relative to the sagittal and transverse planes, for the composite phase of motion of each subject.

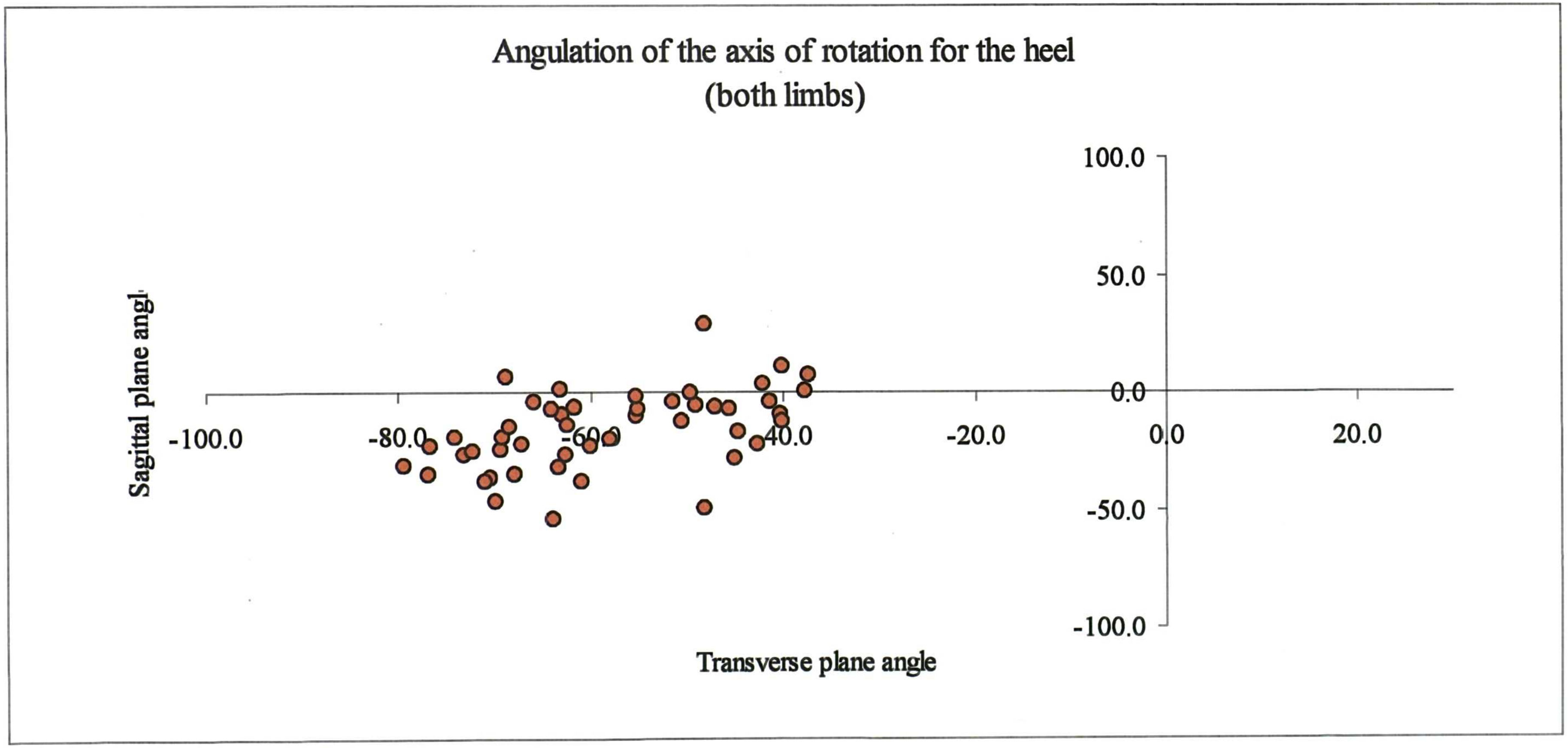


Figure 4.17

Angulation of the axis of rotation of the heel relative to the sagittal and transverse planes, for the composite phase of motion of each subject.

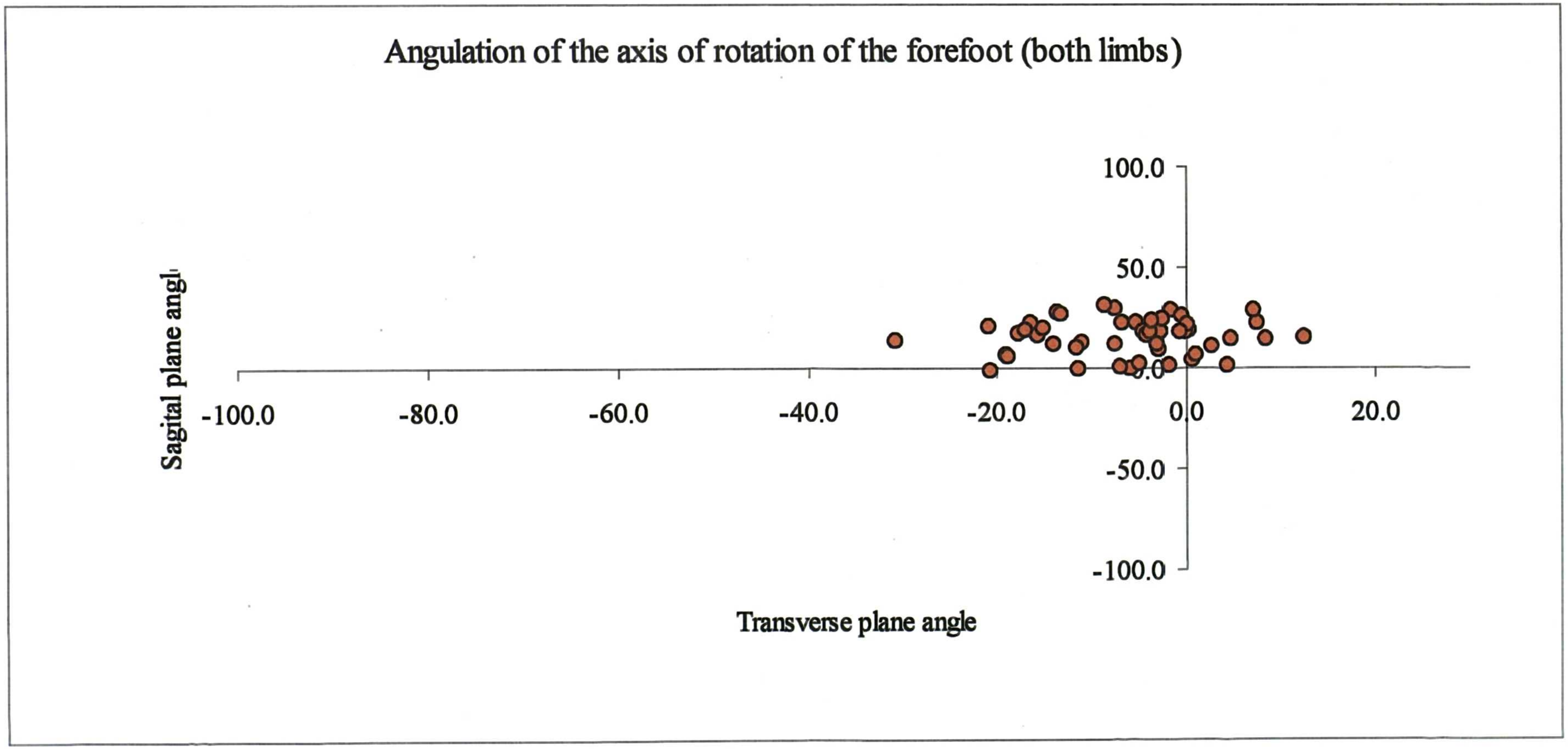


Figure 4.18

Angulation of the axis of rotation of the forefoot relative to the sagittal and transverse planes, for the composite phase of motion of each subject.

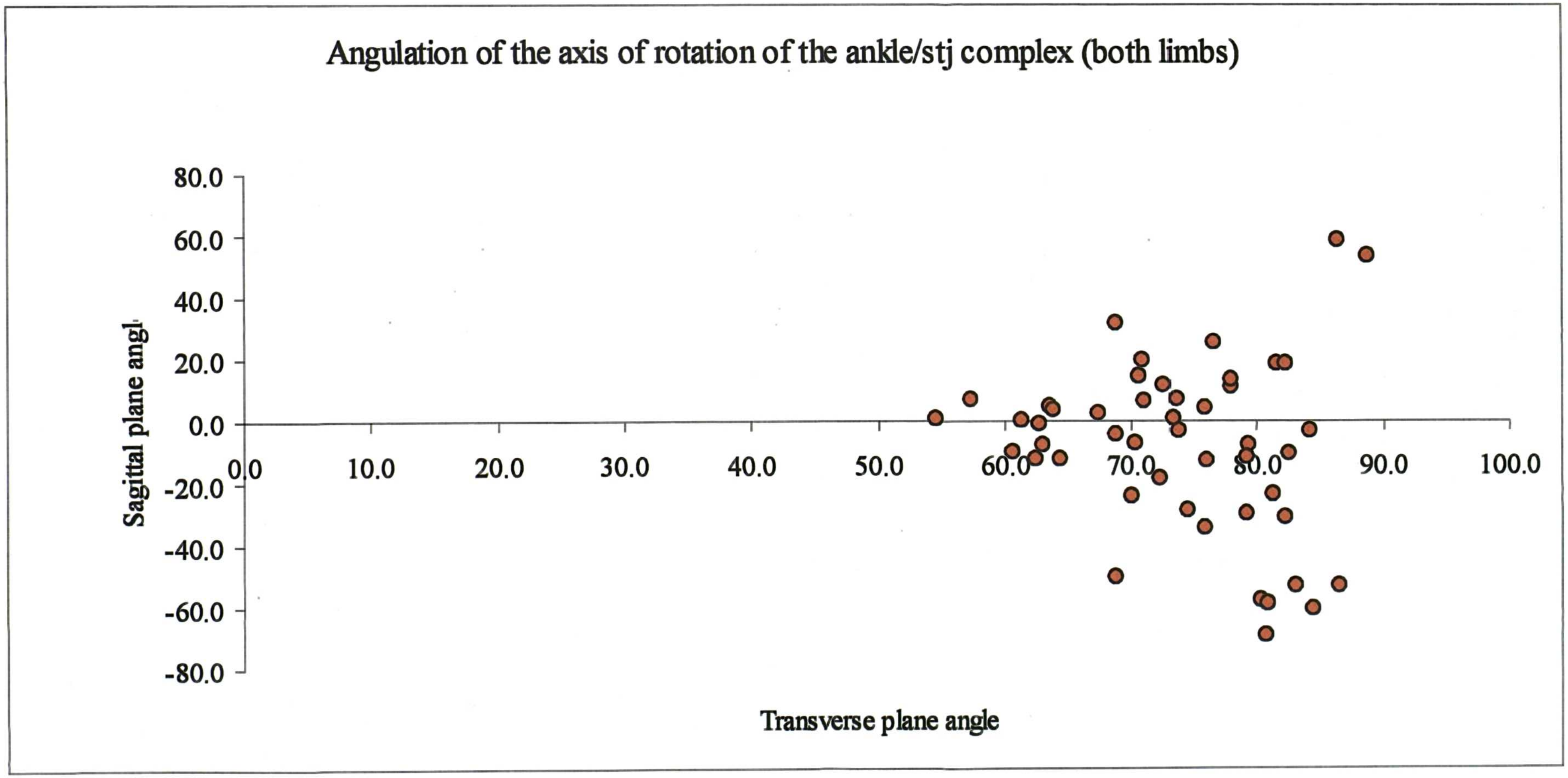


Figure 4.19

Angulation of the axis of rotation of the ankle/sub talar complex relative to the sagittal and transverse planes, for the composite phase of motion of each subject.

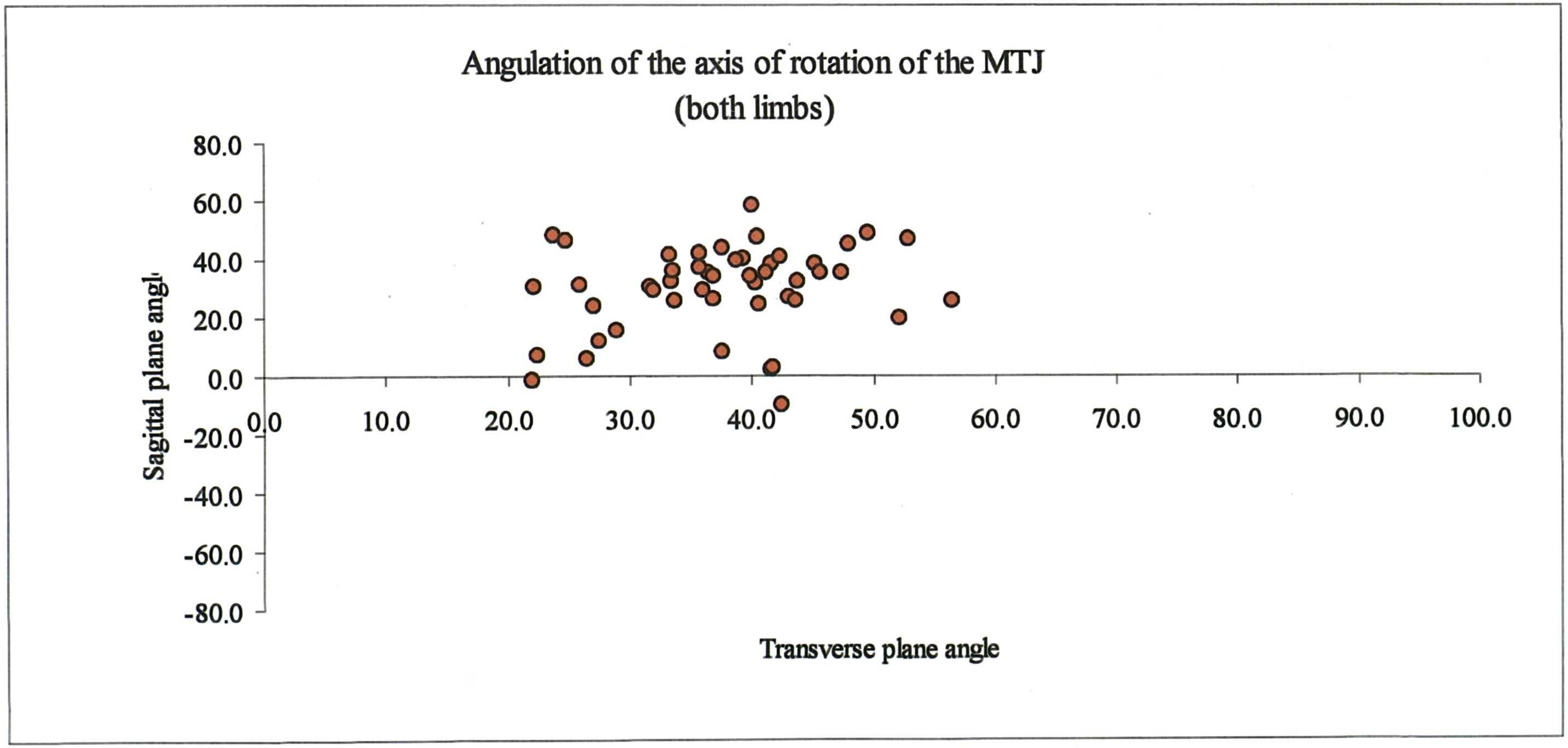


Figure 4.20
Angulation of the axis of rotation of the mid tarsal joint relative to the sagittal and transverse planes, for the composite phase of motion of each subject.

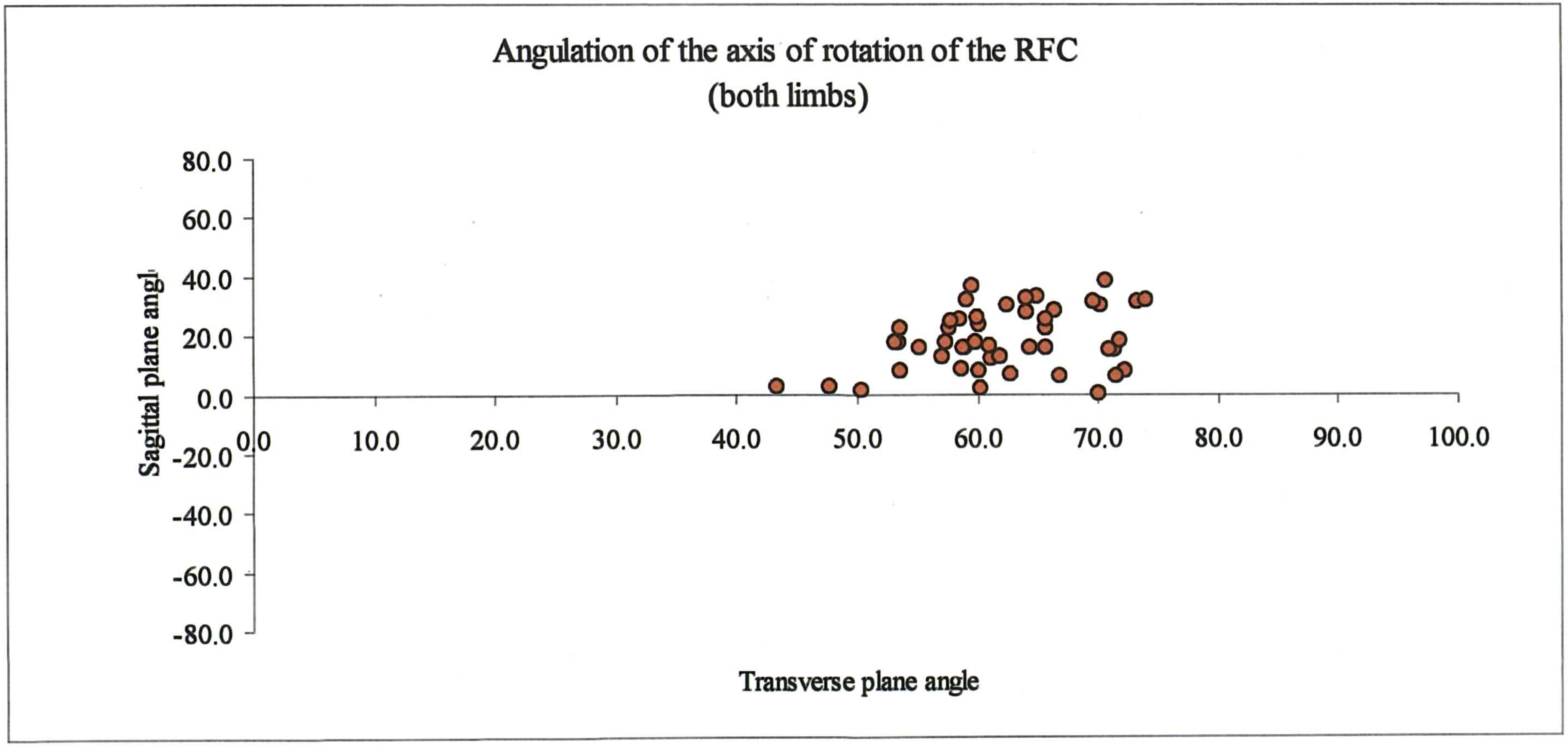


Figure 4.21

Angulation of the axis of rotation of the rearfoot complex relative to the sagittal and transverse planes, for the composite phase of motion of each subject.

The ratios indicating the relative values of frontal, transverse and sagittal plane motions during the composite range of motion for each relative rotation for both left and right limbs of each subject are detailed in figures 4.22 to 4.24. This illustrates the ratio data for the composite phase of motion for the relative rotations detailed in appendix 1.

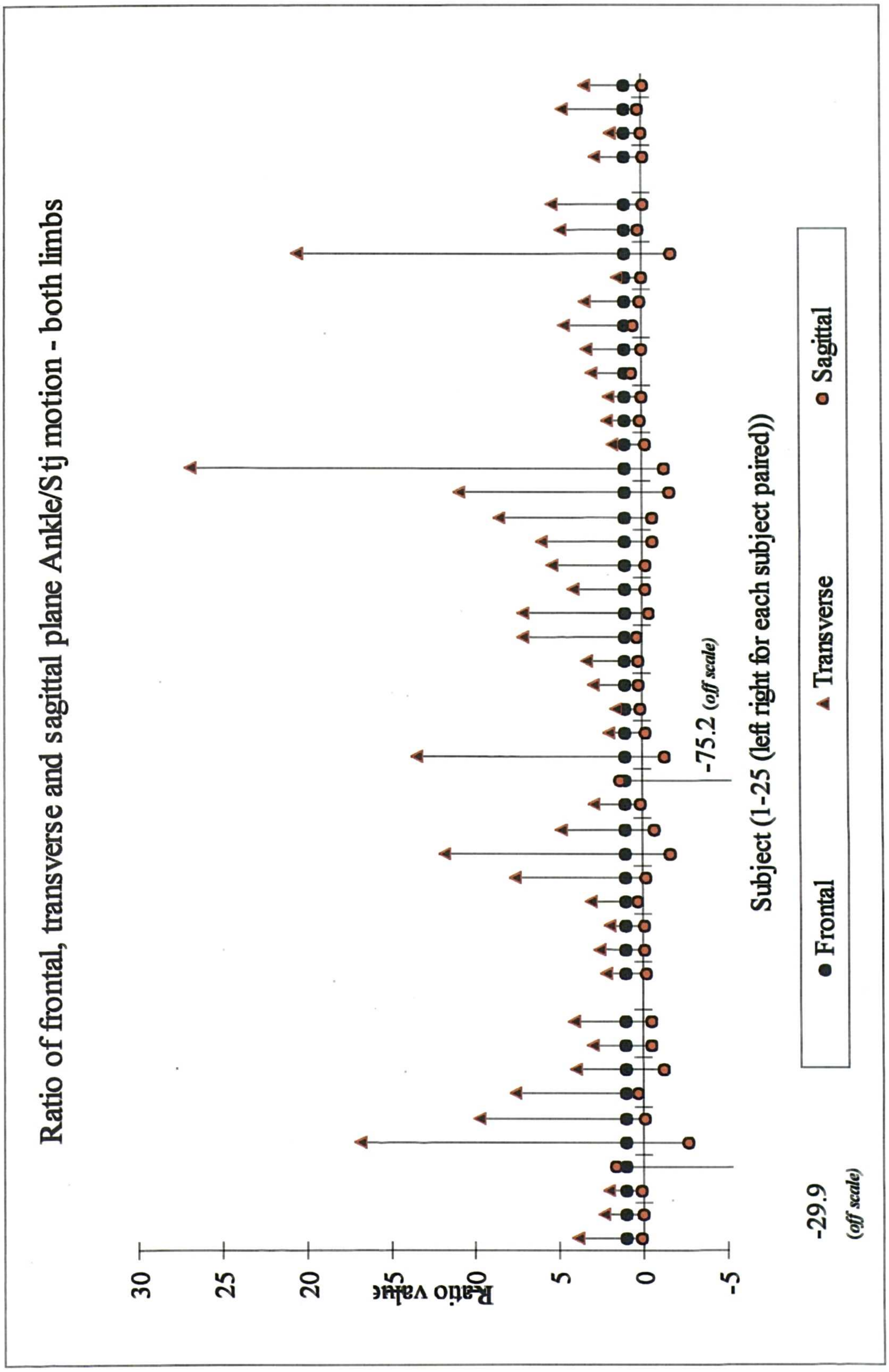


Figure 4.22

Ratio of frontal, transverse and sagittal plane ankle/sub talar complex motion during the composite range of motion.

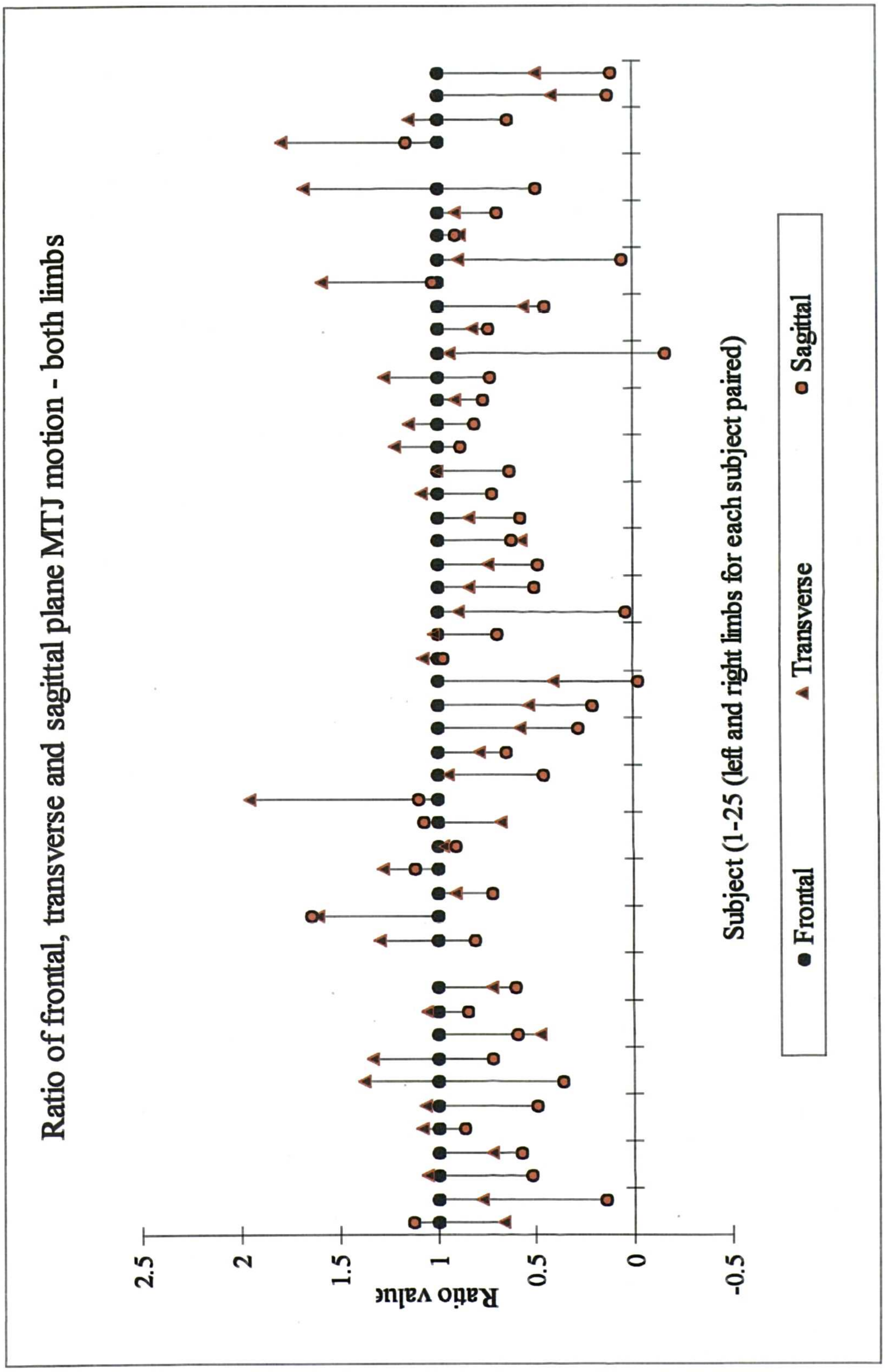


Figure 4.23

Ratio of frontal, transverse and sagittal plane mid tarsal joint motion during the composite range of motion.

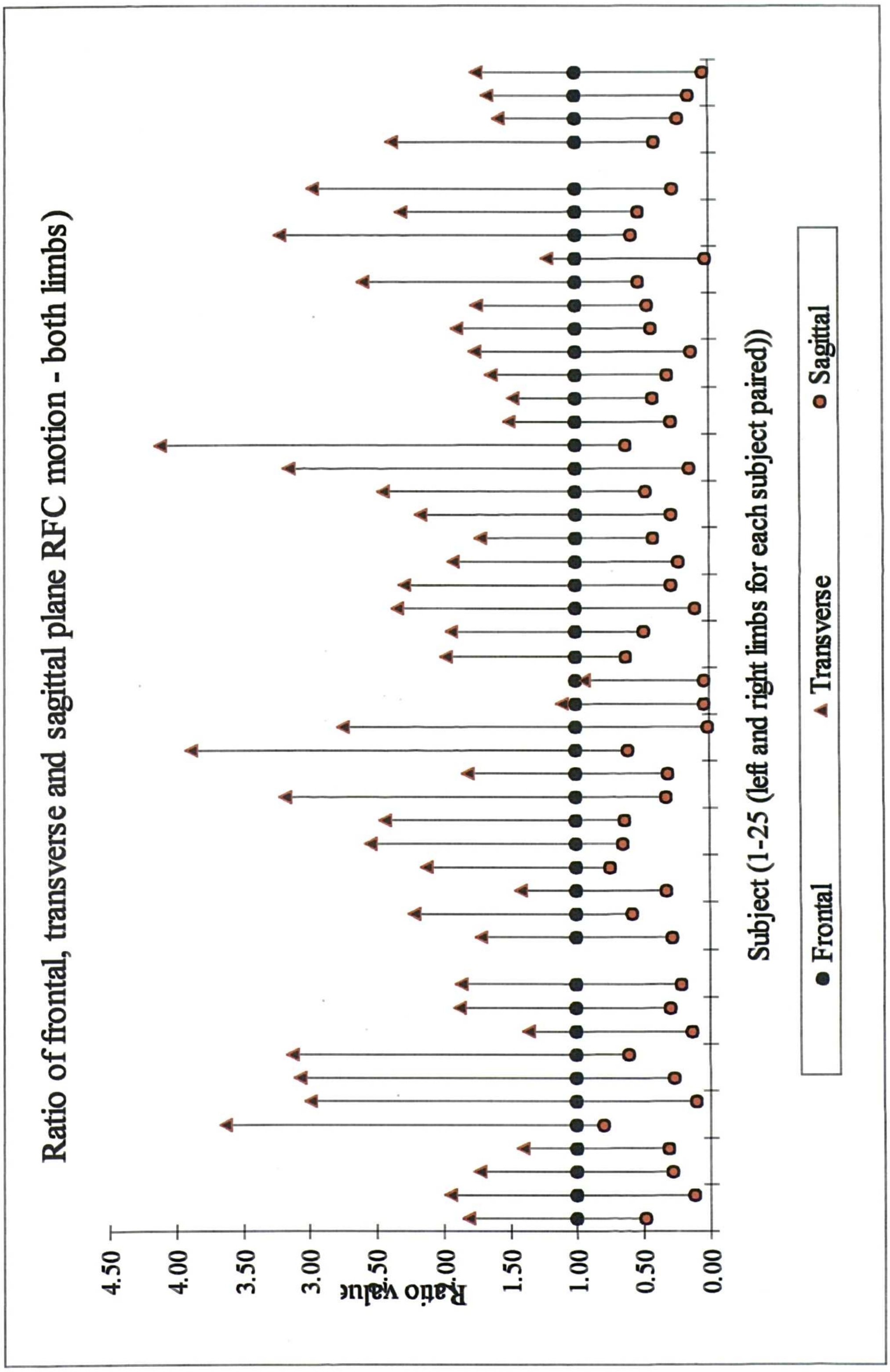


Figure 4.24
Ratio of frontal, transverse and sagittal plane rearfoot complex motion during the composite range of motion.

4.3.1 REPEATABILITY OF STATIC REARFOOT COMPLEX ASSESSMENT.

Tables 4.15 and 4.16 detail the mean differences (of all four subjects) between the ranges of motion in each cardinal body plane and axis orientations measured on two separate days. This is a summary of the data presented in appendix 2. The range of motion in each cardinal body plane and the axis of rotation subsequently calculated for each absolute and each relative rotation, for each phase of motion and for the four subjects used in the repeatability assessment are detailed in tables A2.1 to A2.12 in appendix 2. The differences between the ranges of motion and axis orientations measured on two separate days for each of the absolute and relative rotations, for each of the four phases of motion and for each of the four subjects are detailed in table A2.13 to A2.24 in appendix 2.

The repeatability of the results was assessed in terms of the absolute differences between days in the motion data and the resultant differences between days in the calculated axis orientation data. The results were not subjected to statistical analysis. Whilst the motion data could have been subjected to statistical testing this would not have assessed whether the functional characteristics of the segments and joints was different between days, because the motion data could be different between days but the functional characteristics the same. For example, if the input rotation (transverse plane motion of the leg) were different between days, this would produce different ranges of motion within the segments of the rearfoot kinematic chain between days (tables A2.13 and A2.19). However, the functional characteristics, represented by the proportion of motion displayed in each plane, the order of predominance (see glossary) and the orientation of the axis of rotation, should be repeatable even though the absolute ranges of motion were different. Also, the range of motion was sometimes very small, particularly in the sagittal plane, and even differences between days of less than 1° can be statistically significant in such instances. This does necessarily imply, however, that the difference is significant in experimental or clinical terms.

In the vast majority of instances the difference between days in the ranges of motion was below 1.5°, which should be considered acceptable. The repeatability of the axis of rotation data was also acceptable. The relationship between the difference between days in the range of motion in each plane and the resultant difference between days in the orientation of the axis of rotation is complex. There were some instances when the difference between days in the ranges of motion was very small, but the difference between days in the axis orientation was relatively large (left mid tarsal joint of subject 22, dynamic phase, table A2.23). Conversely, there were instances when the difference between days in the ranges of motion was relatively large but the difference between days in the axis orientation was small (right rearfoot complex of subject 25, composite phase, table A2.18). This is caused by two additional factors. Firstly, the magnitude of the difference between days is important as a proportion of the range of motion being measured. Secondly, the range of motion between days can differ without the functional characteristics of the motion being different.

RIGHT	Range of motion (°)						angle of axis (°)			
	Frt	sd	**Trn**	sd	**Sag**	sd	**Trn**	sd	**Sag**	sd
LEG	0.4	0.4	1.0	1.1	0.7	0.5	0.9	0.7	39.0	38.8
HEEL	0.9	0.7	0.6	0.4	0.6	0.8	3.8	2.6	8.7	10.5
FORFT	1.0	0.7	0.6	0.7	1.0	0.8	2.9	2.8	5.8	3.9
Ank/Stj	1.2	1.0	1.0	1.1	0.6	0.4	4.1	2.7	9.0	6.2
MTJ	1.1	1.0	0.6	0.4	1.2	1.3	5.2	4.2	11.5	10.9
RFC	1.1	0.7	0.9	0.9	1.5	1.1	2.6	1.9	7.4	5.0
MEAN	1.0		0.8		0.9		3.2		13.6	

Table 4.15. The mean difference between days in the range of motion measured in the cardinal body planes and the axis of rotation subsequently calculated, for each segment/joint complex, right limb only, averaged from 4 subjects.

LEFT	Range of motion (°)						angle of axis (°)			
	Frt	sd	**Trn**	sd	**Sag**	sd	**Trn**	sd	**Sag**	sd
LEG	0.4	0.2	1.2	1.2	0.6	0.5	1.4	0.9	18.2	14.7
HEEL	0.7	0.4	0.5	0.6	0.6	0.5	5.3	3.6	14.9	9.8
FORFT	0.8	0.6	0.7	0.7	0.9	0.8	4.1	3.3	4.9	3.9
Ank/Stj	0.8	0.5	1.4	1.1	0.6	0.5	2.7	1.7	26.9	38.0
MTJ	0.6	0.3	0.9	0.7	0.9	1.0	4.2	3.9	6.0	5.6
RFC	0.9	0.8	1.3	1.1	0.7	0.7	2.4	2.0	6.1	8.3
MEAN	0.7		1.0		0.7		3.3		12.8	

Table 4.16. The mean difference between days in the range of motion measured in the cardinal body planes and the axis of rotation subsequently calculated, for each segment/joint complex, left limb only, averaged from 4 subjects.

4.3.2 COMPARISON OF THE FOUR PHASES OF MOTION (COMPOSITE, DYNAMIC, SUPINATION AND PRONATION).

The variation in the ratios of frontal, transverse and sagittal plane motion at the ankle/sub talar complex, the mid tarsal joint and the rearfoot complex between the four phases of rotation is illustrated in figures 4.25 to 4.30. These are mean data (for the whole sample) taken from tables 4.3 to 4.14 in this chapter. The variation in the ratios between phases for each subject is detailed in appendix 1. These illustrate how the functional characteristics of the rearfoot joints change during different parts of the total range of motion.

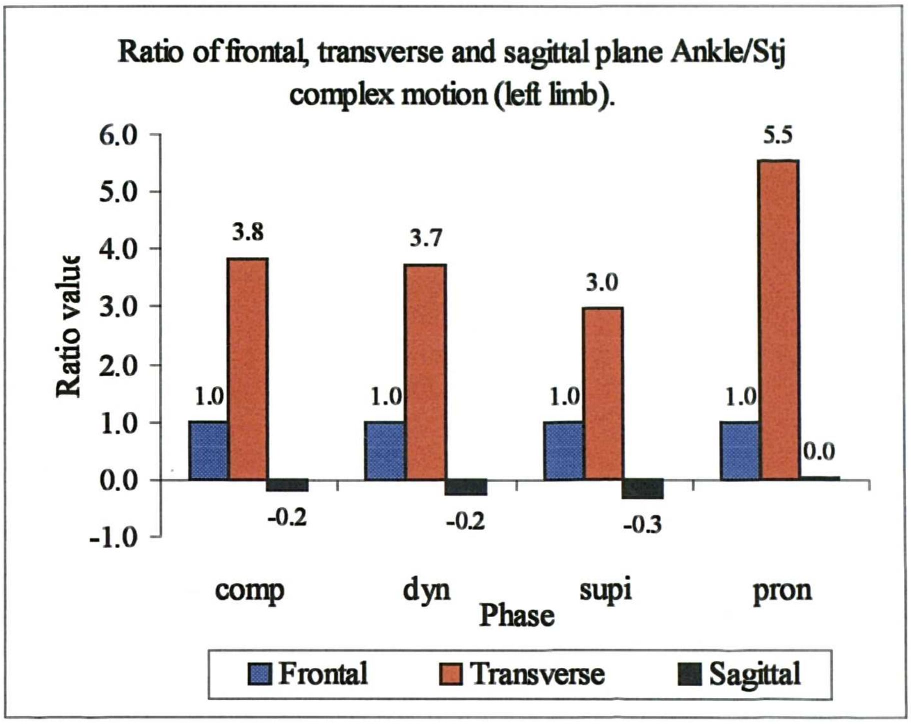


Figure 4.25
Mean ratio of frontal, transverse and sagittal plane ankle/sub talar complex motions during the four phases of rotation - left limb only.

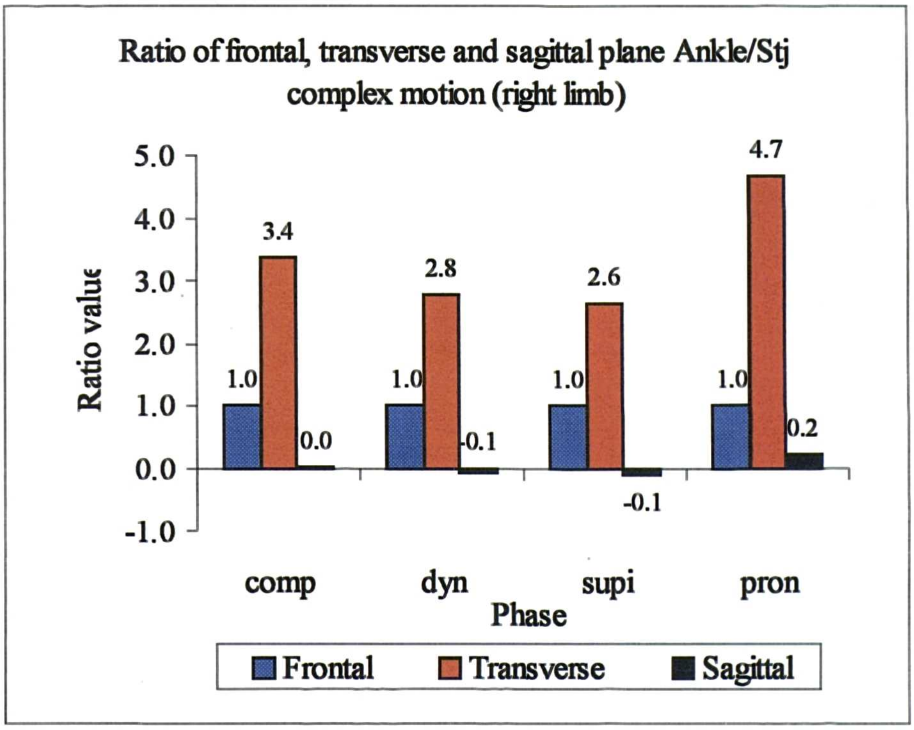


Figure 4.26
Mean ratio of frontal, transverse and sagittal plane ankle/sub talar complex motions during the four phases of rotation - right limb only.

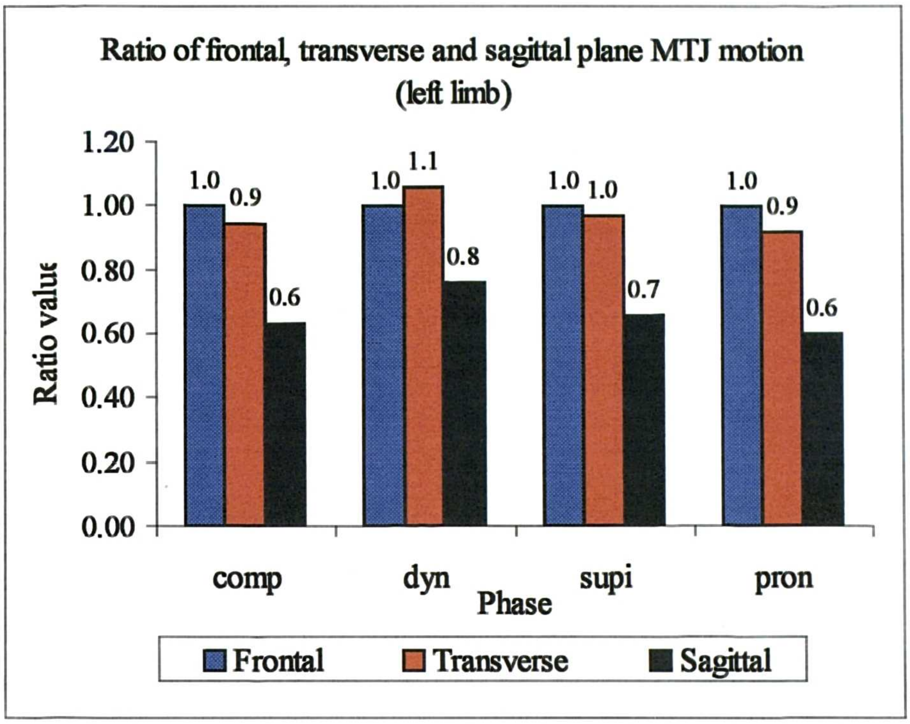


Figure 4.27
Mean ratio of frontal, transverse and sagittal plane mid tarsal joint motions during the four phases of rotation - left limb only.

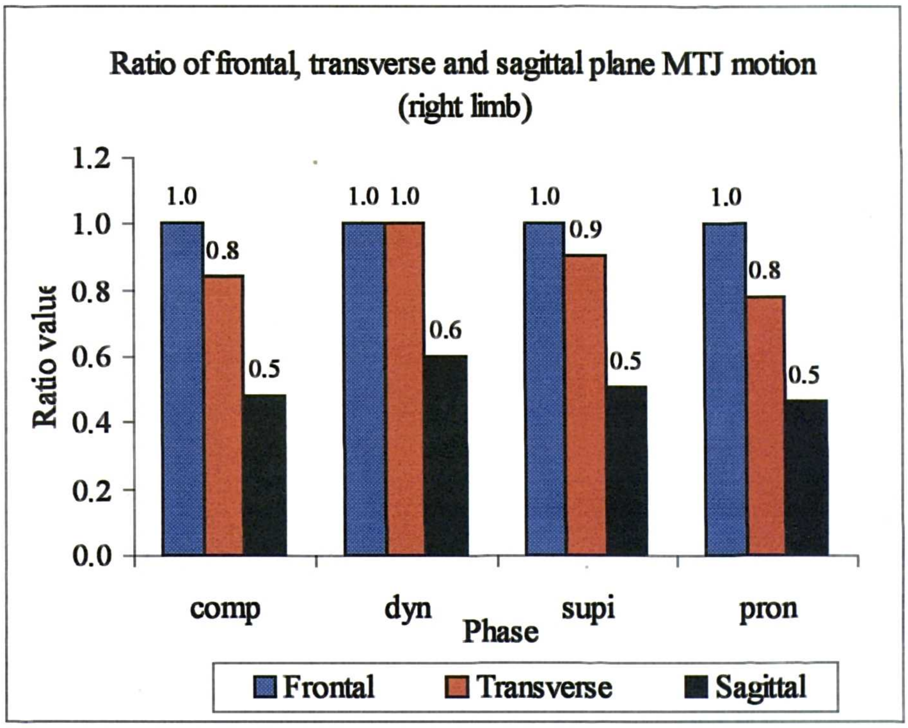


Figure 4.28
Mean ratio of frontal, transverse and sagittal plane mid tarsal joint motions during the four phases of rotation - right limb only.

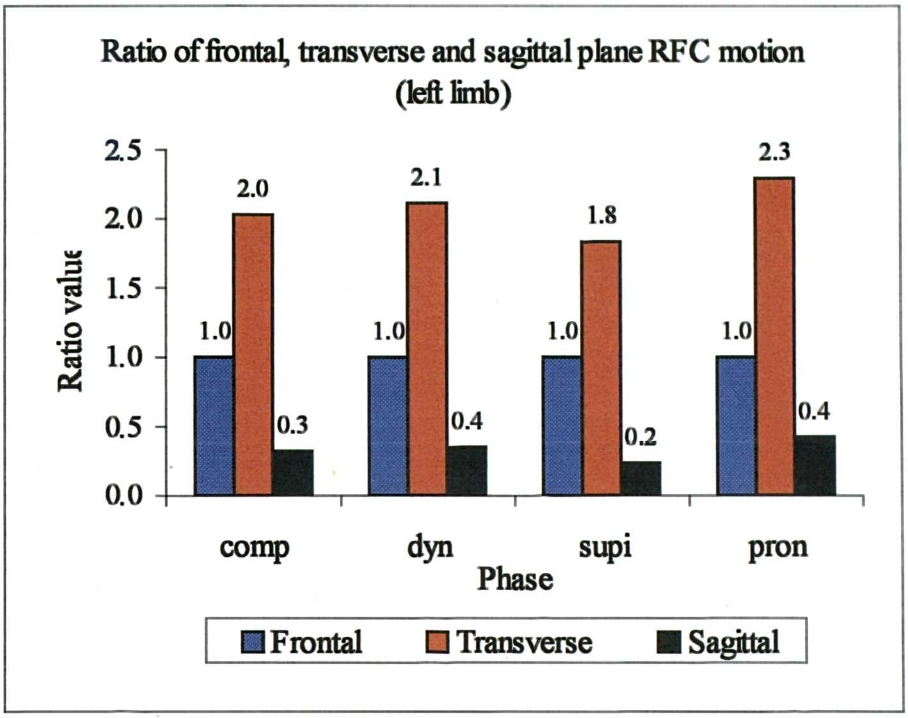


Figure 4.29

Mean ratio of frontal, transverse and sagittal plane rearfoot complex motions during the four phases of rotation - left limb only.

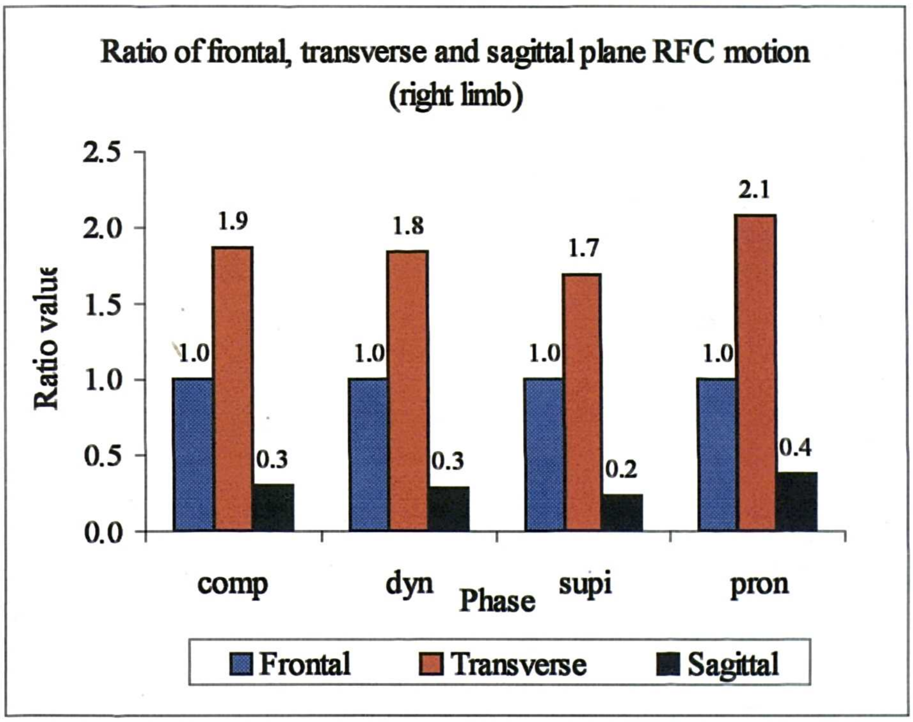


Figure 4.30

Mean ratio of frontal, transverse and sagittal plane rearfoot complex motions during the four phases of rotation - right limb only.

CHAPTER 5

DISCUSSION

5.1 INTRODUCTION.

This chapter will discuss the relevant points with regard to the results presented in chapter 4. The results of the dynamic rearfoot complex assessment will be discussed first, followed by the results of the static rearfoot complex assessment.

5.2 DYNAMIC REARFOOT COMPLEX ASSESSMENT.

The mean total range of transverse plane motion of the leg relative to the foot for the left and right limbs (Table 4.1) is reasonably consistent with the data from Kadaba et al (1990). They reported a mean of 15.7° from a sample of 40 subjects walking at a slightly faster cadence than in this study (112 steps/minute for men, 115 steps/minute for women). This value is reasonably close to the mean of 16.8° for the left limb and 18.1° for the right limb in this study.

There were considerable individual variations within the sample of 47 limbs (Figure 4.2). The right limb of subject 12, for example, displayed almost 3 times the range of motion displayed by subject 11 (29.8° and 10.2° respectively). The left limb of subject 7 displayed almost 2.5 times the range of motion displayed by subject 21 (26.0° and 11.3° respectively). The standard deviation for both limbs was 4.3°. These are similar to the standard deviation that can be estimated from Kadaba et al (1990) (approximately 6.25°, taken from graph), and to other work describing the dynamic motion of the rearfoot joints. Benedetti et al (1998) for example, described a mean total range of frontal plane ankle/sub talar motion of 13.3° in a sample of 20 subjects, with a standard deviation of 5.02°.

The Ang1 and Ang2 values in table 4.1 are consistent with the literature in that the maximum pronated position generally occurred when the rearfoot complex was pronated relative to its position in relaxed standing, and the maximum supination angle generally occurred when the foot was supinated relative to its position in relaxed standing (Kadaba et al 1990, Scott and Winter 1991, Cornwall and McPoil 1995, Mannon et al 1997, Benedetti et al 1998, Nawoczenski et al 1998). This characteristic of the rearfoot complex (being both pronated and supinated relative to its position in relaxed standing at some time during stance) was displayed in all but two subjects (left limb of subjects 12 and 21).

The variation within the sample in the range of transverse plane motion of the leg relative to the foot and the variation in the values of Ang1 and Ang2 relative to the reference position, illustrate the importance of using data that are specific to each subject. It would not, for example, be appropriate to use the mean Ang1 and Ang2 values to define the dynamic phase of motion in the static assessment data for each individual in the sample, since Ang1 and Ang2 values varied considerably. Some subjects displayed Ang1 and Ang2 values that illustrated that their rearfoot complex displayed more pronation in relation to the reference position than supination (left limb subject 13). Other subjects, however, displayed more supination relative to the reference position than pronation (left limb subject 18). Other subjects displayed a balance of supination and pronation (left limb subject 9).

Overall the mean range of motion values, the values of Ang1 and Ang2 and the variations within the sample are consistent with available literature.

5.3 STATIC REARFOOT COMPLEX ASSESSMENT.

This section of the discussion will deal with each of the absolute rotations (leg, heel and forefoot) and each of the relative rotations (ankle/sub talar complex, mid tarsal joint and rearfoot complex) separately. Firstly, however, the repeatability of the static assessment will be addressed.

Throughout the remainder of this thesis the term *order of predominance* is used to indicate the relative values of the ranges of motion in the frontal, transverse and sagittal body planes. The first in the order of predominance is the plane in which the largest range of motion took place, the second the plane in which the second largest range of motion took place and the third the plane in which the smallest range of motion took place. For example, if the heel moved 14° in the frontal plane, 25° in the transverse plane and 3° in the sagittal plane the order of predominance would be transverse, frontal and sagittal plane motion.

5.3.1 REPEATABILITY OF THE STATIC REARFOOT COMPLEX ASSESSMENT.

A reliable measurement is expected to produce the same measure of a particular characteristic on two different occasions, provided that the characteristic being measured does not change. Repeatability is the degree to which this is achieved. Repeatability is one component of reliability, the other being validity. The validity of a measurement is the degree to which the measurement represents the true value of the characteristic being measured. Issues relating to the validity of measurements in this study are addressed a discussion of the limitations of this study in points 4, 5 and 6 in section 5.5.

The mean difference between days in the angular data, reported in tables 4.15 and 4.16, suggests a good level of agreement between the measures taken on different days (range of mean difference between days was 0.7° – 1.0°). These mean values, however, do not reflect the wide variation in the differences between measurements taken on different days. A realistic description of the differences might be that, in general, the differences between measurements taken on different days are below 1.5°, can be as low as a fraction of a degree (0.1°) and rarely exceed 3.0°.

It is important to put the difference between days in the measured range of motion into context. The range of motion being measured, particularly in the sagittal plane, was often very small (less than 2°). With such small movements even differences of 1.0° in the range of motion measured on different days can have a significant effect on the subsequent description of the joint characteristics. This is because the difference is large as a proportion of the range of motion. This has a particularly significant effect on the orientation of the axis of rotation calculated from the range of motion. The range of motion for the right heel of subject 22 illustrates this fact. The difference between days in the ranges of motion in the supination phase and difference between days in the ranges of motion in the pronation phase were very small, and all were below 1° (Table A2.14). The difference between days in the angulation of the axes of rotation for the heel for the supination and pronation phases, however, is very different. The difference in the angulation of the heel axis to the transverse plane between day 1 and day 2 was 0.6° for the supination phase and 9.0° for the pronation phase. The difference in the calculated angulation of the heel axis to the sagittal plane between day 1 and day 2 was 1.3° for the supination phase and 43.5° for the pronation phase. Thus, the angulation of the axis in the pronation phase varies more between days than the angulation of the axis for the supination phase.

The reason why the difference between days in the angulation of the axis is greater for the pronation phase than the supination phase is that the ranges of motion in the pronation phase are smaller than those in the supination phase. During the supination phase there was 3.1°, –6.2° and –1.0° of motion in the frontal, transverse and sagittal planes respectively. During the pronation phase, however, there were 0.7°, –3.9° and -0.02° of motion in the frontal, transverse and sagittal planes respectively. For the supination phase, the effect of the small differences in the range of motion measured on different days on the axis of rotation subsequently calculated was less, because the differences between days were relatively small as a proportion of the range of motion. In the pronation phase, however, differences between days of the same magnitude were greater as a proportion of the range of motion and therefore had a greater effect on the orientation of the axis of rotation calculated on different days. Thus, even small differences in the angular motions between days can produce a large difference in the axis angulation calculated between days.

The relationship between the difference in the ranges of motion measured on different days as a proportion of the range of motion, and the differences in the orientation of the axis of rotation calculated from these ranges of motion is further illustrated in tables 4.15 and 4.16, summarised in table 5.1. The mean difference in the range of motion measured on different days is very similar for the frontal, transverse and sagittal plane.

Consequently, if the difference in the range of motion measured on different days was the only factor influencing the difference in the orientation of the axis of rotation calculated on different days, then the difference between days in the angle of the axis to the transverse plane and difference between days in the angle of the axis to the sagittal plane would also be similar. However, the difference in the angulation of the axis to the transverse plane calculated on different days was different to the difference in the angulation of the axis to the sagittal plane calculated on different days.

Mean difference between days (°)

	Range of motion			Angulation of axis to	
	Frontal	Transverse	Sagittal	Transverse	Sagittal
Right	1.0	0.8	0.9	3.2	13.6
Left	0.7	1.0	0.7	3.4	12.8

Table 5.1

Details the mean differences between days in the ranges of motion and angulation of the axis of rotation to the transverse and sagittal planes.

Since there is less between day variation in the angulation of the axis of rotation to the transverse plane compared to the angulation to the sagittal plane, an additional factor must be involved in producing the large differences between days in the angulation of the axis of rotation to the sagittal plane. This additional factor is the fact that the range of motion in the sagittal plane is often very small, and the range of motion in the transverse plane (which is not used in the calculation of the angulation of the axis to the sagittal plane) is consistently larger. Thus, of greater importance than the magnitude of differences between days is the magnitude of the difference between days as a proportion of the range of motion being measured. The greater that the differences in the ranges of motion measured on different days are as a proportion of the range of motion, the greater the difference in the orientation of the axis of rotation calculated on different days.

The large differences between days in the angulation of the axes of rotation to the sagittal plane are a consequence of the nature of the movements that this study has attempted to measure. Measurement of small movements is hampered by difficulties related to the natural variation in motion patterns. Variations of 0.5° to 1° in the range of motion measured on two separate occasions are significant because they can represent a 100% change in the range of motion measured.

These facts have implications for the interpretation of the data presented in this study. When the range of angular motion is small, though it is difficult to precisely define what constitutes small, the actual range of motion specified should be viewed with caution. It might be more appropriate to describe the range of motion in a particular plane as small, or negligible, in such instances, as opposed to quoting the precise angular value. When the range of motion is greater, though again it is difficult to precisely define what is a sufficiently large range of motion, the angular values can be considered more reliable.

The performance of the motion analysis system has been shown to be as good as can be expected (section 3.2.2.1.4), and certainly comparable to similar systems, and the ranges of absolute and relative motion are generally repeatable (Table 4.15 and 4.16). Thus, the large difference between days in the sagittal plane angulation of the axes of rotation is a consequence of the small differences between days being large as a proportion of the range of motion being measured. They are not a consequence of poor quality measurements or experimental protocol.

5.3.1.1 Comparison with literature.

Van Langelaan (1983), whose cadaver work this study closely resembles, provided a minimal description of the reproducibility of the axes of rotations he deduced. He described repeatability data for the talocalcaneal joint of one cadaver. The motions of the joint were assessed during external rotation of the leg in 5° and 10° increments from an internally rotated position. The leg was then internally rotated to the original position and the experiment performed again. The axes subsequently calculated are only illustrated in Van Langelaan's work and no numerical values relating to the orientation of the axis are provided. From the illustration provided in the text, the sagittal plane angulation of the talocalcaneal joint axis appears to vary between days by approximately 7° on average. This is better than the values in this study. Of notable exception, however, are the first two phases of external rotation of the leg, the axes of rotation during these phases differ more significantly between days (approximately 30° on average).

Van Langelaan suggested that the larger differences between days for these two initial increments was a consequence of the small range of motion (around the axis as opposed to in a cardinal body plane) at the joint. During the first experiment the ranges of motion were 0.3° and 0.7° for increments 1 and 2 respectively, and during the second experiment were 0.1° and 1.4°. Van Langelaan had shown earlier in his work that the smaller the range of motion the less reliable was the axis of rotation subsequently calculated. From the reproducibility experiments he reported, Van Langelaan concluded that the only reliable axes were those calculated for increments 3-7 of external leg rotation because the ranges of motion were sufficiently large (all were greater than 3°). Table 5.1 lists the mean and maximum errors in the axes he calculated for 6 different ranges of motion around an axis of known orientation.

Range of motion around axis (degrees)	Mean error in axis angulation	Maximum error in axis angulation
0.1	98.5°	126.0°
0.3	41.6°	55.0°
1.0	11.1°	14.1°
3.0	4.0°	4.6°
10.0	1.2°	1.5°
30.0	0.4°	0.6°

Table 5.2

Table details data summarised from Van Langelaan (1983). The effect of the magnitude of the range of motion around an axis on the calculated orientation of the axis.

Clearly, there in an inverse relationship between the range of motion and the error in the calculated orientation of the axis of rotation. Panjabi and Goel (1982) also described this relationship in their experimental and theoretical work on parameters affecting the description of joint kinematics. Though their work is not directly comparable to the work presented here, because they calculated the position of centres of rotation for a planar joint, it is clear that the smaller the range of motion the larger the errors in parameters deduced from that range of motion (Figure 5.1)

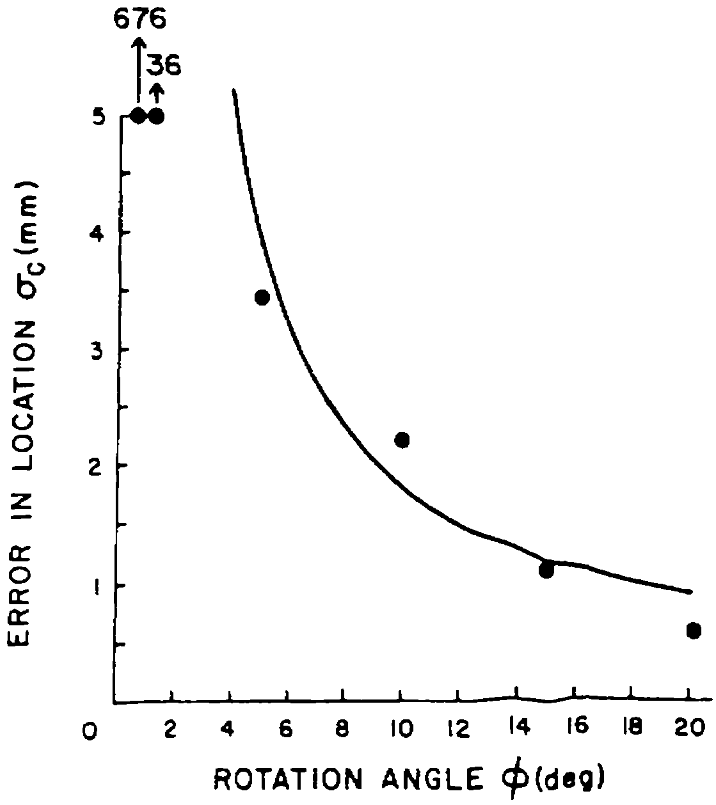


Figure 5.1

Plot of the relationship between the range of motion (degrees) and the error in the calculated position of the centre of rotation (mm) for a planar joint. Dots represent experimental work, the line represents theoretical predictions of the relationship. From Panjabi and Goel (1982).

A further point should be considered when interpreting the results in table 5.2 in relation to the work in this study. Van Langelaan described the range of motion around the axis itself, whereas in this study this range of motion has been broken down into its frontal, transverse and sagittal plane components. Thus, the error in the calculated axis orientation due to the measurement of small ranges of motion will be compounded in this study because the small ranges of motion are broken down into smaller components. For example, 1° of motion around an axis angled 16° to the sagittal plane and 42° to the transverse plane would produce 0.7° of frontal plane motion, 0.7° of transverse plane motion and 0.2° of sagittal plane motion. Thus, the fact that the errors in the calculated axes of rotation are greater in this study than in that of Van Langelaan is to be expected.

The other literature describing axes of rotation for the rearfoot joints, and to which this work has made several references in chapter 2, has not documented repeatability data (Manter 1941, Root et al 1966, Close et al 1967, Isman and Inman 1969, Engsberg 1987, Philips and Lidtke 1992, Lundberg et al 1989c, Lundberg and Svensson 1993). Given the problems in this and Van Langelaan's work and some of the relatively unscientific methodologies used in some of these investigations, some of the axis of rotation data in the literature should be viewed with a degree of caution.

The following points are a summary of the repeatability tests:

- The difference between days in the range of motion in each of cardinal body planes is good.
- The calculated angulation of the axes of rotation to the transverse plane is generally repeatable.

- The calculated angulation of the axes of rotation to the sagittal plane is less repeatable than that to the transverse plane. This is because small variations in the measured range of sagittal plane motion are a large proportion of the range of motion and so have a large effect on the calculated axis orientation. This is generally not the case for the frontal and transverse plane motions because the ranges of motion in these planes are larger.
- The problems associated with the small ranges of movement measured in this study are not a consequence of the measurement system, nor the experimental protocol, but a characteristic of attempting to measure small ranges of movement.
- The variations between days in the calculated angulation of the axes of rotations suggest that they are not the only parameter that should be used in the description of the functional characteristics of the rearfoot joints.

5.3.2 ABSOLUTE ROTATION OF THE LEG.

The movement of the leg was deliberately restricted by the design of the experimental rig. It is by design then that the predominant motion of the leg was in the transverse plane. The mean ranges of motion for both the left and right limbs (Table 4.3 and 4.9) illustrate that the experimental rig did restrict the movement of the leg in the frontal and sagittal planes as desired (both were less than 1°) whilst the leg moved freely in the transverse plane. The largest range of movement in the frontal plane within the sample was 4.9° (for the composite range of motion of the right leg of subject 21). The largest range of movement in the sagittal plane within the sample was 3.3° (for the composite range of motion of the left leg of subject 25). Despite some variation, the input rotation into the rearfoot complex was transverse plane motion of the leg, as the proposed model of rearfoot function detailed in chapter 2 dictated.

The direction of leg motion in the frontal, transverse and sagittal planes was coupled for each subject but showed no pattern within the sample. Thus, whilst internally rotating their leg some individuals everted their leg and others inverted their leg. Also, whilst internally rotating their leg some individuals plantarflexed their leg and others dorsiflexed their leg. These variations between subjects are expected because, unlike those of the talus, calcaneus and navicular and cuboid, the frontal and sagittal plane motions of the leg are not coupled with its transverse plane motions.

The ratios describing the ranges of motion in the three planes were highly variable between different phases and between different subjects. This was because what were actually small differences in the frontal plane angle measured between different phases and subjects, were large as a proportion of the total range of motion in the frontal plane and thus produced a large change in the ratio values.

The axes of rotation for the leg had a near vertical orientation, as would be expected with almost all motion occurring in the transverse plane (Figure 4.4). The angle between the axis and the transverse plane varied between 80.7° and 89.3°. These results are consistent with those documented by Van Langelaan (1983), whose experimental rig was almost identical to that used in this study. In his sample of 10 cadavers the angle of the axis to the transverse plane ranged between 86.0° and 87.6°. The greater range of axis orientations in this study is probably due to the in vivo nature of the assessment. In vitro the motion of the leg can be constrained to a greater degree.

The angle between the axis of rotation of the leg and the sagittal plane showed considerable variation within the sample (from –86.7° to 87.8°). This was expected because small differences in the range of frontal and sagittal plane motions between subjects produced large differences in the orientation of the axis of rotation. This is a consequence of the differences in the range of motion between subjects being large as a proportion of the total range of motion in the frontal and sagittal planes. Van Langelaan's (1983) results show similar variations in the angulation of the axis to the sagittal plane; the angle between the axis of rotation and the sagittal plane varied between –72.4° and 54.7° in his sample.

These characteristics were generally the same for the composite, dynamic, supination and pronation phases of motion. The principal difference between these phases was the range of transverse plane motion of the leg, and thus the magnitude of the input rotation to the rearfoot complex.

The range of transverse plane motion for the dynamic phase should always closely match that measured in the dynamic rearfoot complex assessment. Comparison of the total range of motion for each subject measured during the dynamic rearfoot complex assessment (Table 4.1) with the range of transverse plane leg rotation in the dynamic phase of the static assessment (Tables A1.1 – A1.5 and A1.43 – A1.48) reveals a close association between the two (Table 5.3). Some discrepancy was inevitable because when selecting the particular motion data values to define the dynamic phase within the static rearfoot complex assessment data, the angular value closest to the Ang1 and Ang2 values was chosen. Only occasionally did the static assessment data contain a value that matched the Ang1 or Ang2 value exactly. The principal reason why data values matching Ang1 and Ang2 exactly could not be found, was because the speed of leg rotation and sampling frequency of the motion data was such that in some subjects the leg moved 2° or 3° in the transverse plane between data points.

subject	left	right
1	-0.5	0.1
2	-0.1	*
3	-0.2	0.0
4	1.0	3.5
5	0.2	-0.1
6	1.0	*
7	-0.1	0.0
8	0.1	0.6
9	0.2	0.0
10	0.6	-0.1
11	2.0	-0.4
12	-2.5	0.8
13	-0.1	-0.4
14	-0.4	0.0
15	-0.6	0.0
16	-2.8	-0.3
17	-0.1	-0.1
18	0.3	-0.2
19	0.6	0.4
20	0.0	0.2
21	-1.7	-0.1
22	-0.2	0.0
23	0.0	*
24	2.3	2.3
25	-0.2	-0.1
mean	0.7	0.5
min	0.0	0.0
max	2.8	3.5

Table 5.3

Difference (°) between the range of transverse plane motion of the leg relative to the foot measured during the dynamic rearfoot complex assessment and the range of leg rotation in the static rearfoot complex assessment used to define the dynamic phase of motion.

The range of transverse plane leg rotation during the supination phase was consistently close to 20°. Again some discrepancy was inevitable because of the difficulty in identifying data from the static assessment that described the leg in the equivalent of its relaxed standing position, exactly 0°, and precisely 20° externally rotated relative to the reference position. Of particular note is the data for the left leg of subject 16, whose supination range of motion was 24.8°. This was a consequence of the speed at which this subject rotated their leg in the experimental rig. A similar problem is evident in the dynamic range of motion for the left leg of this subject; the range was 17.5° (Table A1.46) instead of the desired 14. 7° (Table 4.1). The right limb of subject 4 had a similar pattern.

The range of transverse plane leg motion measured during the pronation phase showed considerable variation relative to the mean values of approximately 20°. For the right leg, the range of transverse plane leg rotation ranged from –10.8° to –33.3° and for the left –10.3° to –28.6°. Thus, some individuals were capable of three times more transverse plane leg motion than others during the pronation phase.

Since the range of transverse plane leg motion during the supination phase was fixed at 20°, the range of transverse plane leg motion during the composite phase showed similar amounts of variation within the sample as the range of motion during the pronation phase (composite phase was equal to the supination phase + pronation phase).

5.3.2.1 Summary of the absolute rotation of the leg.

- The motion of the leg was generally restricted to the transverse plane by the experimental rig.
- There was no pattern in the sagittal and frontal plane movements of the leg in relation to the transverse plane movements of the leg.
- The axes of rotation for the leg were consistently angled more than 80° to the transverse plane, but showed considerable variation in their angulation to the sagittal plane. This is to be expected because of the small range of movement in the sagittal and frontal planes.
- The range of transverse plane leg motion during the supination phase was generally close to the desired range of 20°.
- The range of transverse plane leg motion during the dynamic phase was generally close to the range of motion measured in the dynamic rearfoot complex assessment.
- The range of transverse plane leg motion during the pronation phase showed considerable variation within the sample.

5.3.3 ABSOLUTE ROTATION OF THE HEEL.

Phase	Primary order of predominance	Other orders of predominance	
		T – S – F	F – T – S
Composite	T – F – S	R – 9	R – 12, 21, 24
		L – 4, 5	L – 2, 12, 18, 24
Dynamic	T – F – S	R – None	R – 1, 12, 21, 24, 25
		L – 5, 11, 16	L – 2, 7, 12, 18, 21
Supination	T – F – S	R – 3, 4	R – 1, 2, 12, 21, 24, 25
		L – 3, 4, 5	L – 1, 2, 8, 13, 18, 21, 24
Pronation	T – F – S	R – 5, 9, 11, 15	R – 2, 12, 21, 24
		L – 1, 5, 11, 16	L - 12

Table 5.4

Reference table. Details the primary order of predominance for the heel and the other orders of predominance displayed within the sample, for each phase of motion. Numbers relate to the individual subjects. F = frontal plane motion, T = transverse plane motion, S = sagittal plane motion. R = right, L = left.

5.3.3.1Composite phase – ranges of motion.

The order of predominance in the mean range of heel motion during the composite phase was transverse, frontal and sagittal plane motion. Although the mean ranges of transverse, frontal and sagittal plane motion are distinctly different (-13.3°, 7.4° and -0.9° for the right and -12.2°, 7.9° and -2.1° for the left), not all limbs in the sample had the same order of predominance (Table 5.4). In all three instances when subjects displayed more sagittal than frontal plane motion, the range of frontal plane motion was considerably less than the mean of the sample, and the sagittal plane angle was close to the mean. In the subjects who displayed more frontal than transverse plane, the change in the order of predominance was due to an above average range of frontal plane motion.

There is a pattern to these changes in the order of predominance. When the order is frontal, transverse and sagittal plane motion it is generally an above average range of frontal plane motion with a generally average range of transverse and sagittal plane motion that changes the order from that of the mean data (transverse, frontal and sagittal plane motion). When the order of predominance is transverse, sagittal and frontal plane motion, it is generally a below average range of frontal plane motion with a generally average range of transverse and sagittal plane motion that causes the change in the order of predominance. The fact that the range of frontal plane motion is more variable than the range of transverse and sagittal plane motion is also reflected in the standard deviations for the frontal, transverse and sagittal plane motions, 4.3°, 2.9° and 2.2° respectively for the right and 3.6°, 2.4° and 1.8° respectively for the left.

The frontal plane motion of the heel is a good indicator of the frontal plane motion of the sub talar joint because during sub talar joint motion the heel displays most of the frontal plane sub talar joint motion, whilst the talus displays most of the transverse and sagittal plane motion (Christensen et al 1996). The literature describes a variety of functional characteristics for the sub talar joint, some displaying a predominance of transverse plane motion, others a predominance of frontal plane motion. The variation in the sample investigated here shows a similar pattern. Those subjects with the largest range of frontal plane motion are probably the equivalent of the subjects in the literature with a predominance of frontal plane motion. Those in this sample with the least amount of frontal plane motion are probably the equivalent of those in the literature with a predominance of transverse plane motion. The fact that this sample contains variations that are generally consistent with those in the literature indicates that the sample investigated here is similar to those investigated in the literature.

The directions of frontal and transverse plane heel motions during the composite phase were consistently positive and negative respectively. Thus, during absolute internal rotation of the leg, the heel everted and internally rotated and during absolute external leg rotation, the heel inverted and externally rotated.

In the sagittal plane there was a general trend of negative rotation. Thus, during absolute internal leg rotation the heel plantarflexed and during absolute external leg rotation the heel dorsiflexed. Some variation in the direction of the sagittal plane heel motion is consistent with the data of Van Langelaan (1983). He reported that seven of the 10 cadavers he investigated displayed dorsiflexion of the heel coupled with external rotation of the leg and three displayed plantarflexion.

5.3.3.2 Dynamic phase – ranges of motion.

During the dynamic phase the order of predominance in the mean range of heel motion was transverse, frontal and sagittal plane motion. Like the composite phase there were several exceptions to this (Table 5.4). Some subjects displayed more sagittal than frontal plane motion, with transverse plane motion predominant, whilst other displayed more frontal than transverse plane, with the smallest range of motion being displayed in the sagittal plane.

As in the composite phase, the direction of frontal and transverse plane heel motion was consistently positive and negative respectively. The sagittal plane motions again showed some variation though the general trend was negative rotation. Those with a positive direction of sagittal plane motion generally displayed a small range of motion (the right heel of subjects 12, 13, 19 and 20 and the left heel of subject 2).

5.3.3.3 Supination phase – ranges of motion.

The order of predominance in the mean range of heel motion during the supination phase was transverse, frontal and sagittal plane motion. Again there were exceptions to this within the sample (Table 5.4). Some subjects displayed more sagittal than frontal plane motion, with the predominant motion still in the transverse plane. There were a relatively large number of instances (13, 37.5% of the sample) when there was more frontal than transverse plane heel motion and the least range of motion in the sagittal plane.

As with the composite and dynamic phases the direction of frontal and transverse plane heel motion was consistent throughout the sample. The frontal plane motion was always positive and the transverse plane motions always negative. The direction of sagittal plane motion was generally negative, but it was again variable.

5.3.3.4 Pronation phase – ranges of motion.

The order of predominance in the mean range of heel motion during the pronation phase was transverse, frontal and sagittal plane motion. Again there were exceptions to this within the sample (Table 5.4). Some subjects displayed more sagittal than frontal plane motion, with transverse plane motion predominant. In contrast to the supination phase there was a relatively small number of instances (5, 10.5% of the sample) when there was more frontal than transverse plane motion and the least range of motion in the sagittal plane.

The direction of frontal plane heel motion in the pronation phase was generally positive. However, the right heels of subjects 9, 11 and 16 and the left heels of subjects 11, 16 and 17 all displayed negative rotations. The range of negative rotation was less than 1° for the right heels of subjects 9 and 11 and the left heels of subjects 11 and 16. For the right heel of subject 16 and the left heel of subject 17, however, the ranges of negative frontal plane motion were –1.4° and –1.8° respectively.

This pattern of inversion of the heel during absolute internal rotation of the leg and eversion of the heel during external rotation of the leg contradicts all the literature describing the motion of the heel at the sub talar joint. It should first be remembered that this is the motion of the heel relative to the global co-ordinate system. Thus, the heel could be inverted relative to the global co-ordinate system by inversion of the leg during the pronation phase. This is possible if, during the pronation phase, the heel reaches the end of its range of eversion at the sub talar joint, and the leg, talus and calcaneus thereafter invert together in the frontal plane. The right leg of subject 16 and left leg of subject 17, however, everted during the pronation phase.

Another possible explanation is that as the leg continued to internally rotate and evert during the pronation phase, load was progressively transferred to the medial aspect of the plantar surface of the heel. This would create an inversion moment at the sub talar and ankle joints. The nature of the complex articulation and close fitting of the sub talar joint is unlikely to allow the heel to invert whilst the talus continues to invert, adduct and plantarflex. It is more conceivable that the inversion of the heel took place by inversion at the ankle joint. The fact that this pattern was evident in only a few of the sample might be due to the fact that it only occurs at the extremes of the range of absolute internal leg rotation, and that only these subjects forcibly internally rotated their legs to that degree.

The direction of transverse plane heel motion during the pronation phase was consistently negative. The direction of sagittal plane heel motion was again variable within the sample, though the general pattern was of negative rotation. There were 16 instances in which the direction of sagittal plane motion was positive rotation. However, more than half of the heels that displayed positive sagittal plane motion moved less than 0.5°. The other heels that displayed positive rotation in the sagittal plane during the pronation phase displayed motion ranging from 0.6° to 4.7°. It is possible that towards the point of maximum internal leg rotation, some individuals need to dorsiflex the heel (at the ankle) to allow the normal eversion, dorsiflexion and external rotation of the heel at the sub talar joint.

5.3.3.5 Axis of rotation.

The axis of rotation for the heel calculated from the mean range of composite phase motion was orientated downward and laterally from posterior to anterior (Figure 4.5). There were considerable variations within the sample, as would expected given the variations in the predominant motion already highlighted. Relative to the transverse plane the angulation of the heel axis varied between –27.8° (left heel, dynamic phase of subject 1) and -85.1° (right heel, pronation phase of subject 1).

It was expected that the mean angulation of the axis to the transverse plane would be greater than 45° since transverse plane was generally the predominant motion. The mean angles for the axis of rotation relative to the transverse plane (-60.8° and -56.2° for the right and left heels respectively) are larger than those described by Van Langelaan (1983) (mean was -39.1°, range –25.4° to -59.5°). The results of this study, compared to Van Langelaan's, suggest that a greater proportion of the heel motion occurs in the transverse plane. The likely reason for the difference between the values calculated in this study and those reported by Van Langelaan is the use of cadavers in the latter. Van Langelaan made a point of restricting the transverse plane motion of the heel during his experiments, because he needed to ensure that transverse plane rotation of the leg produced rotations within the foot as opposed to of the whole foot relative to the floor. To achieve this the heel was mounted on a board covered by emery paper. There was no attempt to assess whether the degree to which the transverse plane motion of the heel was controlled was similar to the degree to which the normal heel/floor interface restricts the transverse plane motion of the heel. Compared to the results of this study, the use of emery paper in Van Langelaan's experiments might have excessively restricted the transverse plane motion of the heel. The in vivo method used in this study provides a more natural environment within which to assess the kinematics of the rearfoot joints. In particular, the limb to floor interface, for example, was normal plantar tissue and an unpolished painted surface. This is more natural than the ligamentous plantar surface of the heel moving against emery paper.

Relative to the sagittal plane the angulation of the heel axis varied between –88.9° (left heel, dynamic phase of subject 11) and 83.9° (right heel, pronation phase of subject 9). The large variations in the sagittal plane angulation are due to the differences in the direction of sagittal plane motion. The mean angles for the axis of rotation relative to the sagittal plane (-7.2° and –15.0° for the right and left heels respectively) are similar to those described by Van Langelaan (1983) (mean was –6.4°, range –21.5° to 9.4°).

5.3.3.6 Comparison of phases.

The principal difference between the phases was between the supination and pronation phases. The range of transverse plane motion per degree of frontal plane heel motion was less during the supination phase than the pronation phase. This is a consequence of a reduction in the range of frontal plane motion in the pronation phase compared to the supination phase (the range of transverse plane motion in each phase is similar). This reduction in the range of frontal plane motion in the pronation phase is probably due to the heel becoming everted relative to the ground during the pronation phase with a consequent medial shift in the point of application of the ground reaction force under the heel and an increase in the supination moment at the sub talar joint opposing further eversion. Alternatively, the sub talar joint may reach the end of its range of frontal plane motion at some point during the pronation phase.

5.3.3.7 Summary of the absolute rotation of the heel.

- The general order of predominance was transverse, frontal and sagittal plane motion and less frequently frontal, transverse and sagittal plane motion.
- The range of sagittal plane motion was generally small.
- The variation between different individuals in the range of frontal plane heel motion was greater than the variation in the range of transverse and sagittal plane motions. This is consistent with the individual variation in the characteristics of the sub talar joint described in the literature.
- The direction of transverse plane heel motion was consistent throughout the sample. During absolute internal leg rotation the heel internally rotated and during absolute external rotation of the leg the heel externally rotated.
- The direction of frontal plane motion was consistent during the composite, dynamic and supination phases of motion. During absolute internal leg rotation the heel everted and during absolute external leg rotation the heel inverted.
- During the pronation phase the direction of frontal plane motion was generally consistent with the other phases (positive rotation). Some heels, however, inverted whilst the leg was internally rotating and everted whilst the leg was externally rotating.
- The direction of sagittal plane motion was generally plantarflexion during internal leg rotation and dorsiflexion during external leg rotation. There were some exceptions to this and this is consistent with comparable data in the literature.

- The axis of rotation for the heel is orientated downwards and laterally from posterior to anterior.
- The greatest difference between the phases was between the supination and pronation phases. The amount of transverse plane motion per degree of frontal plane motion was greater in the pronation phase than in the supination phase.

5.3.4 ABSOLUTE ROTATION OF THE FOREFOOT.

Phase	Primary order of predominance	Other orders of predominance		
		F – T - S	T – F - S	T – S - F
Composite	F – S – T	R – 1, 3, 10, 11, 12, 14, 15, 16, 21, 25 L – 4, 14, 16, 25		
Dynamic	F – S – T	R – 3, 10, 11, 14, 15, 19, 21 L – 11, 12, 16, 25		
Supination	F – S – T	R – 3, 10, 14, 15, 19, 20, 24, 25 L – 5, 6, 7, 24, 25		
Pronation	F – S – T	R – 1, 2, 11, 15, 25 L – 11, 12, 16, 25	R – 3, 16 L - 17	R - 8

Table 5.5

Reference table. Details the primary order of predominance for the forefoot and the other orders of predominance displayed within the sample, for each phase of motion. Numbers relate to the individual subjects. F = frontal plane motion, T = transverse plane motion, S = sagittal plane motion. R = right, L = left.

5.3.4.1 Composite phase – ranges of motion.

The order of predominance in the mean range of forefoot motion during the composite phase was frontal, sagittal and transverse plane motion. Frontal plane motion was the predominant motion during the composite phase for all subjects (Table 5.5). The mean ranges of motion in the sagittal and transverse planes were very similar and it is not surprising therefore that in contrast to the mean ranges of motion, some subjects in the sample displayed more transverse than sagittal plane motion.

The directions of frontal, transverse and sagittal plane motion during the composite phase of motion were positive, negative and positive respectively. Thus, during absolute internal rotation of the leg the forefoot everted, internally rotated and dorsiflexed and during absolute external rotation of the leg the forefoot inverted, externally rotated and plantarflexed.

The pattern of frontal plane motion was consistent throughout the sample. The direction of sagittal plane motion was consistent with the exception of the left forefoot of subject 25, which had -0.2° of plantarflexion. The direction of motion in the transverse plane was less consistent than the motion in the frontal and sagittal planes. There were instances when the forefoot displayed positive rotation though the actual range of motion in several of these instances was very small.

5.3.4.2 Dynamic phase – ranges of motion.

The order of predominance in the mean range of forefoot motion during the dynamic phase was frontal, sagittal and transverse plane motion. The predominant motion was in the frontal plane for all subjects (Table 5.5). As in the composite phase, and in contrast to the mean values, some subjects had more transverse than sagittal plane motion.

As in the composite phase of motion the direction of frontal plane forefoot motion was consistently positive and the direction of sagittal plane motion was generally positive. However, the right forefeet of subjects 1, 14 and 21 and the left forefoot of subject 14 displayed negative sagittal plane rotations, though these ranged from just –0.4° to –1.8°. The direction of transverse plane forefoot motion was generally negative rotation, but the forefeet in 17 of the 47 limbs displayed positive rotation, though most was less than 1°.

5.3.4.3 Supination phase – ranges of motion.

The order of predominance in the mean range of forefoot motion during the supination phase was frontal, sagittal and transverse plane motion. The predominant motion was in the frontal plane for all subjects (Table 5.5). Some subjects displayed more transverse than sagittal plane motion.

The direction of frontal plane motion during the supination phase was consistently positive. The direction of transverse and sagittal plane forefoot motion was generally negative and positive respectively.

5.3.4.4 Pronation phase – ranges of motion.

The order of predominance in the mean range of forefoot motion during the pronation phase was frontal, sagittal and transverse plane motion. In contrast to the composite, dynamic and supination phases, frontal plane motion was not the predominant motion in all subjects (Table 5.5). There were three instances of subjects who displayed an order of predominance of transverse, frontal and sagittal plane motion and one instance of a subject who displayed an order of predominance of transverse, sagittal and frontal plane motion.

The direction of motion during the pronation phase was consistent with that during the composite, dynamic and supination phases. The frontal plane motion was always positive, transverse plane generally negative and sagittal plane motion generally positive.

The range of eversion of the forefoot during internal rotation of the leg (and equivalent forefoot inversion during external rotation of the leg) in the pronation phase was surprisingly high (8.6° for the right and 8.7° for the left). It was expected that if the navicular, cuboid, three cunieforms and the 2nd, 3rd and 4th metatarsals were a rigid unit once all the metatarsals were weight bearing the eversion of the forefoot would be significantly restricted during the pronation phase. The floor would prevent any further eversion and it was assumed that the metatarsals would stay approximately parallel to the floor. It is a reasonable assumption that in the relaxed standing position all the metatarsal heads are weight bearing, since this will impart greater stability to the posture than if only some of the metatarsal heads are weight bearing. To allow the 'forefoot' segment as it was defined in this study to evert during internal rotation of the leg from its relaxed standing position there is either eversion of the metatarsals relative to the floor or relative motion between the navicular, cuboid, cunieforms and metatarsals.

The metatarsals do not appear to move relative to the floor to the degree to which the forefoot everts during the pronation phase. The most likely mechanism by which the 'forefoot' segment everts without everting the metatarsals relative to the floor is by rotation of the metatarsals along their longitudinal axes. In effect, when the forefoot was inverted relative to the ground the lateral border of the weight bearing metatarsal heads would be in contact with the ground. As the forefoot everts during internal rotation of the leg all metatarsals become weight bearing. Thereafter the navicular/cuboid evert and each metatarsal also everts around its own longitudinal axis. At the end of the range of internal leg rotation, the medial border of each metatarsal head is in contact with the ground. This allows the navicular and cuboid to evert without the metatarsals everting relative to the ground. Without doubt there would also be some motion between the navicular, cuboid and the cunieforms, as Van Langelaan (1983), Benick (1985) and Lundberg et al (1989c) reported.

Conducting the static rearfoot complex assessment whilst the foot was on a pressure measurement system, such as a pedobaragraph, may have provided further information regarding this mechanism. The changes in the loading of the metatarsals could have been assessed, and whether forefoot did evert would have become apparent since it would necessitate the more lateral metatarsals becoming non weight bearing. Also, the lateral to medial shift of pressure on the metatarsal heads as they rotate around their longitudinal axes could have been described.

5.3.4.5 Axis of rotation.

The axis of rotation for the forefoot, calculated from the mean composite range of motion, was orientated downward and medially from posterior to anterior (Figure 4.6). There were considerable variations from the mean values in the angulation of the axis to the transverse plane (mean values were –9.4° and -2.9° for the right and left limbs respectively). The angulation of the forefoot axis relative to the transverse plane varied between –48.3° (right forefoot, pronation phase of subject 3) and 18.1° (left forefoot, supination phase of subject 7). This is to be expected given the variations in the predominant motion and direction of motion already highlighted.

There were also considerable variations from the mean values in the angulation of the forefoot axis to the sagittal plane (mean values were 14.1° and 15.2° for the right and left limbs respectively). The angulation of the axis varied between –19.8° (right forefoot, pronation phase of subject 11) and 49.3° (right forefoot, pronation phase of subject 7).

There are no reports in the literature to which these axes of rotation can be directly compared. This is because the particular attachment of markers and definition of the forefoot segment used in this study is unique and so the results will differ from those of other studies. The results of studies that have calculated axes of rotation for the navicular and cuboid separately are of some relevance. Van Langelaan's (1983) data for the axes of rotation of the navicular and the cuboid differ in only one respect from that presented here for the forefoot. The mean axes for the individual navicular and cuboid are orientated upwards in contrast to the downward orientation found in this study. The degree of upward orientation in Van Langelaan's work and the degree of downward orientation in this study, however, are both small (mean from Van Langelaan was 6.4° for the navicular and 5.1° for the cuboid, mean in this study was -9.4° for the right forefoot and –2.9° for the left). Furthermore, both this study and Van Langelaan's described axes orientated in the opposite direction to the mean axis. Thus, Van Langelaan described some axes orientated the same as the mean axes described in this study, and this study describes some axes that are orientated the same as the mean from Van Langelaan's work. The conflicting mean results of these two studies is probably due to the variability in the direction of transverse plane forefoot, navicular and cuboid motion and the relatively small sample sizes, as opposed to genuinely conflicting motion patterns of the segments.

5.3.4.6 Comparison of phases.

The principal difference between the phases was between the supination and pronation phases. The mean range of motion values indicate a general pattern of less frontal plane motion during the pronation phase than the supination phase. This would be expected because during the pronation phase the metatarsal heads will all become weight bearing, because the forefoot has been everting during the supination phase, and thereafter further eversion is probably restricted to a greater degree than during the supination phase. The majority of subjects (73%) display this difference between the supination and pronation phases.

5.3.4.7 Summary of the absolute rotations of the forefoot.

- In all phases the forefoot generally moved predominantly in the frontal plane.
- The range of transverse plane motion was generally small, and there was, on average, slightly more sagittal than transverse plane motion.
- The direction of frontal plane forefoot motion was consistent throughout the sample. During absolute internal leg rotation the forefoot everted and during absolute external rotation of the leg the forefoot inverted.
- The direction of sagittal plane motion was reasonably consistent. During absolute internal leg rotation the forefoot dorsiflexed and during absolute external leg rotation the forefoot plantarflexed.
- The direction of transverse plane motion was less consistent, through the average pattern was one of internal rotation during absolute internal leg rotation and absolute external rotation during external leg rotation.
- The mean axis of rotation for the forefoot is orientated downwards and medially from posterior to anterior.
- Due to the considerable variations in the direction of sagittal and particularly transverse plane motion, there was considerable variation in the orientation of the forefoot axes of rotation relative to both the transverse and sagittal planes.
- The greatest difference between the phases of motion was between the supination and pronation phases. During the pronation phase the range of frontal plane forefoot motion was decreased.

5.3.5 RELATIVE ROTATION AT THE ANKLE/SUB TALAR COMPLEX.

Phase	Primary order of predominance	Other orders of predominance T – S – F
Composite	T – F – S	R – 3, 4, 9, 11, 17
		L – 3, 5, 11, 17, 22
Dynamic	T – F – S	R – 3, 11
		L – 5, 11, 22
Supination	T – F – S	R – 3
		L – None
Pronation	T – F – S	R – 3, 8, 9, 11, 17, 22
		L – 1, 2, 5

Table 5.6

Reference table. Details the primary order of predominance for the ankle/sub talar complex and the other order of predominance displayed within the sample, for each phase of motion. Numbers relate to the individual subjects. F = frontal plane motion, T = transverse plane motion, S = sagittal plane motion. R = right, L = left.

5.3.5.1 Composite phase – ranges of motion.

The order of predominance in the mean range of ankle/sub talar complex motion during the composite phase was transverse, frontal and sagittal plane motion. Transverse plane motion was the predominant motion during the composite phase in all subjects (Table 5.6). There were, however, 9 limbs that displayed more sagittal than frontal plane motion. In all of these instances the range of frontal plane motion was much smaller than the mean value of 8.0° and 7.2° for the right and left respectively, and the range of sagittal plane motion was close to the average.

The clear predominance of transverse plane motion is consistent with an in vivo study of the maximum range of motion at the ankle/sub talar complex (actively produced by free rotation of the foot by the subjects). Nigg et al (1992) described a mean total of 35.5° of frontal plane motion and 72.4° of transverse plane motion at an equivalent of the ankle/sub talar complex in subjects aged 20-39. Thus, the range of transverse plane motion per degree of frontal plane motion was 2.0°. This is considerably less than the 3.8° for the left and 3.4° for the right calculated in this study. This difference might well be due to the difference methods by which the motion of the ankle/sub talar complex was assessed. The foot was loaded but was moved relative to a stationary leg and motion was induced actively by each subject (using muscles). The musculature around the ankle/sub talar complex is better orientated for producing frontal plane motion than transverse plane motion. Thus, it is unlikely that these individuals were able to exploit the full range of transverse plane motion. In this study, where body weight and proximal transverse plane rotations were used to produce ankle/sub talar motions, it is more likely that the full range of transverse plane ankle/sub talar complex motion was exploited. Thus, the ratio of transverse plane motion to frontal plane motion would be greater.

The direction of transverse plane ankle/sub talar motion during the composite phase was consistently positive. Thus, during absolute internal rotation of the leg the heel externally rotated relative to the leg and during absolute external rotation of the leg the heel internally rotated relative to the leg.

The direction of sagittal plane ankle/sub talar complex motion was highly variable. Sixty percent of the sample displayed negative sagittal plane ankle/sub talar complex motion. Thus, the majority of subjects displayed plantarflexion of the heel during absolute internal rotation of the heel and dorsiflexion during absolute external rotation of the heel. Since the range of heel motion in the sagittal plane was generally small (mean -0.9° for the right and -2.1° for the left) the effect of small sagittal plane motions of the leg on the net ankle/sub talar complex motion was be significant. The direction of absolute sagittal plane motion of the heel was relatively consistent in the sample, whereas the absolute sagittal plane motions of the leg were highly variable. Thus, the small sagittal plane movements of the leg will interfere with the description of the sagittal plane ankle/sub talar complex motion produced by transverse plane rotation of the leg, because the range of sagittal plane heel motion is generally of similar magnitude.

The direction of motion in the frontal plane was consistently positive. Thus, during absolute internal rotation of the leg the heel everted relative to the leg and during absolute external rotation of the leg the heel inverted relative to the leg. There were two exceptions to this, the left ankle/sub talar complex of subjects 3 and 11 both displayed inversion of the heel relative to the leg during absolute internal rotation of the leg and eversion of the heel relative to the leg during absolute external rotation of the leg. In both these instances the absolute rotation of the heel was eversion during absolute internal rotation of the leg and inversion of the heel relative to the leg during absolute external rotation of the leg. Thus, the normal coupling between transverse plane motion of the leg and the frontal plane motion of the heel was present.

The pattern of inversion of the heel relative to the leg during absolute internal rotation of the leg and eversion of the heel relative to the leg during absolute external rotation of the leg must, therefore, be due to the leg moving in the frontal plane in the same direction as the heel, but to a greater degree. It is worth noting that in these two instances the motion of the leg was large in relation to the mean frontal plane motion of the leg (left leg of subject 3 moved 3.4°, the left leg of subject 11 moved 4.4°, the mean movement was 0.7°). In addition, the absolute frontal plane motion of the heel in these two exceptions was much smaller than the mean data (left heel of subject 3 moved 2.7°, the left heel of subject 11 moved 4.0°, the mean frontal plane motion was 7.9°). Thus, the ankle/sub talar complex was not displaying an unusual coupling at the ankle/sub talar complex (inversion of the heel during internal rotation of he leg) but the data is falsified because of the unwanted frontal plane motion of the leg.

These exceptions highlight the importance of restricting motion of the leg to the transverse plane if a description of the motion at ankle/sub talar complex in the three cardinal body planes produced by transverse plane motion of the leg is required. The motion of the leg in the frontal plane might not be so significant when the absolute frontal plane motion of the heel is relatively large, but is more important for the assessment of subjects whose absolute frontal plane motion of the heel is small. These exceptions also highlight the fact that the leg is able, if permitted, to evert relative to an everting heel. This presumably occurs by inversion of the leg at the ankle joint.

The experimental rig designed for this study was intended to prevent the leg moving in the frontal and sagittal planes whilst permitting unrestricted motion of the leg in the transverse plane. The small amounts of frontal and sagittal plane movements of the leg during transverse plane rotation of the leg indicate that it has achieved this to a degree that could not be improved upon. It could not realistically be expected to restrict frontal and sagittal plane motion to 0° in vivo. The small movements in the sagittal and frontal planes are probably a necessary part of a living subject moving their whole body in order to rotate through their range of transverse plane leg rotation, whilst maintaining their postural stability. In restricting frontal and sagittal plane motion to 0° the experimental rig would have interfered with the subjects natural movement pattern. The variability in the pattern sagittal plane ankle/sub talar motion is thus a consequence of the methodological difficulties associated with assessing small ranges of movement in vivo.

5.3.5.2 Dynamic phase – ranges of motion.

The order of predominance in the mean range of ankle/sub talar complex motion during the dynamic phase was transverse, frontal and sagittal plane motion. Transverse plane motion was the predominant motion during the dynamic phase in all subjects (Table 5.6). In contrast to the pattern in the mean data, some subjects displayed more sagittal than frontal plane motion. In all of these instances the range of frontal plane motion was much smaller than the mean value and the range of sagittal plane motion was close to the average. Thus, as in the composite phase, these subjects displayed almost solely transverse plane motion at the ankle/sub talar complex.

The direction of transverse plane ankle/sub talar complex motion during the dynamic phase was, as in the composite phase, always positive. The direction of frontal plane motion was generally positive, with the exception of the left ankle/sub talar complexes of subjects 3, 11 and 16. In each of these instances the motion of the heel was smaller than average and the frontal plane motion of the leg larger than average. The net result of this is that the heel inverts relative to the leg during internal leg rotation and everts relative to the leg during external leg rotation, even though the heel is actually everting and inverting during the respective transverse plane rotations of the leg. As in the composite phase the direction of sagittal plane motion was highly variable within the sample.

5.3.5.3 Supination phase – ranges of motion.

The order of predominance in the mean range of ankle/sub talar complex motion during the supination phase was transverse, frontal and sagittal plane motion. There was only one exception to this, the right ankle/sub talar complex of subject 3, which displayed more sagittal than frontal plane motion (Table 5.6). Again, in this subject the range of frontal plane motion was much smaller than the mean value and the range of sagittal plane motion was close to the average.

The direction of transverse plane ankle/sub talar motion was positive in all subjects during the supination phase. The direction of frontal plane motion was positive in all subjects with the exception of the left ankle/sub talar complex of subject 3. As in the composite and dynamic phases, the motion of the heel in this instance was smaller than average and the frontal plane motion of the leg larger than average. The direction of sagittal plane motion was again highly variable within the sample.

5.3.5.4 Pronation phase – ranges of motion.

The order of predominance in the mean range of ankle/sub talar complex motion during the pronation phase was transverse, frontal and sagittal plane motion. There were several subjects who displayed more sagittal than frontal plane motion, with transverse plane motion predominant (Table 5.6). As in the composite, dynamic and supination phases, in all these instances the range of frontal plane motion was much smaller than the mean value and the range of sagittal plane motion was close to the average.

The direction of transverse plane ankle/sub talar complex motion was always positive. The direction of motion in the frontal plane was generally positive, though there were nine subjects who displayed negative frontal plane ankle/sub talar motion during the pronation phase. The direction of sagittal plane ankle/sub talar complex motion was, as in the other phases, highly variable, with 42% of the sample displaying negative rotation in contrast to the mean pattern of positive rotation.

5.3.5.5 Axis of rotation.

The axis of rotation of the ankle/sub talar complex calculated from the mean composite range of motion was orientated upwards and close to the sagittal plane, from posterior to anterior. The right limb axis was orientated medially and the left limb axis orientated laterally (Figure 4.7). The actual difference in the ranges of motion between the left and right limbs responsible for this gross difference in axis orientation was just 1.5°. Even differences as small as this can have a significant effect on the axis orientation if the difference is large as a proportion of the total range of motion, as it was in this case. The fact that the right limb axis had a positive angulation to the sagittal plane and the left a negative angulation, is because the direction of sagittal plane motion for the right was 0.1° of dorsiflexion and for the left was 1.4° of plantarflexion. Such minimal differences can be explained by the absolute movement of the leg in the sagittal plane affecting the net sagittal plane ankle/sub talar complex motion. The angulation of the ankle/sub talar axis to the sagittal plane varied between –86.8° (left ankle/sub talar complex, pronation phase of subject 1) to 88.3° (right ankle/sub talar complex, pronation phase of subject 17).

The angulation of the ankle/sub talar axis to the transverse plane was consistently high, ranging from 53.2° (left ankle/sub talar complex, dynamic phase of subject 19) to 88.9° (right ankle/sub talar complex, dynamic phase of subject 3), and reflects the predominance of transverse plane motion at the complex. This angulation of the axis is greater than that of the sub talar joint. This reflects the greater range of transverse plane motion available at the combined ankle and sub talar joints and suggests that the ankle joint is moving a considerable degree in the transverse plane.

The literature describes a variety of functional characteristics for the sub talar joint, including those that display more transverse than frontal plane motion and those that display more frontal than transverse plane motion. These variations in the predominant motion at the sub talar joint have been evident in all studies of the sub talar joint characteristics, which have generally involved samples much smaller than the sample in this investigation. It is reasonable to assume, therefore, that the group investigated in this study will also possess such variations in characteristics of the sub talar joint. The results of the absolute motion of the heel have already suggested that the sample investigated in this study contains variations in the characteristics of the sub talar joint that are consistent with the literature (5.3.3.1). Assuming this is the case, then some deductions can be made about the transverse plane motion at the ankle joint.

Some subjects, for example the right ankle/sub talar complex of subjects 12, 21 and 24 and the left ankle/sub talar complex of subjects 8, 12 and 18, displayed at least half as much frontal plane ankle/sub talar complex motion as there was transverse plane motion during the composite phase (the ratio value of transverse to frontal plane motion was less than 2). Since the principal source of frontal plane motion at the ankle/sub talar complex is the sub talar joint (Rosenbaum et al 1998), and within the sample these subjects display the largest range of frontal plane motion, then these individuals probably possess a sub talar joint that displays more frontal than transverse plane motion. If this is the case, then the ankle joint must typically be moving approximately 15° in the transverse plane. For example, the right ankle/sub talar complex of subject 12 displays 19° of motion in the frontal plane and 30° of motion in the transverse plane. It should be remembered that the range of frontal plane sub talar motion would be larger than 19° because the talus would have moved in the frontal plane in the opposite direction to the heel. If the majority of the 19° of frontal plane ankle/sub talar complex motion occurred at the sub talar joint (say 17°), which is likely, and this individual has a sub talar joint that possesses more frontal plane motion than transverse (so the transverse plane sub talar motion was no more than say 15°), then the ankle of this subject must move approximately 15° - 20° in the transverse plane. By the same reckoning the other subjects who possess a sub talar joint that displays more frontal than transverse plane motion, must have 10° to 15° of transverse plane motion at their ankle.

In contrast, some subjects displayed very little frontal plane motion at their ankle/sub talar complex, even allowing for the effect of the absolute motion of the leg in the frontal plane on the net ankle/sub talar complex motions. For example, the right ankle/sub talar complex of subjects 3, 9, 11 and 17 and the left ankle/sub talar complex of subjects 3, 9, 11, 14, 17 and 22 displayed at least seven times as much transverse plane motion than frontal plane motion during the composite phase (the ratio value of transverse plane motion to frontal was at least 7). Again, because it is reasonable to assume that the principal source of frontal plane ankle/sub talar complex motion is the sub talar joint, and within the sample these subjects display the smallest range of frontal plane motion, then these individuals probably possess a sub talar joint that displays more transverse than frontal plane motion. If this is the case, then the ankle joint must typically be moving 20° in the transverse plane. For example, the right ankle/sub talar complex of subject 11 displays 2.6° of motion in the frontal plane and 35° of motion in the transverse plane. It should be remembered that the range of frontal plane sub talar motion would be larger than 2.6° because the talus would have moved in the frontal plane in the opposite direction to the heel. Even if the range of frontal plane ankle/sub talar complex motion is low because of the frontal plane motion of the leg, the sub talar joint cannot realistically have moved more than 6°. If this individual has a sub talar joint that possesses more transverse plane motion than frontal (so the transverse plane sub talar motion is at least say 10°), then the ankle of this subject must move approximately 15° - 25° in the transverse plane. By the same reckoning the other subjects who possess a sub talar joint that displays more transverse than frontal plane motion, must have 10° to 20° of transverse plane motion at their ankle.

McCullough and Burge (1980) have described transverse plane rotations of this magnitude at the ankle joint. In their cadaver study eight ankles were vertically loaded up to 50kg and the maximum range of transverse plane ankle motion measured as the calcaneus was externally and internally rotated relative to the leg (the sub talar joint was fixed using screws). The mean range of transverse plane ankle motion was 17.5° (estimated from graph). Siegler et al (1988) described a mean of 26.5° of transverse plane motion at the ankles of 15 unloaded cadavers. Clearly then, the range of transverse plane motion through which the ankle might move, as suggested by the results of this study, are quite feasible.

If the range of transverse plane ankle joint motion suggested here is correct, then in general the ankle and sub talar joints contribute approximately equal amounts of transverse plane motion to the overall function of the ankle/sub talar complex. This is consistent with other literature that has assessed the ankle and sub talar joint separately. Siegler et al (1988) reported 14.3° of transverse plane ankle motion and 15.7° of transverse plane sub talar joint motion during internal rotation of the leg. Similar figures were reported for external rotation of the leg. Rosenbaum et al (1998) described a mean total of 11.1° of transverse plane motion at the ankle joint and 12.3° at the sub talar joint during transverse plane rotation of the leg.

The ability of the ankle joint to move in the transverse plane is clearly an important part of the kinematic chain which allows the leg and proximal structures to rotate in the transverse plane whilst the foot remains in a relatively fixed transverse plane position on the floor. This confirms the findings of other studies that have concluded that both the ankle joint and the sub talar joint are necessary parts of this mechanism and it is not solely a function of the sub talar joint.

5.3.5.6 Comparison of phases.

The principal difference between the phases was between the supination and pronation phases. During the pronation phase the range of frontal plane ankle/sub talar complex motion was reduced compared to the supination phase with a subsequent increase in the ratio of transverse to frontal plane motion (Figure 4.25 and 4.26). There were 81% and 83% (for the mean data for the right and left respectively) more transverse plane motion per degree of frontal plane motion in the pronation phase than in the supination phase. This pattern, however, was not wholly consistent throughout the sample. Figure 5.2 illustrates the differences between the ratio of transverse to frontal plane motion in the pronation and supination phases for the left limb of each individual in the sample. A negative value indicates that there was more transverse plane motion per degree of frontal plane motion in the supination phase than the pronation phase. A positive value indicates that there was more transverse plane motion per degree of frontal plane motion in the pronation phase compared to the supination phase. Clearly, although the majority had more transverse plane motion per degree of frontal plane motion in the pronation phase compared to the supination phase, not all subjects followed this pattern.

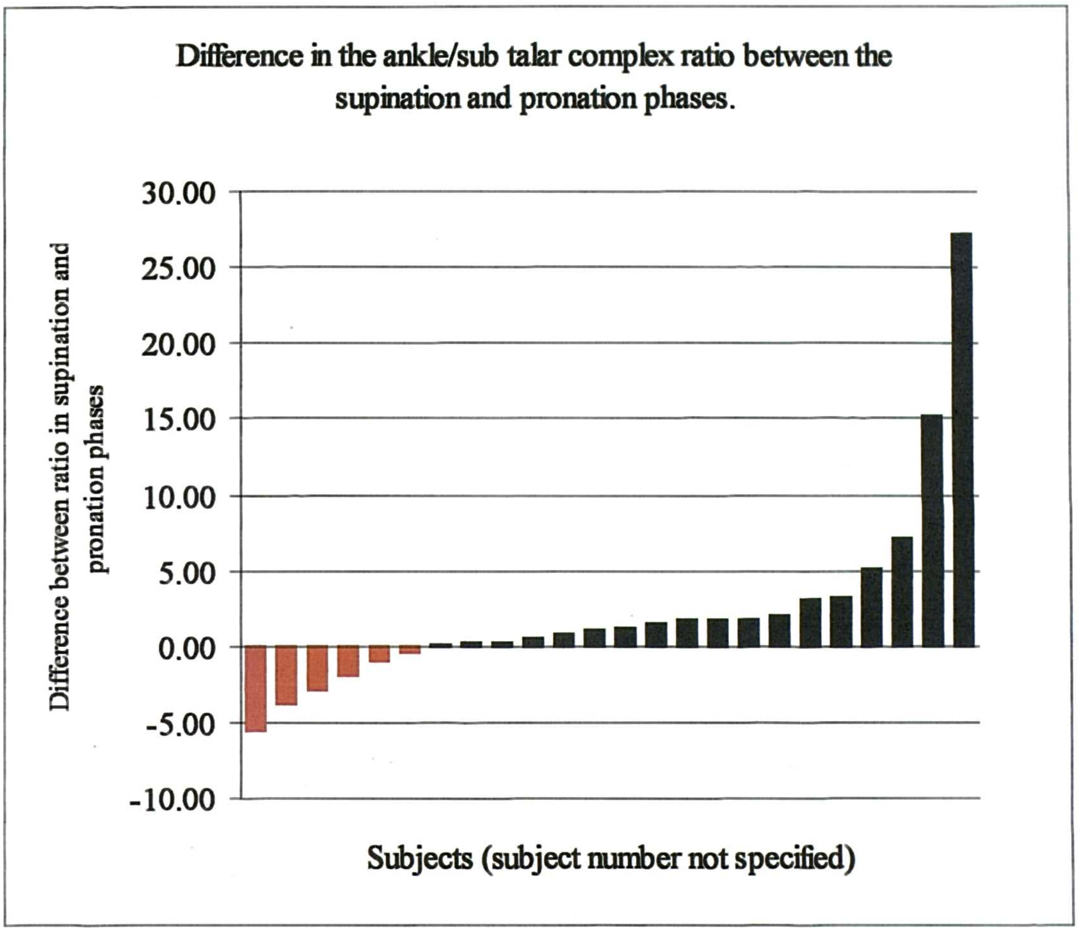


Figure 5.2

Graph illustrates the difference between the supination and pronation phases in the ratio of transverse to frontal plane motion. A negative value indicates more transverse plane motion per degree of frontal plane motion during the supination phase than the pronation phase. A positive value indicates more transverse plane motion per degree of frontal plane motion during the pronation phase than the supination phase – left limb only.

The general trend of an increase in the range of transverse plane motion per degree of frontal plane motion in the pronation phase compared to the supination phase is consistent with the literature. Hintermann et al (1994), for example, found that the resulting frontal plane motion of the heel was generally less when the leg was internally rotated compared to when it was externally rotated.

The relative contributions of the ankle and the sub talar joints to the range of transverse plane motion at the ankle/sub talar complex may differ in the supination and pronation phases. All the literature that describes the axis of rotation for the sub talar joint during different parts of its total range of motion, report that the axis is angled less to the transverse plane in pronation than in supination (Van Langelaan 1983, Benick 1985, Lundberg and Svensson 1993). Thus, the sub talar joint displays less transverse plane motion during the equivalent of the pronation phase in this study, than in the equivalent of the supination phase of this study. In addition, Lundberg et al (1989c) described a considerable reduction in the range of sub talar joint motion when the rearfoot was pronated, further reducing the contribution of the sub talar joint to the transverse plane motions at the ankle/sub talar complex during the pronation phase.

In contrast, Lundberg et al (1989a) described a relative increase in the transverse plane motion at the ankle joint during the equivalent of the pronation phase. Lundberg et al calculated the axes of rotation of the ankle joint during three phases of transverse plane rotation of the leg. The ankle joint axes relating to the pronation phase in this study were generally more vertically orientated than during the phase relating to the supination phase in this study. Thus, the proportion of transverse plane motion at the ankle was greater when the leg was internally rotated (pronation phase) than when it was externally rotated (supination phase).

In another publication Lundberg et al (1989c) described the changes in the range of transverse, frontal and sagittal plane motions in the ankle and sub talar joints during the transverse plane rotation of the leg. When the leg was externally rotated (equivalent of the supination phase in this study), the ankle joint displayed very little transverse plane motion, but considerable sagittal and frontal plane motion. When the leg was internally rotated (equivalent of the pronation phase in this study) the ankle displayed almost solely transverse plane motion.

The reason for the increased range of transverse plane ankle joint when the leg is internally rotated might be related to the anatomical shape of the talus. When the leg is internally rotated and the sub talar joint pronated the talus is plantarflexed relative to the tibia. The talus is narrower posteriorly than anteriorly. Thus, as it plantarflexes its freedom of movement within the ankle mortise increases and a greater range of transverse plane motion will be permitted.

5.3.5.7 Summary of the relative rotation at the ankle/sub talar complex.

- The predominant motion at the ankle/sub talar complex was always in the transverse plane.
- The second largest range of motion was usually in the frontal plane, though there were exceptions to this in each of the phases of leg rotation. When the sagittal plane motion is greater than the frontal plane motion it was because of a below

average range of frontal plane motion and the ankle/sub talar complex moves almost solely in the transverse plane.

- The direction of transverse plane motion was always external rotation of the heel relative to the leg during absolute internal rotation of the leg and internal rotation of the heel relative to the leg during absolute external rotation of the leg.
- The direction of motion in the frontal plane was generally eversion of the heel relative to the leg during absolute internal rotation of the leg and inversion of the heel relative to the leg during absolute external rotation of the leg.
- The small range of absolute motion of the leg in the sagittal plane produced a highly variable pattern of sagittal plane ankle/sub talar complex motion.
- The axis of rotation for the ankle/sub talar complex was always orientated upwards from posterior to anterior. The orientation of the axis of rotation relative to the sagittal plane was variable because of the variation in the direction of sagittal plane motion. Thus, in some individuals the axis was orientated upwards and medially and in other individuals it was orientated upwards and laterally.
- The principal difference between phases was the greater amount of transverse plane motion per degree of frontal plane motion in the pronation phase compared to the supination phase. This was due to a decrease in the range of frontal plane heel motion in the pronation phase compared to the supination phase.

5.3.6 RELATIVE ROTATION AT THE MID TARSAL JOINT.

5.3.6.1 Composite phase – ranges of motion.

The order of predominance in the mean range of mid tarsal joint motion during the composite phase was frontal, transverse and sagittal plane motion. There were considerable variations in the order of predominance within the sample. Table 5.7 lists the subjects whose mid tarsal joint displayed an order of predominance different than that of the mean data and the order of predominance that they displayed.

COMPOSITE PHASE	**Subject number and side**	
Order of predominance	**Right mid tarsal joint**	**Left mid tarsal joint**
T – F – S	3, 4, 5, 13, 16, 17, 24	2, 3, 4, 7, 13, 18, 19, 23
T – S – F	8	10, 21, 24
S – T – F	7	NONE
S – F – T	9	1
F – S - T	15	5, 22

Table 5.7

Lists the number of each subject whose mid tarsal joint displayed an order of predominance different than that of the mean data, and the order of predominance displayed. Subjects not listed displayed an order of predominance that was the same as that displayed in the mean data for the composite phase of motion (F – T – S).
T = Transverse plane, F = Frontal plane and S = Sagittal plane.

The fact that the most common order of predominance in table 5.7 is transverse, frontal and sagittal plane motion is not surprising since the values of frontal and transverse plane motion are very similar in the mean data (11.9° and 10.0° for the right and 11.8° and 11.2° for the left). Consequently, only a small amount of variation between subjects in the range of motion in these two planes will produce a change in the order of predominance. In such instances the order of predominance maybe misleading because it suggests the existence of a definite order. A more realistic interpretation would be that the ranges of motion are effectively equal and the order of predominance may be re written as frontal/transverse and sagittal plane motion.

The directions of frontal and transverse plane motion at the mid tarsal joint during the composite phase were always positive. Thus, the forefoot everted and externally rotated relative to the heel during absolute internal rotation of the leg and the forefoot inverted and internally rotated relative to the heel during absolute external rotation of the leg.

The direction of motion in the sagittal plane was relatively consistent with only the right mid tarsal joints of subjects 12 and 19 displaying negative rotation and all other subjects displaying positive rotation. Thus, the forefoot dorsiflexed relative to the heel during absolute internal rotation of the leg and plantarflexed relative to the heel during absolute external rotation of the leg.

There are no descriptions in the literature of the motions at the mid tarsal joint as it has been defined in this study as thus no data to which these patterns are directly comparable. Lundberg and Svensson (1993) described the rotations at the talonavicular joint during internal and external rotation of the leg and this provides a reasonable comparison. The order of predominance in the mean talonavicular data, as in this study, was frontal, transverse and sagittal plane motion. The range of frontal and transverse plane motion reported was similar to that reported here (frontal 15.5° and transverse was 14.6°) and the direction of motion at the talonavicular joint was identical to that described for the mid tarsal joint. Van Langelaan (1983) described adduction and inversion motion at the calcaneocuboid joint during external leg rotation. This too is identical to the results here.

5.3.6.2 Dynamic phase – ranges of motion.

DYNAMIC PHASE	**Subject number and side**	
Order of predominance	**Right mid tarsal joint**	**Left mid tarsal joint**
F –T – S	10, 11, 12, 20, 25	8, 9, 11, 12, 14, 15, 25
T – S – F	3, 7, 13, 14, 17, 24	3, 10, 13, 20, 21, 24
S – T – F	18	22
S – F – T	None	1
F – S - T	9, 15	5, 6

Table 5.8

Lists the number of each subject whose mid tarsal joint displayed an order of predominance different than that of the mean data, and the order of predominance displayed. Subjects not listed displayed an order of predominance that was the same as that displayed in the mean data for the dynamic phase of motion (T - F – S).
T = Transverse plane, F = Frontal plane and S = Sagittal plane.

The order of predominance in the mean range of mid tarsal joint motion during the dynamic phase was transverse, frontal and sagittal plane motion (Table 5.8). The actual difference between the range of motion in the transverse and frontal planes, however, was very small; 0.02° for the right and 0.3° for the left. Again, the ranges of transverse and frontal plane motion can be considered effectively equal and the order of predominance transverse/frontal and sagittal plane motion.

As would be expected with small differences in the range of motion in each plane there were 12 instances when the order of predominance was frontal, transverse and sagittal plane motion. There were a further 12 instances when the order of predominance was sagittal, frontal and transverse plane motion. As in the composite phase there are still further variations, with one subject displaying an order of predominance that was the opposite of the order of predominance in the mean data. In many cases the difference between the range of motion in the frontal and transverse planes was negligible.

The direction of motion during the dynamic phase was similar to that in the composite phase. The frontal and transverse plane motions were always positive and the sagittal plane motion was generally positive, with only two instances when the sagittal plane motion was negative.

5.3.6.3 Supination phase – ranges of motion.

The order of predominance in the mean range of mid tarsal joint motion during the supination phase was frontal, transverse and sagittal plane motion (Table 5.9). As in the composite and dynamic phases the actual differences between the range of frontal and transverse plane motion was very small, 0.6° for the right and 0.2° for the left. The order of predominance can be considered to be frontal/transverse and sagittal plane motion. Again, variations in the order of predominant motion were considerable. There were 16 instances when the order of predominance was transverse, frontal and sagittal plane motion, and further instances when the order of predominance was sagittal, transverse and frontal plane motion (the opposite of the order of predominance in the mean data).

SUPINATION PHASE	**Subject number and side**	
Order of predominance	**Right mid tarsal joint**	**Left mid tarsal joint**
T – F – S	1, 4, 5, 8, 16, 17, 19, 21, 22	4, 10, 17, 18, 19, 23, 24
T – S – F	7	2, 21
F – S – T	9, 11, 12	5, 6, 11, 12, 13, 25
S – T – F	2	22
S – F - T	18	1, 19

Table 5.9

Lists the number of each subject whose mid tarsal joint displayed an order of predominance different than that of the mean data, and the order of predominance displayed. Subjects not listed displayed an order of predominance that was the same as that displayed in the mean data for the supination phase of motion (T - F – S).
T = Transverse plane, F = Frontal plane and S = Sagittal plane.

The direction of frontal and transverse plane mid tarsal joint motion during the supination phase was always positive. The direction of sagittal plane motion was generally positive, with only five instances when the sagittal plane motion was negative.

5.3.6.4 Pronation phase – ranges of motion.

PRONATION PHASE	**Subject number and side**	
Order of predominance	**Right mid tarsal joint**	**Left mid tarsal joint**
T – F – S	3, 4, 10, 13	4, 6, 9, 16, 18, 21, 23
T – S – F	14, 24	3, 10, 13, 24
F – S – T	12, 15, 20, 22	1, 5, 17
S – T – F	7	None
S – F - T	5, 8, 9, 17	None

Table 5.10

Lists the number of each subject whose mid tarsal joint displayed an order of predominance different than that of the mean data, and the order of predominance displayed. Subjects not listed displayed an order of predominance that was the same as that displayed in the mean data for the pronation phase of motion (T - F – S).
T = Transverse plane, F = Frontal plane and S = Sagittal plane.

The order of predominance in the mean range of mid tarsal joint motion during the pronation phase was frontal, transverse and sagittal plane motion (Table 5.10). As in the composite, dynamic and supination phases the actual differences between the range of frontal and transverse plane motion was very small, 1.3° for the right and 0.4° for the left. The order of predominance can be considered to be frontal/transverse and sagittal plane motion. Again, variations in the order of predominance were considerable. There were 11 instances when the order of predominance was transverse, frontal and sagittal plane motion and further instances when the order of predominance was sagittal, transverse and frontal plane motion (the opposite of the order of predominance in the mean data).

5.3.6.5 Axis of rotation.

The axis of rotation for the mid tarsal joint calculated from the mean range of motion during the composite phase was orientated upwards and medially from posterior to anterior (Figure 4.8). The angle of the mid tarsal joint axis to the transverse plane varied between 70.0° (right mid tarsal joint, subject 3 pronation phase) and 15.9° (left mid tarsal joint, subject 1 dynamic phase). This range reflects the variations in the predominant motion already highlighted. The angle of the mid tarsal joint axis to the sagittal plane varied between 67.6° (right mid tarsal joint, subject 7 pronation phase) and –27.9° (right mid tarsal joint, subject 12 pronation phase).

There are no studies in the literature which describe an axis of rotation for the mid tarsal joint as it has been defined here. Thus, there are no studies to which these data are directly comparable. There are, however, several studies that have described the characteristics of the talonavicular and calcaneocuboid joints separately and the data from these studies is relevant.

The upward and medial orientation for the mid tarsal joint axis described in this study is consistent with the general orientation of the talonavicular and calcaneocuboid joint axes described by Van Langelaan (1983) and the talonavicular axis described by Lundberg and Svensson (1993).

In Van Langelaan's (1983) work based on 10 cadavers, the angle of the talonavicular axis varied from 3.8° to 21.4° (mean 14.1°) relative to the sagittal plane and 27.0° to 47.4° (mean 38.5°) to the transverse plane. The angle of the calcaneocuboid axes varied from –15.5° to 19.9° (mean 2.7°) relative to the sagittal plane and 43.3° to 72.0° (mean 51.9°) to the transverse plane. The axes of rotation for the talonavicular joint described by Lundberg and Svensson (1993) were for the rotation of the leg from an internally rotated position to their neutral position and from neutral to an externally rotated position. For the rotation from an internally rotated position to their neutral the axis was angled 7° to the sagittal plane and 27° to the transverse plane. For the rotation of the leg from neutral to an externally rotated position the axis was angled 22° from the sagittal plane and 34° from the transverse plane.

The angulation of the mid tarsal joint axis to the transverse plane (37° for the right and 38° for the left) is in reasonably consistent with the axes for talonavicular and calcaneocuboid joints (Figure 5.3). The principal difference between the results of this study and those of Van Langelaan (1983) and Lundberg and Svensson (1993) is that the angle of the mid tarsal joint axis relative to the sagittal plane (25.9° for the right and 32.2° for the left) is greater than that of the talonavicular and calcaneocuboid joint axes. This reflects either a smaller range of frontal plane motion at the mid tarsal joint compared to either the talonavicular or calcaneocuboid joints, or a greater range of sagittal plane motion. Both would have an identical effect on the angulation of the axis relative to the sagittal plane. Some additional sagittal plane motion might have been measured in this study if there was sagittal plane motion between the cunieforms and metatarsals. Thus, whilst the navicular and cuboid dorsiflex relative to the heel, the cunieforms and metatarsals dorsiflex relative to the navicular and cuboid. This would increase the vertical displacement of the marker mounted over the second metatarsal shaft and increase the range of sagittal plane motion measured at the mid tarsal joint. This is perhaps a limitation of the marker set used in this study, but it should be remembered that it was essential to extend the navicular and cuboid rigid body model to allow proper kinematic analysis to take place.

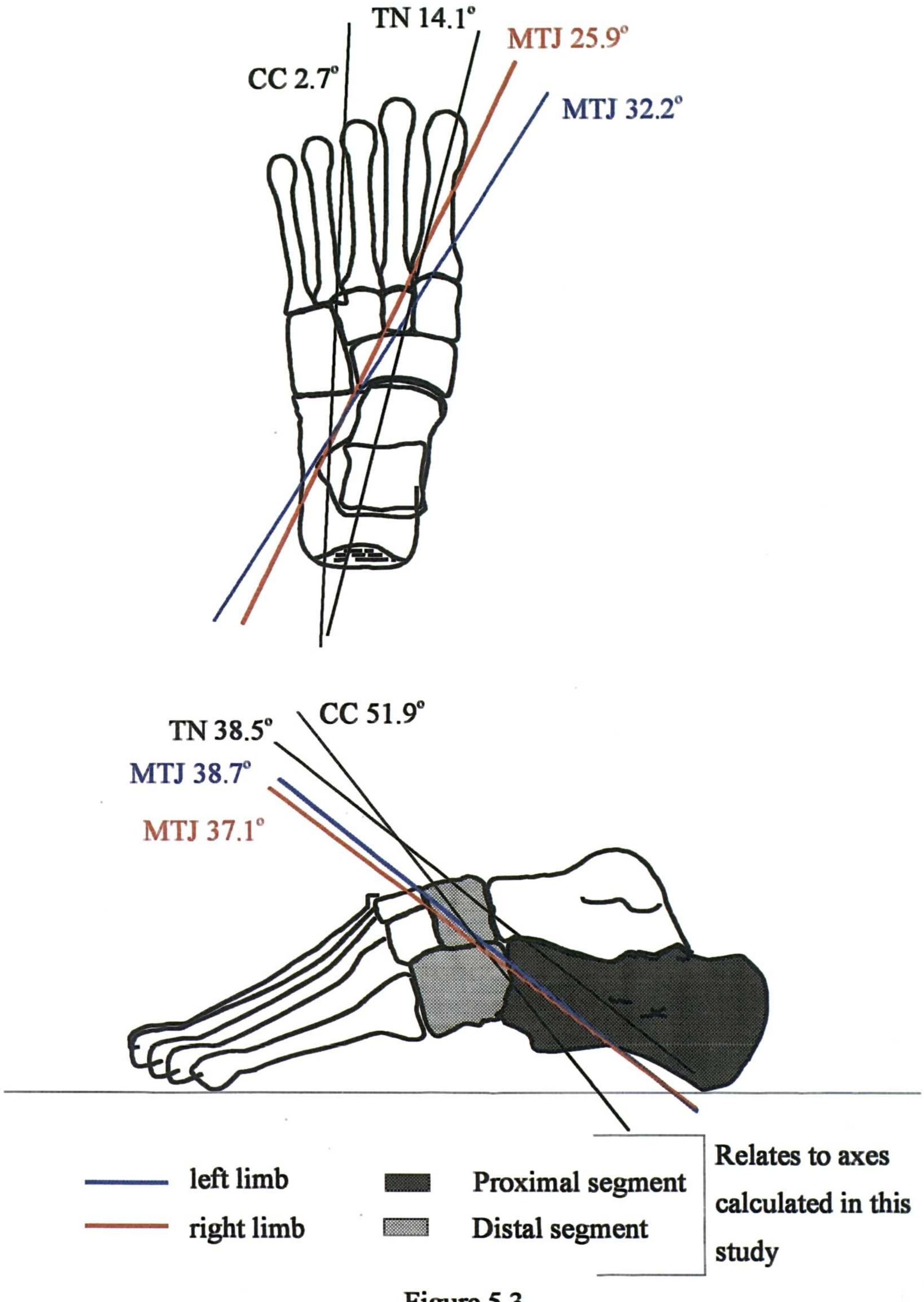


Figure 5.3

Mean axis of rotation of the left and right mid tarsal joint determined in this study and the axes of rotation for the talonavicular (TN) and calcaneocuboid (CC) joints calculated by Van Langelaan (1983), projected on transverse and sagittal plane images of a left foot (calculated from mean range of motion in 3 cardinal body planes). Angles relate to the angulation of the axis to the sagittal and transverse planes.

In the current literature there is no description of the axis of rotation for the mid tarsal joint determined in an acceptable scientific manner. The first description of the oblique axis was based on study of the articular surfaces of the joint (Elftman and Manter 1938). The longitudinal axis of the mid tarsal was based on a study of cadavers and the methodology used was not fully described (Manter 1941), though an illustration of the experiment questions the validity of the joint characteristics subsequently described. 'Confirmation' of the orientation of the oblique and longitudinal axes by Hicks (1953) is also of questionable scientific merit. The description provided here supersedes the description of the oblique and longitudinal axes of the mid tarsal joint in the literature because this description is based on a kinematic assessment, whereas the currently accepted model is based on conceptual motions (Figure 5.4). It is proposed, therefore, that the axes of rotation described here be adopted as the basis of the model of mid tarsal joint function.

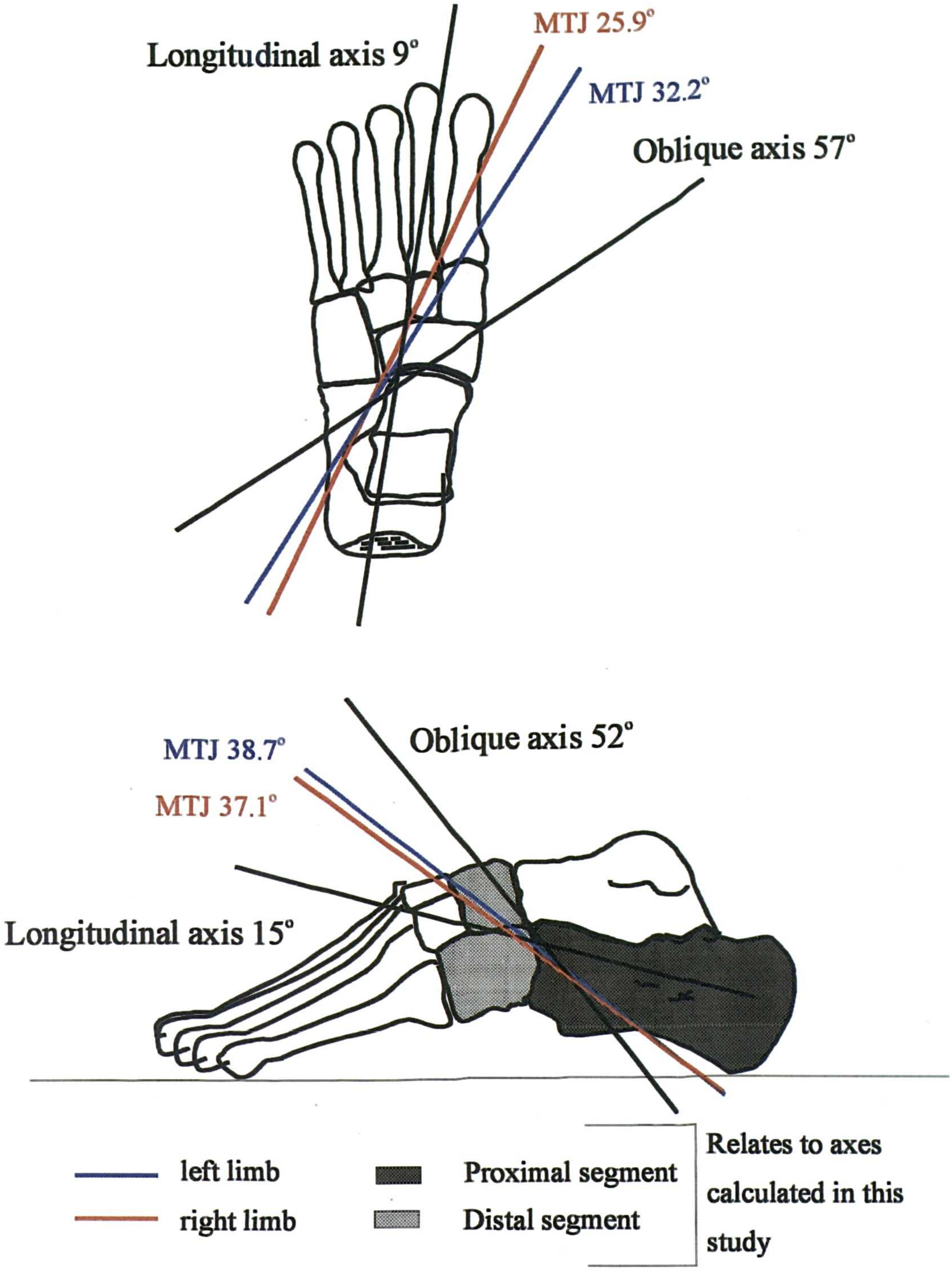


Figure 5.4

Mean axis of rotation of the left and right mid tarsal joint determined in this study and the conceptual axes of rotation described by Manter (1941), projected on transverse and sagittal plane images of a left foot (calculated from mean range of motion in 3 cardinal body planes). Angles relate to the angulation of the axis to the sagittal and transverse planes. Anatomical position was not calculated, and is assumed from work by Van Langelaan (1983), Benick (1983) and Lundberg et al (1989).

The head of the talus is convex in all directions and the talonavicular joint is somewhat like a ball and socket joint. To this extent it is able to move in almost any direction in which it is forced to move. When investigating the kinematic characteristics of this type of joint it is important to derive the kinematic data from experimental work involving the joint moving in as natural an environment and manner as possible. If the environment interferes with the natural motion pattern at the joint then the axis of rotation determined will be incorrect. Axes of rotation cannot be derived by assessing the contours of the articular surface in a joint with such a freedom of movement.

The in vivo experiment conducted in this study, when compared to those in the literature, provides a more natural environment. Thus the data is of greater relevance than previous studies describing the mid tarsal joint (Elftman and Manter 1938, Manter 1941). This in vivo assessment includes the natural limb to floor interface, normal weight bearing, inducement of rearfoot motion by transverse plane motion of the leg and some influence of muscles and ligaments on joint kinematics.

5.3.6.6 Comparison of phases.

The principal difference between the phases was between the supination and pronation phases. The ratio of transverse to frontal plane motion for the mean mid tarsal joint was relatively similar for the supination and pronation phases (Figure 4.27 and 4.28). This consistency, however, is not representative of the whole sample. For example, 12 of the 25 left limbs displayed more transverse plane motion per degree of frontal plane motion in the supination phase than the pronation phase. Twelve of the left limbs displayed more transverse plane motion per degree of frontal plane motion in the pronation phase than the supination phase. The range of transverse plane mid tarsal joint motion in one left limb (subject 14) was the same in the supination and pronation phases. This pattern is displayed in figure 5.5. Thus, the majority of individuals did have some differences between the supination and pronation phases, the difference between the phases was variable, and this was not evident in the mean data.

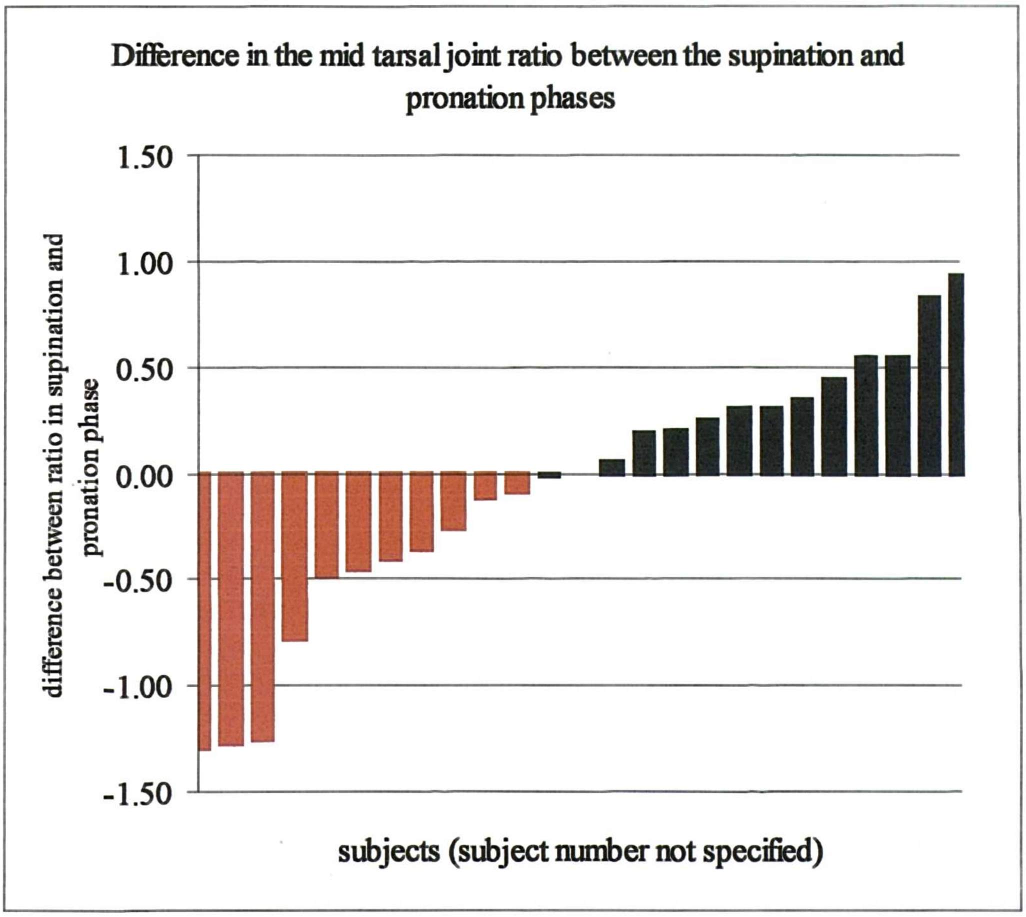


Figure 5.5

Graph illustrates the difference between the supination and pronation phasesin the ratio of transverse to frontal plane motion. A negative value indicates more transverse plane motion per degree of frontal plane motion during the supination phase than the pronation phase. A positive value indicates more transverse plane motion per degree of frontal plane motion during the pronation phase than the supination phase – left limb only

5.3.6.7 Summary of the relative rotation at the mid tarsal joint.

- The order of predominance in the mean range of mid tarsal joint motion was frontal, transverse and sagittal plane motion. However, more than 50% of the sample have an order of predominance that was different than this, typically transverse, frontal and sagittal plane motion. The ranges of transverse and frontal plane motion at the mid tarsal joint were generally very similar.
- The directions of frontal and transverse plane motions were always positive. Thus the forefoot everts and externally rotates relative to the heel during absolute internal rotation of the leg and inverts and internally rotates relative to the heel during absolute external rotation of the leg.
- The direction of motion in the sagittal plane was generally positive, with only a few exceptions in each phase of motion. Thus, the forefoot dorsiflexes relative to the heel during absolute internal rotation of the leg and plantarflexes relative to the heel during absolute external rotation of the leg.
- The axis of rotation for the mid tarsal joint was directed upwards and medially from posterior to anterior.

5.3.7 RELATIVE ROTATION AT THE REARFOOT COMPLEX.

Phase	Primary order of predominance	Other orders of predominance	
		F – T - S	T – S - F
Composite	T – F - S	R – 12 L – None	
Dynamic	T – F - S	R – 12 L – None	R – None L – 3, 16
Supination	T – F - S	R – 12 L – None	
Pronation	T – F - S	R – 12 L – None	R – 7, 8, 9, 11, 16 L – 16, 17

Table 5.11

Reference table. Details the primary order of predominance for the rearfoot complex and the other order of predominance displayed within the sample, for each phase of motion. Numbers relate to the individual subjects. F = frontal plane motion, T = transverse plane motion, S = sagittal plane motion. R = right, L = left.

5.3.7.1 Composite phase – ranges of motion.

The order of predominance in the mean range of rearfoot complex motion during the composite phase was transverse, frontal and sagittal plane motion. There was only one exception to this in the sample (Table 5.11). In this instance the range of frontal plane motion was more than twice the mean range and the range of transverse plane motion was close to the average.

The direction of frontal, transverse and sagittal plane motion during the composite phase was also very consistent. Without exception, the frontal, transverse and sagittal plane motions at the rearfoot complex were all positive. Thus, the forefoot everted, externally rotated and dorsiflexed relative to the leg during absolute internal rotation of the leg and inverted, internally rotated and plantarflexed relative to the leg during absolute external rotation of the leg.

There is no literature that describes the rotation of the forefoot relative to the leg as they have been defined in this study. The piece of work that most closely resembles this study was completed by Lundberg et al (1989c). They described the motion of the first metatarsal relative to the leg during external rotation of the leg from an internally rotated position. They too were attempting to describe the composite function of the rearfoot. The order of predominance for the motion between the metatarsal and leg, as in this study, was transverse, frontal and sagittal plane motion. The ratio of the motion in these three planes was also very close to that described in this study. For the total of 30° of external leg rotation the ratio of the motions described by Lundberg et al (1989c) was 1: 2.0: 0.5 (frontal: transverse: sagittal) compared to 1: 1.9: 0.3 and 1: 2.0: 0.3 for the right and left limbs in this study (composite phase).

The direction of motion between the first metatarsal and leg described by Lundberg et al (1989c) was also in agreement with that described in this study. The first metatarsal internally rotated, inverted and plantarflexed relative to the leg as the leg externally rotated.

5.3.7.2 Dynamic phase – ranges of motion.

The order of predominance in the mean range of rearfoot complex motion during the dynamic phase was also transverse, frontal and sagittal plane motion. There were three exceptions to this (Table 5.11).

As in the composite phase the direction of motion in the frontal, transverse and sagittal planes was consistently positive. There were, however, two subjects who displayed a pattern of negative rotation in the sagittal plane (right rearfoot complex of subject 21 and left rearfoot complex of subject 14). In both these instances the range of absolute sagittal plane forefoot motion was less than 1° and thus small sagittal plane movements of the leg will greatly influence the direction of sagittal plane rearfoot complex motion.

5.3.7.3 Supination phase – ranges of motion.

The order of predominance in the mean range of rearfoot complex motion data during the supination phase was also transverse, frontal and sagittal plane motion. Again the right rearfoot complex of subject 12 was an exception to this (Table 5.11). As in the other phases, the direction of motion in the frontal and transverse planes was always positive and in the sagittal plane was generally positive. The right rearfoot complex of subjects 1, 14, 19 and 21 and the left rearfoot complex of subjects 14, 17 and 23 all displayed negative sagittal plane motion.

5.3.7.4 Pronation phase – ranges of motion.

The order of predominance in the mean range of rearfoot complex motion data during the pronation phase was also transverse, frontal and sagittal plane motion. There were eight exceptions to this (Table 5.11). Seven subjects displayed an order of predominance of transverse, sagittal and frontal plane motion. In all these instances the range of frontal plane motion was considerably less than the average of approximately 8°, the range of sagittal plane motion was close to the average of approximately 3°. The right rearfoot complex of subject 12 displayed an order of predominance of frontal, transverse and sagittal plane motion.

The direction of frontal and transverse plane motion was again consistently positive within the sample. The direction of sagittal plane motion was generally positive, with only the right rearfoot complex of subjects 3, 11and 12 and the left rearfoot complex of subject 12 displaying negative motion.

5.3.7.5 Axis of rotation.

The axis of rotation for the rearfoot complex calculated from the mean ranges of motion was orientated upwards and medially (Figure 4.9). The angulation of the axis to the transverse plane varied between 42.5° (right rearfoot complex, subject 12 pronation phase) to 85.1° (left rearfoot complex, subject 11 pronation phase). The angulation of the axis to the sagittal plane varied between –52.7° (right rearfoot complex, subject 11 pronation phase) to 80.5° (left rearfoot complex, subject 16 pronation phase). The wide variation in the sagittal plane angulation is to be expected since the direction of sagittal plane motion was variable.

The only comparable data is from Lundberg et al (1989c). They measured the motion of the first metatarsal relative to the tibia during transverse plane motion of the leg. From the motion data documented, the axis of rotation for the total range of motion can be calculated as angled 61.7° to the transverse plane and 24.3° to the sagittal plane. These compare well with the means of 60.7° and 16.3° relative to the transverse and sagittal planes for the right and 62.7° and 17.6° for the left. The difference in the sagittal plane angle of the axis could be due to more sagittal plane motion being measured, probably at the first metatarsal medial cuneiform joint and at the navicular cuneiform joint.

5.3.7.6 Comparison of phases.

The principal difference between the phases was between the supination and pronation phases. There was an increase in the range of transverse plane rearfoot complex motion per degree of frontal plane rearfoot complex motion in the pronation phase compared to the supination phase (Figure 4.29 and 4.30). For the right limb, the mean rearfoot complex moved 2.1° in the transverse plane per 1° of frontal plane motion during the pronation phase, compared to 1.7° during the supination phase. For the left limb, the mean rearfoot complex moved 2.3° in the transverse plane per 1° of frontal plane motion during the pronation phase, compared to 1.8° during the supination phase. This pattern was reasonably consistent within the sample. Figure 5.6 illustrates the difference between the ratio of transverse to frontal plane motion in the supination and pronation phases.

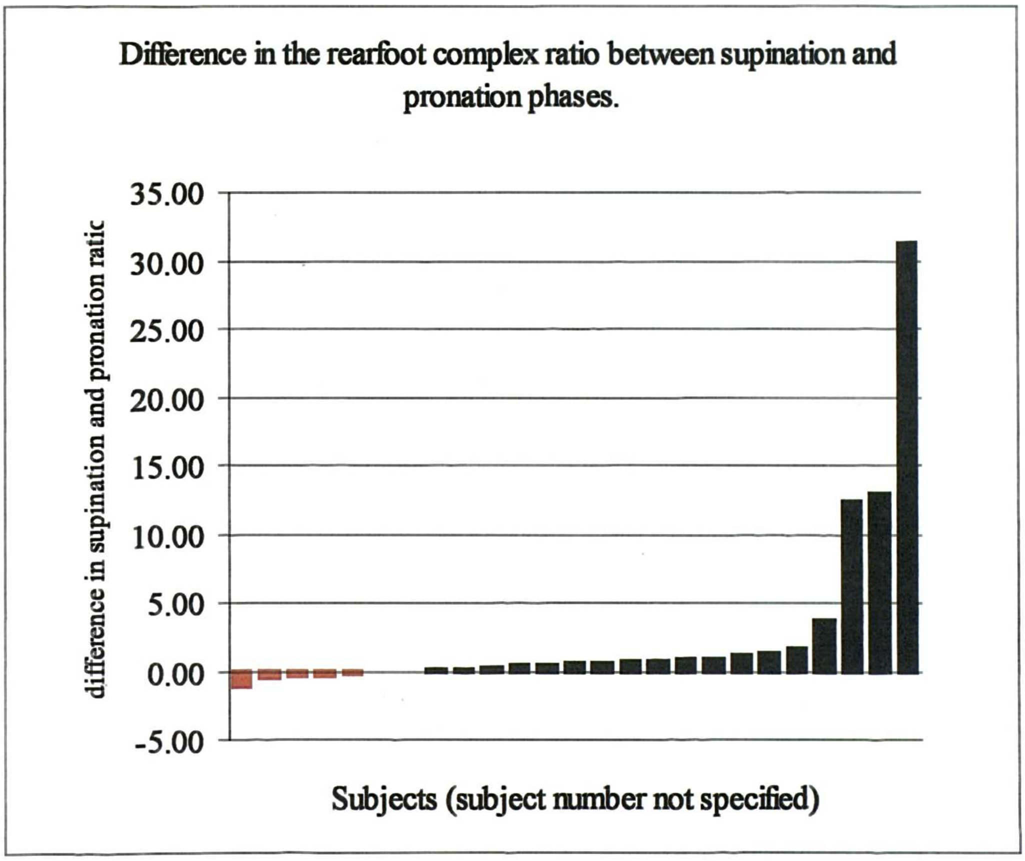


Figure 5.6

Graph illustrates the difference between the supination and pronation phases in the ratio of transverse to frontal plane motion. A negative value indicates more transverse plane motion per degree of frontal plane motion during the supination phase than the pronation phase. A positive value indicates more transverse plane motion per degree of frontal plane motion during the pronation phase than the supination phase – left limb only.

5.3.7.7 Contribution of the ankle/sub talar complex and mid tarsal joint to the functional characteristics of the rearfoot complex.

The rearfoot complex provides an overall description of the combined function of the ankle, sub talar and mid tarsal joints. The contribution of each component of the rearfoot complex to the overall function of the rearfoot provides some indication of the role and the importance of each joint within the complex. Tables 5.12 and 5.13 detail the contribution of the ankle/sub talar complex and mid tarsal joint to the frontal, transverse and sagittal plane motions of the rearfoot complex. These percentages were calculated from the mean range of motion during the composite phase of each joint movement.

RIGHT LIMB	Range of motion (degrees)		
	Frontal	Transverse	Sagittal
Ankle/sub talar complex	8.0	27.0	0.1
Mid Tarsal Joint	11.9	10.0	5.8
Rearfoot complex	19.9	37.0	5.8
Contribution of ankle/sub talar complex	40 %	73 %	1 %
Contribution of mid tarsal joint	60 %	27 %	99 %

Table 5.12

Table expresses the contribution of the ankle/sub talar complex and mid tarsal joint to the characteristics of the rearfoot complex as a percentage – right limb.

LEFT LIMB	Range of motion (degrees)		
	Frontal	Transverse	Sagittal
Ankle/sub talar complex	7.2	27.4	-1.4
Mid Tarsal Joint	11.8	11.2	7.5
Rearfoot complex	19.0	38.6	6.0
Contribution of ankle/sub talar complex	38 %	71 %	*
Contribution of mid tarsal joint	62 %	29 %	*

Table 5.13

Table expresses the contribution of the ankle/sub talar complex and mid tarsal joint to the characteristics of the rearfoot complex as a percentage – left limb. * Could not be calculated because of negative sign of ankle/sub talar complex motion.

Clearly, the ankle/sub talar complex is the principal source of transverse plane rearfoot complex motion and the mid tarsal joint is the principal source of frontal plane motion. This contradicts traditional descriptions of the motion in the rearfoot, which generally describes the sub talar joint as the principal source of frontal plane motion.

The ankle/sub talar complex contributes approximately 72% of the total transverse plane motion in the rearfoot complex. Siegler et al (1988) and Rosenbaum et al (1998) both described the ankle and sub talar joints as having equal contribution to the range of ankle/sub talar complex motion. If this is true, and applied to the results here, the ankle, sub talar and mid tarsal joints have similar contributions to the transverse plane motion of the rearfoot complex (approximately 36%, 36% and 28% for the ankle, sub talar and mid tarsal joints respectively). This is further confirmation that the mechanism that allows the leg and proximal structures to rotate in the transverse plane whilst the foot is in a relatively fixed transverse plane position of the floor is a consequence of all three rearfoot joints. Furthermore, the joints have near equal role in this mechanism.

The percentage contributions to the overall sagittal plane rearfoot complex motions are difficult to interpret, particularly for the left limb. It is clearly the case, however, that the principal source of sagittal plane motion in the rearfoot complex is the mid tarsal joint.

The percentage contributions of each of the components of the rearfoot complex confirm that the functional capacity of the rearfoot is a consequence of the motion at three joints and that each makes an important contribution to the overall function.

5.3.7.8 Summary of the relative rotations of the rearfoot complex.

- The order of predominance in the rearfoot complex during the composite, dynamic and supination phases was transverse, frontal and sagittal plane motion. This was the case for all but one subject, who displayed slightly more frontal plane motion than transverse.
- The order of predominance during the pronation phase was typically transverse, frontal and sagittal plane motion, but this was more variable within the sample due to a reduction in the range of frontal plane motion compared to the other phases. As a consequence the order of predominance was transverse, sagittal and frontal plane motion for some subjects.

- The direction of motion in the frontal and transverse planes was consistently positive. Thus, the forefoot everted and externally rotated relative to the leg during absolute internal rotation of the leg and inverted and internally rotated relative to the leg during absolute external rotation of the leg.
- The direction of sagittal plane motion was generally positive. Thus, the forefoot dorsiflexed relative to the leg during absolute internal rotation of the leg and plantarflexed relative to the leg during absolute external rotation of the leg.
- The axis of rotation for the rearfoot complex was consistently orientated upwards and medially from posterior to anterior.
- The amount of transverse plane motion per degree of frontal plane motion during the pronation phase was generally greater than during the supination phase.
- There was considerable variation within the sample in the ratio of transverse plane motion to frontal plane motion.
- The mid tarsal joint is the principal source of frontal plane motion and the ankle/sub talar complex is the principal source of transverse plane motion.
- The ankle, sub talar and mid tarsal joints probably have almost equal contributions to the transverse plane motion of the rearfoot complex.
- The rearfoot is a combination of three joints and each makes an important contribution to the overall function.

5.3.8 SUMMARY OF THE DIFFERENCES BETWEEN THE COMPOSITE, DYNAMIC, SUPINATION AND PRONATION PHASES OF MOTION.

The review of the literature describing the rearfoot joints in chapter 2 highlighted the fact that the characteristics of all of the rearfoot joints change during the total range of motion. It is important to know what these changes are and when they take place in order that a proper understanding of how the joints function can be established.

The ranges of motion and ratios of motion were different for each phase of rotation in each segment and joint complex. The constantly varying nature of the motion at the rearfoot joints is consistent with the literature (Van Langelaan 1983, Lundberg et al 1989a, Lundberg and Svensson 1989c). The principal differences were between the supination and pronation phases. The dynamic phases generally had characteristics that were in between those of the supination and pronation phase. Since the dynamic phase typically comprised part of the supination and part of the pronation phase this was not surprising. The functional characteristics of the composite phase were also in between those of the supination and pronation phases. Again this was expected since the composite phase is the combined supination and pronation phases.

At the ankle/sub talar complex the range of frontal plane motion during the pronation phase was reduced compared to the supination phase with a subsequent increase in the ratio of transverse to frontal plane motion. There was 81% and 83% more transverse plane motion per degree of frontal plane motion in the pronation phase than in the supination phase, for the right and left respectively (from mean data of composite phase).

At the mid tarsal joint the ratio of transverse to frontal plane motion in the mean data was relatively consistent between supination and pronation phases. This consistency, however, was not representative of the whole sample. Two patterns were evident in the data, with an even distribution within the sample. Some subjects displayed more transverse plane motion per degree of frontal plane motion in the supination phase than the pronation phase. Others displayed more transverse plane motion per degree of frontal plane motion in the pronation phase than the supination phase.

At the rearfoot complex there was an increase in the range of transverse plane rearfoot complex motion per degree of frontal plane rearfoot complex motion in the pronation phase compared to the supination phase. This pattern was reasonably consistent within the sample. This was due to the decrease in the range of frontal plane forefoot motion during the pronation phase compared to the supination phase.

It was intended that the functional characteristics described during the dynamic phase would be more representative of the motion during gait. Since the motion of the leg, heel and forefoot during gait was not determined, the degree to which the dynamic phase achieves this cannot be determined. The functional characteristics described during the dynamic phase cannot be used to directly represent the dynamic function of that individual anymore than the supination or pronation phase. This is because the assessment was static and this is a major limitation. The value of the dynamic phase is that it confirms that the characteristics of the motion during the part of the total range of motion used during gait are different than in the other phases (composite, supination and pronation). Clearly, for a conclusive description of the joint characteristics the particular part of the total range of motion used during walking must be assessed. The ultimate answer to this is a dynamic assessment of the ankle/sub talar complex, the mid tarsal joint and the rearfoot complex. This should be the focus for future work.

The definition of the supination and pronation phases is dependent upon the reference position. A different reference position would define different supination and pronation phases within the total range of motion. The relaxed standing position was chosen as the reference position for this study because it was believed to be more repeatable than other possible reference positions, in particular the sub talar joint neutral position. Other reference positions, such as aligning bisections of the posterior heel and leg parallel to each other using some mechanical alignment system, may have provided equal repeatability to the relaxed standing position. This would have produced descriptions of the functional characteristics of the rearfoot complex and its components during the supination and pronation phases that are different than those currently presented.

5.3.9 SUMMARY OF THE INDIVIDUAL VARIATIONS IN THE FUNCTIONAL CHARACTERISTICS OF THE REARFOOT.

The review of the literature describing the rearfoot joints in chapter 2 highlighted the fact that the characteristics of all of the rearfoot joints are variable between individuals. It is important to know in what manner the characteristics are variable and to what degree they are variable, so that the value of a description of the mean joint or complex can be put into context. For example, if the characteristics of the ankle/sub talar complex were constant within the sample, then the description of the mean ankle/sub talar complex could be reliably used to describe any of the individuals in that sample. However, if the characteristics varied greatly, then the description of the mean ankle/sub talar complex would not provide an accurate description of the ankle/sub talar complex of some of the individuals in the sample.

The order of predominance of the motions at the rearfoot joints provides a more general description of the functional characteristics and was frequently different between individuals. However, when the order of predominance was more consistent, such as at the rearfoot complex during the composite phase, the ratio of the motions highlighted considerable individual variations. Thus, both the order of predominance and the ratio of motion were important in describing the functional characteristics of the rearfoot joints and defining differences between individuals.

At the ankle/sub talar complex the order of predominance during the composite phase was reasonably consistent throughout the sample. Transverse plane motion was predominant for all subjects, however, the predominance of frontal plane motion over sagittal plane motion was variable between individuals. The ratios of transverse to frontal plane motion were highly variable. Some individuals displayed nearly equal amounts of transverse and frontal plane motion, others 10 to 25 times the range of frontal plane motion. This pattern was present in all the phases of motion and was generally due to changes in the range of frontal plane heel motion.

At the mid tarsal joint during the composite phase the order of predominance is variable, typically being either frontal, transverse and sagittal plane motion or transverse, frontal and sagittal plane motion. Within each of these sub groups there was further variation (Figure 5.7).

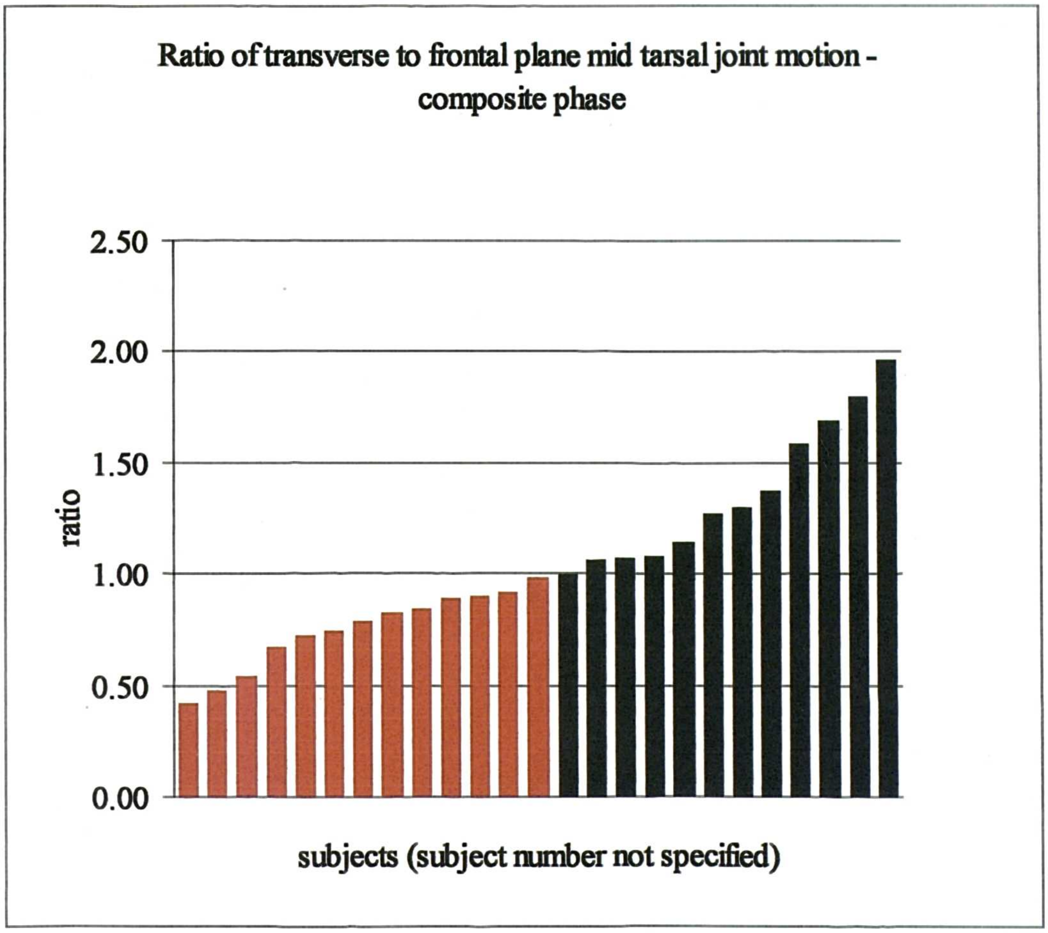


Figure 5.7

The ratio of transverse to frontal plane motion at the mid tarsal joint during the composite phase. Ratio of less than 1indicates more frontal plane motion than transverse, a ratio of greater than 1 indicates more transverse plane motion than frontal. There are two distinct sub groups, those with ratios less than 1, those with ratios greater than 1. Within these sub groups there is still further variation. Data for the left limb only

At the rearfoot complex the order of predominance during the composite phase was consistent within the sample, with only one exception (right rearfoot complex of subject 12). The ratios of transverse to frontal plane motion, however, illustrate considerable variations within the sample. Some subjects displayed only slightly more transverse plane motion than frontal plane motion, whilst others display up to 4 times the range.

As an illustration of the variation within the sample figures 5.8 and 5.9 detail the ratio of the range of motion in the frontal, transverse and sagittal planes for the ankle/sub talar complex and mid tarsal joints of subjects 2 (left and right limbs), 16 (left only) and 3, 7 and 12 (right limb only). Subjects 3 and 16 displayed 5.9° and 16.8 ° of transverse plane motion per degree of frontal plane motion at their ankle/sub talar complex respectively. These are very different than subjects 2, 7 and 12 who all displayed less than 2.7° per degree of frontal plane motion.

Data for mid tarsal joint of the same subjects illustrates further individual variation, but also that the existence of individual differences or similarities at one joint/complex does not necessarily relate to differences at other joints/complexes. The ankle/sub talar complex of subjects 2 (right limb) and 16 were markedly different (figure 5.8), their mid tarsal joints, however, were similar (figure 5.9). In contrast, the ankle/sub talar complex of subjects 7 and 12 were similar, their mid tarsal joints, however, were markedly different. Range of motion data for the ankle/sub talar complex, mid tarsal joint and rearfoot complex for each individual subject are detailed in figures 4.14 to 4.15.

In summary, there was no clear pattern in the variations between individuals. There were a wide variety of differences between individuals and between joints. Some subjects displayed the same predominance of motion at the ankle/sub talar complex, mid tarsal joint and rearfoot complex, others a mix of predominance at each joint/complex. Overall the results suggest wide ranging individual variation in the functional characteristics of the rearfoot joints consistent with the literature. Using mean values to describe the characteristics of a rearfoot joint may have limited application in clinical practice, because it is possible for patients to possess functional characteristics at their rearfoot joints which vary considerably from the mean.

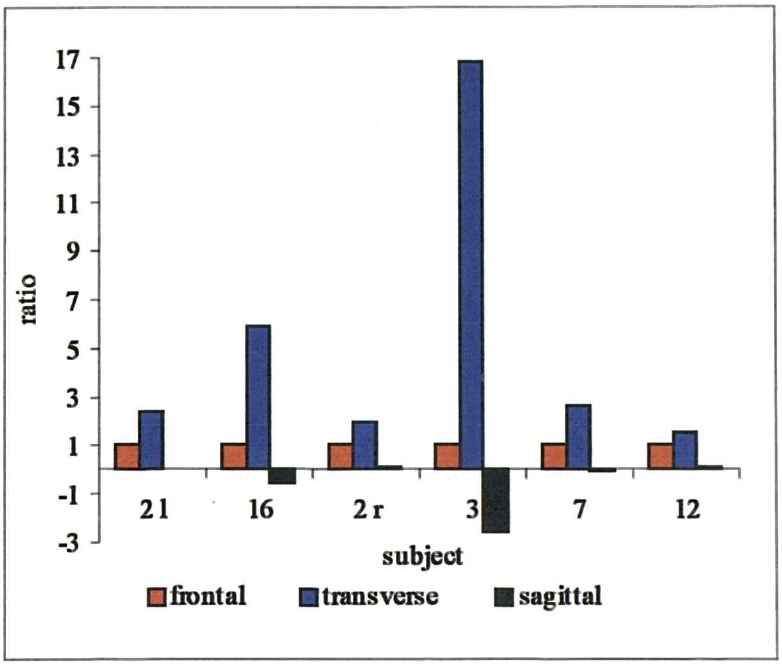


Figure 5.8

Details the ratio of frontal, transverse and sagittal plane ankle/sub talar complex motion for subjects 2, 16 (left limb only) and 2, 3, 7 and 12 (right limb only).

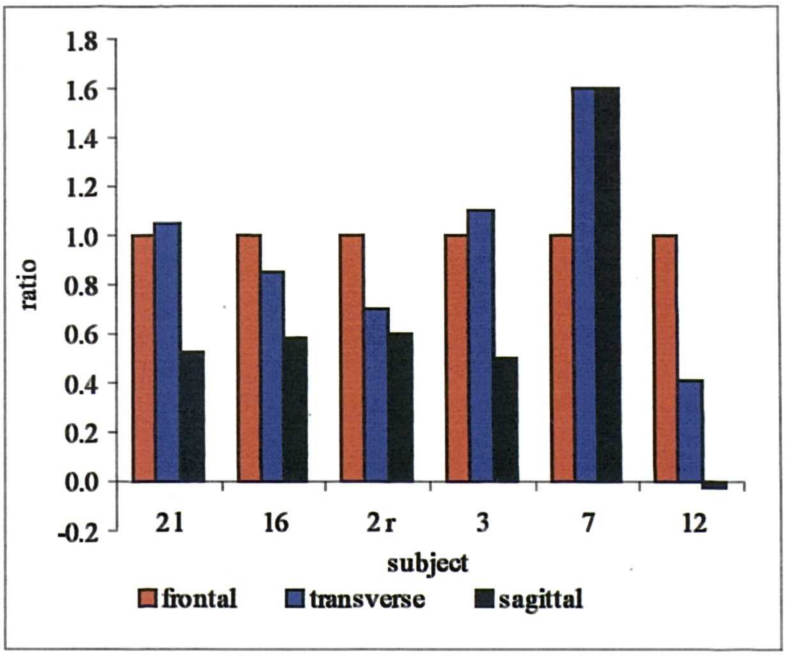


Figure 5.9

Details the ratio of frontal, transverse and sagittal plane mid tarsal joint motion for subjects 2, 16 (left limb only) and 2, 3, 7 and 12 (right limb only).

5.4 THE REARFOOT COMPLEX KINEMATIC CHAIN

This study has involved recording the motion of the leg, heel and forefoot and the ankle/sub talar complex, mid tarsal joint and rearfoot complex during transverse plane rotation of the leg. They provide a description of the kinematic coupling in the rearfoot joints. The following descriptions are taken as the general patterns displayed in the sample.

5.4.1 MOTION PATTERN.

During transverse plane rotation of the leg from an externally rotated position to maximally internally rotated:

- **The Heel:**

  everts, internally rotates and plantarflexes
- **The Forefoot:**

  everts, internally rotates and dorsiflexes
- **The Ankle/Sub talar complex:**

  everts, externally rotates and plantarflexes
- **The Mid Tarsal joint:**

  everts, externally rotates and dorsiflexes
- **The Rearfoot Complex:**

  everts, externally rotates and dorsiflexes.

During transverse plane rotation of the leg from a maximally internally rotated position to a position of external rotation:

- **The Heel:**

  inverts, externally rotates and dorsiflexes

- **The Forefoot:**

  inverts, externally rotates and plantarflexes

- **The Ankle/Sub talar complex:**

  inverts, internally rotates and dorsiflexes

- **The Mid Tarsal joint:**

  inverts, internally rotates and plantarflexes

- **The Rearfoot Complex:**

  inverts, internally rotates and plantarflexes.

There is an important difference between the description of rearfoot complex motion here and that given earlier in this thesis (section 2.3.1). The description in chapter 2 was based on theoretical descriptions of the rearfoot joints in the literature. It stated that during rearfoot complex pronation (internal rotation of the leg) the mid tarsal joint pronated around its oblique axis (everted, externally rotated and dorsiflexed) and supinated (inverted, internally rotated and plantarflexed) around the longitudinal axis. The description of mid tarsal motion recorded in this study indicates that the mid tarsal joint everts as the rearfoot complex pronates, not inverts as the previous description stated. The difference in the descriptions is due to the former being based on the conceptual oblique and longitudinal axes of the mid tarsal joint and the latter on the axes of rotation from kinematic analysis. This highlights the problem with the conceptual axes of the mid tarsal joint. Clearly, a joint cannot undergo opposite motions (inversion and eversion) at the same time, it either inverts or everts.

The reason why it was believed that the mid tarsal joint inverted was that as the heel everted during pronation and all the metatarsals became weight bearing, further eversion at the mid tarsal joint was thought to be impossible because this would mean the forefoot everting relative to the ground. It was known, however, that the heel continued to evert. Thus, if the heel everts and the mid tarsal joint ceases to evert then the relative motion between them is inversion. It has already been explained earlier in this chapter how the mid tarsal joint may continue to evert after all the metatarsal have become weight bearing, by rotation of metatarsals around their longitudinal axes in a lateral to medial rolling movement.

The primary importance of this is that the forefoot to rearfoot relationship (the frontal plane alignment of the metatarsals to the plantar surface of the heel) is not a function solely of the mid tarsal joint, as if often assumed. If it was and the mid tarsal joint everted after all the metatarsals were weight bearing (as this study suggests) then the forefoot would become everted relative to the floor. Instead, it is through motion of the cunieforms and the metatarsals that the mid tarsal joint is able to move without affecting the frontal plane position of the forefoot. It is by this mechanism that the mid tarsal joint everts during rearfoot complex pronation but the forefoot becomes inverted relative to the plantar surface of the heel.

5.4.2 AXES OF ROTATION.

The mean axis of rotation for the heel was orientated downward and laterally from posterior to anterior, with its downward angulation greater than its lateral angulation.

The mean axis of rotation for the forefoot was orientated slightly downwards and medially from posterior to anterior.

The mean axis of rotation for the ankle/sub talar complex was inclined upwards more than 45° and slightly laterally from posterior to anterior.

The mean axis of rotation for the mid tarsal joint was inclined upwards and medially from posterior to anterior, with its upward angulation slightly greater than its medial angulation.

The mean axis of rotation for the rearfoot complex was inclined upwards and slightly medially from posterior to anterior, with its upward angulation slightly less than that of the ankle/sub talar complex.

5.5 LIMITATIONS OF THIS WORK.

1. The principal limitation of this work is that the kinematic assessment was conducted in the static situation. This work supersedes several previous works because it was conducted non invasively in vivo, the limbs were loaded with each individuals own body weight, the motion was produced by motion of the leg relative to the foot and the influence of muscles and ligaments on the joint kinematics are included. It cannot, however, replicate the situation during walking. For example, this study did not take into account the effect of the sagittal plane motion of the leg over the foot, which occurs during normal walking, on the rotations in the rearfoot complex. In this investigation the sagittal plane position of the leg was fixed. The effect of the variations in the forces generated by the muscles of the foot and leg on joint kinematics are not included. Finally, the externally applied load (ground reaction force) on the limb was relatively constant in magnitude and direction, whereas during walking the external load on the limb varies in both magnitude and direction.

   Consequently, the kinematic description provided by this work must be put into context. It provides a description of the kinematics of the rearfoot complex joints under the constraints of the experimental protocol. The results here describe what the rearfoot complex joints are capable of, not necessarily what they do. Static assessment of this type cannot supersede an equivalent dynamic assessment.

2. The static nature of this assessment and the fact that the input to the rearfoot kinematic chain model was restricted to transverse plane motion of the leg, prevent any conclusions being applied directly to the clinical environment, which must be

the end goal of all biomedical related research. It was hoped that by using the data from the static assessment categories of patients could be developed, which would relate the functional characteristic of the rearfoot complex to pathology. However, without some knowledge of the relationship between the data from the static assessment and the dynamic function of the foot this is impossible. An inability to relate the findings of static assessments to dynamic foot function is a major limitation common to many of the investigations in this area.

3. The ranges of motion being measured at the segments and joints were frequently very small. A limitation of this is that the effects of any residual noise in the kinematic data and natural variations in motion patterns can produce highly variable orientations in the calculated axes of rotation. The sagittal plane movements of the heel for example are frequently below 1°. It would be inappropriate to describe the sagittal plane motion of the heel as plantarflexion or dorsiflexion when the range of motion is so small. Rather the description should be qualitative: the heel displays little or no motion in the sagittal plane.

4. The experimental rig designed to restrain the frontal and sagittal plane motion of the leg whilst it rotated freely in the transverse plane did perform this role adequately. However, in some instances when a larger than average range of sagittal or frontal plane motion of the leg was accompanied by a below average range of sagittal or frontal plane heel motion, the calculated range and direction of ankle/sub talar complex motion in the sagittal and frontal planes became falsified. In these instances the description does not provide a true description of the ankle/sub talar

complex motion resulting from transverse plane rotation of the leg. This was also the case for the descriptions of the rearfoot complex motion in some subjects.

5. Reflective markers mounted on the skin surface are intended to represent the position and motion of the underlying anatomical structures. Clearly, however, skin is able to move relative to the underlying structures. Reinschmidt et al (1997) found significant differences between the description of rearfoot motion during gait derived from bone mounted markers and that derived from skin surface mounted markers. The effects of skin movement on the kinematic description derived from gait are probably greater than those in this study. This is because the relative displacement between skin and underlying bone is probably greater the higher the velocity of movement, and the speed at which the movements in this study took place was much less than the speed of movements during gait. Without doubt, however, there was some movement of the markers relative to the underlying anatomy they are intended to represent. This was probably a greater problem with the leg mounted markers than those on the heel or forefoot because of the greater depth of soft tissue at this site.

6. Of greater influence on the position of the markers mounted on the forefoot relative to the underlying anatomy would be changes in the tension of the long extensor tendons on the dorsum on the foot. Contraction of the associated musculature will cause the tension in the tendons to increase and a relative bow string effect across the dorsum of the foot. This will move the forefoot platform on which the markers were mounted. Whilst subjects were instructed not to consciously use the muscles of the foot and leg to produce the rotational movements required, clearly subjects

would need some muscular activity to maintain postural balance and joint stability. Considering the small ranges of motion of the forefoot, particularly in the transverse and sagittal planes, the action of the underlying tendons might have influenced the eventual kinematic patterns.

7. The strict definition of the mid tarsal joint is the movement of the navicular and cuboid together relative to the calcaneus and talus. Ideally, then, to deduce the characteristics of the joint the movement of both components of the distal segment and both components of the proximal segment should be known. This study did measure the motion of both the navicular and cuboid. However, in the proximal segment only the motion of the calcaneus was deduced. Thus, the mid tarsal joint defined here is the motion of the navicular and cuboid together relative to the calcaneus. Whether this is different than if the motion was measured relative to both the calcaneus and talus is unknown. It is not possible to measure the motion of the talus in vivo unless invasive techniques are used. Furthermore, there is so much movement between the talus and calcaneus that even if the motions of both were known, it would be difficult to define them as a rigid body. This is more an issue relating to whether the mid tarsal joint exists, since it is a conceptual as opposed to anatomical joint defined for the purposes of modelling the kinematics of the foot.

8. This work involved the description of joint motions as they occur in the cardinal body planes defined by the global co-ordinate system. Angular rotations at each segment and joint complex were calculated relative to the axes of the global co-ordinate system because of the need to maintain the same rotation axes for the different rearfoot joints. This in contrary to the recommendations for the description

of joint kinematics specified by the International Society of Biomechanics (ISB) (Wu and Cavanagh 1995). They proposed the use of a joint co-ordinate system to describe the relative motion between two rigid body segments, each defined by a local co-ordinate system. The joint co-ordinate system defines the axes of rotation around which joint rotation angles are calculated. The joint co-ordinate system is derived from the medial/lateral axis of the proximal segment, the inferior/superior axis of the distal system and a floating axis that is perpendicular to the other two axes. The joint co-ordinate system method defines different axes of rotation for each joint and therefore the different components of the rearfoot complex would not be comparable. Not using the joint co-ordinate system method is a limitation because the data documented here will not always be directly comparable to other studies that, in the main, will adopt the recommendations of the ISB.

5.6 INNOVATIONS OF THIS WORK

1. A non invasive in vivo method for determining the functional characteristics of the rearfoot joints has been developed and tested. All previous kinematic assessments of this type have either been in vitro or have involved the use of invasive techniques in vivo. The results of his study are consistent with those of the in vitro and invasive in vivo studies. Two important concepts have been confirmed. Firstly, the rearfoot joints operate as a kinematic chain. Secondly, that the function of each joint is important in the overall function of the complex. In particular, the ankle, sub talar and mid tarsal joints appear to have almost equal contribution to the capacity of the rearfoot complex to allow the leg and proximal structures to rotate in

the transverse plane whilst the foot remains in a relatively fixed transverse plane position on the floor.

Depending on the precise aims of the study, the use of cadavers and the use of invasive techniques in vivo may not be necessary in future investigations. For example, there is a considerable volume of literature describing the effects of rearfoot surgery on rearfoot kinematics in cadavers. Using the methods described in this work the effect of a variety of surgical procedures on rearfoot kinematics could in future be carried out in a patient population, which would provide more meaningful data.

2. This investigation has provided the first description of the functional characteristics of the combined ankle, sub talar and mid tarsal joints during transverse plane rotation of the leg. Previous investigations have generally focused on individual joints or only the ankle/sub talar component of the rearfoot complex. These characteristics have been defined by the range of motion in each of the cardinal body planes, the ratio of the ranges of motion, the orientation of the axis of rotation for the rearfoot complex and the changes in the characteristics of the complex between the supination and pronation phases.

3. This study has provided a quantification of the functional characteristics of the mid tarsal joint defined as the motion of the navicular and cuboid relative to the heel. These characteristics have been defined by the range of motion in each of the cardinal body planes, the ratio of the ranges of motion and the orientation of the axis of rotation for the mid tarsal joint. Previous works have either determined an axis of

rotation for the mid tarsal joint without proper kinematic assessment or described axes for the separate talonavicular and calcaneocuboid joints. The axis of rotation determined in this study supersedes the conceptual oblique and longitudinal axes of rotation around which the current model of mid tarsal joint kinematics is based because it has been derived through kinematic assessment.

4. The range of motion used during gait has been identified within the total range of motion measured statically. Although the data within the dynamic phase of motion cannot directly describe the function of the rearfoot joints during walking, it has highlighted that the characteristics of motion during the phase are different than those in either of the supination, pronation and composite phases. Previous investigations have used arbitrary divisions of the total range of motion, in 10° increments of transverse plane leg rotation for example. The part of the total range of motion used during gait has not previously been identified within data from a static assessment.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 CONCLUSIONS.

1. An experimental design and methodology can be achieved to measure the functional characteristics of the rearfoot complex non invasively in vivo.

2. The joints of the rearfoot complex operate as a kinematic chain.

3. During internal rotation of the leg the heel everts, internally rotates and plantarflexes. During external rotation of the leg the heel inverts, externally rotates and dorsiflexes.

4. During internal rotation of the leg the forefoot everts, internally rotates and dorsiflexes. During external rotation of the leg the forefoot inverts, externally rotates and plantarflexes.

5. During internal rotation of the leg the ankle/sub talar complex everts, externally rotates and plantarflexes. During external rotation of the leg the ankle/sub talar complex inverts, internally rotates and dorsiflexes.

6. During internal rotation of the leg the mid tarsal joint everts, externally rotates and dorsiflexes. During external rotation of the leg the mid tarsal joint inverts, internally rotates and plantarflexes.

7. During internal rotation of the leg the rearfoot complex everts, externally rotates and dorsiflexes. During external rotation of the leg the rearfoot complex inverts, internally rotates and plantarflexes.

8. The axis of rotation for the ankle/sub talar complex is on average angled approximately 74° to the transverse plane. This is greater than the average angle made by the sub talar joint axis to the transverse plane and reflects the transverse plane motion available at the ankle joint.

9. The axes of rotation for the mid tarsal joint are on average angled approximately 29° to the sagittal plane and 38° to the transverse plane. These axes are different from, and supersede, the conceptual oblique and longitudinal axes previously accepted as the axes of rotation for the mid tarsal joint.

10. The axis of rotation for the rearfoot complex is on average angled approximately 17° to the sagittal plane and 61° to the transverse plane. This illustrates the considerable capacity for the rearfoot complex to allow the leg and proximal structures to rotate in the transverse plane whilst the foot remains in a relatively fixed transverse plane position on the floor.

11. The ankle, sub talar and mid tarsal joints have nearly equal contribution to the range of transverse plane motion available in the rearfoot complex.

12. All three joints are important in the mechanism which allows the leg and proximal structures to rotate in the transverse plane whilst the foot remains in a relatively fixed transverse plane position on the floor.

13. There was considerable variation within the sample in the functional characteristics of the ankle/sub talar complex, mid tarsal joint and rearfoot complex. The mid tarsal joint, however, was the most variable.

14. The most marked difference in the functional characteristics of the rearfoot complex components was between the supination and pronation phases. The ratios for the dynamic and composite phases are, as would be expected, generally somewhere in between the ratios for the supination and pronation phases.

15. The model of rearfoot complex function proposed in this thesis is limited because the input rotation to the rearfoot kinematic chain was restricted to transverse plane rotation of the leg. This prevents the results of the assessment of the model being applied in a dynamic situation, such as gait, because in such instances there are varied inputs to the kinematic chain, in particular the effects of ground reaction and muscular forces.

16. The methodology has highlighted differences between individuals that may allow categorisation of subjects. The ratio of the ranges of motion and the orientation of the axis of rotation are likely to be of greater value than the order or predominance as criteria for categorisation.

17. The issue of categorising patients according the functional characteristics of their rearfoot complex remains unresolved. This is because the relationship between the static measures taken in this investigation and dynamic lower limb function are unknown, and without this knowledge the parameters for categories of patients cannot be defined. The precise point at which the function of an individual's joint/joint complex is significantly different than another individual's is not clear, but is a key issue if categorisation is to be achieved.

6.2 FUTURE WORK.

The purpose of this study was to design a method that would allow the functional characteristics of the rearfoot complex to be determined, with a view to categorising individuals according to these characteristics. The next step in this process would be to determine whether the functional characteristics measured using this static assessment relate to the dynamic function of the rearfoot complex and the other joints in the lower limb. If they do, then the results of the static assessment may be a useful tool for categorising individuals. If they do not, however, then the results cannot be used as a basis upon which to categorise individuals. Furthermore, categories of rearfoot type could only be defined with some knowledge of at what point one rearfoot complex becomes sufficiently different to another to warrant separate consideration.

With regard to the description of the functional characteristics of the rearfoot joints, future work should incorporate two developments. Firstly, the computation of axes of rotation should involve helical axes. The principal reason for this is in an attempt to reduce the errors in the calculated positions of the axis. Helical axes are derived from the three dimensional segment data, not from ranges of motion in each plane. As explained in section 5.3.1.1 this prevents the already small ranges of motion being resolved into smaller components. These axes can also be derived for each instant in time and so a more complete picture of the changes in the functional characteristics of the rearfoot complex can be achieved.

Secondly, this work and that in the literature have completed almost all possible descriptions of the movements in the rearfoot joints in a static situation. Future work, therefore, should concentrate on dynamic assessment since this will provide the best description of the functional characteristics of the rearfoot joints. Some work along these lines has already been published (Siegel et al 1995, Rattanaprasert et al 1999), though neither describe the rearfoot complex as it has been defined here. A comparison of the static assessment performed here and a dynamic assessment using the same definition of the leg, heel and forefoot, would provide a valuable comparison of static and dynamic measures. This would enable the results of this and other static assessments to be put into context.

Having achieved a satisfactory description of dynamic rearfoot kinematics and the helical axes for the rearfoot joints only a kinetic description of the rearfoot would remain to be achieved. Despite a large volume of literature describing the kinematics of the rearfoot, little work has been carried out on the kinetics of the rearfoot. The difficulties with the three dimensional description of dynamic rearfoot motion will have hampered any kinetic description, since the kinematics must be derived if joint moments etc. are to be calculated. When combined with the dynamic rearfoot complex assessment and descriptions of the helical axes for the rearfoot joints, a kinetic description would complete the picture of the functional characteristics of the rearfoot complex.

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APPENDIX 1

A.1 INTRODUCTION.

Appendix 1 details the range of motion, standard deviations, axes of rotation, and the ranges of motion expressed as a ratio for each absolute (leg, forefoot and heel) and each relative (ankle/sub talar complex, mid tarsal joint and rearfoot complex) rotation of each limb of each subject. The data is further broken down into the four rotation phases: composite (comp); dynamic (dyn); supination (supi); and pronation (pron). The tables of the mean data are included for completeness. Tables A1.1 to A1.42 contain the data for the right limbs, tables A1.43 to A1.84 the data for the left limbs.

SUBJ	RIGHT LEG	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
1	comp	-1.4	-44.5	-2.2	0.6	2.6	0.4	-86.6	57.9	1.0	31.7	1.6
	dyn	-1.3	-21.0	-1.1	0.3	0.3	0.2	-85.4	40.0	1.0	16.3	0.8
	supi	-1.3	-20.7	-1.4	0.3	0.2	0.2	-84.7	48.6	1.0	16.3	1.1
	pron	-0.1	-23.8	-0.8	0.4	2.6	0.4	-88.0	80.4	1.0	176.6	5.9
2	comp	-2.0	-38.1	-0.4	1.1	2.7	0.8	-86.9	11.1	1.0	19.1	0.2
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	-1.4	-20.4	-0.4	0.6	0.3	0.5	-85.8	15.1	1.0	14.2	0.3
	pron	-0.6	-17.7	0.0	0.6	2.6	0.5	-88.2	0.2	1.0	31.9	0.0
3	comp	1.5	-41.3	1.8	0.7	2.4	0.7	-86.7	50.0	1.0	-26.8	1.2
	dyn	0.6	-18.3	1.3	0.6	0.1	0.2	-85.4	65.5	1.0	-30.0	2.2
	supi	0.2	-20.5	1.3	0.4	0.8	0.5	-86.2	81.6	1.0	-103.4	6.7
	pron	1.3	-20.7	0.5	0.8	1.9	0.3	-86.0	20.3	1.0	-15.5	0.4
4	comp	-0.3	-28.8	-2.0	0.6	2.0	0.3	-85.9	81.9	1.0	99.2	7.0
	dyn	-0.2	-14.3	-1.0	0.4	2.9	0.3	-85.9	79.7	1.0	78.6	5.5
	supi	0.1	-18.1	-1.2	0.4	2.7	0.3	-86.2	-86.7	1.0	-265.5	-17.6
	pron	-0.4	-10.8	-0.8	0.3	1.3	0.1	-85.1	67.1	1.0	30.0	2.4
5	comp	-2.8	-34.7	-0.3	0.4	2.4	0.3	-85.3	7.0	1.0	12.4	0.1
	dyn	-2.3	-21.1	0.6	0.3	0.4	0.4	-83.5	-15.2	1.0	9.1	-0.3
	supi	-2.5	-21.0	0.5	0.4	0.4	0.4	-83.1	-11.4	1.0	8.4	-0.2
	pron	-0.3	-13.7	-0.8	0.4	2.7	0.5	-86.2	70.4	1.0	45.5	2.8

Table A1.1

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right leg of subjects 1-5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT LEG	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
6	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
7	comp	-1.4	-36.7	-0.3	0.7	2.3	0.9	-87.8	12.4	1.0	26.5	0.2
	dyn	-1.4	-24.4	-0.2	0.5	0.4	0.5	-86.6	6.4	1.0	16.9	0.1
	supi	-1.6	-21.2	0.0	0.3	0.6	0.5	-85.7	-1.3	1.0	13.2	0.0
	pron	0.2	-15.5	-0.3	0.6	2.6	0.6	-88.5	-56.9	1.0	-69.8	-1.5
8	comp	-0.4	-34.8	-3.3	0.5	1.7	0.5	-84.6	82.6	1.0	82.0	7.7
	dyn	-0.9	-17.5	-1.3	0.4	2.4	0.3	-84.9	57.0	1.0	20.5	1.5
	supi	-1.2	-20.7	-1.4	0.3	0.3	0.3	-84.9	51.2	1.0	17.8	1.2
	pron	0.7	-14.1	-1.8	0.6	1.8	0.5	-82.0	-67.9	1.0	-19.0	-2.5
9	comp	1.1	-31.9	-0.9	0.3	1.0	0.4	-87.5	-40.0	1.0	-30.0	-0.8
	dyn	-0.1	-17.7	-0.5	0.3	0.3	0.3	-88.2	80.7	1.0	201.8	6.1
	supi	-0.3	-20.2	-0.8	0.4	0.2	0.4	-87.5	72.3	1.0	74.9	3.1
	pron	1.3	-11.7	-0.1	0.4	1.0	0.2	-83.5	-2.2	1.0	-8.8	0.0
10	comp	-0.4	-43.6	-2.1	0.3	1.2	0.7	-87.2	80.0	1.0	117.5	5.7
	dyn	0.1	-16.3	-0.7	0.2	2.8	0.6	-87.4	-81.2	1.0	-145.2	-6.5
	supi	0.3	-19.8	-1.3	0.3	1.4	0.9	-86.2	-74.9	1.0	-57.9	-3.7
	pron	-0.7	-23.8	-0.8	0.2	1.5	0.8	-87.4	49.5	1.0	33.4	1.2

Table A1.2

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right leg of subjects 6-10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT LEG	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
11	comp	1.1	-48.6	1.7	0.3	1.9	0.5	-87.5	56.9	1.0	-42.9	1.5
	dyn	0.2	-10.6	0.1	0.1	1.0	0.2	-88.8	28.0	1.0	-54.9	0.5
	supi	-0.7	-20.7	-0.1	0.2	0.2	0.2	-88.1	8.5	1.0	30.4	0.1
	pron	1.8	-27.8	1.8	0.4	1.7	0.5	-84.7	45.4	1.0	-15.3	1.0
12	comp	-3.3	-42.5	-0.2	0.6	3.3	3.5	-85.6	3.9	1.0	13.0	0.1
	dyn	-2.6	-29.0	0.0	0.4	0.6	2.3	-84.9	0.1	1.0	11.2	0.0
	supi	-0.9	-20.2	0.6	0.3	1.0	2.7	-86.8	-32.0	1.0	21.4	-0.6
	pron	-2.3	-22.4	-0.8	0.5	3.8	0.9	-83.7	19.2	1.0	9.6	0.3
13	comp	-1.7	-39.5	-1.5	0.9	1.0	1.0	-86.7	41.4	1.0	23.2	0.9
	dyn	-1.1	-16.3	-0.5	0.5	0.0	0.5	-85.8	25.9	1.0	15.3	0.5
	supi	-0.7	-20.8	-0.6	0.5	0.3	0.3	-87.4	40.6	1.0	29.6	0.9
	pron	-1.0	-18.7	-0.9	0.4	1.2	1.2	-85.9	42.0	1.0	18.7	0.9
14	comp	1.2	-53.9	-2.1	0.5	4.7	2.0	-87.4	-61.1	1.0	-46.4	-1.8
	dyn	0.2	-15.5	-0.8	0.4	0.3	0.2	-87.1	-77.7	1.0	-92.1	-4.6
	supi	0.3	-20.6	-0.9	0.4	0.1	0.3	-87.5	-72.3	1.0	-75.5	-3.1
	pron	0.9	-33.3	-1.3	0.6	4.7	2.0	-87.4	-54.6	1.0	-37.5	-1.4
15	comp	-0.8	-44.3	-2.4	0.5	3.3	0.8	-86.7	72.2	1.0	57.6	3.1
	dyn	-0.6	-17.0	-0.4	0.3	0.5	0.4	-87.7	31.4	1.0	29.2	0.6
	supi	-0.5	-20.6	-0.3	0.4	0.6	0.7	-88.4	30.6	1.0	42.3	0.6
	pron	-0.3	-23.7	-2.1	0.3	3.2	0.4	-84.9	82.4	1.0	84.2	7.5

Table A1.3

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right leg of subjects 11-15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT LEG	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
16	comp	1.0	-40.0	-0.9	1.3	1.8	1.2	-88.1	-41.5	1.0	-41.6	-0.9
	dyn	-0.3	-22.3	0.2	1.0	0.3	0.2	-89.1	-29.2	1.0	70.5	-0.6
	supi	-1.0	-20.4	0.2	0.5	0.4	0.3	-87.1	-11.4	1.0	20.4	-0.2
	pron	2.0	-19.6	-1.1	0.9	1.8	1.1	-83.5	-28.2	1.0	-10.0	-0.5
17	comp	3.9	-41.4	-0.3	0.4	0.9	0.8	-84.5	-4.2	1.0	-10.5	-0.1
	dyn	1.4	-13.6	0.1	0.3	0.2	0.3	-84.1	4.0	1.0	-9.8	0.1
	supi	2.5	-20.3	0.1	0.4	0.3	0.4	-82.9	3.0	1.0	-8.0	0.1
	pron	1.4	-21.1	-0.4	0.4	0.8	0.9	-86.0	-16.7	1.0	-15.1	-0.3
18	comp	-2.6	-38.3	-1.1	0.6	1.8	0.8	-85.8	22.5	1.0	14.9	0.4
	dyn	-1.9	-20.8	-0.8	0.5	0.4	0.5	-84.3	24.2	1.0	11.1	0.4
	supi	-1.8	-20.9	-0.8	0.5	1.0	0.5	-84.6	25.1	1.0	11.8	0.5
	pron	-0.8	-17.4	-0.2	0.5	1.4	0.5	-87.3	16.2	1.0	21.8	0.3
19	comp	0.9	-44.8	-0.2	0.2	3.9	0.2	-88.8	-9.2	1.0	-48.2	-0.2
	dyn	0.5	-17.1	-0.2	0.2	1.2	0.2	-88.2	-24.1	1.0	-34.7	-0.4
	supi	0.6	-20.5	-0.4	0.3	0.9	0.2	-87.9	-36.4	1.0	-33.5	-0.7
	pron	0.3	-24.4	0.3	0.3	3.3	0.3	-89.0	43.0	1.0	-76.0	0.9
20	comp	-0.3	-38.5	-2.0	0.3	2.4	0.5	-86.9	80.5	1.0	114.4	6.0
	dyn	-0.4	-14.2	-0.8	0.2	0.4	0.2	-86.3	65.3	1.0	37.6	2.2
	supi	-0.4	-20.9	-1.2	0.3	1.1	0.3	-86.5	70.2	1.0	49.1	2.8
	pron	0.1	-17.6	-0.8	0.3	3.1	0.3	-87.3	-83.9	1.0	-198.0	-9.4

Table A1.4

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right leg of subjects 16-20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT LEG	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
21	comp	-4.9	-49.2	-0.2	0.8	1.7	0.8	-84.3	1.8	1.0	10.0	0.0
	dyn	-1.1	-11.7	0.0	0.3	0.4	0.3	-84.6	-2.5	1.0	10.6	0.0
	supi	-1.8	-20.4	0.5	0.5	0.4	1.1	-84.9	-15.6	1.0	11.6	-0.3
	pron	-3.1	-28.9	-0.6	0.5	1.6	0.6	-83.6	11.7	1.0	9.2	0.2
22	comp	-1.9	-37.6	-2.4	0.2	1.4	0.5	-85.4	52.2	1.0	20.2	1.3
	dyn	-1.4	-20.7	-0.7	0.2	0.2	0.3	-85.8	26.9	1.0	15.3	0.5
	supi	-1.3	-20.3	-0.7	0.2	0.2	0.3	-85.7	27.4	1.0	15.2	0.5
	pron	-0.5	-17.3	-1.7	0.1	1.3	0.4	-84.1	73.0	1.0	33.1	3.3
23	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
24	comp	-2.7	-31.8	-0.8	0.3	1.6	0.6	-85.0	16.5	1.0	11.9	0.3
	dyn	-1.7	-15.3	-0.5	0.3	0.4	0.3	-83.5	16.7	1.0	9.1	0.3
	supi	-1.6	-17.8	-0.1	0.4	0.4	0.5	-84.7	4.1	1.0	10.9	0.1
	pron	-1.0	-14.0	-0.7	0.3	1.9	0.4	-84.9	33.1	1.0	13.5	0.7
25	comp	1.3	-41.6	-0.8	0.5	1.6	0.3	-87.9	-30.6	1.0	-32.5	-0.6
	dyn	0.2	-14.4	0.2	0.3	0.6	0.2	-88.7	48.3	1.0	-68.9	1.1
	supi	0.3	-19.0	0.3	0.4	1.7	0.3	-88.7	53.4	1.0	-73.6	1.3
	pron	1.0	-22.6	-1.1	0.3	0.8	0.4	-86.2	-47.2	1.0	-22.1	-1.1

Table A1.5

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right leg of subjects 21-25.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT LEG	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
MEAN	comp	-0.6	-40.3	-1.0	2.0	5.9	1.3	-86.5	23.7	-88.3	57.0	1.0	62.7	1.5
	dyn	-0.6	-17.7	-0.3	1.0	4.3	0.6	-86.2	16.8	-87.7	26.4	1.0	27.9	0.5
	supi	-0.6	-20.3	-0.4	1.1	0.9	0.7	-86.1	8.2	-87.9	28.7	1.0	31.7	0.5
	pron	0.0	-20.0	-0.6	1.3	5.7	0.8	-85.8	12.9	-88.2	89.8	1.0	8434.4	268.6

Table A1.6

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the right leg. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT LEG	Range of motion (rom) Frt	Trn	Sag	angle of axis to Trn	Sag
comp	MIN	-4.9	-53.9	-3.3	-88.8	-61.1
	MAX	3.9	-28.8	1.8	-84.3	82.6
	RANGE	8.8	25.0	5.1	4.5	143.7
dyn	MIN	-2.6	-29.0	-1.3	-89.1	-81.2
	MAX	1.4	-10.6	1.3	-83.5	80.7
	RANGE	4.0	18.4	2.7	5.6	161.9
supi	MIN	-2.5	-21.2	-1.4	-88.7	-86.7
	MAX	2.5	-17.8	1.3	-82.9	81.6
	RANGE	5.0	3.4	2.8	5.8	168.3
pron	MIN	-3.1	-33.3	-2.1	-89.0	-83.9
	MAX	2.0	-10.8	1.8	-82.0	82.4
	RANGE	5.1	22.5	4.0	6.9	166.3

Table A1.7

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the right leg of all subjects.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT HEEL	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
1	comp	6.6	-13.0	-1.6	2.1	1.8	0.9	-62.5	-13.6	1.0	-2.0	-0.2
	dyn	5.4	-5.3	-1.3	1.4	0.4	0.4	-43.7	-13.9	1.0	-1.0	-0.2
	supi	5.9	-5.6	-1.5	1.2	0.4	0.3	-42.5	-14.5	1.0	-0.9	-0.3
	pron	0.6	-7.4	0.0	1.4	1.6	0.6	-85.1	-4.4	1.0	-11.7	-0.1
2	comp	11.7	-10.6	0.8	0.8	1.6	2.4	-42.2	4.0	1.0	-0.9	0.1
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	6.0	-5.0	-1.3	0.5	0.4	0.8	-39.3	-11.9	1.0	-0.8	-0.2
	pron	5.7	-5.6	2.1	1.2	1.3	2.4	-42.8	20.0	1.0	-1.0	0.4
3	comp	2.9	-18.2	-1.7	1.3	2.2	0.5	-79.5	-30.7	1.0	-6.3	-0.6
	dyn	2.2	-7.8	-1.1	1.3	1.0	0.7	-72.5	-27.8	1.0	-3.6	-0.5
	supi	0.7	-10.0	-1.1	0.9	1.0	0.2	-82.6	-59.4	1.0	-15.1	-1.7
	pron	2.3	-8.3	-0.6	1.8	1.5	0.5	-74.2	-15.2	1.0	-3.7	-0.3
4	comp	2.3	-8.7	-1.1	1.2	1.4	1.0	-73.4	-26.1	1.0	-3.7	-0.5
	dyn	1.0	-4.4	-0.6	0.8	1.1	0.5	-74.5	-30.5	1.0	-4.2	-0.6
	supi	1.2	-5.6	-0.7	0.8	1.0	0.8	-75.7	-27.9	1.0	-4.5	-0.5
	pron	1.1	-3.2	-0.5	0.6	1.0	0.3	-69.4	-23.9	1.0	-2.9	-0.4
5	comp	5.0	-11.3	-3.8	0.8	0.6	0.4	-61.1	-37.7	1.0	-2.3	-0.8
	dyn	4.1	-7.1	-2.5	0.6	0.8	0.3	-56.0	-30.8	1.0	-1.7	-0.6
	supi	4.5	-7.0	-2.5	0.9	0.7	0.3	-53.8	-29.4	1.0	-1.6	-0.6
	pron	0.5	-4.3	-1.3	1.0	1.0	0.3	-72.3	-69.9	1.0	-9.1	-2.7

Table A1.8

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right heel of subjects 1-5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT HEEL	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
6	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
7	comp	8.2	-11.9	-0.9	1.7	1.0	0.2	-55.2	-6.5	1.0	-1.4	-0.1
	dyn	6.2	-7.6	-1.3	1.1	0.7	0.1	-50.2	-11.8	1.0	-1.2	-0.2
	supi	6.1	-7.2	-1.4	0.9	0.2	0.3	-49.3	-12.9	1.0	-1.2	-0.2
	pron	2.2	-4.7	0.4	1.6	0.9	0.4	-64.7	11.7	1.0	-2.2	0.2
8	comp	6.5	-13.6	-0.8	0.8	1.0	0.6	-64.1	-6.7	1.0	-2.1	-0.1
	dyn	4.3	-6.3	-0.3	1.2	0.9	0.7	-55.8	-3.7	1.0	-1.5	-0.1
	supi	5.6	-7.2	-0.4	1.0	0.4	0.6	-52.3	-4.2	1.0	-1.3	-0.1
	pron	1.0	-6.3	-0.4	1.2	0.8	0.8	-80.9	-20.5	1.0	-6.6	-0.4
9	comp	2.9	-10.0	-3.9	0.6	0.7	0.6	-63.9	-53.4	1.0	-3.4	-1.3
	dyn	2.2	-4.3	-1.7	1.1	0.4	0.4	-57.4	-37.1	1.0	-2.0	-0.8
	supi	3.2	-5.4	-1.7	1.3	0.4	0.4	-56.5	-28.6	1.0	-1.7	-0.5
	pron	-0.2	-4.6	-2.2	1.0	0.7	0.6	-64.1	83.9	1.0	19.4	9.4
10	comp	8.8	-16.6	-1.0	0.5	0.6	1.0	-61.9	-6.2	1.0	-1.9	-0.1
	dyn	2.6	-5.7	-0.3	0.9	1.0	0.3	-65.6	-6.7	1.0	-2.2	-0.1
	supi	3.6	-7.9	-0.8	0.6	0.6	0.4	-64.8	-12.1	1.0	-2.2	-0.2
	pron	5.2	-8.7	-0.2	0.3	0.7	0.7	-59.2	-2.0	1.0	-1.7	0.0

Table A1.9

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right heel of subjects 6-10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT HEEL	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
11	comp	3.8	-13.2	-1.8	0.5	0.5	0.5	-72.5	-25.1	1.0	-3.5	-0.5
	dyn	0.4	-2.5	-0.4	0.3	0.6	0.2	-78.0	-44.3	1.0	-6.6	-1.0
	supi	4.5	-6.4	-1.0	0.7	0.4	0.2	-54.5	-12.2	1.0	-1.4	-0.2
	pron	-0.7	-6.8	-0.8	0.6	0.5	0.3	-81.1	49.1	1.0	9.8	1.2
12	comp	16.0	-12.3	2.2	0.7	1.0	0.8	-37.4	7.9	1.0	-0.8	0.1
	dyn	12.0	-8.2	0.9	1.4	0.6	0.8	-34.2	4.1	1.0	-0.7	0.1
	supi	6.8	-6.4	-0.8	1.3	0.5	0.2	-42.8	-7.0	1.0	-0.9	-0.1
	pron	9.1	-5.9	3.0	1.3	1.2	0.7	-31.7	18.4	1.0	-0.7	0.3
13	comp	6.5	-12.9	0.2	0.4	1.1	0.8	-63.2	1.9	1.0	-2.0	0.0
	dyn	3.3	-4.7	0.0	0.7	0.9	0.2	-54.6	0.4	1.0	-1.4	0.0
	supi	4.4	-5.6	-0.3	1.2	0.5	0.2	-52.0	-3.5	1.0	-1.3	-0.1
	pron	2.1	-7.3	0.5	0.9	0.9	0.8	-73.2	12.6	1.0	-3.4	0.2
14	comp	6.2	-18.5	-4.3	1.1	0.7	0.3	-67.9	-34.7	1.0	-3.0	-0.7
	dyn	2.2	-7.4	-1.9	0.6	0.3	0.3	-68.3	-40.9	1.0	-3.3	-0.9
	supi	2.6	-9.9	-2.7	0.6	0.4	0.2	-69.1	-46.4	1.0	-3.8	-1.1
	pron	3.6	-8.7	-1.6	1.3	0.5	0.5	-65.8	-23.4	1.0	-2.4	-0.4
15	comp	4.5	-16.5	-3.5	0.9	0.9	0.6	-71.0	-37.9	1.0	-3.7	-0.8
	dyn	1.7	-5.0	-0.6	0.7	0.7	0.4	-69.9	-18.9	1.0	-2.9	-0.3
	supi	2.2	-6.2	-0.3	0.9	0.4	0.2	-70.5	-6.6	1.0	-2.8	-0.1
	pron	2.3	-10.2	-3.2	0.9	1.0	0.6	-68.9	-54.9	1.0	-4.5	-1.4

Table A1.10

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right heel of subjects 11-15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	HEEL	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
16	comp	3.5	-18.3	-2.4	2.6	1.9	1.4	-76.9	-34.2	1.0	-5.2	-0.7
	dyn	3.1	-9.7	-1.5	2.4	1.3	1.0	-70.8	-25.4	1.0	-3.2	-0.5
	supi	4.9	-9.0	-1.0	0.8	0.9	0.5	-60.7	-11.7	1.0	-1.8	-0.2
	pron	-1.4	-9.3	-1.4	1.8	1.1	1.2	-77.9	43.6	1.0	6.5	1.0
17	comp	5.0	-13.9	-1.7	0.9	1.2	0.8	-69.4	-18.5	1.0	-2.8	-0.3
	dyn	2.4	-3.9	-0.2	0.5	0.4	0.2	-58.6	-5.1	1.0	-1.6	-0.1
	supi	3.6	-7.1	-0.5	0.6	1.0	0.3	-63.1	-8.1	1.0	-2.0	-0.1
	pron	1.4	-6.7	-1.2	0.9	1.2	0.7	-75.1	-39.9	1.0	-4.9	-0.8
18	comp	9.5	-13.7	-0.2	1.3	1.1	1.0	-55.3	-1.4	1.0	-1.4	0.0
	dyn	6.0	-7.0	-0.8	0.9	0.4	0.5	-49.1	-7.7	1.0	-1.2	-0.1
	supi	6.1	-7.0	-0.8	1.0	0.6	0.3	-48.4	-7.7	1.0	-1.1	-0.1
	pron	3.4	-6.8	0.6	1.0	0.7	0.7	-63.2	9.9	1.0	-2.0	0.2
19	comp	11.1	-14.2	6.1	1.0	1.3	1.1	-48.2	29.0	1.0	-1.3	0.6
	dyn	3.8	-5.2	1.5	0.5	0.4	0.4	-51.5	21.3	1.0	-1.3	0.4
	supi	4.4	-6.7	1.4	0.8	0.5	0.6	-55.5	18.1	1.0	-1.5	0.3
	pron	6.7	-7.5	4.7	1.3	1.0	0.9	-42.4	35.1	1.0	-1.1	0.7
20	comp	5.1	-13.3	0.6	0.9	0.8	0.5	-68.9	6.7	1.0	-2.6	0.1
	dyn	2.0	-4.6	0.5	0.6	0.2	0.3	-65.9	15.2	1.0	-2.3	0.3
	supi	3.7	-6.9	0.7	0.9	0.4	0.2	-61.3	10.5	1.0	-1.9	0.2
	pron	1.4	-6.4	-0.1	0.9	1.0	0.5	-77.8	-3.6	1.0	-4.6	-0.1

Table A1.11

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right heel of subjects 16-20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT HEEL	Range of motion (rom) Frt	Range of motion (rom) Trn	Range of motion (rom) Sag	Standard deviation (rom) Frt	Standard deviation (rom) Trn	Standard deviation (rom) Sag	angle of axis to Trn	angle of axis to Sag	Ratio (rom) Frt	Ratio (rom) Trn	Ratio (rom) Sag
21	comp	19.4	-15.1	0.2	1.9	0.8	0.6	-37.8	0.6	1.0	-0.8	0.0
	dyn	4.0	-3.3	-1.1	0.5	0.3	0.2	-38.3	-15.5	1.0	-0.8	-0.3
	supi	8.1	-6.8	-1.7	0.8	0.5	0.2	-39.3	-11.7	1.0	-0.8	-0.2
	pron	11.3	-8.3	1.9	2.0	0.7	0.6	-35.9	9.5	1.0	-0.7	0.2
22	comp	3.9	-10.2	-1.0	0.3	0.6	0.5	-68.6	-14.4	1.0	-2.6	-0.3
	dyn	3.0	-5.5	-0.8	0.3	0.5	0.2	-60.4	-15.3	1.0	-1.8	-0.3
	supi	3.1	-6.2	-1.0	0.3	0.5	0.2	-62.3	-17.3	1.0	-2.0	-0.3
	pron	0.7	-3.9	0.0	0.3	0.3	0.5	-79.5	-1.5	1.0	-5.4	0.0
23	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
24	comp	9.9	-8.8	-0.6	1.1	1.1	0.3	-41.5	-3.7	1.0	-0.9	-0.1
	dyn	5.6	-4.1	-0.5	1.1	0.4	0.1	-36.0	-5.1	1.0	-0.7	-0.1
	supi	6.4	-5.4	-0.3	1.1	0.4	0.2	-40.4	-2.8	1.0	-0.9	0.0
	pron	3.6	-3.4	-0.3	1.0	1.0	0.2	-43.4	-5.4	1.0	-1.0	-0.1
25	comp	10.3	-10.6	-1.2	0.6	1.0	0.9	-45.6	-6.8	1.0	-1.0	-0.1
	dyn	5.2	-2.7	-0.1	0.5	0.5	0.4	-27.9	-0.8	1.0	-0.5	0.0
	supi	5.8	-4.7	-0.5	0.7	0.7	0.6	-38.9	-5.3	1.0	-0.8	-0.1
	pron	4.6	-6.0	-0.7	0.5	1.3	0.4	-52.2	-8.8	1.0	-1.3	-0.2

Table A1.12

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right heel of subjects 21-25.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT HEEL	mean Range of motion (rom)			Standard deviation (rom)			mean angle of axis to		Axis calculated from mean rom. angle of axis to		Ratio of mean rom		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Trn	Sag	Frt	Trn	Sag
MEAN	comp	7.4	-13.3	-0.9	4.3	2.9	2.2	-60.4	-13.4	-60.8	-7.2	1.0	-1.8	-0.1
	dyn	3.8	-5.6	-0.6	2.4	1.9	0.9	-56.3	-13.7	-55.5	-9.7	1.0	-1.5	-0.2
	supi	4.5	-6.8	-0.9	1.8	1.4	0.9	-55.5	-13.6	-55.9	-11.1	1.0	-1.5	-0.2
	pron	2.9	-6.5	-0.1	3.1	1.9	1.7	-64.4	0.9	-66.2	-1.0	1.0	-2.3	0.0

Table A1.13

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the right heel. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT HEEL	Range of motion (rom) Frt	Trn	Sag	angle of axis to Trn	Sag
comp	MIN	2.3	-18.5	-4.3	-79.5	-53.4
	MAX	19.4	-8.7	6.1	-37.4	29.0
	RANGE	17.1	9.8	10.4	42.1	82.4
dyn	MIN	0.4	-9.7	-2.5	-78.0	-44.3
	MAX	12.0	-2.5	1.5	-27.9	21.3
	RANGE	11.6	7.3	3.9	50.1	65.6
supi	MIN	0.7	-10.0	-2.7	-82.6	-59.4
	MAX	8.1	-4.7	1.4	-38.9	18.1
	RANGE	7.4	5.3	4.1	43.7	77.4
pron	MIN	-1.4	-10.2	-3.2	-85.1	-69.9
	MAX	11.3	-3.2	4.7	-31.7	83.9
	RANGE	12.8	7.1	7.9	53.4	153.8

Table A1.14

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the right heel of all subjects.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT FORFT	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
1	comp	20.1	-2.5	0.4	2.8	0.8	2.2	-7.1	1.1	1.0	-0.1	0.0
	dyn	11.2	0.6	-0.8	1.8	0.7	1.5	3.3	-4.3	1.0	0.1	-0.1
	supi	11.5	0.4	-2.2	1.6	0.6	1.7	1.8	-10.9	1.0	0.0	-0.2
	pron	8.7	-2.9	2.6	1.8	0.5	1.2	-17.6	16.6	1.0	-0.3	0.3
2	comp	24.0	-1.8	7.9	0.9	1.3	1.0	-4.0	18.2	1.0	-0.1	0.3
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	10.1	0.7	6.2	1.2	1.0	0.7	3.6	31.3	1.0	0.1	0.6
	pron	13.9	-2.5	1.7	1.4	0.8	0.5	-10.1	7.0	1.0	-0.2	0.1
3	comp	12.7	-7.8	3.1	0.8	0.6	0.7	-30.7	13.6	1.0	-0.6	0.2
	dyn	5.3	-3.1	2.8	1.4	0.7	0.8	-27.3	28.1	1.0	-0.6	0.5
	supi	9.0	-3.6	3.4	1.8	0.6	0.6	-20.5	20.7	1.0	-0.4	0.4
	pron	3.7	-4.2	-0.3	2.1	0.6	0.5	-48.3	-4.8	1.0	-1.1	-0.1
4	comp	8.9	0.0	3.5	1.7	0.7	1.4	0.0	21.7	1.0	0.0	0.4
	dyn	4.3	-0.2	1.8	1.1	0.6	0.9	-2.3	22.3	1.0	0.0	0.4
	supi	5.8	0.1	2.1	0.9	1.1	0.6	1.0	19.5	1.0	0.0	0.4
	pron	3.1	-0.1	1.5	1.0	0.4	1.1	-1.9	25.5	1.0	0.0	0.5
5	comp	15.5	-0.2	5.1	2.8	1.7	1.3	-0.8	18.3	1.0	0.0	0.3
	dyn	10.5	0.6	3.5	2.2	1.5	1.0	3.3	18.4	1.0	0.1	0.3
	supi	11.4	0.5	2.7	2.5	1.7	1.2	2.4	13.2	1.0	0.0	0.2
	pron	4.2	-0.7	2.5	1.4	0.5	0.5	-8.2	30.5	1.0	-0.2	0.6

Table A1.15

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right forefoot of subjects 1-5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT FORFT	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
6	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
7	comp	14.1	-2.5	8.6	2.2	1.3	0.9	-8.7	31.5	1.0	-0.2	0.6
	dyn	10.2	-0.4	5.1	1.9	1.7	0.6	-2.0	26.5	1.0	0.0	0.5
	supi	10.3	-0.2	4.2	1.4	1.3	0.6	-0.9	22.3	1.0	0.0	0.4
	pron	3.8	-2.4	4.4	2.0	0.3	1.2	-22.1	49.3	1.0	-0.6	1.2
8	comp	14.1	-3.9	7.6	1.3	0.7	0.8	-13.8	28.3	1.0	-0.3	0.5
	dyn	8.1	-0.2	3.5	2.0	0.5	0.9	-1.1	23.1	1.0	0.0	0.4
	supi	10.4	-0.1	4.2	1.5	0.6	0.7	-0.6	21.8	1.0	0.0	0.4
	pron	3.7	-3.8	3.4	1.9	0.7	1.1	-37.3	43.1	1.0	-1.0	0.9
9	comp	12.7	-3.4	6.5	1.2	0.6	0.9	-13.4	27.2	1.0	-0.3	0.5
	dyn	8.2	-1.5	3.0	1.8	0.5	0.5	-9.6	20.2	1.0	-0.2	0.4
	supi	10.0	-1.7	3.8	2.3	0.6	0.7	-9.2	20.9	1.0	-0.2	0.4
	pron	2.7	-1.7	2.7	1.3	0.4	0.8	-23.3	45.0	1.0	-0.6	1.0
10	comp	20.8	-5.3	4.5	1.8	1.4	1.5	-14.1	12.3	1.0	-0.3	0.2
	dyn	7.5	-1.6	1.0	2.1	0.9	0.4	-12.2	7.4	1.0	-0.2	0.1
	supi	9.8	-3.7	0.8	0.9	0.7	0.3	-20.7	4.5	1.0	-0.4	0.1
	pron	11.1	-1.6	3.8	1.2	0.9	1.4	-8.0	18.8	1.0	-0.1	0.3

Table A1.16

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right forefoot of subjects 6-10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT FORFT	Range of motion (rom) Frt	Range of motion (rom) Trn	Range of motion (rom) Sag	Standard deviation (rom) Frt	Standard deviation (rom) Trn	Standard deviation (rom) Sag	angle of axis to Trn	angle of axis to Sag	Ratio (rom) Frt	Ratio (rom) Trn	Ratio (rom) Sag
11	comp	16.7	-5.8	1.9	1.2	1.0	0.6	-19.0	6.4	1.0	-0.3	0.1
	dyn	2.9	-1.1	0.6	0.9	0.4	0.7	-20.2	12.6	1.0	-0.4	0.2
	supi	12.3	-2.3	3.5	0.6	0.7	0.4	-10.1	15.8	1.0	-0.2	0.3
	pron	4.4	-3.5	-1.6	0.8	0.7	0.7	-36.7	-19.8	1.0	-0.8	-0.4
12	comp	38.2	-3.4	1.7	3.4	1.5	1.8	-5.0	2.5	1.0	-0.1	0.0
	dyn	25.4	-2.2	3.8	3.1	1.6	1.1	-4.8	8.5	1.0	-0.1	0.1
	supi	17.2	-2.5	4.9	2.1	2.0	1.0	-8.0	15.9	1.0	-0.1	0.3
	pron	21.0	-0.9	-3.2	3.3	1.4	1.3	-2.4	-8.7	1.0	0.0	-0.2
13	comp	18.4	-0.9	8.4	2.2	0.7	1.7	-2.6	24.5	1.0	-0.1	0.5
	dyn	7.6	0.9	4.5	1.7	0.3	1.1	5.7	30.9	1.0	0.1	0.6
	supi	9.6	-0.6	3.3	1.4	0.4	0.6	-3.3	18.7	1.0	-0.1	0.3
	pron	8.7	-0.3	5.1	0.8	1.0	1.5	-1.9	30.3	1.0	0.0	0.6
14	comp	22.6	-4.8	4.0	1.2	0.8	1.1	-11.8	10.1	1.0	-0.2	0.2
	dyn	8.8	-2.3	-0.4	1.1	0.9	0.4	-14.8	-2.9	1.0	-0.3	-0.1
	supi	12.9	-4.3	-1.7	1.9	0.5	0.6	-18.4	-7.6	1.0	-0.3	-0.1
	pron	9.7	-0.5	5.8	1.6	0.9	0.9	-2.3	30.8	1.0	0.0	0.6
15	comp	21.0	-7.1	6.7	2.1	1.3	1.1	-17.9	17.8	1.0	-0.3	0.3
	dyn	7.1	-2.7	2.2	0.8	1.0	0.5	-19.7	17.3	1.0	-0.4	0.3
	supi	8.0	-2.3	2.1	0.9	1.7	0.5	-15.3	14.5	1.0	-0.3	0.3
	pron	13.0	-4.8	4.7	1.9	1.1	1.5	-19.3	19.8	1.0	-0.4	0.4

Table A1.17

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right forefoot of subjects 11-15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT FORFT	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
16	comp	14.8	-6.1	5.8	2.7	1.5	2.3	-21.0	21.2	1.0	-0.4	0.4
	dyn	8.8	-2.2	3.1	2.8	0.9	1.1	-13.2	19.7	1.0	-0.2	0.4
	supi	10.9	-1.4	3.3	1.0	0.6	0.3	-7.1	17.0	1.0	-0.1	0.3
	pron	3.9	-4.7	2.4	1.9	1.2	2.2	-45.4	31.9	1.0	-1.2	0.6
17	comp	13.0	-4.2	5.4	1.9	0.8	0.8	-16.5	22.7	1.0	-0.3	0.4
	dyn	4.1	-0.8	2.0	0.2	0.4	0.5	-10.1	26.3	1.0	-0.2	0.5
	supi	7.0	-1.7	1.8	0.9	1.1	0.7	-13.5	14.2	1.0	-0.2	0.3
	pron	6.0	-2.4	3.7	1.2	1.1	0.6	-19.1	31.3	1.0	-0.4	0.6
18	comp	21.6	-2.8	9.0	1.8	0.7	0.4	-6.9	22.7	1.0	-0.1	0.4
	dyn	11.7	-1.1	5.5	1.0	0.6	0.5	-4.8	25.1	1.0	-0.1	0.5
	supi	11.9	-1.4	5.0	1.0	0.5	0.6	-6.1	22.6	1.0	-0.1	0.4
	pron	9.6	-1.5	4.0	1.8	0.4	0.5	-7.9	22.7	1.0	-0.2	0.4
19	comp	26.8	0.4	3.4	2.4	0.5	0.4	0.9	7.3	1.0	0.0	0.1
	dyn	9.2	0.3	0.0	0.6	0.3	0.4	2.1	0.0	1.0	0.0	0.0
	supi	10.2	1.1	-0.8	1.0	0.6	0.8	5.8	-4.3	1.0	0.1	-0.1
	pron	16.6	-0.6	4.2	2.6	0.4	0.6	-2.0	14.3	1.0	0.0	0.3
20	comp	18.3	-6.0	6.5	1.4	0.9	0.9	-17.1	19.7	1.0	-0.3	0.4
	dyn	6.9	-2.0	2.5	0.9	0.3	0.4	-15.5	20.0	1.0	-0.3	0.4
	supi	11.3	-3.2	2.1	1.4	0.4	0.4	-15.7	10.4	1.0	-0.3	0.2
	pron	7.0	-2.7	4.5	1.6	1.0	1.0	-18.3	32.5	1.0	-0.4	0.6

Table A1.18

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right forefoot of subjects 16-20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT FORFT	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
21	comp	35.1	-1.1	1.0	3.1	1.1	0.7	-1.9	1.7	1.0	0.0	0.0
	dyn	6.3	1.3	-0.6	0.6	0.6	0.4	11.9	-5.8	1.0	0.2	-0.1
	supi	14.3	0.5	-2.3	1.1	1.2	0.7	2.0	-9.1	1.0	0.0	-0.2
	pron	20.7	-1.7	3.3	2.3	0.9	0.3	-4.5	9.1	1.0	-0.1	0.2
22	comp	13.9	-1.0	6.0	0.9	0.6	0.2	-3.8	23.3	1.0	-0.1	0.4
	dyn	7.9	1.0	3.8	0.7	0.4	0.3	6.3	25.7	1.0	0.1	0.5
	supi	8.8	0.5	3.4	0.9	0.4	0.3	3.0	21.0	1.0	0.1	0.4
	pron	5.1	-1.5	2.6	0.4	0.4	0.2	-14.5	27.1	1.0	-0.3	0.5
23	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
24	comp	16.9	-1.0	3.8	1.1	0.8	0.2	-3.2	12.6	1.0	-0.1	0.2
	dyn	8.3	0.8	2.5	1.1	0.5	0.3	5.1	16.7	1.0	0.1	0.3
	supi	11.6	-1.2	0.7	0.8	0.4	0.2	-5.8	3.5	1.0	-0.1	0.1
	pron	5.3	0.2	3.1	1.1	0.7	0.3	2.2	30.2	1.0	0.0	0.6
25	comp	22.5	-4.6	0.0	1.6	0.9	1.2	-11.4	0.1	1.0	-0.2	0.0
	dyn	8.9	0.0	0.2	0.8	0.6	0.5	0.0	1.5	1.0	0.0	0.0
	supi	10.8	-1.2	1.1	1.8	1.1	0.7	-6.1	6.0	1.0	-0.1	0.1
	pron	11.7	-3.4	-1.1	1.2	1.4	0.9	-16.1	-5.3	1.0	-0.3	-0.1

Table A1.19

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right forefoot of subjects 21-25.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	mean *Range of motion (rom)*			Standard deviation (rom)			mean angle of axis to		Axis calculated from mean rom. angle of axis to		Ratio of mean rom		
	FORFT	**Frt**	**Trn**	**Sag**	**Frt**	**Trn**	**Sag**	**Trn**	**Sag**	**Trn**	**Sag**	**Frt**	**Trn**	**Sag**
MEAN	**comp**	19.2	-3.3	4.8	7.0	2.4	2.7	-10.0	15.9	-9.4	14.1	1.0	-0.2	0.3
	dyn	8.6	-0.7	2.3	4.4	1.3	1.9	-5.5	15.3	-4.6	14.7	1.0	-0.1	0.3
	supi	10.7	-1.2	2.2	2.3	1.6	2.3	-6.2	12.3	-6.3	11.8	1.0	-0.1	0.2
	pron	8.6	-2.1	2.6	5.5	1.5	2.3	-15.9	20.7	-13.1	16.8	1.0	-0.2	0.3

Table A1.20

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the right forefoot. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			angle of axis to	
	FORFT	Frt	Trn	Sag	Trn	Sag
comp	MIN	8.9	-7.8	0.0	-30.7	0.1
	MAX	38.2	0.4	9.0	0.9	31.5
	RANGE	29.3	8.2	9.0	31.7	31.4
dyn	MIN	2.9	-3.1	-0.8	-27.3	-5.8
	MAX	25.4	1.3	5.5	11.9	28.1
	RANGE	22.5	4.4	6.3	39.2	33.9
supi	MIN	5.8	-4.3	-2.3	-20.7	-10.9
	MAX	17.2	1.1	6.2	5.8	31.3
	RANGE	11.4	5.4	8.5	26.5	42.2
pron	MIN	2.7	-4.8	-3.2	-48.3	-19.8
	MAX	21.0	0.2	5.8	2.2	49.3
	RANGE	18.3	5.1	9.0	50.4	69.0

Table A1.21

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the right forefoot of all subjects.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT Ank/Stj	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
1	comp	8.0	31.5	0.6	2.6	1.1	0.9	75.7	4.6	1.0	3.9	0.1
	dyn	6.7	15.7	-0.3	1.7	0.4	0.5	66.8	-2.2	1.0	2.3	0.0
	supi	7.2	15.1	-0.1	1.5	0.4	0.5	64.4	-0.8	1.0	2.1	0.0
	pron	0.8	16.4	0.7	1.8	1.3	0.5	86.3	44.3	1.0	21.4	1.0
2	comp	13.7	27.5	1.2	0.9	2.3	2.3	63.5	5.0	1.0	2.0	0.1
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	7.4	15.4	-0.9	0.9	0.4	0.6	64.0	-6.7	1.0	2.1	-0.1
	pron	6.2	12.1	2.1	1.0	2.1	2.5	61.6	18.4	1.0	1.9	0.3
3	comp	1.4	23.0	-3.6	2.0	1.2	0.6	80.6	-69.0	1.0	16.8	-2.6
	dyn	1.6	10.5	-2.5	1.8	1.0	0.7	74.4	-57.9	1.0	6.7	-1.6
	supi	0.5	10.6	-2.4	1.2	0.7	0.5	76.7	-79.4	1.0	23.0	-5.3
	pron	0.9	12.5	-1.1	2.6	1.0	0.5	83.4	-50.7	1.0	13.7	-1.2
4	comp	2.6	20.1	0.9	1.8	1.9	0.9	82.1	18.9	1.0	7.6	0.3
	dyn	1.2	9.9	0.4	1.1	1.9	0.5	82.6	17.6	1.0	8.1	0.3
	supi	1.2	12.5	0.5	1.2	2.8	0.7	84.1	24.5	1.0	10.6	0.5
	pron	1.5	7.6	0.4	1.0	1.5	0.3	78.8	14.0	1.0	5.2	0.2
5	comp	7.7	23.3	-3.5	1.1	2.1	0.5	70.0	-24.2	1.0	3.0	-0.4
	dyn	6.4	14.0	-3.1	0.8	0.7	0.5	63.0	-25.6	1.0	2.2	-0.5
	supi	7.0	14.0	-3.0	1.2	0.7	0.5	61.4	-23.5	1.0	2.0	-0.4
	pron	0.8	9.4	-0.4	1.4	1.7	0.5	84.5	-30.1	1.0	12.1	-0.6

Table A1.22

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right ankle/sub talar complex of subjects 1-5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT Ank/Stj	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
6	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
7	comp	9.6	24.8	-0.6	2.2	1.5	1.0	68.8	-3.8	1.0	2.6	-0.1
	dyn	7.6	16.8	-1.1	1.3	0.7	0.6	65.4	-8.4	1.0	2.2	-0.1
	supi	7.7	14.0	-1.4	1.0	0.7	0.7	60.9	-10.5	1.0	1.8	-0.2
	pron	1.9	10.8	0.8	2.1	1.8	0.7	79.0	22.1	1.0	5.6	0.4
8	comp	7.0	21.2	2.5	1.0	1.3	0.6	70.8	19.8	1.0	3.0	0.4
	dyn	5.1	11.2	1.0	1.5	1.8	0.6	64.9	11.4	1.0	2.2	0.2
	supi	6.8	13.5	1.0	1.3	0.6	0.6	63.1	8.7	1.0	2.0	0.2
	pron	0.2	7.8	1.5	1.7	1.3	0.9	79.2	81.8	1.0	36.9	7.0
9	comp	1.9	21.8	-3.0	0.8	1.3	0.7	80.7	-58.6	1.0	11.8	-1.6
	dyn	2.3	13.3	-1.1	1.4	0.4	0.5	79.1	-26.4	1.0	5.8	-0.5
	supi	3.4	14.8	-0.9	1.7	0.5	0.5	76.5	-14.3	1.0	4.3	-0.3
	pron	-1.6	7.1	-2.2	1.3	1.2	0.6	69.4	54.0	1.0	-4.5	1.4
10	comp	9.2	26.9	1.1	0.8	1.3	1.2	71.0	7.1	1.0	2.9	0.1
	dyn	2.4	10.6	0.4	1.1	2.0	0.6	76.8	9.9	1.0	4.3	0.2
	supi	3.3	11.9	0.5	0.8	1.3	0.8	74.3	8.5	1.0	3.6	0.1
	pron	5.9	15.1	0.7	0.4	1.1	1.4	68.4	6.3	1.0	2.5	0.1

Table A1.23

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right ankle/sub talar complex of subjects 6 -10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	**Ank/Stj**	**Frt**	**Trn**	**Sag**	**Frt**	**Trn**	**Sag**	**Trn**	**Sag**	**Frt**	**Trn**	**Sag**
11	**comp**	2.6	35.4	-3.5	0.6	1.8	0.6	82.9	-53.1	1.0	13.4	-1.3
	dyn	0.2	8.2	-0.5	0.4	0.7	0.4	86.5	-69.0	1.0	45.3	-2.6
	supi	5.1	14.3	-0.9	0.7	0.5	0.3	70.0	-9.5	1.0	2.8	-0.2
	pron	-2.5	21.1	-2.6	0.9	1.6	0.6	80.2	46.5	1.0	-8.4	1.1
12	**comp**	19.3	30.2	2.4	1.2	3.5	3.9	57.2	7.2	1.0	1.6	0.1
	dyn	14.6	20.8	0.9	1.8	0.4	2.6	54.9	3.4	1.0	1.4	0.1
	supi	7.8	13.8	-1.4	1.5	1.0	2.7	60.1	-10.4	1.0	1.8	-0.2
	pron	11.5	16.4	3.9	1.8	4.3	1.4	53.5	18.6	1.0	1.4	0.3
13	**comp**	8.2	26.6	1.7	1.2	0.2	1.7	72.5	11.8	1.0	3.2	0.2
	dyn	4.4	11.6	0.5	1.2	0.9	0.5	69.3	7.0	1.0	2.7	0.1
	supi	5.1	15.2	0.3	1.7	0.5	0.3	71.4	3.8	1.0	3.0	0.1
	pron	3.1	11.5	1.4	0.5	0.4	2.0	73.4	23.8	1.0	3.7	0.4
14	**comp**	5.0	35.3	-2.2	1.4	5.2	2.0	81.2	-23.5	1.0	7.0	-0.4
	dyn	2.1	8.1	-1.2	0.9	0.5	0.4	73.7	-29.3	1.0	3.9	-0.6
	supi	2.3	10.7	-1.9	1.0	0.5	0.4	74.4	-38.9	1.0	4.6	-0.8
	pron	2.7	24.6	-0.3	1.8	5.1	2.0	83.7	-6.4	1.0	9.1	-0.1
15	**comp**	5.2	27.9	-1.1	0.7	2.6	1.0	79.1	-11.6	1.0	5.3	-0.2
	dyn	2.3	11.9	-0.2	0.8	0.9	0.6	78.9	-5.9	1.0	5.1	-0.1
	supi	2.7	14.4	0.0	1.1	0.8	0.7	79.4	0.7	1.0	5.4	0.0
	pron	2.5	13.5	-1.1	0.9	2.5	0.7	78.3	-23.5	1.0	5.3	-0.4

Table A1.24

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right ankle/sub talar complex of subjects 11- 15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT Ank/Stj	Range of motion (rom) Frt	Range of motion (rom) Trn	Range of motion (rom) Sag	Standard deviation (rom) Frt	Standard deviation (rom) Trn	Standard deviation (rom) Sag	angle of axis to Trn	angle of axis to Sag	Ratio (rom) Frt	Ratio (rom) Trn	Ratio (rom) Sag
16	comp	2.5	21.7	-1.5	3.5	1.7	2.4	82.2	-31.1	1.0	8.5	-0.6
	dyn	3.4	12.6	-1.6	3.2	1.4	1.0	73.4	-25.8	1.0	3.7	-0.5
	supi	5.9	11.4	-1.2	1.1	0.8	0.5	61.9	-11.7	1.0	1.9	-0.2
	pron	-3.4	10.4	-0.3	2.5	1.8	2.1	71.8	5.2	1.0	-3.1	0.1
17	comp	1.0	27.5	-1.4	1.1	0.7	1.3	86.4	-53.4	1.0	27.0	-1.3
	dyn	1.0	9.7	-0.3	0.7	0.6	0.3	83.8	-17.4	1.0	9.7	-0.3
	supi	1.0	13.2	-0.6	0.9	0.9	0.6	84.7	-31.6	1.0	12.6	-0.6
	pron	0.0	14.4	-0.7	1.3	1.3	1.4	87.1	88.3	1.0	-668.3	34.1
18	comp	12.1	24.5	0.8	1.9	1.4	1.3	63.7	3.9	1.0	2.0	0.1
	dyn	7.9	13.8	0.0	1.4	0.5	0.7	60.4	0.2	1.0	1.8	0.0
	supi	7.9	13.9	0.0	1.5	0.8	0.6	60.3	0.0	1.0	1.8	0.0
	pron	4.2	10.6	0.8	1.5	1.2	0.9	68.3	11.1	1.0	2.6	0.2
19	comp	10.2	30.6	6.3	0.9	2.7	1.0	68.7	31.8	1.0	3.0	0.6
	dyn	3.4	11.9	1.7	0.7	1.1	0.4	72.4	27.1	1.0	3.5	0.5
	supi	3.7	13.8	1.9	1.0	0.7	0.5	73.1	26.5	1.0	3.7	0.5
	pron	6.4	16.8	4.4	1.4	2.4	0.8	65.2	34.6	1.0	2.6	0.7
20	comp	5.4	25.1	2.6	1.1	1.8	0.6	76.5	25.7	1.0	4.6	0.5
	dyn	2.4	9.6	1.4	0.8	0.3	0.4	74.0	29.8	1.0	4.0	0.6
	supi	4.1	13.9	1.9	1.2	0.8	0.4	71.9	24.3	1.0	3.4	0.5
	pron	1.3	11.2	0.7	1.2	2.3	0.5	82.4	30.1	1.0	8.7	0.6

Table A1.25

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right ankle/sub talar complex of subjects 16 - 20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	Ank/Stj	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
21	comp	24.3	34.2	0.4	2.1	1.8	0.9	54.5	0.9	1.0	1.4	0.0
	dyn	5.1	8.4	-1.2	0.8	0.5	0.2	58.0	-12.8	1.0	1.6	-0.2
	supi	9.9	13.6	-2.2	1.2	0.6	1.0	53.4	-12.4	1.0	1.4	-0.2
	pron	14.5	20.5	2.5	2.2	1.7	1.2	54.4	10.0	1.0	1.4	0.2
22	comp	5.7	27.4	1.4	0.4	1.3	0.7	77.9	13.8	1.0	4.8	0.2
	dyn	4.4	15.2	-0.1	0.4	0.6	0.4	73.9	-1.8	1.0	3.5	0.0
	supi	4.5	14.1	-0.3	0.4	0.5	0.3	72.4	-3.6	1.0	3.2	-0.1
	pron	1.2	13.3	1.7	0.3	1.2	0.6	81.1	53.5	1.0	10.7	1.4
23	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
24	comp	12.6	23.0	0.1	1.4	1.1	0.7	61.2	0.7	1.0	1.8	0.0
	dyn	7.3	11.1	0.0	1.4	0.5	0.3	56.7	-0.1	1.0	1.5	0.0
	supi	8.0	12.4	-0.2	1.5	0.4	0.6	57.1	-1.4	1.0	1.5	0.0
	pron	4.6	10.6	0.3	1.2	1.2	0.4	66.4	4.3	1.0	2.3	0.1
25	comp	9.1	31.0	-0.5	0.7	1.1	0.9	73.7	-3.0	1.0	3.4	-0.1
	dyn	5.0	11.7	-0.3	0.7	0.6	0.3	66.9	-3.6	1.0	2.3	-0.1
	supi	5.5	14.4	-0.9	0.8	1.6	0.7	68.8	-9.1	1.0	2.6	-0.2
	pron	3.6	16.6	0.4	0.6	1.4	0.5	77.8	6.4	1.0	4.7	0.1

Table A1.26

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right ankle/sub talar complex of subjects 21- 25.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT Ank/Stj	mean Range of motion (rom) Frt	Trn	Sag	*Standard deviation (rom)* Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
MEAN	comp	8.0	27.0	0.1	5.7	4.5	2.4	73.1	-7.8	73.4	0.4	1.0	3.4	0.0
	dyn	4.4	12.1	-0.3	3.2	3.1	1.2	70.7	-8.2	70.0	-4.2	1.0	2.8	-0.1
	supi	5.1	13.5	-0.5	2.6	1.3	1.3	68.9	-7.3	69.1	-5.9	1.0	2.6	-0.1
	pron	2.9	13.5	0.6	4.1	4.5	1.7	74.5	20.1	77.7	11.5	1.0	4.7	0.2

Table A1.27

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the right ankle/sub talar complex. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			angle of axis to	
	Ank/Stj	Frt	Trn	Sag	Trn	Sag
comp	MIN	1.0	20.1	-3.6	54.5	-69.0
	MAX	24.3	35.4	6.3	86.4	31.8
	RANGE	23.3	15.3	9.9	31.9	100.8
dyn	MIN	0.2	8.1	-3.1	54.9	-69.0
	MAX	14.6	20.8	1.7	86.5	29.8
	RANGE	14.4	12.7	4.8	31.6	98.8
supi	MIN	0.5	10.6	-3.0	53.4	-79.4
	MAX	9.9	15.4	1.9	84.7	26.5
	RANGE	9.4	4.8	4.9	31.2	105.9
pron	MIN	-3.4	7.1	-2.6	53.5	-50.7
	MAX	14.5	24.6	4.4	87.1	88.3
	RANGE	17.9	17.5	7.1	33.5	139.0

Table A1.28

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the right ankle/sub talar complex of all subjects.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	MTJ	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
1	comp	13.6	10.5	2.0	1.2	1.4	2.0	37.5	8.2	1.0	0.8	0.1
	dyn	5.8	6.0	0.5	0.7	0.9	1.2	45.9	5.0	1.0	1.0	0.1
	supi	5.5	6.0	-0.7	0.7	0.7	1.4	47.1	-7.0	1.0	1.1	-0.1
	pron	8.0	4.5	2.6	0.8	1.3	1.6	28.1	18.1	1.0	0.6	0.3
2	comp	12.3	8.9	7.1	1.2	1.8	1.9	31.9	29.8	1.0	0.7	0.6
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	4.1	5.8	7.4	1.0	1.2	1.1	34.1	60.9	1.0	1.4	1.8
	pron	8.2	3.1	-0.4	1.3	1.0	2.3	20.6	-2.5	1.0	0.4	0.0
3	comp	9.8	10.4	4.8	1.1	2.0	0.9	43.6	26.1	1.0	1.1	0.5
	dyn	3.1	4.7	3.9	0.4	0.6	0.4	43.4	52.0	1.0	1.5	1.3
	supi	8.4	6.3	4.5	1.3	0.9	0.5	33.7	28.4	1.0	0.8	0.5
	pron	1.5	4.1	0.3	0.7	1.2	0.9	70.0	11.6	1.0	2.8	0.2
4	comp	6.6	8.7	4.7	1.3	1.8	2.2	47.3	35.5	1.0	1.3	0.7
	dyn	3.3	4.2	2.4	0.9	1.4	1.2	45.6	35.9	1.0	1.3	0.7
	supi	4.5	5.7	2.7	0.9	1.3	1.0	47.1	30.9	1.0	1.3	0.6
	pron	2.0	3.1	2.0	0.5	0.6	1.4	47.2	44.1	1.0	1.5	1.0
5	comp	10.6	11.1	9.0	2.1	2.2	1.4	38.7	40.2	1.0	1.0	0.8
	dyn	6.4	7.7	6.0	2.0	1.7	1.1	41.5	42.9	1.0	1.2	0.9
	supi	6.9	7.5	5.2	2.1	1.8	1.2	41.0	37.1	1.0	1.1	0.8
	pron	3.7	3.6	3.8	0.6	1.1	0.7	34.4	45.3	1.0	1.0	1.0

Table A1.29

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right mid tarsal joint of subjects 1- 5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	MTJ	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
6	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
7	comp	5.8	9.4	9.6	0.9	0.9	1.0	39.9	58.6	1.0	1.6	1.6
	dyn	4.0	7.2	6.4	0.9	1.2	0.7	43.5	57.8	1.0	1.8	1.6
	supi	4.2	7.0	5.6	0.7	1.1	0.8	45.1	53.1	1.0	1.7	1.3
	pron	1.6	2.3	4.0	0.6	0.7	1.2	28.6	67.6	1.0	1.4	2.4
8	comp	7.6	9.6	8.4	0.7	0.8	0.8	40.5	47.9	1.0	1.3	1.1
	dyn	3.9	6.1	3.8	0.9	0.9	1.0	48.6	44.1	1.0	1.6	1.0
	supi	4.8	7.1	4.6	0.6	0.5	0.8	47.1	43.5	1.0	1.5	0.9
	pron	2.7	2.5	3.8	0.7	0.4	0.9	27.9	54.3	1.0	0.9	1.4
9	comp	9.8	6.6	10.5	1.0	0.7	1.0	24.7	46.8	1.0	0.7	1.1
	dyn	5.9	2.9	4.7	0.9	0.5	0.5	20.8	38.2	1.0	0.5	0.8
	supi	6.9	3.7	5.5	1.3	0.4	0.6	22.7	38.9	1.0	0.5	0.8
	pron	3.0	2.9	4.9	0.6	0.7	0.8	26.9	59.0	1.0	1.0	1.7
10	comp	12.0	11.3	5.5	1.7	1.0	0.9	40.5	24.6	1.0	0.9	0.5
	dyn	4.9	4.1	1.3	1.4	1.0	0.3	38.5	14.4	1.0	0.8	0.3
	supi	6.2	4.2	1.5	0.7	0.8	0.5	33.4	14.1	1.0	0.7	0.3
	pron	5.8	7.1	4.0	1.1	0.5	0.8	45.2	34.1	1.0	1.2	0.7

Table A1.30

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right mid tarsal joint of subjects 6 - 10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	MTJ	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
11	comp	12.9	7.4	3.6	0.8	0.9	0.8	28.8	15.7	1.0	0.6	0.3
	dyn	2.5	1.4	1.0	0.6	0.4	0.8	26.6	21.8	1.0	0.5	0.4
	supi	7.8	4.1	4.4	0.4	0.9	0.3	24.7	29.6	1.0	0.5	0.6
	pron	5.1	3.2	-0.8	0.8	0.5	0.8	32.1	-8.8	1.0	0.6	-0.2
12	comp	22.2	9.0	-0.5	2.9	1.3	2.5	22.0	-1.4	1.0	0.4	0.0
	dyn	13.4	6.0	2.9	1.8	1.2	1.9	23.7	12.4	1.0	0.4	0.2
	supi	10.4	3.9	5.7	1.3	1.9	1.0	18.1	29.0	1.0	0.4	0.6
	pron	11.9	5.1	-6.3	2.0	1.6	1.9	20.7	-27.9	1.0	0.4	-0.5
13	comp	11.8	12.0	8.1	1.8	0.6	1.0	39.8	34.5	1.0	1.0	0.7
	dyn	4.3	5.5	4.5	1.1	0.5	1.2	41.7	46.5	1.0	1.3	1.1
	supi	5.3	5.0	3.5	0.8	0.9	0.7	38.5	33.9	1.0	1.0	0.7
	pron	6.6	6.9	4.6	1.7	1.1	0.8	40.8	35.0	1.0	1.1	0.7
14	comp	16.4	13.8	8.3	1.1	1.5	1.3	36.8	26.9	1.0	0.8	0.5
	dyn	6.6	5.1	1.5	0.7	0.8	0.4	36.8	12.7	1.0	0.8	0.2
	supi	10.3	5.5	1.0	1.4	0.5	0.6	28.1	5.6	1.0	0.5	0.1
	pron	6.1	8.2	7.3	0.7	1.2	1.2	40.8	50.2	1.0	1.3	1.2
15	comp	16.5	9.4	10.2	1.4	1.5	0.7	25.8	31.7	1.0	0.6	0.6
	dyn	5.4	2.4	2.8	0.6	1.0	0.6	21.5	27.6	1.0	0.4	0.5
	supi	5.8	4.0	2.3	0.3	1.8	0.6	32.6	21.8	1.0	0.7	0.4
	pron	10.7	5.4	7.9	1.2	1.0	1.2	22.0	36.3	1.0	0.5	0.7

Table A1.31

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right mid tarsal joint of subjects 11- 15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT MTJ	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
16	comp	11.3	12.2	8.1	1.7	0.8	2.4	41.2	35.8	1.0	1.1	0.7
	dyn	5.7	7.5	4.6	0.8	0.9	0.3	45.8	38.8	1.0	1.3	0.8
	supi	6.0	7.6	4.3	0.3	0.4	0.5	45.8	36.1	1.0	1.3	0.7
	pron	5.3	4.6	3.8	1.4	0.6	2.2	35.0	35.4	1.0	0.9	0.7
17	comp	8.0	9.7	7.1	1.4	0.7	0.6	42.2	41.4	1.0	1.2	0.9
	dyn	1.7	3.1	2.2	0.5	0.4	0.4	48.4	53.0	1.0	1.9	1.3
	supi	3.4	5.4	2.3	1.0	0.5	0.5	52.9	33.9	1.0	1.6	0.7
	pron	4.6	4.3	4.8	0.9	0.6	0.5	32.9	46.0	1.0	0.9	1.0
18	comp	12.1	10.9	9.3	0.9	1.1	1.2	35.6	37.5	1.0	0.9	0.8
	dyn	5.7	5.9	6.3	0.3	0.8	0.8	34.7	47.9	1.0	1.0	1.1
	supi	5.8	5.6	5.8	0.2	0.7	0.8	34.3	45.1	1.0	1.0	1.0
	pron	6.3	5.3	3.5	1.0	0.7	0.5	36.5	28.8	1.0	0.8	0.5
19	comp	15.7	14.6	-2.7	1.5	1.6	1.3	42.5	-9.8	1.0	0.9	-0.2
	dyn	5.3	5.5	-1.5	0.2	0.6	0.6	45.0	-15.7	1.0	1.0	-0.3
	supi	5.9	7.7	-2.2	0.4	0.7	1.1	50.9	-20.5	1.0	1.3	-0.4
	pron	9.8	6.9	-0.5	1.4	1.1	0.4	35.0	-3.0	1.0	0.7	-0.1
20	comp	13.2	7.4	5.9	0.8	0.7	1.0	27.0	24.2	1.0	0.6	0.5
	dyn	4.9	2.6	2.0	0.5	0.3	0.5	26.5	22.0	1.0	0.5	0.4
	supi	7.6	3.7	1.4	0.6	0.4	0.5	25.6	10.3	1.0	0.5	0.2
	pron	5.6	3.7	4.5	0.9	0.6	1.2	26.9	39.0	1.0	0.7	0.8

Table A1.32

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right mid tarsal joint of subjects 16 - 20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	MTJ	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
21	comp	15.6	13.9	0.8	1.2	1.1	1.0	41.7	2.9	1.0	0.9	0.1
	dyn	2.3	4.6	0.5	0.7	0.7	0.5	63.5	11.8	1.0	2.0	0.2
	supi	6.2	7.3	-0.6	0.9	1.0	0.7	49.2	-5.7	1.0	1.2	-0.1
	pron	9.4	6.7	1.4	0.5	0.8	0.5	35.0	8.6	1.0	0.7	0.2
22	comp	10.1	9.2	7.0	0.8	0.3	0.5	36.8	34.7	1.0	0.9	0.7
	dyn	4.9	6.5	4.6	0.6	0.5	0.3	43.8	43.5	1.0	1.3	0.9
	supi	5.7	6.7	4.4	0.7	0.5	0.2	43.1	37.4	1.0	1.2	0.8
	pron	4.4	2.5	2.6	0.4	0.4	0.5	25.8	31.0	1.0	0.6	0.6
23	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
24	comp	6.9	7.9	4.4	0.9	0.9	0.4	43.7	32.6	1.0	1.1	0.6
	dyn	2.7	4.9	3.0	0.4	0.5	0.3	50.7	48.5	1.0	1.8	1.1
	supi	5.2	4.2	1.0	0.6	0.4	0.3	38.6	11.2	1.0	0.8	0.2
	pron	1.7	3.6	3.4	0.9	1.0	0.5	43.6	63.3	1.0	2.1	2.0
25	comp	12.2	6.1	1.3	1.4	1.1	1.7	26.4	6.0	1.0	0.5	0.1
	dyn	3.7	2.7	0.3	0.7	0.4	0.8	36.5	4.7	1.0	0.7	0.1
	supi	5.1	3.5	1.7	1.3	0.8	1.2	33.3	18.2	1.0	0.7	0.3
	pron	7.1	2.6	-0.4	1.3	1.0	1.2	19.8	-3.1	1.0	0.4	-0.1

Table A1.33

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right mid tarsal joint of subjects 21 - 25.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT MTJ	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
MEAN	comp	11.9	10.0	5.8	3.8	2.3	3.6	36.3	27.4	37.1	25.9	1.0	0.8	0.5
	dyn	4.8	4.8	2.9	2.4	1.8	2.1	39.7	30.3	40.7	30.9	1.0	1.0	0.6
	supi	6.2	5.5	3.1	1.8	1.4	2.5	37.7	25.5	38.8	26.8	1.0	0.9	0.5
	pron	5.7	4.4	2.6	3.0	1.7	3.0	33.7	28.8	35.2	24.9	1.0	0.8	0.5

Table A1.34

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the right mid tarsal joint. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT MTJ	Range of motion (rom) Frt	Trn	Sag	angle of axis to Trn	Sag
comp	MIN	5.8	6.1	-2.7	22.0	-9.8
	MAX	22.2	14.6	10.5	47.3	58.6
	RANGE	16.4	8.5	13.2	25.3	68.4
dyn	MIN	1.7	1.4	-1.5	20.8	-15.7
	MAX	13.4	7.7	6.4	63.5	57.8
	RANGE	11.7	6.4	7.9	42.7	73.5
supi	MIN	3.4	3.5	-2.2	18.1	-20.5
	MAX	10.4	7.7	7.4	52.9	60.9
	RANGE	7.0	4.2	9.6	34.8	81.4
pron	MIN	1.5	2.3	-6.3	19.8	-27.9
	MAX	11.9	8.2	7.9	70.0	67.6
	RANGE	10.4	5.9	14.2	50.1	95.5

Table A1.35

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the right mid tarsal joint of all subjects. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	RFC	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
1	comp	21.5	42.0	2.6	3.3	2.2	2.4	62.7	6.9	1.0	1.9	0.1
	dyn	12.5	21.6	0.2	2.1	0.6	1.5	60.0	1.1	1.0	1.7	0.0
	supi	12.7	21.1	-0.8	1.8	0.6	1.8	58.8	-3.5	1.0	1.7	-0.1
	pron	8.8	20.9	3.4	2.2	2.2	1.5	65.7	21.0	1.0	2.4	0.4
2	comp	26.0	36.4	8.3	1.7	2.7	0.8	53.1	17.6	1.0	1.4	0.3
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	11.6	21.1	6.6	1.4	1.1	0.7	57.8	29.5	1.0	1.8	0.6
	pron	14.4	15.2	1.7	1.7	2.4	0.4	46.3	6.7	1.0	1.1	0.1
3	comp	11.2	33.5	1.3	1.3	2.1	0.9	71.4	6.4	1.0	3.0	0.1
	dyn	4.6	15.2	1.5	1.9	0.7	0.7	72.3	17.5	1.0	3.3	0.3
	supi	8.8	16.9	2.1	2.2	1.0	0.6	61.8	13.2	1.0	1.9	0.2
	pron	2.4	16.6	-0.8	2.8	1.6	0.6	81.4	-18.9	1.0	7.0	-0.3
4	comp	9.2	28.8	5.6	1.9	2.7	1.3	69.5	31.3	1.0	3.1	0.6
	dyn	4.5	14.1	2.8	1.3	3.3	0.7	69.3	31.6	1.0	3.1	0.6
	supi	5.7	18.2	3.3	1.0	3.6	0.5	70.1	29.6	1.0	3.2	0.6
	pron	3.5	10.6	2.3	1.3	1.3	1.1	68.5	33.8	1.0	3.1	0.7
5	comp	18.3	34.4	5.5	3.0	3.5	1.3	60.9	16.6	1.0	1.9	0.3
	dyn	12.8	21.7	2.9	2.4	1.6	0.8	58.8	12.6	1.0	1.7	0.2
	supi	13.8	21.5	2.2	2.8	1.4	0.8	56.8	8.9	1.0	1.6	0.2
	pron	4.5	13.0	3.3	1.8	2.6	0.6	66.7	36.4	1.0	2.9	0.7

Table A1.36

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right rearfoot complex of subjects 1 -5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	RFC	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
6	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
7	comp	15.4	34.2	8.9	2.7	1.7	0.5	62.4	30.0	1.0	2.2	0.6
	dyn	11.7	24.0	5.3	2.1	1.7	0.3	61.9	24.3	1.0	2.1	0.5
	supi	11.9	21.0	4.2	1.6	1.4	0.8	59.1	19.4	1.0	1.8	0.4
	pron	3.6	13.2	4.7	2.6	2.4	1.1	65.7	53.0	1.0	3.7	1.3
8	comp	14.5	30.9	10.9	1.5	1.4	0.7	59.5	36.8	1.0	2.1	0.7
	dyn	9.0	17.3	4.8	2.3	2.6	1.0	59.5	28.1	1.0	1.9	0.5
	supi	11.6	20.6	5.6	1.8	0.7	0.8	58.0	25.8	1.0	1.8	0.5
	pron	2.9	10.3	5.3	2.3	1.2	1.2	59.5	60.8	1.0	3.5	1.8
9	comp	11.7	28.5	7.4	1.3	1.5	0.6	64.1	32.5	1.0	2.4	0.6
	dyn	8.3	16.2	3.5	2.0	0.4	0.3	61.0	23.2	1.0	2.0	0.4
	supi	10.3	18.4	4.7	2.7	0.7	0.5	58.5	24.4	1.0	1.8	0.5
	pron	1.4	10.0	2.8	1.6	1.3	0.8	72.8	63.3	1.0	7.2	2.0
10	comp	21.2	38.2	6.6	1.8	2.2	1.5	59.8	17.4	1.0	1.8	0.3
	dyn	7.4	14.7	1.7	2.2	2.8	0.7	62.7	13.0	1.0	2.0	0.2
	supi	9.4	16.1	2.0	1.1	1.8	0.8	59.0	12.2	1.0	1.7	0.2
	pron	11.8	22.2	4.6	1.2	1.4	2.1	60.3	21.4	1.0	1.9	0.4

Table A1.37

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right rearfoot complex of subjects 6 -10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT RFC	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
11	comp	15.6	42.8	0.1	1.2	1.8	0.8	70.0	0.5	1.0	2.7	0.0
	dyn	2.7	9.5	0.5	1.0	1.0	0.6	73.8	11.4	1.0	3.5	0.2
	supi	12.9	18.4	3.6	0.7	0.7	0.5	53.9	15.4	1.0	1.4	0.3
	pron	2.6	24.3	-3.4	0.8	1.5	0.8	79.9	-52.7	1.0	9.3	-1.3
12	comp	41.5	39.2	1.9	3.6	3.4	3.0	43.3	2.6	1.0	0.9	0.0
	dyn	28.0	26.8	3.8	3.2	1.5	2.4	43.5	7.8	1.0	1.0	0.1
	supi	18.1	17.7	4.3	1.9	1.5	2.7	43.5	13.4	1.0	1.0	0.2
	pron	23.3	21.5	-2.4	3.7	3.5	1.4	42.5	-5.9	1.0	0.9	-0.1
13	comp	20.1	38.6	9.9	3.0	0.6	2.6	59.9	26.2	1.0	1.9	0.5
	dyn	8.6	17.1	5.0	2.2	0.3	1.5	59.7	30.3	1.0	2.0	0.6
	supi	10.3	20.2	3.9	2.0	0.6	0.7	61.3	20.5	1.0	2.0	0.4
	pron	9.7	18.4	6.0	1.1	1.2	2.7	58.2	31.6	1.0	1.9	0.6
14	comp	21.4	49.1	6.1	1.2	4.3	2.4	65.6	16.0	1.0	2.3	0.3
	dyn	8.7	13.2	0.3	1.4	0.8	0.6	56.6	2.1	1.0	1.5	0.0
	supi	12.6	16.2	-0.9	2.3	0.5	0.5	52.0	-3.9	1.0	1.3	-0.1
	pron	8.8	32.8	7.0	2.0	4.3	1.9	71.1	38.6	1.0	3.7	0.8
15	comp	21.7	37.2	9.1	2.0	3.3	1.7	57.6	22.8	1.0	1.7	0.4
	dyn	7.7	14.3	2.6	0.8	1.3	0.6	60.5	18.4	1.0	1.9	0.3
	supi	8.5	18.4	2.3	1.1	1.9	0.9	64.4	15.5	1.0	2.2	0.3
	pron	13.3	18.9	6.8	1.8	2.6	1.8	51.7	27.1	1.0	1.4	0.5

Table A1.38

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right rearfoot complex of subjects 11 - 15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	RFC	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
16	comp	13.8	33.9	6.6	3.1	2.0	3.3	65.7	25.5	1.0	2.5	0.5
	dyn	9.1	20.1	3.0	3.5	1.2	1.1	64.6	18.1	1.0	2.2	0.3
	supi	11.9	19.0	3.1	1.1	0.4	0.3	57.0	14.7	1.0	1.6	0.3
	pron	1.9	14.9	3.5	2.2	2.2	3.1	75.0	60.8	1.0	7.7	1.8
17	comp	9.0	37.2	5.7	1.9	0.6	1.4	74.0	32.3	1.0	4.1	0.6
	dyn	2.7	12.8	1.9	0.3	0.5	0.6	75.6	35.5	1.0	4.8	0.7
	supi	4.4	18.6	1.6	0.8	1.0	0.8	75.7	20.3	1.0	4.2	0.4
	pron	4.6	18.7	4.1	1.4	1.5	1.5	71.7	41.4	1.0	4.0	0.9
18	comp	24.1	35.4	10.1	2.3	1.7	0.9	53.5	22.7	1.0	1.5	0.4
	dyn	13.5	19.7	6.3	1.5	0.5	0.6	52.8	25.0	1.0	1.5	0.5
	supi	13.7	19.5	5.8	1.4	1.1	0.8	52.6	23.0	1.0	1.4	0.4
	pron	10.4	15.9	4.3	2.2	1.4	0.7	54.7	22.2	1.0	1.5	0.4
19	comp	25.9	45.3	3.6	2.3	4.2	0.4	60.0	7.9	1.0	1.7	0.1
	dyn	8.7	17.4	0.2	0.8	1.5	0.5	63.5	1.4	1.0	2.0	0.0
	supi	9.6	21.5	-0.3	1.2	1.1	0.9	65.9	-1.9	1.0	2.2	0.0
	pron	16.3	23.7	3.9	2.8	3.4	0.7	54.8	13.5	1.0	1.5	0.2
20	comp	18.6	32.5	8.5	1.5	2.0	1.0	57.8	24.7	1.0	1.7	0.5
	dyn	7.2	12.2	3.3	1.1	0.5	0.6	56.8	24.7	1.0	1.7	0.5
	supi	11.7	17.6	3.3	1.7	1.1	0.5	55.4	15.5	1.0	1.5	0.3
	pron	6.9	14.9	5.3	1.8	2.6	1.0	59.6	37.5	1.0	2.2	0.8

Table A1.39

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right rearfoot complex of subjects 16 - 20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT RFC	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
21	comp	40.0	48.1	1.2	3.3	2.3	1.2	50.3	1.7	1.0	1.2	0.0
	dyn	7.4	13.0	-0.7	0.6	0.6	0.5	60.3	-5.3	1.0	1.8	-0.1
	supi	16.1	20.9	-2.8	1.3	1.3	1.6	52.0	-9.8	1.0	1.3	-0.2
	pron	23.9	27.2	4.0	2.5	1.9	0.8	48.4	9.4	1.0	1.1	0.2
22	comp	15.8	36.6	8.4	1.0	1.1	0.6	63.9	28.0	1.0	2.3	0.5
	dyn	9.3	21.7	4.5	0.8	0.4	0.5	64.6	25.9	1.0	2.3	0.5
	supi	10.2	20.8	4.1	1.0	0.4	0.4	62.2	21.9	1.0	2.0	0.4
	pron	5.6	15.8	4.3	0.4	1.1	0.5	65.9	37.5	1.0	2.8	0.8
23	comp	*	*	*	*	*	*	*	*	*	*	*
	dyn	*	*	*	*	*	*	*	*	*	*	*
	supi	*	*	*	*	*	*	*	*	*	*	*
	pron	*	*	*	*	*	*	*	*	*	*	*
24	comp	19.6	30.9	4.6	1.2	1.7	0.7	56.9	13.2	1.0	1.6	0.2
	dyn	10.0	16.0	3.0	1.3	0.5	0.5	57.0	16.7	1.0	1.6	0.3
	supi	13.2	16.6	0.8	1.1	0.6	0.7	51.4	3.6	1.0	1.3	0.1
	pron	6.3	14.2	3.7	1.3	2.0	0.5	62.7	30.7	1.0	2.3	0.6
25	comp	21.2	37.0	0.8	1.7	1.2	1.4	60.1	2.2	1.0	1.7	0.0
	dyn	8.7	14.4	0.0	0.9	0.7	0.6	59.0	0.0	1.0	1.7	0.0
	supi	10.6	17.9	0.8	1.8	2.1	0.7	59.3	4.3	1.0	1.7	0.1
	pron	10.7	19.2	0.0	1.5	1.2	1.3	60.9	0.1	1.0	1.8	0.0

Table A1.40

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the right rearfoot complex of subjects 21 - 25.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT RFC	mean Range of motion (rom)			Standard deviation (rom)			mean angle of axis to		Axis calculated from mean rom. angle of axis to		Ratio of mean rom		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Trn	Sag	Frt	Trn	Sag
MEAN	comp	19.9	37.0	5.8	8.2	5.6	3.3	61.0	18.3	60.7	16.3	1.0	1.9	0.3
	dyn	9.2	17.0	2.6	5.1	4.3	1.9	61.5	16.5	60.6	15.6	1.0	1.8	0.3
	supi	11.3	19.0	2.6	3.0	1.8	2.3	58.6	13.6	58.7	12.9	1.0	1.7	0.2
	pron	8.6	17.9	3.2	6.4	5.6	2.7	62.8	24.8	62.9	20.6	1.0	2.1	0.4

Table A1.41

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the right rearfoot complex. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	Range of motion (rom)			angle of axis to	
	RFC	Frt	Trn	Sag	Trn	Sag
comp	MIN	9.0	28.5	0.1	43.3	0.5
	MAX	41.5	49.1	10.9	74.0	36.8
	RANGE	32.4	20.6	10.7	30.6	36.3
dyn	MIN	2.7	9.5	-0.7	43.5	-5.3
	MAX	28.0	26.8	6.3	75.6	35.5
	RANGE	25.3	17.3	7.0	32.1	40.8
supi	MIN	4.4	16.1	-2.8	43.5	-9.8
	MAX	18.1	21.5	6.6	75.7	29.6
	RANGE	13.7	5.5	9.4	32.2	39.5
pron	MIN	1.4	10.0	-3.4	42.5	-52.7
	MAX	23.9	32.8	7.0	81.4	63.3
	RANGE	22.5	22.8	10.4	38.9	116.0

Table A1.42

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the right rearfoot complex of all subjects. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT LEG	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
1	comp	-0.6	-39.7	-1.5	0.6	2.2	0.4	-87.7	69.2	1.0	69.3	2.6
	dyn	-0.1	-15.7	-0.4	0.3	0.7	0.3	-88.5	76.5	1.0	163.0	4.2
	supi	-1.3	-20.5	-0.1	0.3	0.3	0.3	-86.2	3.4	1.0	15.3	0.1
	pron	0.8	-19.3	-1.4	0.5	2.3	0.4	-85.2	-61.9	1.0	-25.2	-1.9
2	comp	2.2	-35.3	2.0	1.1	2.7	0.4	-85.1	42.2	1.0	-15.9	0.9
	dyn	1.4	-25.8	1.4	1.1	0.2	0.4	-85.5	45.4	1.0	-18.1	1.0
	supi	0.4	-20.5	1.3	0.9	0.2	0.4	-86.1	73.5	1.0	-52.5	3.4
	pron	1.8	-14.8	0.7	0.5	2.6	0.3	-82.5	20.5	1.0	-8.1	0.4
3	comp	3.4	-34.4	0.1	0.9	3.5	0.6	-84.3	1.3	1.0	-10.1	0.0
	dyn	2.5	-24.4	-0.1	0.6	3.0	0.4	-84.2	-2.4	1.0	-9.8	0.0
	supi	2.1	-18.1	0.0	0.9	1.7	0.4	-83.4	-0.5	1.0	-8.6	0.0
	pron	1.3	-16.3	0.1	0.3	2.6	0.4	-85.4	4.3	1.0	-12.4	0.1
4	comp	0.6	-35.8	-3.0	0.3	2.6	0.5	-85.1	-78.1	1.0	-56.3	-4.7
	dyn	0.1	-11.9	-0.9	0.2	3.5	0.4	-85.5	-86.5	1.0	-211.1	-16.6
	supi	0.4	-19.5	-1.5	0.3	3.0	0.3	-85.4	-73.8	1.0	-45.0	-3.5
	pron	0.2	-16.3	-1.5	0.1	3.2	0.6	-84.6	-82.4	1.0	-80.5	-7.5
5	comp	-0.3	-35.2	0.7	0.4	1.0	0.4	-88.7	-68.2	1.0	120.0	-2.5
	dyn	0.1	-18.2	0.7	0.1	0.4	0.3	-87.8	85.7	1.0	-347.1	13.3
	supi	-0.6	-20.8	0.6	0.1	0.4	0.2	-87.5	-44.8	1.0	32.6	-1.0
	pron	0.3	-14.4	0.1	0.3	1.2	0.5	-88.6	16.6	1.0	-41.9	0.3

Table A1.43

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left leg of subjects 1 - 5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT LEG	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
6	comp	1.4	-44.0	0.8	0.5	2.2	0.8	-87.9	31.7	1.0	-32.2	0.6
	dyn	0.1	-10.7	-0.1	0.1	0.8	0.3	-89.2	-21.0	1.0	-73.5	-0.4
	supi	0.8	-20.3	0.0	0.4	0.7	0.5	-87.7	1.0	1.0	-24.6	0.0
	pron	0.5	-23.6	0.8	0.3	1.9	0.5	-87.6	56.9	1.0	-43.8	1.5
7	comp	-1.0	-44.9	-0.9	0.5	2.6	0.6	-88.3	44.3	1.0	47.2	1.0
	dyn	-1.0	-26.1	-0.2	0.4	0.4	0.3	-87.7	9.1	1.0	24.8	0.2
	supi	-1.1	-20.5	-0.7	0.2	0.3	0.3	-86.5	32.4	1.0	19.2	0.6
	pron	0.1	-24.4	-0.3	0.5	2.4	0.4	-89.3	-65.1	1.0	-210.3	-2.2
8	comp	0.5	-32.4	0.4	0.8	2.1	0.9	-88.9	41.1	1.0	-70.4	0.9
	dyn	0.7	-17.0	-0.3	0.7	0.2	0.5	-87.3	-23.6	1.0	-23.3	-0.4
	supi	-0.4	-20.6	-1.0	0.3	0.2	0.5	-87.0	68.4	1.0	52.1	2.5
	pron	0.9	-11.9	1.4	0.7	2.1	1.0	-82.1	58.5	1.0	-13.9	1.6
9	comp	0.5	-32.3	-0.9	0.3	1.4	0.2	-88.2	-60.3	1.0	-65.6	-1.8
	dyn	0.6	-17.2	-0.8	0.1	0.1	0.1	-86.7	-53.8	1.0	-29.6	-1.4
	supi	0.3	-20.0	-0.8	0.1	0.2	0.5	-87.5	-66.8	1.0	-57.7	-2.3
	pron	0.1	-12.3	-0.1	0.2	1.3	0.7	-89.3	-20.9	1.0	-84.2	-0.4
10	comp	1.9	-31.0	0.3	0.4	1.1	0.5	-86.4	8.2	1.0	-16.1	0.1
	dyn	1.2	-20.3	0.0	0.3	0.4	0.5	-86.7	1.2	1.0	-17.1	0.0
	supi	1.4	-20.7	0.5	0.2	0.4	0.2	-85.9	21.7	1.0	-15.0	0.4
	pron	0.5	-10.3	-0.3	0.3	1.1	0.5	-86.6	-26.5	1.0	-18.8	-0.5

Table A1.44

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left leg of subjects 6 - 10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT LEG	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
11	comp	4.4	-49.1	-2.2	0.9	1.8	1.3	-84.2	-26.8	1.0	-11.0	-0.5
	dyn	1.1	-11.9	-0.6	0.4	0.2	0.4	-84.0	-30.6	1.0	-11.0	-0.6
	supi	1.1	-20.5	-1.3	0.4	0.3	0.3	-85.3	-50.7	1.0	-19.1	-1.2
	pron	3.4	-28.6	-0.9	0.9	1.9	1.4	-83.0	-15.4	1.0	-8.5	-0.3
12	comp	-1.4	-42.0	1.0	0.4	2.1	0.6	-87.6	-35.2	1.0	29.0	-0.7
	dyn	-1.0	-20.7	-0.3	0.3	0.3	0.6	-87.1	19.2	1.0	21.3	0.3
	supi	-0.7	-20.1	1.1	0.2	1.6	0.2	-86.2	-56.2	1.0	26.8	-1.5
	pron	-0.7	-21.9	-0.1	0.3	2.3	0.5	-88.1	7.7	1.0	31.3	0.1
13	comp	-0.1	-36.0	-2.4	0.5	4.0	0.5	-86.2	87.8	1.0	400.9	26.3
	dyn	-0.3	-15.1	-1.0	0.2	0.4	0.2	-86.0	73.9	1.0	51.9	3.5
	supi	0.1	-20.2	-1.1	0.1	0.6	0.1	-86.8	-84.3	1.0	-180.8	-10.0
	pron	-0.2	-15.9	-1.2	0.4	3.5	0.6	-85.5	80.8	1.0	78.9	6.2
14	comp	2.1	-44.4	-1.9	0.3	1.5	0.3	-86.3	-41.5	1.0	-20.7	-0.9
	dyn	0.3	-14.3	-0.1	0.1	1.1	0.2	-88.7	-21.1	1.0	-48.3	-0.4
	supi	0.7	-21.0	-0.2	0.3	0.4	0.3	-87.9	-12.0	1.0	-28.6	-0.2
	pron	1.4	-23.5	-1.7	0.4	1.8	0.4	-84.5	-51.0	1.0	-16.6	-1.2
15	comp	1.7	-48.6	0.1	0.4	4.5	0.3	-88.0	4.8	1.0	-28.9	0.1
	dyn	0.3	-16.9	0.0	0.3	0.1	0.2	-88.8	-4.1	1.0	-48.8	-0.1
	supi	0.6	-20.7	0.1	0.1	2.1	0.4	-88.2	9.5	1.0	-32.8	0.2
	pron	1.1	-27.9	0.0	0.3	0.4	0.7	-87.8	2.0	1.0	-26.5	0.0

Table A1.45

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left leg of subjects 11 - 15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT LEG	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
16	comp	2.9	-41.3	-2.0	0.6	1.2	0.1	-85.1	-34.7	1.0	-14.1	-0.7
	dyn	2.1	-17.5	-0.7	0.1	0.3	0.4	-82.9	-18.5	1.0	-8.5	-0.3
	supi	0.7	-24.8	-0.5	0.5	0.3	0.1	-87.9	-33.4	1.0	-33.3	-0.7
	pron	2.2	-16.5	-1.5	1.0	1.5	0.2	-80.8	-35.1	1.0	-7.5	-0.7
17	comp	0.9	-40.4	2.9	1.2	2.3	1.6	-85.8	73.1	1.0	-46.5	3.3
	dyn	0.3	-17.4	1.6	0.7	0.2	0.8	-84.5	78.3	1.0	-51.1	4.9
	supi	-1.4	-21.4	3.2	0.7	3.2	1.0	-80.7	-66.7	1.0	15.4	-2.3
	pron	2.3	-19.0	-0.4	0.6	2.4	0.8	-83.2	-9.1	1.0	-8.4	-0.2
18	comp	0.1	-37.9	-0.6	0.5	5.4	0.6	-89.1	-83.8	1.0	-602.0	-9.2
	dyn	-0.4	-16.4	-0.1	0.3	0.4	0.2	-88.6	17.7	1.0	42.4	0.3
	supi	-0.5	-21.4	-0.4	0.3	3.2	0.4	-88.3	38.4	1.0	44.3	0.8
	pron	0.5	-16.5	-0.2	0.3	3.8	0.4	-88.0	-19.7	1.0	-30.2	-0.4
19	comp	-3.2	-46.9	-0.8	0.5	2.1	0.7	-86.0	13.5	1.0	14.8	0.2
	dyn	-1.5	-12.9	-0.4	0.3	0.2	0.3	-82.9	15.2	1.0	8.3	0.3
	supi	-1.2	-20.2	-1.8	0.3	0.2	0.5	-83.8	55.6	1.0	16.3	1.5
	pron	-1.9	-26.7	1.1	0.3	2.1	0.8	-85.3	-28.7	1.0	13.9	-0.5
20	comp	-0.2	-38.9	-2.0	0.3	1.0	0.5	-87.0	84.3	1.0	193.3	10.0
	dyn	-0.3	-12.0	-0.5	0.2	0.5	0.1	-87.4	60.2	1.0	44.8	1.7
	supi	-0.1	-20.6	-0.7	0.2	0.4	0.1	-88.0	79.8	1.0	165.5	5.6
	pron	-0.1	-18.2	-1.3	0.2	1.1	0.5	-85.9	86.7	1.0	238.8	17.2

Table A1.46

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left leg of subjects 16 - 20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT LEG	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
21	comp	-0.2	-41.0	-2.2	0.3	1.9	0.8	-87.0	84.7	1.0	203.9	10.7
	dyn	-0.2	-13.0	-0.4	0.2	0.4	0.4	-88.2	65.9	1.0	77.4	2.2
	supi	-0.4	-20.7	-0.8	0.2	0.4	0.5	-87.5	60.5	1.0	46.9	1.8
	pron	0.2	-20.3	-1.4	0.4	1.9	0.4	-86.0	-80.1	1.0	-84.5	-5.7
22	comp	2.1	-39.0	0.9	0.2	1.6	0.2	-86.7	22.2	1.0	-18.6	0.4
	dyn	1.2	-19.0	0.7	0.2	0.4	0.3	-85.7	30.0	1.0	-15.5	0.6
	supi	0.6	-20.3	0.8	0.1	0.2	0.2	-87.3	53.9	1.0	-36.3	1.4
	pron	1.5	-18.6	0.1	0.2	1.5	0.2	-85.3	3.1	1.0	-12.2	0.1
23	comp	2.4	-43.1	-0.6	1.2	3.8	0.8	-86.8	-13.5	1.0	-18.3	-0.2
	dyn	1.7	-22.8	-0.7	0.4	0.3	0.4	-85.3	-23.0	1.0	-13.3	-0.4
	supi	0.2	-20.9	-0.2	0.1	0.7	0.6	-89.2	-34.5	1.0	-84.1	-0.7
	pron	2.1	-22.2	-0.4	1.2	3.5	0.8	-84.5	-10.6	1.0	-10.5	-0.2
24	comp	-0.8	-35.0	-2.3	0.6	1.7	0.3	-86.0	70.5	1.0	42.9	2.8
	dyn	-0.3	-10.6	-0.6	0.2	4.8	0.4	-86.5	63.0	1.0	36.5	2.0
	supi	-0.2	-17.5	-0.7	0.4	2.8	0.3	-87.4	71.5	1.0	70.3	3.0
	pron	-0.6	-17.5	-1.6	0.2	1.1	0.4	-84.6	70.0	1.0	30.9	2.8
25	comp	-1.4	-41.5	-3.3	0.5	1.4	0.8	-85.1	67.6	1.0	30.8	2.4
	dyn	-0.5	-13.2	-0.7	0.2	0.4	0.2	-86.2	58.7	1.0	29.0	1.6
	supi	-0.9	-20.4	-1.9	0.3	0.9	0.4	-84.1	63.3	1.0	21.5	2.0
	pron	-0.4	-21.1	-1.4	0.6	1.1	0.4	-86.0	74.0	1.0	52.6	3.5

Table A1.47

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left leg of subjects 21 - 25.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT LEG	mean Range of motion (rom)			Standard deviation (rom)			mean angle of axis to		Axis calculated from mean rom. angle of axis to		Ratio of mean rom		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Trn	Sag	Frt	Trn	Sag
MEAN	comp	0.7	-39.6	-0.7	1.7	5.1	1.6	-86.7	12.2	-88.5	-43.8	1.0	-55.0	-1.0
	dyn	0.3	-16.8	-0.2	1.0	4.5	0.7	-86.5	16.6	-88.7	-28.8	1.0	-51.4	-0.5
	supi	0.0	-20.5	-0.2	0.9	1.2	1.1	-86.5	4.4	-89.3	-84.8	1.0	-961.5	-11.1
	pron	0.7	-19.1	-0.5	1.1	4.9	0.9	-85.6	-1.0	-87.5	-33.1	1.0	-27.3	-0.7

Table A1.48

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the left leg. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			angle of axis to	
	LEG	Frt	Trn	Sag	Trn	Sag
comp	MIN	-3.2	-49.1	-3.3	-89.1	-83.8
	MAX	4.4	-31.0	2.9	-84.2	87.8
	RANGE	7.6	18.1	6.1	4.9	171.6
dyn	MIN	-1.5	-26.1	-0.9	-89.2	-86.5
	MAX	2.5	-10.6	1.6	-82.9	85.7
	RANGE	4.0	15.5	2.6	6.3	172.2
supi	MIN	-1.4	-24.8	-1.9	-89.2	-84.3
	MAX	2.1	-17.5	3.2	-80.7	79.8
	RANGE	3.5	7.3	5.1	8.5	164.1
pron	MIN	-1.9	-28.6	-1.7	-89.3	-82.4
	MAX	3.4	-10.3	1.4	-80.8	86.7
	RANGE	5.3	18.3	3.1	8.6	169.0

Table A1.49

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the left leg of all subjects.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT HEEL	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
1	comp	8.6	-9.7	-4.5	1.6	0.7	1.0	-45.1	-27.7	1.0	-1.1	-0.5
	dyn	3.2	-3.4	-1.4	1.1	0.2	0.6	-44.7	-23.2	1.0	-1.1	-0.4
	supi	7.9	-4.5	-3.6	1.1	0.4	0.8	-27.7	-24.4	1.0	-0.6	-0.5
	pron	0.7	-5.2	-0.9	0.8	0.7	0.3	-77.0	-52.0	1.0	-7.0	-1.3
2	comp	12.4	-10.7	2.6	0.8	1.6	1.2	-40.2	11.7	1.0	-0.9	0.2
	dyn	9.7	-8.0	1.6	0.9	1.4	1.8	-39.2	9.2	1.0	-0.8	0.2
	supi	8.7	-5.5	-0.4	1.0	1.3	1.4	-32.3	-2.5	1.0	-0.6	0.0
	pron	3.7	-5.2	3.0	1.2	0.8	0.9	-47.7	38.4	1.0	-1.4	0.8
3	comp	2.7	-12.4	-1.1	1.4	1.3	0.5	-76.8	-22.8	1.0	-4.6	-0.4
	dyn	2.2	-9.2	-0.2	1.4	1.3	0.6	-76.4	-5.8	1.0	-4.1	-0.1
	supi	0.2	-6.8	-1.4	1.4	1.7	0.5	-77.9	-81.6	1.0	-31.8	-6.7
	pron	2.5	-5.6	0.3	1.2	1.3	0.5	-66.0	7.4	1.0	-2.3	0.1
4	comp	3.1	-12.1	-3.1	0.8	1.6	0.3	-70.0	-45.6	1.0	-3.9	-1.0
	dyn	1.4	-3.6	-1.0	0.5	0.8	0.3	-64.6	-34.1	1.0	-2.5	-0.7
	supi	1.3	-7.7	-2.1	0.9	1.1	0.3	-72.3	-57.4	1.0	-5.8	-1.6
	pron	1.8	-4.4	-1.1	0.7	1.1	0.1	-64.8	-31.5	1.0	-2.5	-0.6
5	comp	6.0	-10.1	-6.7	0.5	0.7	0.4	-48.3	-48.6	1.0	-1.7	-1.1
	dyn	3.1	-5.4	-3.6	0.4	0.5	0.3	-48.7	-49.1	1.0	-1.7	-1.2
	supi	3.9	-6.3	-4.6	0.3	0.6	0.3	-46.2	-49.5	1.0	-1.6	-1.2
	pron	2.0	-3.8	-2.2	0.6	0.9	0.4	-52.1	-46.8	1.0	-1.9	-1.1

Table A1.50

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left heel of subjects 1 - 5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT HEEL	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
6	comp	8.6	-14.7	-3.1	1.0	1.4	1.0	-58.2	-19.7	1.0	-1.7	-0.4
	dyn	2.1	-3.2	-1.3	0.5	0.4	0.3	-52.1	-31.6	1.0	-1.5	-0.6
	supi	3.4	-6.7	-2.2	0.4	0.9	0.4	-58.6	-32.6	1.0	-1.9	-0.6
	pron	5.1	-8.0	-0.9	1.2	0.9	0.9	-56.9	-9.6	1.0	-1.6	-0.2
7	comp	13.5	-14.0	-4.0	1.3	1.2	0.6	-44.7	-16.6	1.0	-1.0	-0.3
	dyn	8.6	-7.9	-3.8	0.8	0.7	0.3	-40.0	-23.6	1.0	-0.9	-0.4
	supi	6.3	-6.7	-3.1	0.4	0.5	0.2	-43.8	-26.1	1.0	-1.1	-0.5
	pron	7.2	-7.3	-1.0	1.0	1.1	0.6	-44.9	-7.5	1.0	-1.0	-0.1
8	comp	10.6	-12.4	-0.9	1.1	1.0	0.5	-49.2	-5.0	1.0	-1.2	-0.1
	dyn	4.4	-5.9	-0.8	0.8	0.5	0.5	-52.7	-10.0	1.0	-1.3	-0.2
	supi	8.0	-5.9	-0.9	1.0	0.4	0.5	-36.3	-6.5	1.0	-0.7	-0.1
	pron	2.7	-6.5	0.0	1.2	1.2	0.8	-67.6	-0.7	1.0	-2.4	0.0
9	comp	3.5	-9.1	-1.4	0.1	0.6	0.1	-67.2	-22.0	1.0	-2.6	-0.4
	dyn	1.2	-4.7	-0.7	0.1	0.4	0.1	-74.2	-29.6	1.0	-4.1	-0.6
	supi	2.5	-5.0	-1.4	0.5	0.0	0.4	-60.2	-30.2	1.0	-2.0	-0.6
	pron	1.1	-4.1	0.0	0.4	0.6	0.3	-75.4	0.4	1.0	-3.8	0.0
10	comp	6.0	-11.4	-2.5	0.6	0.4	0.3	-60.2	-22.5	1.0	-1.9	-0.4
	dyn	4.2	-7.3	-1.6	0.5	0.4	0.2	-58.2	-20.7	1.0	-1.7	-0.4
	supi	4.3	-8.3	-1.9	0.3	0.4	0.2	-60.5	-23.7	1.0	-1.9	-0.4
	pron	1.7	-3.1	-0.6	0.4	0.3	0.2	-59.4	-19.3	1.0	-1.8	-0.4

Table A1.51

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left heel of subjects 6 - 10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT HEEL	Range of motion (rom) Frt	Range of motion (rom) Trn	Range of motion (rom) Sag	Standard deviation (rom) Frt	Standard deviation (rom) Trn	Standard deviation (rom) Sag	angle of axis to Trn	angle of axis to Sag	Ratio (rom) Frt	Ratio (rom) Trn	Ratio (rom) Sag
11	comp	4.0	-14.0	-2.9	0.9	0.5	0.6	-70.6	-35.9	1.0	-3.5	-0.7
	dyn	0.0	-3.4	-0.6	0.6	0.4	0.1	-80.4	-88.9	1.0	-322.9	-54.5
	supi	4.2	-6.9	-1.4	0.8	0.7	0.4	-57.6	-19.2	1.0	-1.7	-0.3
	pron	-0.2	-7.0	-1.4	0.4	0.4	0.3	-78.5	83.0	1.0	40.3	8.2
12	comp	13.9	-11.9	-2.2	0.4	1.1	0.3	-40.3	-9.0	1.0	-0.9	-0.2
	dyn	9.6	-6.0	-0.5	0.7	0.9	0.6	-32.2	-2.8	1.0	-0.6	0.0
	supi	4.9	-5.7	-2.4	0.5	0.9	0.5	-46.0	-26.4	1.0	-1.2	-0.5
	pron	9.0	-6.3	0.2	0.7	0.7	0.6	-34.9	1.5	1.0	-0.7	0.0
13	comp	8.7	-10.3	0.0	0.5	1.3	0.5	-49.7	0.0	1.0	-1.2	0.0
	dyn	3.4	-4.8	-0.2	0.4	0.3	0.3	-54.2	-2.6	1.0	-1.4	0.0
	supi	5.4	-4.9	0.0	0.2	0.3	0.2	-42.2	0.0	1.0	-0.9	0.0
	pron	3.3	-5.4	0.0	0.5	1.1	0.6	-58.3	0.1	1.0	-1.6	0.0
14	comp	6.4	-14.4	-0.4	1.0	0.6	0.6	-66.0	-4.0	1.0	-2.3	-0.1
	dyn	2.1	-4.7	-0.3	0.6	0.4	0.3	-65.7	-7.2	1.0	-2.2	-0.1
	supi	2.3	-6.8	-0.4	0.4	0.5	0.3	-70.8	-9.4	1.0	-2.9	-0.2
	pron	4.1	-7.6	-0.1	0.7	0.7	0.4	-61.9	-0.8	1.0	-1.9	0.0
15	comp	10.0	-14.7	-1.7	0.6	1.6	1.1	-55.4	-9.7	1.0	-1.5	-0.2
	dyn	3.6	-4.6	-1.1	1.1	0.5	0.3	-50.2	-17.1	1.0	-1.3	-0.3
	supi	2.9	-5.3	-0.9	0.4	0.3	0.2	-60.0	-17.4	1.0	-1.8	-0.3
	pron	7.1	-9.4	-0.8	1.0	0.1	1.3	-52.9	-6.5	1.0	-1.3	-0.1

Table A1.52

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left heel of subjects 11 - 15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	HEEL	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
16	comp	7.1	-16.6	-4.4	1.0	0.9	0.7	-63.4	-31.7	1.0	-2.3	-0.6
	dyn	0.6	-6.3	-1.3	0.7	0.2	0.1	-77.1	-66.9	1.0	-11.2	-2.4
	supi	7.9	-10.4	-3.3	0.9	0.5	0.4	-50.5	-22.7	1.0	-1.3	-0.4
	pron	-0.8	-6.2	-1.1	0.8	1.4	0.4	-77.6	52.1	1.0	7.4	1.3
17	comp	3.4	-12.7	-1.2	0.4	2.2	0.3	-74.2	-18.8	1.0	-3.7	-0.3
	dyn	1.7	-4.7	-0.1	1.6	0.7	0.3	-70.6	-4.7	1.0	-2.8	-0.1
	supi	5.2	-7.0	-0.7	0.6	1.6	0.3	-53.0	-7.9	1.0	-1.3	-0.1
	pron	-1.8	-5.8	-0.4	0.4	1.4	0.3	-72.1	13.7	1.0	3.2	0.2
18	comp	14.2	-12.3	-3.0	0.7	1.4	0.7	-40.2	-12.0	1.0	-0.9	-0.2
	dyn	6.8	-5.5	-2.0	0.5	0.5	0.3	-38.1	-16.4	1.0	-0.8	-0.3
	supi	9.0	-6.9	-2.6	0.6	0.3	0.3	-36.4	-16.3	1.0	-0.8	-0.3
	pron	5.3	-5.4	-0.4	0.6	1.1	0.5	-45.6	-4.4	1.0	-1.0	-0.1
19	comp	12.8	-16.1	-0.9	1.4	0.8	0.6	-51.5	-3.8	1.0	-1.3	-0.1
	dyn	4.3	-5.0	-0.8	0.5	0.4	0.2	-48.8	-9.9	1.0	-1.2	-0.2
	supi	5.6	-8.0	-1.1	0.8	0.3	0.2	-54.5	-11.2	1.0	-1.4	-0.2
	pron	7.2	-8.1	0.3	1.8	0.8	0.5	-48.4	2.1	1.0	-1.1	0.0
20	comp	8.3	-10.4	-1.8	1.1	0.6	0.3	-50.7	-12.4	1.0	-1.3	-0.2
	dyn	3.5	-3.5	-0.8	0.6	0.3	0.2	-44.5	-12.8	1.0	-1.0	-0.2
	supi	4.3	-4.9	-2.0	0.6	0.3	0.2	-45.6	-24.8	1.0	-1.1	-0.5
	pron	4.0	-5.5	0.2	0.9	0.6	0.3	-54.2	2.6	1.0	-1.4	0.0

Table A1.53

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left heel of subjects 16 - 20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT HEEL	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
21	comp	8.9	-9.7	-0.9	0.9	0.9	0.3	-47.2	-6.0	1.0	-1.1	-0.1
	dyn	2.9	-2.7	-0.5	0.7	0.2	0.2	-42.7	-10.4	1.0	-0.9	-0.2
	supi	5.4	-4.7	-1.3	0.6	0.3	0.2	-40.4	-13.0	1.0	-0.9	-0.2
	pron	3.5	-5.0	0.3	0.9	0.7	0.3	-54.7	5.1	1.0	-1.4	0.1
22	comp	3.6	-7.8	-1.8	0.6	0.6	0.4	-62.8	-26.6	1.0	-2.2	-0.5
	dyn	1.8	-2.9	-0.8	0.3	0.4	0.2	-54.9	-24.6	1.0	-1.6	-0.5
	supi	3.3	-5.0	-1.8	0.7	0.2	0.2	-53.1	-28.0	1.0	-1.5	-0.5
	pron	0.3	-2.8	0.0	0.8	0.5	0.4	-84.4	-7.1	1.0	-10.3	-0.1
23	comp	7.6	-15.2	-1.2	0.4	1.2	0.5	-63.1	-9.3	1.0	-2.0	-0.2
	dyn	2.7	-8.1	-0.5	0.9	0.5	0.4	-71.3	-11.0	1.0	-3.0	-0.2
	supi	5.0	-6.9	-1.2	0.8	0.7	0.5	-53.1	-13.9	1.0	-1.4	-0.2
	pron	2.6	-8.2	0.0	0.9	0.8	0.5	-72.7	0.1	1.0	-3.2	0.0
24	comp	8.6	-8.6	-3.5	1.6	0.6	0.4	-42.8	-21.9	1.0	-1.0	-0.4
	dyn	2.6	-2.9	-0.9	1.5	1.2	0.6	-46.0	-19.7	1.0	-1.1	-0.4
	supi	4.6	-4.3	-1.8	0.9	0.6	0.2	-40.6	-21.1	1.0	-0.9	-0.4
	pron	4.0	-4.3	-1.7	0.9	0.1	0.5	-45.2	-22.9	1.0	-1.1	-0.4
25	comp	4.6	-13.5	-2.1	1.0	0.5	1.0	-69.6	-24.3	1.0	-2.9	-0.5
	dyn	1.4	-3.8	-0.7	0.7	0.3	0.1	-68.1	-26.2	1.0	-2.8	-0.5
	supi	3.2	-7.1	-1.8	0.9	0.5	0.7	-62.7	-29.0	1.0	-2.2	-0.6
	pron	1.4	-6.4	-0.3	1.2	0.7	0.5	-77.6	-12.0	1.0	-4.6	-0.2

Table A1.54

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left heel of subjects 21 - 25.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT HEEL	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
MEAN	comp	7.9	-12.2	-2.1	3.6	2.4	1.8	-56.3	-17.8	-56.2	-15.0	1.0	-1.5	-0.3
	dyn	3.5	-5.1	-1.0	2.6	1.9	1.1	-55.8	-21.6	-54.7	-15.3	1.0	-1.5	-0.3
	supi	4.8	-6.3	-1.8	2.3	1.4	1.1	-51.3	-23.8	-51.1	-20.3	1.0	-1.3	-0.4
	pron	3.1	-5.9	-0.3	2.7	1.7	1.0	-61.2	-0.6	-62.0	-6.3	1.0	-1.9	-0.1

Table A1.55

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the left heel. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			angle of axis to	
	HEEL	Frt	Trn	Sag	Trn	Sag
comp	MIN	2.7	-16.6	-6.7	-76.8	-48.6
	MAX	14.2	-7.8	2.6	-40.2	11.7
	RANGE	11.6	8.8	9.3	36.6	60.2
dyn	MIN	0.0	-9.2	-3.8	-80.4	-88.9
	MAX	9.7	-2.7	1.6	-32.2	9.2
	RANGE	9.7	6.5	5.3	48.2	98.2
supi	MIN	0.2	-10.4	-4.6	-77.9	-81.6
	MAX	9.0	-4.3	0.0	-27.7	0.0
	RANGE	8.8	6.2	4.6	50.2	81.6
pron	MIN	-1.8	-9.4	-2.2	-84.4	-52.0
	MAX	9.0	-2.8	3.0	-34.9	83.0
	RANGE	10.8	6.6	5.1	49.5	135.0

Table A1.56

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the left heel of all subjects.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	FORFT	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
1	comp	20.2	-2.1	8.5	2.1	1.2	0.9	-5.4	22.9	1.0	-0.1	0.4
	dyn	7.8	-1.5	3.9	1.7	1.2	0.9	-9.6	26.3	1.0	-0.2	0.5
	supi	13.8	0.1	4.9	1.5	1.3	0.9	0.5	19.7	1.0	0.0	0.4
	pron	6.5	-2.2	3.6	1.1	1.2	0.9	-16.4	29.1	1.0	-0.3	0.6
2	comp	22.7	0.1	7.9	2.8	1.6	1.1	0.2	19.2	1.0	0.0	0.3
	dyn	17.1	-0.5	6.2	2.1	1.5	1.3	-1.6	20.1	1.0	0.0	0.4
	supi	12.7	0.6	4.8	1.7	1.0	1.0	2.5	20.6	1.0	0.0	0.4
	pron	10.0	-0.5	3.2	2.0	1.0	1.5	-2.8	17.5	1.0	-0.1	0.3
3	comp	12.4	-1.9	7.2	2.1	1.4	0.9	-7.7	30.2	1.0	-0.2	0.6
	dyn	8.0	-1.7	5.6	2.1	1.0	1.2	-9.7	34.9	1.0	-0.2	0.7
	supi	6.7	-1.0	3.2	0.8	1.4	0.6	-7.8	25.3	1.0	-0.2	0.5
	pron	5.7	-0.9	4.1	1.7	0.8	1.0	-7.6	35.5	1.0	-0.2	0.7
4	comp	12.6	0.9	0.3	0.9	1.1	1.0	4.3	1.4	1.0	0.1	0.0
	dyn	4.5	0.3	0.6	1.2	0.6	1.0	4.3	7.2	1.0	0.1	0.1
	supi	7.3	0.4	-0.8	1.0	1.1	1.0	3.0	-6.0	1.0	0.1	-0.1
	pron	5.3	0.6	1.1	0.9	0.4	1.0	5.9	11.7	1.0	0.1	0.2
5	comp	24.5	-1.3	4.3	2.4	1.7	1.3	-3.0	9.9	1.0	-0.1	0.2
	dyn	12.9	-0.1	3.4	1.3	1.3	1.2	-0.2	14.9	1.0	0.0	0.3
	supi	16.5	-1.6	0.8	1.3	1.1	0.8	-5.5	2.9	1.0	-0.1	0.0
	pron	8.1	0.3	3.5	1.4	0.6	0.7	1.8	23.2	1.0	0.0	0.4

Table A1.57

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left forefoot of subjects 1 - 5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT FORFT	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
6	comp	22.6	-4.6	5.4	2.5	1.4	0.9	-11.2	13.4	1.0	-0.2	0.2
	dyn	5.8	-1.2	1.5	0.8	0.8	0.7	-11.2	14.5	1.0	-0.2	0.3
	supi	10.9	-4.2	0.7	0.6	0.8	0.3	-21.1	3.5	1.0	-0.4	0.1
	pron	11.7	-0.4	4.7	2.7	1.7	0.8	-1.9	21.9	1.0	0.0	0.4
7	comp	27.6	4.2	7.4	3.0	0.8	1.0	8.3	14.9	1.0	0.2	0.3
	dyn	15.6	3.9	4.5	1.7	0.7	0.4	13.7	16.0	1.0	0.3	0.3
	supi	11.2	3.7	1.8	1.2	0.6	0.6	18.1	9.3	1.0	0.3	0.2
	pron	16.4	0.5	5.5	2.5	0.8	1.2	1.6	18.6	1.0	0.0	0.3
8	comp	22.1	-1.9	7.3	2.9	0.9	0.4	-4.7	18.4	1.0	-0.1	0.3
	dyn	8.7	0.1	3.5	1.5	0.3	0.5	0.8	21.8	1.0	0.0	0.4
	supi	13.4	-0.7	3.8	1.5	1.1	0.4	-2.8	15.9	1.0	0.0	0.3
	pron	8.7	-1.3	3.5	2.2	0.9	0.7	-7.6	22.0	1.0	-0.1	0.4
9	comp	13.3	-0.4	7.5	2.4	0.0	0.3	-1.7	29.2	1.0	0.0	0.6
	dyn	5.8	-0.4	4.2	0.4	0.7	0.0	-3.0	36.3	1.0	-0.1	0.7
	supi	9.1	-0.5	5.3	0.4	0.4	1.0	-2.8	30.1	1.0	-0.1	0.6
	pron	4.3	0.1	2.2	2.0	0.3	0.7	0.8	27.3	1.0	0.0	0.5
10	comp	11.4	-0.9	3.4	1.3	0.4	0.7	-4.3	16.5	1.0	-0.1	0.3
	dyn	7.5	-0.6	2.9	1.1	0.4	0.4	-4.5	21.0	1.0	-0.1	0.4
	supi	8.3	-0.7	1.6	0.9	0.4	0.5	-4.9	11.0	1.0	-0.1	0.2
	pron	3.1	-0.2	1.8	0.6	0.4	0.7	-2.7	29.6	1.0	-0.1	0.6

Table A1.58

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left forefoot of subjects 6 - 10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT FORFT	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
11	comp	15.9	-4.7	4.8	1.3	0.9	1.2	-15.8	16.7	1.0	-0.3	0.3
	dyn	3.2	-1.4	1.0	1.0	0.6	0.9	-22.1	17.8	1.0	-0.4	0.3
	supi	10.8	-1.7	4.3	1.6	0.5	0.7	-8.6	21.8	1.0	-0.2	0.4
	pron	5.1	-2.9	0.5	0.9	0.9	1.6	-29.9	5.0	1.0	-0.6	0.1
12	comp	37.1	0.3	2.7	1.1	1.3	1.0	0.5	4.2	1.0	0.0	0.1
	dyn	20.8	1.5	1.3	2.6	1.2	1.2	4.1	3.6	1.0	0.1	0.1
	supi	16.6	-1.3	3.0	1.6	0.8	0.6	-4.3	10.1	1.0	-0.1	0.2
	pron	20.5	1.6	-0.2	1.8	1.1	0.7	4.5	-0.7	1.0	0.1	0.0
13	comp	18.1	-0.2	9.1	1.3	1.1	0.7	-0.6	26.7	1.0	0.0	0.5
	dyn	7.8	1.5	4.6	0.6	0.5	0.2	9.1	30.8	1.0	0.2	0.6
	supi	10.5	-1.6	3.9	0.6	1.1	0.8	-8.2	20.6	1.0	-0.2	0.4
	pron	7.7	1.4	5.2	1.2	0.5	0.8	8.5	34.1	1.0	0.2	0.7
14	comp	20.2	-2.1	0.1	2.1	0.9	1.7	-5.9	0.2	1.0	-0.1	0.0
	dyn	6.7	-0.7	-1.8	1.4	0.2	0.3	-5.8	-14.8	1.0	-0.1	-0.3
	supi	8.6	-1.2	-1.8	1.4	1.0	0.7	-8.1	-11.9	1.0	-0.1	-0.2
	pron	11.6	-0.9	1.9	1.3	0.6	2.0	-4.2	9.1	1.0	-0.1	0.2
15	comp	25.2	-3.5	5.6	2.6	1.5	1.1	-7.6	12.6	1.0	-0.1	0.2
	dyn	8.6	-0.9	1.8	0.9	1.1	0.9	-6.1	11.9	1.0	-0.1	0.2
	supi	8.5	0.2	1.8	1.2	1.0	0.9	1.0	11.8	1.0	0.0	0.2
	pron	16.7	-3.6	3.9	3.8	0.8	0.2	-11.9	13.0	1.0	-0.2	0.2

Table A1.59

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left forefoot of subjects 11 - 15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	FORFT	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
16	comp	19.0	-6.7	2.5	1.6	1.6	1.2	-19.1	7.4	1.0	-0.4	0.1
	dyn	4.0	-2.1	1.7	1.1	1.2	0.1	-26.4	23.6	1.0	-0.5	0.4
	supi	16.4	-4.2	1.4	1.2	1.2	1.4	-14.3	5.0	1.0	-0.3	0.1
	pron	2.6	-2.5	1.0	0.4	0.5	0.4	-41.3	21.6	1.0	-0.9	0.4
17	comp	12.5	-3.6	4.5	1.1	0.6	0.3	-15.3	19.9	1.0	-0.3	0.4
	dyn	4.1	-1.8	2.1	1.3	0.5	0.4	-21.5	27.0	1.0	-0.4	0.5
	supi	9.2	-0.1	1.8	1.3	0.8	0.7	-0.8	11.2	1.0	0.0	0.2
	pron	3.3	-3.5	2.7	1.1	0.9	0.8	-39.2	39.1	1.0	-1.1	0.8
18	comp	27.0	2.3	7.2	2.3	0.8	0.8	4.6	15.0	1.0	0.1	0.3
	dyn	12.7	2.1	3.5	0.8	0.4	0.4	9.2	15.6	1.0	0.2	0.3
	supi	16.1	1.6	2.9	0.9	0.7	0.6	5.6	10.1	1.0	0.1	0.2
	pron	10.9	0.7	4.4	2.0	0.9	0.7	3.3	21.9	1.0	0.1	0.4
19	comp	25.4	-0.1	8.3	2.1	2.4	0.8	-0.3	18.1	1.0	0.0	0.3
	dyn	8.4	-0.2	2.8	1.0	0.7	0.3	-1.1	18.8	1.0	0.0	0.3
	supi	10.0	1.2	2.8	1.9	0.6	0.9	6.4	15.6	1.0	0.1	0.3
	pron	15.4	-1.3	5.5	3.2	2.1	1.4	-4.6	19.7	1.0	-0.1	0.4
20	comp	19.8	-1.0	6.6	1.8	0.7	0.8	-2.8	18.6	1.0	-0.1	0.3
	dyn	6.9	0.0	2.8	1.0	0.3	0.4	0.3	21.6	1.0	0.0	0.4
	supi	10.1	-0.7	1.8	0.9	0.7	0.4	-4.0	10.3	1.0	-0.1	0.2
	pron	9.7	-0.3	4.8	1.5	0.5	0.6	-1.7	26.4	1.0	0.0	0.5

Table A1.60

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left forefoot of subjects 16 - 20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	FORFT	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
21	comp	16.5	2.3	6.8	1.1	0.9	0.6	7.4	22.4	1.0	0.1	0.4
	dyn	5.1	1.3	2.5	0.8	0.5	0.5	13.1	25.7	1.0	0.3	0.5
	supi	9.4	2.5	3.3	1.0	0.9	0.9	13.9	19.2	1.0	0.3	0.3
	pron	7.1	-0.2	3.5	1.2	0.9	0.7	-1.1	26.4	1.0	0.0	0.5
22	comp	14.8	2.1	8.3	0.8	0.6	0.5	7.0	29.3	1.0	0.1	0.6
	dyn	6.4	1.7	4.0	0.8	0.5	0.4	13.0	31.7	1.0	0.3	0.6
	supi	10.3	2.4	5.9	1.1	0.6	0.8	11.5	29.8	1.0	0.2	0.6
	pron	4.6	-0.3	2.4	1.0	0.5	0.6	-3.6	28.2	1.0	-0.1	0.5
23	comp	17.1	0.8	3.4	1.6	1.1	1.1	2.6	11.3	1.0	0.0	0.2
	dyn	8.9	0.0	2.6	1.5	0.7	1.6	-0.2	16.2	1.0	0.0	0.3
	supi	9.1	1.0	-1.7	1.5	1.4	1.3	5.9	-10.4	1.0	0.1	-0.2
	pron	8.0	-0.1	5.1	1.1	1.0	1.1	-0.9	32.7	1.0	0.0	0.6
24	comp	15.3	3.5	4.3	2.0	0.6	0.5	12.3	15.7	1.0	0.2	0.3
	dyn	4.2	1.2	1.6	2.7	0.6	0.9	15.4	20.5	1.0	0.3	0.4
	supi	8.3	1.5	1.4	1.1	0.4	0.3	10.0	9.4	1.0	0.2	0.2
	pron	7.0	2.0	2.9	0.9	0.2	0.5	14.7	22.8	1.0	0.3	0.4
25	comp	19.3	-7.3	-0.2	2.1	1.6	1.3	-20.9	-0.5	1.0	-0.4	0.0
	dyn	5.2	-2.4	0.0	0.9	1.0	0.5	-24.6	0.4	1.0	-0.5	0.0
	supi	10.9	-4.5	0.9	2.1	1.1	0.9	-22.5	5.0	1.0	-0.4	0.1
	pron	8.3	-2.8	-1.1	2.2	0.7	0.9	-18.4	-7.7	1.0	-0.3	-0.1

Table A1.61

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left forefoot of subjects 21 - 25.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT FORFT	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
MEAN	comp	19.7	-1.0	5.3	6.0	2.9	2.8	-3.2	15.8	-2.9	15.1	1.0	-0.1	0.3
	dyn	8.3	-0.1	2.7	4.4	1.5	1.8	-2.6	18.5	-0.4	17.9	1.0	0.0	0.3
	supi	11.0	-0.4	2.3	2.9	2.0	2.0	-1.5	11.6	-1.9	11.9	1.0	0.0	0.2
	pron	8.7	-0.7	3.0	4.6	1.5	1.8	-6.2	21.1	-4.2	19.1	1.0	-0.1	0.3

Table A1.62

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the left forefoot. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			angle of axis to	
	FORFT	Frt	Trn	Sag	Trn	Sag
comp	MIN	11.4	-7.3	-0.2	-20.9	-0.5
	MAX	37.1	4.2	9.1	12.3	30.2
	RANGE	25.7	11.5	9.3	33.2	30.7
dyn	MIN	3.2	-2.4	-1.8	-26.4	-14.8
	MAX	20.8	3.9	6.2	15.4	36.3
	RANGE	17.6	6.3	8.0	41.8	51.1
supi	MIN	6.7	-4.5	-1.8	-22.5	-11.9
	MAX	16.6	3.7	5.9	18.1	30.1
	RANGE	9.9	8.2	7.7	40.6	42.0
pron	MIN	2.6	-3.6	-1.1	-41.3	-7.7
	MAX	20.5	2.0	5.5	14.7	39.1
	RANGE	17.9	5.6	6.6	55.9	46.8

Table A1.63

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the left forefoot of all subjects.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT Ank/Stj	Range of motion (rom) Frt	Range of motion (rom) Trn	Range of motion (rom) Sag	Standard deviation (rom) Frt	Standard deviation (rom) Trn	Standard deviation (rom) Sag	angle of axis to Trn	angle of axis to Sag	Ratio (rom) Frt	Ratio (rom) Trn	Ratio (rom) Sag
1	comp	9.2	30.0	-3.0	2.0	1.7	1.2	72.2	-18.1	1.0	3.3	-0.3
	dyn	3.3	12.3	-1.0	1.3	0.7	0.8	74.3	-16.4	1.0	3.7	-0.3
	supi	9.2	15.9	-3.5	1.3	0.2	0.9	58.3	-20.8	1.0	1.7	-0.4
	pron	0.0	14.1	0.5	1.3	1.7	0.5	88.0	-86.8	1.0	-506.2	-17.7
2	comp	10.2	24.5	0.6	1.5	2.2	1.3	67.4	3.1	1.0	2.4	0.1
	dyn	8.3	17.8	0.1	1.8	1.3	1.7	65.0	0.9	1.0	2.1	0.0
	supi	8.3	15.0	-1.7	1.8	1.3	1.4	60.5	-11.6	1.0	1.8	-0.2
	pron	1.9	9.6	2.3	1.0	2.4	0.9	72.8	50.0	1.0	5.0	1.2
3	comp	-0.7	22.0	-1.2	1.7	2.9	1.0	86.3	58.6	1.0	-29.9	1.6
	dyn	-0.2	15.2	-0.1	1.7	2.4	1.0	88.9	26.6	1.0	-60.9	0.5
	supi	-1.9	11.3	-1.4	2.2	1.8	0.7	78.2	37.0	1.0	-6.0	0.8
	pron	1.2	10.7	0.2	1.3	2.1	0.5	83.7	10.7	1.0	9.2	0.2
4	comp	2.4	23.7	-0.1	1.0	2.5	0.2	84.1	-3.1	1.0	9.7	-0.1
	dyn	1.4	8.4	0.0	0.7	2.9	0.4	80.8	-0.5	1.0	6.2	0.0
	supi	0.9	11.8	-0.6	0.9	2.5	0.3	84.8	-32.7	1.0	13.2	-0.6
	pron	1.6	11.9	0.4	0.6	2.5	0.6	82.3	15.8	1.0	7.7	0.3
5	comp	6.2	25.1	-7.5	0.9	0.7	0.6	68.8	-50.2	1.0	4.0	-1.2
	dyn	3.1	12.8	-4.3	0.5	0.7	0.5	67.6	-54.5	1.0	4.2	-1.4
	supi	4.6	14.5	-5.2	0.3	0.6	0.4	64.5	-48.9	1.0	3.2	-1.1
	pron	1.7	10.6	-2.3	0.8	1.0	0.8	75.0	-53.3	1.0	6.3	-1.3

Table A1.64

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left ankle/sub talar complex of subjects 1 - 5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	Ank/Stj	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
6	comp	7.2	29.3	-3.9	1.3	1.4	0.7	74.4	-28.5	1.0	4.1	-0.5
	dyn	2.0	7.6	-1.2	0.6	0.7	0.3	72.9	-32.3	1.0	3.8	-0.6
	supi	2.6	13.7	-2.2	0.6	1.0	0.5	76.0	-40.3	1.0	5.3	-0.8
	pron	4.6	15.6	-1.7	1.5	1.2	0.7	72.5	-20.3	1.0	3.4	-0.4
7	comp	14.5	30.9	-3.1	1.8	1.8	1.0	64.3	-12.1	1.0	2.1	-0.2
	dyn	9.7	18.2	-3.6	1.1	0.7	0.3	60.4	-20.4	1.0	1.9	-0.4
	supi	7.4	13.7	-2.4	0.6	0.5	0.5	60.6	-18.1	1.0	1.9	-0.3
	pron	7.1	17.1	-0.7	1.4	1.7	0.7	67.3	-5.6	1.0	2.4	-0.1
8	comp	10.2	20.1	-1.3	1.5	2.5	1.2	62.9	-7.5	1.0	2.0	-0.1
	dyn	3.7	11.1	-0.5	1.4	0.4	0.7	71.4	-7.1	1.0	3.0	-0.1
	supi	8.4	14.7	0.1	1.3	0.5	0.7	60.3	0.6	1.0	1.8	0.0
	pron	1.8	5.4	-1.4	1.8	2.4	1.6	66.9	-38.3	1.0	3.0	-0.8
9	comp	3.0	23.2	-0.6	0.2	0.8	0.1	82.4	-10.4	1.0	7.6	-0.2
	dyn	0.6	12.5	0.1	0.0	0.5	0.0	87.3	13.1	1.0	21.6	0.2
	supi	2.1	15.0	-0.6	0.5	0.1	0.9	81.6	-16.4	1.0	7.1	-0.3
	pron	0.9	8.2	0.1	0.7	0.7	1.0	83.5	3.9	1.0	8.8	0.1
10	comp	4.1	19.6	-2.8	0.9	1.1	0.4	75.8	-34.0	1.0	4.8	-0.7
	dyn	3.1	13.0	-1.6	0.7	0.4	0.4	75.0	-28.1	1.0	4.2	-0.5
	supi	2.9	12.4	-2.4	0.5	0.4	0.3	73.0	-39.9	1.0	4.3	-0.8
	pron	1.2	7.2	-0.3	0.6	0.9	0.5	80.2	-15.8	1.0	6.0	-0.3

Table A1.65

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left ankle/sub talar complex of subjects 6 - 10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	Ank/Stj	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
11	comp	-0.5	35.1	-0.6	1.4	1.6	1.3	88.7	53.6	1.0	-75.2	1.4
	dyn	-1.1	8.5	0.1	0.9	0.4	0.4	82.8	-3.2	1.0	-7.9	-0.1
	supi	3.1	13.6	-0.1	1.1	0.6	0.5	77.2	-2.5	1.0	4.4	0.0
	pron	-3.5	21.6	-0.5	1.2	1.8	1.2	80.6	8.0	1.0	-6.1	0.1
12	comp	15.3	30.0	-3.2	0.6	2.3	0.5	62.4	-11.9	1.0	2.0	-0.2
	dyn	10.5	14.7	-0.1	1.0	1.1	0.8	54.3	-0.7	1.0	1.4	0.0
	supi	5.7	14.4	-3.6	0.6	1.3	0.4	65.1	-32.1	1.0	2.5	-0.6
	pron	9.7	15.6	0.3	0.9	1.9	0.6	58.2	2.0	1.0	1.6	0.0
13	comp	8.8	25.8	2.4	0.2	2.8	0.8	70.5	15.1	1.0	2.9	0.3
	dyn	3.7	10.4	0.9	0.6	0.4	0.4	69.7	13.0	1.0	2.8	0.2
	supi	5.2	15.3	1.1	0.3	0.7	0.2	70.7	12.0	1.0	2.9	0.2
	pron	3.5	10.5	1.2	0.3	2.5	0.9	70.2	19.3	1.0	3.0	0.4
14	comp	4.2	30.0	1.5	1.2	1.8	0.8	81.5	19.0	1.0	7.1	0.3
	dyn	1.8	9.6	-0.2	0.5	0.6	0.3	79.4	-4.8	1.0	5.3	-0.1
	supi	1.6	14.2	-0.2	0.7	0.5	0.5	83.5	-8.1	1.0	8.9	-0.1
	pron	2.6	15.9	1.7	1.0	1.7	0.5	78.8	32.6	1.0	6.0	0.6
15	comp	8.3	33.9	-1.9	0.5	3.0	1.3	75.9	-12.6	1.0	4.1	-0.2
	dyn	3.3	12.4	-1.1	1.3	0.4	0.3	74.4	-18.4	1.0	3.8	-0.3
	supi	2.3	15.5	-1.0	0.5	1.8	0.7	80.9	-24.1	1.0	6.8	-0.4
	pron	6.0	18.5	-0.8	0.8	0.5	2.0	71.7	-8.0	1.0	3.1	-0.1

Table A1.66

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left ankle/sub talar complex of subjects 11 - 15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT Ank/Stj	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
16	comp	4.2	24.7	-2.4	1.4	0.3	0.7	79.1	-29.5	1.0	5.9	-0.6
	dyn	-1.5	11.1	-0.6	0.6	0.4	0.4	81.7	23.5	1.0	-7.5	0.4
	supi	7.2	14.4	-2.8	1.4	0.4	0.3	61.8	-21.4	1.0	2.0	-0.4
	pron	-3.0	10.3	0.5	1.7	0.3	0.5	73.4	-8.8	1.0	-3.4	-0.2
17	comp	2.5	27.7	-4.0	1.5	0.6	1.7	80.3	-57.7	1.0	10.9	-1.6
	dyn	1.3	12.7	-1.8	2.2	0.5	0.7	80.1	-53.6	1.0	9.6	-1.4
	supi	6.6	14.4	-3.9	1.2	1.9	1.1	61.9	-30.8	1.0	2.2	-0.6
	pron	-4.1	13.3	-0.1	0.9	2.0	0.9	73.0	1.1	1.0	-3.3	0.0
18	comp	14.2	25.6	-2.5	1.0	3.3	0.7	60.6	-9.8	1.0	1.8	-0.2
	dyn	7.2	10.9	-1.9	0.5	0.5	0.4	55.7	-14.7	1.0	1.5	-0.3
	supi	9.5	14.5	-2.2	0.5	0.6	0.4	56.1	-13.4	1.0	1.5	-0.2
	pron	4.7	11.1	-0.2	0.7	3.1	0.5	67.0	-2.5	1.0	2.4	0.0
19	comp	15.9	30.8	-0.1	1.8	1.8	0.7	62.6	-0.3	1.0	1.9	0.0
	dyn	5.9	7.9	-0.3	0.7	0.4	0.4	53.2	-3.2	1.0	1.3	-0.1
	supi	6.8	12.2	0.7	0.8	0.4	0.6	60.6	5.9	1.0	1.8	0.1
	pron	9.1	18.6	-0.8	2.0	1.7	0.9	63.8	-5.0	1.0	2.0	-0.1
20	comp	8.5	28.4	0.2	1.2	0.8	0.5	73.3	1.2	1.0	3.3	0.0
	dyn	3.8	8.5	-0.3	0.8	0.4	0.2	65.8	-5.0	1.0	2.2	-0.1
	supi	4.5	15.8	-1.3	0.7	0.2	0.2	73.5	-16.3	1.0	3.5	-0.3
	pron	4.1	12.7	1.5	1.0	0.7	0.5	71.1	20.1	1.0	3.1	0.4

Table A1.67

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left ankle/sub talar complex of subjects 11 - 15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT Ank/Stj	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
21	comp	9.1	31.3	1.2	1.2	1.6	0.7	73.6	7.6	1.0	3.4	0.1
	dyn	3.1	10.3	-0.2	0.8	0.3	0.4	73.5	-2.8	1.0	3.4	0.0
	supi	5.9	16.0	-0.5	0.8	0.4	0.4	69.7	-4.6	1.0	2.7	-0.1
	pron	3.3	15.4	1.7	1.2	1.5	0.4	76.5	27.5	1.0	4.7	0.5
22	comp	1.5	31.1	-2.7	0.6	1.3	0.5	84.4	-60.3	1.0	20.6	-1.8
	dyn	0.6	16.1	-1.6	0.4	0.5	0.3	84.1	-68.2	1.0	25.9	-2.5
	supi	2.8	15.3	-2.5	0.8	0.3	0.3	76.2	-42.5	1.0	5.5	-0.9
	pron	-1.3	15.8	-0.1	0.9	1.3	0.4	85.4	5.3	1.0	-12.6	0.1
23	comp	5.2	27.9	-0.7	1.4	3.3	1.1	79.3	-7.3	1.0	5.3	-0.1
	dyn	1.0	14.7	0.2	1.3	0.4	0.4	86.2	12.1	1.0	15.2	0.2
	supi	4.8	14.0	-1.1	0.9	0.6	1.0	70.7	-12.6	1.0	2.9	-0.2
	pron	0.5	14.0	0.4	2.1	2.8	1.1	87.5	40.6	1.0	30.0	0.9
24	comp	9.4	26.4	-1.2	2.2	1.4	0.6	70.2	-7.0	1.0	2.8	-0.1
	dyn	2.9	7.7	-0.4	1.7	3.7	0.7	69.1	-7.2	1.0	2.6	-0.1
	supi	4.9	13.3	-1.0	1.3	2.5	0.2	69.4	-12.1	1.0	2.7	-0.2
	pron	4.5	13.2	-0.1	1.2	1.2	0.4	70.9	-1.5	1.0	2.9	0.0
25	comp	5.9	28.1	1.2	1.3	1.3	1.2	77.8	11.6	1.0	4.7	0.2
	dyn	1.8	9.4	0.1	0.8	0.6	0.3	79.1	2.7	1.0	5.2	0.0
	supi	4.1	13.3	0.1	1.1	0.7	0.8	72.7	1.6	1.0	3.2	0.0
	pron	1.8	14.7	1.1	1.6	1.0	0.7	81.9	32.0	1.0	8.3	0.6

Table A1.68

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left ankle/sub talar complex of subjects 16 - 20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT Ank/Stj	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
MEAN	comp	7.2	27.4	-1.4	4.7	4.0	2.2	74.3	-7.6	75.1	-11.2	1.0	3.8	-0.2
	dyn	3.2	11.7	-0.8	3.1	3.1	1.2	73.3	-10.0	74.5	-13.7	1.0	3.7	-0.2
	supi	4.8	14.2	-1.5	2.8	1.3	1.5	69.9	-15.7	70.5	-17.9	1.0	3.0	-0.3
	pron	2.4	13.3	0.1	3.5	3.8	1.1	75.3	0.9	79.7	2.7	1.0	5.5	0.0

Table A1.69

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the left ankle/sub talar complex. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			angle of axis to	
	Ank/Stj	Frt	Trn	Sag	Trn	Sag
comp	MIN	-0.7	19.6	-7.5	60.6	-60.3
	MAX	15.9	35.1	2.4	88.7	58.6
	RANGE	16.7	15.5	9.8	28.1	119.0
dyn	MIN	-1.5	7.6	-4.3	53.2	-68.2
	MAX	10.5	18.2	0.2	88.9	26.6
	RANGE	12.0	10.6	4.5	35.8	94.8
supi	MIN	-1.9	11.3	-5.2	56.1	-48.9
	MAX	9.5	16.0	1.1	84.8	37.0
	RANGE	11.3	4.7	6.3	28.7	85.9
pron	MIN	-4.1	5.4	-2.3	58.2	-86.8
	MAX	9.7	21.6	2.3	88.0	50.0
	RANGE	13.7	16.2	4.5	29.7	136.7

Table A1.70

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the left ankle/sub talar complex of all subjects.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT MTJ	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
1	comp	11.6	7.7	13.0	1.1	1.5	1.7	23.7	48.3	1.0	0.7	1.1
	dyn	4.6	2.0	5.2	1.0	1.1	1.1	15.9	48.7	1.0	0.4	1.1
	supi	5.9	4.7	8.5	0.9	1.2	1.4	24.3	55.2	1.0	0.8	1.4
	pron	5.7	3.0	4.6	1.0	1.2	0.9	22.4	38.4	1.0	0.5	0.8
2	comp	10.3	10.8	5.4	2.3	1.8	2.1	43.0	27.6	1.0	1.1	0.5
	dyn	7.4	7.5	4.7	1.6	1.5	2.9	40.7	32.3	1.0	1.0	0.6
	supi	4.0	6.1	5.2	1.3	1.5	1.9	43.2	52.4	1.0	1.5	1.3
	pron	6.3	4.7	0.2	1.2	1.1	1.9	36.8	1.9	1.0	0.7	0.0
3	comp	9.7	10.5	8.3	0.9	0.5	0.9	39.3	40.7	1.0	1.1	0.9
	dyn	5.8	7.6	5.8	0.8	0.6	0.7	42.8	45.1	1.0	1.3	1.0
	supi	6.5	5.8	4.6	1.2	0.4	1.2	36.2	35.4	1.0	0.9	0.7
	pron	3.2	4.6	3.7	1.7	0.9	1.0	43.3	49.2	1.0	1.4	1.2
4	comp	9.5	13.1	3.5	0.1	2.4	1.1	52.2	19.9	1.0	1.4	0.4
	dyn	3.1	3.9	1.5	0.8	1.2	1.2	48.5	26.1	1.0	1.3	0.5
	supi	6.0	8.1	1.3	0.8	2.0	1.0	52.8	12.1	1.0	1.3	0.2
	pron	3.5	5.0	2.2	0.8	1.2	0.9	50.1	31.6	1.0	1.4	0.6
5	comp	18.6	8.8	11.0	**2.1**	**1.9**	**1.6**	22.1	30.7	1.0	0.5	0.6
	dyn	9.7	5.4	7.0	**1.2**	**1.2**	**1.2**	24.1	35.8	1.0	0.6	0.7
	supi	12.6	4.7	5.4	1.3	1.4	1.0	19.0	23.3	1.0	0.4	0.4
	pron	6.0	4.1	5.6	1.4	1.0	0.7	26.4	43.0	1.0	0.7	0.9

Table A1.71

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left mid tarsal joint of subjects 1 - 5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT MTJ	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
6	comp	14.0	10.1	8.4	1.6	1.7	1.0	31.6	31.1	1.0	0.7	0.6
	dyn	3.6	2.0	2.8	0.5	0.7	0.5	23.7	37.5	1.0	0.6	0.8
	supi	7.4	2.5	2.9	0.5	1.0	0.6	17.2	21.0	1.0	0.3	0.4
	pron	6.6	7.6	5.6	1.7	1.6	1.0	41.4	40.4	1.0	1.2	0.9
7	comp	14.1	18.2	11.4	2.0	1.1	1.2	45.1	39.0	1.0	1.3	0.8
	dyn	7.0	11.8	8.2	1.2	0.8	0.5	47.6	49.7	1.0	1.7	1.2
	supi	4.9	10.4	4.9	1.0	0.8	0.5	56.4	45.3	1.0	2.1	1.0
	pron	9.2	7.8	6.5	1.6	1.1	1.3	34.6	35.2	1.0	0.8	0.7
8	comp	11.5	10.4	8.3	1.9	0.8	0.8	36.3	35.7	1.0	0.9	0.7
	dyn	4.3	6.0	4.3	0.8	0.6	0.8	44.9	44.8	1.0	1.4	1.0
	supi	5.4	5.2	4.7	0.7	1.0	0.8	35.9	40.9	1.0	1.0	0.9
	pron	6.1	5.2	3.6	1.4	1.3	1.3	36.6	30.4	1.0	0.9	0.6
9	comp	9.8	9.5	8.9	2.3	0.7	0.2	35.7	42.2	1.0	1.0	0.9
	dyn	4.6	5.1	4.9	0.3	0.3	0.1	37.3	46.8	1.0	1.1	1.1
	supi	6.6	5.5	6.7	0.1	0.4	0.6	30.2	45.3	1.0	0.8	1.0
	pron	3.2	4.0	2.2	2.4	0.2	0.4	46.2	34.5	1.0	1.3	0.7
10	comp	5.4	10.5	5.9	0.9	0.6	0.9	52.9	47.6	1.0	2.0	1.1
	dyn	3.2	6.7	4.5	0.7	0.5	0.6	50.4	54.1	1.0	2.1	1.4
	supi	4.0	7.5	3.5	0.8	0.6	0.5	54.9	41.1	1.0	1.9	0.9
	pron	1.4	2.9	2.4	0.3	0.6	0.8	47.0	60.0	1.0	2.1	1.7

Table A1.72

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left mid tarsal joint of subjects 1 - 5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT MTJ	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
11	comp	11.9	9.3	7.6	0.6	1.1	1.6	33.3	32.7	1.0	0.8	0.6
	dyn	3.2	2.1	1.6	0.5	0.4	0.9	30.0	26.7	1.0	0.6	0.5
	supi	6.6	5.2	5.8	0.9	0.6	0.5	30.6	41.1	1.0	0.8	0.9
	pron	5.3	4.1	1.9	0.7	0.8	1.7	36.1	19.6	1.0	0.8	0.4
12	comp	23.2	12.3	4.9	1.2	1.6	1.1	27.4	12.0	1.0	0.5	0.2
	dyn	11.3	7.5	1.8	2.1	1.4	1.0	33.4	9.0	1.0	0.7	0.2
	supi	11.7	4.4	5.4	1.3	0.8	0.3	18.9	24.8	1.0	0.4	0.5
	pron	11.5	7.9	-0.5	1.5	0.9	1.1	34.3	-2.4	1.0	0.7	0.0
13	comp	9.4	10.1	9.1	0.6	1.9	1.9	37.5	44.0	1.0	1.1	1.0
	dyn	4.4	6.2	4.8	0.9	1.2	0.5	43.8	47.7	1.0	1.4	1.1
	supi	5.1	3.3	3.9	0.8	1.4	0.7	26.8	37.6	1.0	0.6	0.8
	pron	4.3	6.8	5.2	0.4	2.4	1.9	45.2	50.2	1.0	1.6	1.2
14	comp	13.8	12.3	0.5	1.1	1.0	1.6	41.6	2.1	1.0	0.9	0.0
	dyn	4.6	4.0	-1.5	0.8	0.3	0.4	39.3	-18.2	1.0	0.9	-0.3
	supi	6.2	5.5	-1.4	1.0	0.7	0.8	40.9	-12.8	1.0	0.9	-0.2
	pron	7.6	6.7	1.9	0.7	1.2	2.0	40.7	14.2	1.0	0.9	0.3
15	comp	15.2	11.2	7.4	2.2	1.1	2.1	33.6	25.8	1.0	0.7	0.5
	dyn	4.9	3.6	2.9	1.1	0.8	0.8	32.2	30.6	1.0	0.7	0.6
	supi	5.6	5.4	2.7	0.8	1.3	0.7	41.1	25.6	1.0	1.0	0.5
	pron	9.6	5.8	4.7	2.9	0.7	1.4	28.6	25.9	1.0	0.6	0.5

Table A1.73

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left mid tarsal joint of subjects 6 - 10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT MTJ	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
16	comp	11.9	10.0	6.9	1.0	0.7	1.4	35.9	29.9	1.0	0.8	0.6
	dyn	3.4	4.2	3.1	0.5	1.4	0.1	42.5	42.1	1.0	1.2	0.9
	supi	8.5	6.2	4.7	0.3	1.7	1.5	32.7	29.2	1.0	0.7	0.6
	pron	3.5	3.7	2.1	0.9	1.1	0.0	42.7	31.4	1.0	1.1	0.6
17	comp	9.1	9.1	5.7	0.8	2.1	0.2	40.2	32.0	1.0	1.0	0.6
	dyn	2.5	2.9	2.2	0.8	0.7	0.5	40.6	42.0	1.0	1.2	0.9
	supi	4.0	6.8	2.5	1.1	1.2	0.9	55.3	32.5	1.0	1.7	0.6
	pron	5.1	2.2	3.2	1.2	0.9	1.0	20.4	31.5	1.0	0.4	0.6
18	comp	12.8	14.6	10.3	3.4	2.4	1.2	41.6	38.8	1.0	1.1	0.8
	dyn	5.9	7.7	5.5	0.5	0.7	0.7	43.6	43.3	1.0	1.3	0.9
	supi	7.1	8.5	5.5	1.3	1.0	1.7	43.3	37.5	1.0	1.2	0.8
	pron	5.6	6.1	4.8	1.4	1.5	0.4	39.3	40.3	1.0	1.1	0.8
19	comp	12.6	16.0	9.2	1.0	2.0	1.3	45.7	36.0	1.0	1.3	0.7
	dyn	4.0	4.9	3.6	0.7	0.9	0.3	42.0	41.7	1.0	1.2	0.9
	supi	4.4	9.2	3.9	1.5	0.6	0.8	57.3	41.6	1.0	2.1	0.9
	pron	8.2	6.8	5.3	1.5	1.6	1.9	34.8	32.6	1.0	0.8	0.6
20	comp	11.5	9.4	8.5	1.0	0.5	1.1	33.4	36.5	1.0	0.8	0.7
	dyn	3.4	3.6	3.5	0.4	0.4	0.5	35.8	45.8	1.0	1.0	1.0
	supi	5.8	4.2	3.9	0.5	0.5	0.5	31.0	33.7	1.0	0.7	0.7
	pron	5.7	5.2	4.6	0.9	0.3	0.8	35.6	39.2	1.0	0.9	0.8

Table A1.74

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left mid tarsal joint of subjects 11 - 15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	MTJ	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
21	comp	7.6	12.0	7.7	0.4	0.5	0.7	47.9	45.6	1.0	1.6	1.0
	dyn	2.2	4.0	3.0	0.4	0.5	0.6	47.3	53.5	1.0	1.8	1.3
	supi	4.0	7.2	4.5	0.6	0.8	1.0	50.0	48.5	1.0	1.8	1.1
	pron	3.6	4.8	3.2	0.5	0.9	0.6	45.0	41.8	1.0	1.3	0.9
22	comp	11.2	9.9	10.1	1.1	0.7	0.8	33.2	42.0	1.0	0.9	0.9
	dyn	4.6	4.6	4.8	0.6	0.8	0.5	34.9	46.4	1.0	1.0	1.0
	supi	7.0	7.4	7.7	0.8	0.6	0.7	35.7	47.7	1.0	1.1	1.1
	pron	4.3	2.5	2.5	0.9	0.8	0.6	26.6	30.0	1.0	0.6	0.6
23	comp	9.5	16.0	4.7	1.7	1.4	1.4	56.4	26.1	1.0	1.7	0.5
	dyn	6.2	8.0	3.1	0.6	0.6	1.5	49.0	26.5	1.0	1.3	0.5
	supi	4.1	7.9	-0.4	1.7	1.7	1.3	62.2	-6.0	1.0	1.9	-0.1
	pron	5.4	8.1	5.1	0.5	0.4	1.0	47.5	43.4	1.0	1.5	0.9
24	comp	6.7	12.1	7.8	0.4	0.6	0.9	49.6	49.2	1.0	1.8	1.2
	dyn	1.6	4.1	2.5	1.1	1.7	0.3	54.0	57.3	1.0	2.5	1.6
	supi	3.7	5.7	3.2	0.9	0.5	0.4	49.7	40.5	1.0	1.6	0.9
	pron	3.0	6.3	4.6	0.7	0.1	1.0	48.9	56.8	1.0	2.1	1.5
25	comp	14.7	6.1	1.9	1.3	1.6	1.9	22.4	7.3	1.0	0.4	0.1
	dyn	3.8	1.4	0.7	0.6	0.9	0.4	19.8	10.4	1.0	0.4	0.2
	supi	7.8	2.5	2.7	1.4	0.8	1.5	17.2	19.3	1.0	0.3	0.4
	pron	6.9	3.6	-0.8	1.1	1.2	1.1	27.0	-6.8	1.0	0.5	-0.1

Table A1.75

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left mid tarsal joint of subjects 16 - 20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT MTJ	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
MEAN	comp	11.8	11.2	7.5	3.7	2.7	2.9	38.5	32.9	38.7	32.2	1.0	0.9	0.6
	dyn	4.8	5.1	3.6	2.2	2.4	2.1	38.6	37.0	40.2	37.2	1.0	1.1	0.8
	supi	6.2	6.0	4.1	2.2	2.0	2.2	38.5	32.5	39.0	33.4	1.0	1.0	0.7
	pron	5.6	5.2	3.4	2.3	1.7	1.9	37.5	32.5	38.3	30.9	1.0	0.9	0.6

Table A1.76

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the left mid tarsal joint. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			angle of axis to	
	MTJ	**Frt**	**Trn**	**Sag**	**Trn**	**Sag**
comp	MIN	5.4	6.1	0.5	22.1	2.1
	MAX	23.2	18.2	13.0	56.4	49.2
	RANGE	17.8	12.1	12.5	34.3	47.1
dyn	MIN	1.6	1.4	-1.5	15.9	-18.2
	MAX	11.3	11.8	8.2	54.0	57.3
	RANGE	9.7	10.4	9.7	38.1	75.4
supi	MIN	3.7	2.5	-1.4	17.2	-12.8
	MAX	12.6	10.4	8.5	62.2	55.2
	RANGE	8.8	8.0	9.9	45.1	68.0
pron	MIN	1.4	2.2	-0.8	20.4	-6.8
	MAX	11.5	8.1	6.5	50.1	60.0
	RANGE	10.1	5.9	7.3	29.7	66.7

Table A1.77

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the left mid tarsal joint of all subjects. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	RFC	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
1	comp	20.8	37.7	10.0	2.4	2.7	0.9	58.5	25.8	1.0	1.8	0.5
	dyn	7.9	14.3	4.3	1.9	1.6	1.0	57.8	28.3	1.0	1.8	0.5
	supi	15.1	20.6	5.0	1.7	1.2	1.1	52.3	18.3	1.0	1.4	0.3
	pron	5.7	17.1	5.0	1.2	2.1	0.8	66.0	41.4	1.0	3.0	0.9
2	comp	20.5	35.4	5.9	3.2	3.2	1.0	58.9	16.1	1.0	1.7	0.3
	dyn	15.7	25.3	4.8	2.8	1.3	1.5	57.0	17.0	1.0	1.6	0.3
	supi	12.3	21.1	3.4	2.4	0.9	1.2	58.8	15.7	1.0	1.7	0.3
	pron	8.2	14.3	2.5	1.8	2.9	1.5	59.0	16.8	1.0	1.7	0.3
3	comp	9.0	32.5	7.1	2.6	1.6	0.6	70.6	38.5	1.0	3.6	0.8
	dyn	5.5	22.7	5.7	2.4	0.9	0.5	70.8	45.8	1.0	4.1	1.0
	supi	4.6	17.1	3.2	1.6	1.8	0.8	72.0	34.8	1.0	3.7	0.7
	pron	4.4	15.3	4.0	1.7	1.0	0.9	68.9	42.1	1.0	3.5	0.9
4	comp	12.0	36.8	3.3	1.0	3.8	1.2	71.3	15.5	1.0	3.1	0.3
	dyn	4.5	12.3	1.5	1.4	3.9	1.3	69.0	18.7	1.0	2.8	0.3
	supi	6.9	19.9	0.7	1.2	3.9	0.9	70.7	5.9	1.0	2.9	0.1
	pron	5.1	16.9	2.6	0.9	3.5	1.3	71.3	27.2	1.0	3.3	0.5
5	comp	24.8	33.9	3.5	2.4	1.5	1.3	53.5	8.1	1.0	1.4	0.1
	dyn	12.8	18.2	2.7	1.4	1.4	1.2	54.3	12.0	1.0	1.4	0.2
	supi	17.1	19.2	0.2	1.4	0.9	0.9	48.3	0.6	1.0	1.1	0.0
	pron	7.7	14.7	3.4	1.4	1.1	0.9	60.1	23.4	1.0	1.9	0.4

Table A1.78

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left rearfoot complex of subjects 1 - 5.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT RFC	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
6	comp	21.2	39.4	4.5	2.8	2.5	1.0	61.1	12.1	1.0	1.9	0.2
	dyn	5.6	9.6	1.5	0.8	0.6	0.7	58.7	15.4	1.0	1.7	0.3
	supi	10.0	16.1	0.6	0.7	0.6	0.6	58.1	3.7	1.0	1.6	0.1
	pron	11.2	23.2	3.9	2.8	2.4	0.9	63.0	19.2	1.0	2.1	0.3
7	comp	28.6	49.1	8.3	3.5	2.6	1.0	58.8	16.2	1.0	1.7	0.3
	dyn	16.6	30.0	4.6	1.9	0.6	0.6	60.1	15.5	1.0	1.8	0.3
	supi	12.2	24.2	2.5	1.4	0.6	0.8	62.6	11.6	1.0	2.0	0.2
	pron	16.3	24.9	5.8	2.9	2.6	1.1	55.2	19.5	1.0	1.5	0.4
8	comp	21.7	30.5	6.9	3.2	2.1	0.7	53.3	17.8	1.0	1.4	0.3
	dyn	8.0	17.1	3.8	2.0	0.3	0.7	62.7	25.5	1.0	2.1	0.5
	supi	13.8	19.9	4.8	1.7	1.2	0.7	53.7	19.2	1.0	1.4	0.3
	pron	7.9	10.6	2.1	2.8	1.6	0.8	52.5	15.2	1.0	1.3	0.3
9	comp	12.9	32.7	8.3	2.1	1.5	0.1	64.9	33.0	1.0	2.5	0.6
	dyn	5.2	17.6	5.0	0.3	0.8	0.1	67.7	44.2	1.0	3.4	1.0
	supi	8.7	20.5	6.1	0.3	0.6	1.5	62.5	34.8	1.0	2.3	0.7
	pron	4.1	12.2	2.3	1.8	0.9	1.4	69.0	28.7	1.0	3.0	0.5
10	comp	9.5	30.1	3.1	1.5	1.2	0.8	71.7	18.1	1.0	3.2	0.3
	dyn	6.3	19.7	2.9	1.3	0.7	0.7	70.6	24.3	1.0	3.1	0.5
	supi	6.9	19.9	1.0	0.9	0.7	0.6	70.7	8.7	1.0	2.9	0.2
	pron	2.6	10.1	2.0	0.8	1.2	1.1	72.0	38.5	1.0	3.9	0.8

Table A1.79

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left rearfoot complex of subjects 6 - 10.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
SUBJ	RFC	Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
11	comp	11.4	44.4	7.0	1.7	2.1	1.6	73.2	31.5	1.0	3.9	0.6
	dyn	2.1	10.6	1.7	1.3	0.7	1.0	75.6	38.1	1.0	4.9	0.8
	supi	9.7	18.8	5.6	1.9	0.5	0.8	59.2	30.1	1.0	1.9	0.6
	pron	1.7	25.6	1.4	1.6	2.3	1.8	85.0	38.5	1.0	14.8	0.8
12	comp	38.5	42.3	1.7	1.0	2.8	1.1	47.6	2.5	1.0	1.1	0.0
	dyn	21.8	22.2	1.6	2.9	1.3	1.3	45.4	4.3	1.0	1.0	0.1
	supi	17.4	18.8	1.8	1.8	1.7	0.5	47.1	6.1	1.0	1.1	0.1
	pron	21.2	23.5	-0.1	1.8	1.8	0.9	48.0	-0.4	1.0	1.1	0.0
13	comp	18.2	35.8	11.5	1.0	3.0	1.1	59.0	32.2	1.0	2.0	0.6
	dyn	8.1	16.6	5.7	0.8	0.5	0.4	59.2	34.9	1.0	2.1	0.7
	supi	10.3	18.6	5.0	0.6	0.6	0.8	58.2	26.0	1.0	1.8	0.5
	pron	7.9	17.3	6.4	1.1	3.5	1.1	59.5	39.3	1.0	2.2	0.8
14	comp	18.1	42.3	2.0	2.3	2.1	1.8	66.8	6.2	1.0	2.3	0.1
	dyn	6.4	13.6	-1.7	1.3	0.9	0.3	64.0	-14.5	1.0	2.1	-0.3
	supi	7.8	19.7	-1.6	1.7	0.9	0.8	67.9	-11.9	1.0	2.5	-0.2
	pron	10.2	22.6	3.6	1.6	1.7	1.9	64.3	19.5	1.0	2.2	0.4
15	comp	23.5	45.2	5.5	2.3	3.5	0.8	61.9	13.2	1.0	1.9	0.2
	dyn	8.2	16.0	1.8	1.0	1.0	1.0	62.2	12.6	1.0	1.9	0.2
	supi	7.9	20.9	1.7	1.3	2.8	1.4	68.9	12.0	1.0	2.7	0.2
	pron	15.7	24.3	3.8	3.6	1.3	0.6	56.4	13.7	1.0	1.6	0.2

Table A1.80

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left rearfoot complex of subjects 11 - 15.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT RFC	Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	angle of axis to Trn	Sag	Ratio (rom) Frt	Trn	Sag
16	comp	16.1	34.7	4.5	1.6	0.4	1.3	64.3	15.6	1.0	2.2	0.3
	dyn	1.9	15.3	2.4	1.0	1.3	0.5	78.7	51.7	1.0	8.1	1.3
	supi	15.7	20.6	1.9	1.6	1.5	1.3	52.6	7.0	1.0	1.3	0.1
	pron	0.4	14.0	2.6	0.9	1.2	0.5	79.5	80.5	1.0	32.6	6.0
17	comp	11.7	36.8	1.7	1.8	2.2	1.7	72.2	8.2	1.0	3.2	0.1
	dyn	3.8	15.5	0.5	1.9	0.4	1.0	76.1	6.9	1.0	4.1	0.1
	supi	10.6	21.2	-1.4	1.6	2.9	1.5	63.3	-7.5	1.0	2.0	-0.1
	pron	1.1	15.5	3.1	1.0	1.7	1.0	78.1	70.6	1.0	14.3	2.8
18	comp	27.0	40.1	7.8	2.8	2.7	1.9	55.0	16.2	1.0	1.5	0.3
	dyn	13.0	18.6	3.7	1.9	1.3	1.6	53.9	15.7	1.0	1.4	0.3
	supi	16.6	23.0	3.2	1.9	1.2	1.3	53.6	11.0	1.0	1.4	0.2
	pron	10.4	17.2	4.6	2.2	3.9	1.3	56.6	23.8	1.0	1.7	0.4
19	comp	28.5	46.7	9.1	2.5	1.8	1.2	57.3	17.6	1.0	1.6	0.3
	dyn	9.9	12.7	3.3	1.2	0.9	0.5	50.6	18.2	1.0	1.3	0.3
	supi	11.2	21.4	4.6	1.9	0.7	1.0	60.4	22.3	1.0	1.9	0.4
	pron	17.3	25.4	4.5	3.4	1.4	1.7	54.8	14.5	1.0	1.5	0.3
20	comp	20.0	37.8	8.7	2.0	1.1	1.3	60.0	23.4	1.0	1.9	0.4
	dyn	7.2	12.0	3.2	1.2	0.5	0.5	56.7	24.0	1.0	1.7	0.4
	supi	10.3	19.9	2.5	1.1	0.5	0.5	62.0	13.9	1.0	1.9	0.2
	pron	9.7	17.9	6.1	1.6	0.8	1.0	57.3	32.1	1.0	1.8	0.6

Table A1.81

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left rearfoot complex of subjects 16 - 20.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	LEFT RFC	Range of motion (rom)			Standard deviation (rom)			angle of axis to		Ratio (rom)		
		Frt	Trn	Sag	Frt	Trn	Sag	Trn	Sag	Frt	Trn	Sag
21	comp	16.7	43.4	9.0	1.3	1.9	1.1	66.4	28.2	1.0	2.6	0.5
	dyn	5.3	14.3	2.8	0.9	0.6	0.7	67.4	28.3	1.0	2.7	0.5
	supi	9.9	23.2	4.1	1.2	0.7	1.2	65.2	22.3	1.0	2.3	0.4
	pron	6.8	20.2	4.9	1.4	2.3	0.6	67.4	35.6	1.0	3.0	0.7
22	comp	12.8	41.1	7.5	0.8	1.8	0.4	70.2	30.4	1.0	3.2	0.6
	dyn	5.2	20.7	3.3	0.9	0.7	0.5	73.4	32.1	1.0	4.0	0.6
	supi	9.7	22.7	5.1	1.2	0.7	0.9	64.2	27.8	1.0	2.3	0.5
	pron	3.0	18.3	2.4	1.1	1.7	0.7	78.2	37.9	1.0	6.1	0.8
23	comp	14.8	43.9	4.0	2.1	4.1	1.1	70.8	15.2	1.0	3.0	0.3
	dyn	7.2	22.8	3.3	1.8	0.7	1.4	70.8	24.7	1.0	3.2	0.5
	supi	8.9	21.8	-1.5	1.5	1.7	1.7	67.5	-9.6	1.0	2.5	-0.2
	pron	5.9	22.1	5.5	2.2	2.8	1.0	70.0	43.2	1.0	3.8	0.9
24	comp	16.1	38.5	6.6	2.5	1.1	0.6	65.6	22.3	1.0	2.4	0.4
	dyn	4.5	11.8	2.2	2.9	5.4	0.9	67.0	25.4	1.0	2.6	0.5
	supi	8.6	19.0	2.1	1.4	2.4	0.3	65.1	13.9	1.0	2.2	0.2
	pron	7.6	19.5	4.5	1.1	1.3	0.9	65.7	30.8	1.0	2.6	0.6
25	comp	20.6	34.2	3.1	2.3	1.5	1.6	58.6	8.6	1.0	1.7	0.2
	dyn	5.6	10.8	0.8	1.0	1.1	0.3	62.4	7.9	1.0	1.9	0.1
	supi	11.9	15.9	2.8	2.2	1.1	1.1	52.4	13.4	1.0	1.3	0.2
	pron	8.7	18.3	0.3	2.6	1.1	1.0	64.5	1.8	1.0	2.1	0.0

Table A1.82

Table details the range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the axes of rotation calculated from these values and the ranges of motion expressed as a ratio - for the left rearfoot complex of subjects 21 - 25.

Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT RFC	mean Range of motion (rom) Frt	Trn	Sag	Standard deviation (rom) Frt	Trn	Sag	mean angle of axis to Trn	Sag	Axis calculated from mean rom. angle of axis to Trn	Sag	Ratio of mean rom Frt	Trn	Sag
MEAN	comp	19.0	38.6	6.0	7.0	5.1	2.8	62.9	18.9	62.7	17.6	1.0	2.0	0.3
	dyn	7.9	16.8	2.9	4.7	5.1	1.7	63.7	22.3	63.3	19.8	1.0	2.1	0.4
	supi	11.0	20.2	2.5	3.4	2.0	2.2	60.7	13.2	60.8	13.1	1.0	1.8	0.2
	pron	8.0	18.4	3.5	5.2	4.6	1.7	64.9	30.1	64.6	23.4	1.0	2.3	0.4

Table A1.83

Table details the mean (of the whole sample) range of motion in the frontal, transverse and sagittal planes, standard deviations of these values, the mean axes of rotation, the axes of rotation calculated from the mean range of motion values and the mean ranges of motion expressed as a ratio - for the left rearfoot complex. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	LEFT	Range of motion (rom)			angle of axis to	
	RFC	Frt	Trn	Sag	Trn	Sag
comp	MIN	9.0	30.1	1.7	47.6	2.5
	MAX	38.5	49.1	11.5	73.2	38.5
	RANGE	29.6	19.0	9.8	25.6	36.0
dyn	MIN	1.9	9.6	-1.7	45.4	-14.5
	MAX	21.8	30.0	5.7	78.7	51.7
	RANGE	19.9	20.4	7.3	33.3	66.3
supi	MIN	4.6	15.9	-1.6	47.1	-11.9
	MAX	17.4	24.2	6.1	72.0	34.8
	RANGE	12.8	8.3	7.7	24.9	46.7
pron	MIN	0.4	10.1	-0.1	48.0	-0.4
	MAX	21.2	25.6	6.4	85.0	80.5
	RANGE	20.8	15.5	6.6	37.1	80.9

Table A1.84

Table details the minimum, maximum and range of range of motion values in the frontal, transverse and sagittal planes, and the minimum, maximum and range of axes of rotation values in the sample - for the left rearfoot complex of all subjects. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

APPENDIX 2

A2.1 INRODUCTION.

Appendix 2 details the range of motion and axis angulation calculated from data taken on two separate days using four subjects (tables A2.1 to A2.12). The data are separated into right and left limbs, and the data for each absolute and each relative rotation for each subject are presented. Tables A2.13 to A2.24 detail the differences between days in the ranges of motion and the axis orientations for each absolute and each relative rotation, for the right and left limbs of each of the four subjects.

		Range of motion (°)						Angle of axis to			
	RIGHT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	LEG	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	1.1	1.5	-31.9	-32.1	-0.9	-1.2	-87.5	-86.6	-40.0	-39.9
	dyn	-0.1	0.0	-17.7	-17.7	-0.5	-0.5	-88.2	-88.3	80.7	89.7
	supi	-0.3	-0.2	-20.2	-20.6	-0.8	-0.8	-87.5	-87.6	72.3	79.0
	pron	1.3	1.3	-11.7	-11.5	-0.1	-0.4	-83.5	-83.2	-2.2	-16.6
19	comp	0.9	-0.5	-44.8	-43.4	-0.2	-2.2	-88.8	-87.0	-9.2	77.9
	dyn	0.5	-0.2	-17.1	-17.6	-0.2	-0.8	-88.2	-87.3	-24.1	76.7
	supi	0.6	-0.3	-20.5	-20.6	-0.4	-1.3	-87.9	-86.3	-36.4	79.0
	pron	0.3	-0.2	-24.4	-22.8	0.3	-0.9	-89.0	-87.6	43.0	76.3
22	comp	-1.9	-1.6	-37.6	-34.2	-2.4	-1.0	-85.4	-86.9	52.2	31.9
	dyn	-1.4	-1.1	-20.7	-19.0	-0.7	-0.2	-85.8	-86.7	26.9	12.5
	supi	-1.3	-1.4	-20.3	-19.9	-0.7	0.0	-85.7	-86.0	27.4	0.0
	pron	-0.5	-0.2	-17.3	-14.2	-1.7	-1.0	-84.1	-86.0	73.0	79.6
25	comp	1.3	1.0	-41.6	-41.6	-0.8	-0.4	-87.9	-88.5	-30.6	-20.1
	dyn	0.2	0.3	-14.4	-14.2	0.2	0.0	-88.7	-88.9	48.3	7.7
	supi	0.3	0.2	-19.0	-20.6	0.3	-0.2	-88.7	-89.1	53.4	-45.5
	pron	1.0	0.8	-22.6	-21.0	-1.1	-0.1	-86.2	-87.8	-47.2	-9.6

Table A2.1

Range of leg motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - right limb only

		Range of motion (°)						Angle of axis to			
	RIGHT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	HEEL	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	2.9	2.6	-10.0	-9.6	-3.9	-3.6	-63.9	-65.4	-53.4	-54.4
	dyn	2.2	2.0	-4.3	-4.5	-1.7	-1.6	-57.4	-60.2	-37.1	-38.7
	supi	3.2	2.9	-5.4	-5.9	-1.7	-1.6	-56.5	-60.7	-28.6	-29.1
	pron	-0.2	-0.3	-4.6	-3.7	-2.2	-2.0	-64.1	-62.0	83.9	80.7
19	comp	11.1	13.7	-14.2	-15.5	6.1	3.3	-48.2	-47.7	29.0	13.5
	dyn	3.8	5.4	-5.2	-6.1	1.5	1.1	-51.5	-47.8	21.3	11.6
	supi	4.4	6.0	-6.7	-6.9	1.4	1.0	-55.5	-48.8	18.1	9.0
	pron	6.7	7.7	-7.5	-8.6	4.7	2.3	-42.4	-46.7	35.1	16.7
22	comp	3.9	2.7	-10.2	-9.4	-1.0	-1.0	-68.6	-73.0	-14.4	-19.4
	dyn	3.0	1.8	-5.5	-4.9	-0.8	-0.8	-60.4	-68.6	-15.3	-23.1
	supi	3.1	2.6	-6.2	-5.4	-1.0	-0.9	-62.3	-62.8	-17.3	-18.6
	pron	0.7	0.1	-3.9	-4.0	0.0	-0.1	-79.5	-88.6	-1.5	-45.0
25	comp	10.3	9.0	-10.6	-10.2	-1.2	-2.0	-45.6	-47.9	-6.8	-12.2
	dyn	5.2	4.1	-2.7	-2.6	-0.1	-0.5	-27.9	-32.3	-0.8	-7.2
	supi	5.8	5.5	-4.7	-5.5	-0.5	-1.1	-38.9	-44.4	-5.3	-11.0
	pron	4.6	3.5	-6.0	-4.7	-0.7	-0.9	-52.2	-52.5	-8.8	-14.2

Table A2.2

Range of heel motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - right limb only

		Range of motion (°)						Angle of axis to			
	RIGHT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	FORFT	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	12.7	11.8	-3.4	-3.4	6.5	7.1	-13.4	-13.8	27.2	31.1
	dyn	8.2	7.6	-1.5	-1.4	3.0	3.2	-9.6	-9.9	20.2	22.8
	supi	10.0	9.3	-1.7	-1.9	3.8	4.1	-9.2	-10.4	20.9	24.0
	pron	2.7	2.5	-1.7	-1.5	2.7	3.0	-23.3	-21.3	45.0	49.9
19	comp	26.8	26.3	0.4	0.0	3.4	3.9	0.9	0.1	7.3	8.4
	dyn	9.2	10.3	0.3	0.3	0.0	3.2	2.1	1.7	0.0	17.5
	supi	10.2	11.8	1.1	1.3	-0.8	-2.0	5.8	6.3	-4.3	-9.7
	pron	16.6	14.5	-0.6	-1.4	4.2	5.9	-2.0	-4.9	14.3	22.3
22	comp	13.9	14.7	-1.0	-0.1	6.0	5.0	-3.8	-0.3	23.3	18.7
	dyn	7.9	8.0	1.0	0.5	3.8	2.8	6.3	3.6	25.7	19.6
	supi	8.8	9.6	0.5	0.8	3.4	2.6	3.0	4.8	21.0	15.1
	pron	5.1	5.1	-1.5	-0.9	2.6	2.4	-14.5	-9.2	27.1	25.0
25	comp	22.5	21.1	-4.6	-5.1	0.0	2.0	-11.4	-13.4	0.1	5.5
	dyn	8.9	7.4	0.0	0.7	0.2	1.3	0.0	5.2	1.5	9.6
	supi	10.8	12.2	-1.2	-3.6	1.1	0.4	-6.1	-16.3	6.0	1.9
	pron	11.7	8.9	-3.4	-1.5	-1.1	-2.5	-16.1	-9.2	-5.3	-15.4

Table A2.3

Range of forefoot motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - right limb only

		Range of motion (^{0})						Angle of axis to			
	RIGHT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	Ank/Stj	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	1.9	1.1	21.8	22.6	-3.0	-2.3	80.7	83.5	-58.6	-65.3
	dyn	2.3	2.0	13.3	13.2	-1.1	-1.1	79.1	80.2	-26.4	-28.3
	supi	3.4	3.0	14.8	14.8	-0.9	-0.8	76.5	78.0	-14.3	-14.0
	pron	-1.6	-1.6	7.1	7.8	-2.2	-1.6	69.4	73.8	54.0	43.7
19	comp	10.2	14.1	30.6	27.9	6.3	5.5	68.7	61.5	31.8	21.2
	dyn	3.4	5.6	11.9	11.5	1.7	1.9	72.4	62.6	27.1	18.9
	supi	3.7	6.2	13.8	13.7	1.9	2.2	73.1	64.2	26.5	19.8
	pron	6.4	7.9	16.8	14.3	4.4	3.3	65.2	59.0	34.6	22.3
22	comp	5.7	4.3	27.4	24.8	1.4	0.0	77.9	80.2	13.8	0.3
	dyn	4.4	2.8	15.2	14.1	-0.1	-0.5	73.9	78.5	-1.8	-10.3
	supi	4.5	4.0	14.1	14.6	-0.3	-0.9	72.4	74.2	-3.6	-12.4
	pron	1.2	0.2	13.3	10.3	1.7	0.9	81.1	84.8	53.5	74.6
25	comp	9.1	8.0	31.0	31.4	-0.5	-1.6	73.7	75.4	-3.0	-11.2
	dyn	5.0	3.8	11.7	11.6	-0.3	-0.6	66.9	71.8	-3.6	-8.3
	supi	5.5	5.3	14.4	15.1	-0.9	-0.8	68.8	70.4	-9.1	-9.0
	pron	3.6	2.7	16.6	16.3	0.4	-0.7	77.8	80.3	6.4	-15.5

Table A2.4

Range of ankle/sub talar complex motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - right limb only

		Range of motion (°)						Angle of axis to			
	RIGHT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	MTJ	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	9.8	9.2	6.6	6.2	10.5	10.7	24.7	23.8	46.8	49.1
	dyn	5.9	5.6	2.9	3.0	4.7	4.8	20.8	22.3	38.2	40.6
	supi	6.9	6.4	3.7	4.0	5.5	5.7	22.7	24.9	38.9	41.8
	pron	3.0	2.8	2.9	2.2	4.9	4.9	26.9	21.5	59.0	60.2
19	comp	15.7	12.6	14.6	15.5	-2.7	0.6	42.5	50.8	-9.8	2.9
	dyn	5.3	4.9	5.5	6.5	-1.5	2.1	45.0	50.4	-15.7	23.5
	supi	5.9	5.9	7.7	8.2	-2.2	-3.0	50.9	51.3	-20.5	-26.9
	pron	9.8	6.7	6.9	7.2	-0.5	3.6	35.0	43.2	-3.0	28.2
22	comp	10.1	12.1	9.2	9.3	7.0	6.0	36.8	34.6	34.7	26.3
	dyn	4.9	6.2	6.5	5.4	4.6	3.6	43.8	37.0	43.5	30.0
	supi	5.7	7.0	6.7	6.2	4.4	3.5	43.1	38.5	37.4	26.4
	pron	4.4	5.1	2.5	3.1	2.6	2.5	25.8	28.5	31.0	26.0
25	comp	12.2	12.1	6.1	5.1	1.3	-0.1	26.4	23.0	6.0	-0.4
	dyn	3.7	3.4	2.7	3.3	0.3	1.8	36.5	40.5	4.7	27.7
	supi	5.1	6.6	3.5	2.0	1.7	1.5	33.3	16.0	18.2	12.6
	pron	7.1	5.4	2.6	3.2	-0.4	-1.6	19.8	29.2	-3.1	-16.1

Table A2.5

Range of mid tarsal joint motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - right limb only

		Range of motion (^{o})						Angle of axis to			
	RIGHT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	RFC	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	11.7	10.3	28.5	28.8	7.4	8.3	64.1	65.3	32.5	39.0
	dyn	8.3	7.6	16.2	16.3	3.5	3.7	61.0	62.5	23.2	26.1
	supi	10.3	9.4	18.4	18.7	4.7	5.0	58.5	60.3	24.4	27.8
	pron	1.4	1.2	10.0	10.0	2.8	3.3	72.8	70.5	63.3	70.7
19	comp	25.9	26.8	45.3	43.4	3.6	6.1	60.0	57.7	7.9	12.9
	dyn	8.7	10.5	17.4	18.0	0.2	4.1	63.5	57.9	1.4	21.1
	supi	9.6	12.1	21.5	21.9	-0.3	-0.7	65.9	61.1	-1.9	-3.5
	pron	16.3	14.7	23.7	21.5	3.9	6.9	54.8	52.9	13.5	25.1
22	comp	15.8	16.3	36.6	34.1	8.4	6.0	63.9	63.0	28.0	20.1
	dyn	9.3	9.0	21.7	19.5	4.5	3.1	64.6	63.9	25.9	18.8
	supi	10.2	11.0	20.8	20.8	4.1	2.6	62.2	61.4	21.9	13.3
	pron	5.6	5.3	15.8	13.3	4.3	3.4	65.9	64.7	37.5	32.4
25	comp	21.2	20.1	37.0	36.5	0.8	2.4	60.1	61.0	2.2	6.8
	dyn	8.7	7.2	14.4	14.9	0.0	1.2	59.0	64.0	0.0	9.7
	supi	10.6	11.9	17.9	17.0	0.8	0.6	59.3	54.9	4.3	3.1
	pron	10.7	8.1	19.2	19.5	0.0	-2.3	60.9	66.5	0.1	-15.9

Table A2.6

Range of rearfoot complex motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - right limb only

		Range of motion (°)						Angle of axis to			
	LEFT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	LEG	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	0.5	1.3	-32.3	-30.1	-0.9	-0.9	-88.2	-87.0	-60.3	-34.8
	dyn	0.6	0.8	-17.2	-17.4	-0.8	-0.3	-86.7	-87.1	-53.8	-19.3
	supi	0.3	0.9	-20.0	-20.2	-0.8	-0.7	-87.5	-86.7	-66.8	-37.7
	pron	0.1	0.4	-12.3	-10.0	-0.1	-0.2	-89.3	-87.7	-20.9	-27.2
19	comp	-3.2	-2.9	-46.9	-44.2	-0.8	-1.0	-86.0	-86.0	13.5	18.8
	dyn	-1.5	-1.0	-12.9	-13.1	-0.4	-0.1	-82.9	-85.7	15.2	5.3
	supi	-1.2	-1.6	-20.2	-20.4	-1.8	-1.1	-83.8	-84.7	55.6	34.9
	pron	-1.9	-1.4	-26.7	-23.8	1.1	0.1	-85.3	-86.7	-28.7	-3.7
22	comp	2.1	2.3	-39.0	-36.1	0.9	2.2	-86.7	-85.0	22.2	42.9
	dyn	1.2	1.6	-19.0	-18.8	0.7	0.5	-85.7	-85.1	30.0	16.9
	supi	0.6	1.3	-20.3	-20.4	0.8	0.5	-87.3	-86.2	53.9	21.8
	pron	1.5	1.1	-18.6	-15.7	0.1	1.7	-85.3	-82.9	3.1	57.3
25	comp	-1.4	-0.8	-41.5	-42.8	-3.3	-1.9	-85.1	-87.3	67.6	66.6
	dyn	-0.5	-0.4	-13.2	-13.8	-0.8	-0.6	-86.2	-86.9	58.7	55.2
	supi	-1.0	-0.4	-20.4	-20.6	-1.9	-0.9	-84.1	-87.3	63.3	66.3
	pron	-0.4	-0.4	-21.1	-22.1	-1.4	-1.0	-86.0	-87.3	74.0	66.9

Table A2.7

Range of leg motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - left limb only

		Range of motion (^{o})						Angle of axis to			
	LEFT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	HEEL	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	3.5	2.3	-9.1	-8.1	-1.4	-1.4	-67.2	-71.8	-22.0	-30.9
	dyn	1.2	1.5	-4.7	-4.3	-0.7	-0.4	-74.2	-69.8	-29.6	-13.2
	supi	2.5	1.5	-5.0	-5.3	-1.4	-2.1	-60.2	-64.4	-30.2	-54.1
	pron	1.1	0.8	-4.1	-2.8	0.0	0.7	-75.4	-69.2	0.4	41.5
19	comp	12.8	14.0	-16.1	-15.9	-0.9	0.0	-51.5	-48.5	-3.8	-0.2
	dyn	4.3	4.5	-5.0	-4.8	-0.8	-0.2	-48.8	-46.5	-9.9	-2.4
	supi	5.6	5.8	-8.0	-7.8	-1.1	-1.0	-54.5	-52.8	-11.2	-9.3
	pron	7.2	8.2	-8.1	-8.1	0.3	0.9	-48.4	-44.4	2.1	6.4
22	comp	3.6	4.7	-7.8	-7.8	-1.8	-1.1	-62.8	-58.5	-26.6	-12.7
	dyn	1.9	1.3	-2.9	-3.1	-0.8	-1.0	-54.9	-62.2	-24.6	-36.8
	supi	3.3	4.4	-5.0	-4.9	-1.8	-1.0	-53.1	-47.0	-28.0	-12.2
	pron	0.3	0.2	-2.8	-2.9	0.0	-0.1	-84.4	-85.4	-7.1	-22.2
25	comp	4.6	5.0	-13.5	-11.5	-2.1	-0.3	-69.6	-66.3	-24.3	-3.0
	dyn	1.4	2.3	-3.8	-3.3	-0.7	-0.4	-68.1	-55.2	-26.2	-9.5
	supi	3.2	2.5	-7.1	-6.3	-1.8	-0.2	-62.7	-68.6	-29.0	-4.4
	pron	1.4	2.5	-6.4	-5.1	-0.3	-0.1	-77.6	-63.6	-12.0	-1.6

Table A2.8

Range of heel motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - left limb only

		Range of motion (°)						Angle of axis to			
	LEFT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	FORFT	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	13.3	11.2	0.4	0.9	7.5	7.9	3.5	3.6	24.3	35.3
	dyn	5.8	5.7	0.4	0.5	4.2	4.4	1.7	4.1	34.4	37.7
	supi	9.1	8.5	0.5	0.6	5.3	6.3	1.8	3.1	23.2	36.5
	pron	4.3	2.7	-0.1	0.3	2.2	1.7	6.5	5.2	26.2	31.4
19	comp	25.4	25.5	-0.1	2.5	8.3	6.3	-0.3	5.4	18.1	13.9
	dyn	8.4	7.4	-0.2	-1.1	2.8	3.0	-1.1	-7.8	18.8	22.0
	supi	10.0	9.7	1.2	2.9	2.8	3.8	6.4	15.3	15.6	21.4
	pron	15.4	15.8	-1.3	-0.4	5.5	2.5	-4.6	-1.3	19.7	8.9
22	comp	14.9	15.4	2.1	1.7	8.3	8.8	7.0	5.4	29.3	29.8
	dyn	6.4	6.5	1.7	0.7	4.0	3.7	13.0	5.0	31.7	29.8
	supi	10.3	11.7	2.4	2.6	5.9	6.9	11.5	11.0	29.8	30.5
	pron	4.6	3.8	-0.3	-1.0	2.4	2.0	-3.6	-12.6	28.2	27.4
25	comp	19.3	19.3	-7.3	-7.3	-0.2	1.3	-20.9	-20.6	-0.5	4.0
	dyn	5.2	6.6	-2.4	-2.0	0.0	0.4	-24.6	-16.3	0.4	3.3
	supi	11.0	9.8	-4.5	-4.9	0.9	1.5	-22.5	-26.4	5.0	8.6
	pron	8.3	9.5	-2.8	-2.4	-1.1	-0.1	-18.4	-13.9	-7.7	-0.8

Table A2.9

Range of forefoot motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - left limb only

		Range of motion (^{0})						Angle of axis to			
	LEFT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	Ank/Stj	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	3.0	1.0	23.2	22.0	-0.6	-0.5	82.4	87.1	-10.4	-25.4
	dyn	0.6	0.7	12.5	13.1	0.1	-0.1	87.3	86.9	13.1	-5.7
	supi	2.1	0.6	15.0	14.8	-0.6	-1.4	81.6	84.3	-16.4	-66.9
	pron	0.9	0.4	8.2	7.2	0.1	0.9	83.5	82.2	3.9	63.4
19	comp	15.9	17.0	30.8	28.3	-0.1	1.0	62.6	59.0	-0.3	3.2
	dyn	5.9	5.5	7.9	8.3	-0.3	-0.1	53.2	56.6	-3.2	-1.0
	supi	6.8	7.4	12.2	12.6	0.7	0.1	60.6	59.6	5.9	1.0
	pron	9.1	9.6	18.6	15.7	-0.8	0.8	63.8	58.5	-5.0	5.0
22	comp	1.5	2.3	31.1	28.3	-2.7	-3.2	84.4	82.0	-60.3	-53.8
	dyn	0.6	-0.2	16.1	15.7	-1.6	-1.5	84.1	84.6	-68.2	80.6
	supi	2.8	3.2	15.3	15.5	-2.5	-1.5	76.2	77.3	-42.5	-24.7
	pron	-1.3	-0.8	15.8	12.8	-0.1	-1.7	85.4	81.4	5.3	64.2
25	comp	5.9	5.8	28.1	31.3	1.2	1.6	77.8	79.1	11.6	15.3
	dyn	1.8	2.7	9.4	10.4	0.1	0.2	79.1	75.4	2.7	5.1
	supi	4.1	2.9	13.3	14.3	0.1	0.7	72.7	78.4	1.6	13.8
	pron	1.8	3.0	14.7	17.0	1.1	0.9	81.9	79.7	32.0	16.8

Table A2.10

Range of ankle/sub talar complex motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - left limb only

		Range of motion (^{o})						Angle of axis to			
	LEFT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	MTJ	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	9.8	8.9	9.5	9.0	8.9	9.3	34.6	34.9	35.1	46.3
	dyn	4.6	4.2	5.1	4.8	4.9	4.8	36.0	37.0	44.6	48.7
	supi	6.6	7.0	5.5	5.9	6.7	8.3	29.4	28.5	37.2	50.1
	pron	3.2	1.9	4.0	3.1	2.2	1.0	42.4	55.2	31.2	26.4
19	comp	12.6	11.5	16.0	18.4	9.2	6.3	45.7	54.4	36.0	28.9
	dyn	4.0	2.9	4.9	3.7	3.6	3.2	42.0	40.5	41.7	47.7
	supi	4.4	3.9	9.2	10.7	3.9	4.8	57.3	60.0	41.6	50.9
	pron	8.2	7.6	6.8	7.7	5.3	1.6	34.8	44.7	32.6	11.6
22	comp	11.2	10.8	9.9	9.5	10.1	9.9	33.2	32.9	42.0	42.5
	dyn	4.6	5.2	4.6	3.8	4.8	4.7	34.9	28.2	46.4	42.1
	supi	7.0	7.3	7.4	7.5	7.7	7.8	35.7	35.1	47.7	47.2
	pron	4.3	3.5	2.5	2.0	2.5	2.0	26.6	26.0	30.0	29.9
25	comp	14.7	14.3	6.1	4.2	1.9	1.6	22.4	16.2	7.3	6.4
	dyn	3.8	4.4	1.4	1.4	0.7	0.8	19.8	17.3	10.4	9.9
	supi	7.8	7.3	2.5	1.4	2.7	1.7	17.2	10.9	19.3	12.9
	pron	6.9	7.0	3.6	2.8	-0.8	-0.1	27.0	21.5	-6.8	-0.5

Table A2.11

Range of mid tarsal joint motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days -left limb only

		Range of motion (^{0})						Angle of axis to			
	LEFT	Frontal		Transverse		Sagittal		Transverse		Sagittal	
SUBJ	RFC	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2	DAY 1	DAY2
9	comp	12.9	9.9	32.7	31.0	8.3	8.8	63.0	66.9	27.6	41.7
	dyn	5.2	4.9	17.6	17.9	5.0	4.7	67.2	69.1	42.1	43.9
	supi	8.7	7.5	20.5	20.7	6.1	7.0	61.8	63.6	27.8	42.8
	pron	4.1	2.4	12.2	10.3	2.3	1.8	64.8	73.8	27.2	37.9
19	comp	28.5	28.5	46.7	46.7	9.1	7.3	57.3	57.8	17.6	14.4
	dyn	9.9	8.4	12.7	12.0	3.3	3.1	50.6	53.3	18.2	20.2
	supi	11.2	11.3	21.4	23.3	4.6	4.9	60.4	62.2	22.3	23.5
	pron	17.3	17.2	25.4	23.4	4.5	2.4	54.8	53.4	14.5	7.9
22	comp	12.8	13.1	41.1	37.8	7.5	6.7	70.2	68.7	30.4	27.0
	dyn	5.2	5.0	20.7	19.4	3.3	3.3	73.4	73.0	32.1	33.3
	supi	9.7	10.4	22.7	23.0	5.1	6.4	64.2	62.0	27.8	31.4
	pron	3.0	2.7	18.3	14.8	2.4	0.3	78.2	79.6	37.9	6.3
25	comp	20.6	20.1	34.2	35.5	3.1	3.2	58.6	60.2	8.6	9.0
	dyn	5.6	7.1	10.8	11.8	0.8	1.0	62.4	58.9	7.9	8.0
	supi	11.9	10.1	15.9	15.7	2.8	2.4	52.4	56.5	13.4	13.2
	pron	8.7	9.9	18.3	19.8	0.3	0.8	64.5	63.2	1.8	4.8

Table A2.12

Range of rearfoot complex motion in the frontal, transverse and sagittal planes and the axis of rotation calculated from these, derived from data recorded on two separate days - left limb only

		DIFFERENCE BETWEEN DAYS				
	RIGHT	Range of motion (^{o})			angle of axis (^{o})	
SUBJ	LEG	Frt	Trn	Sag	Trn	Sag
9	comp	0.4	0.3	0.3	0.9	0.1
	dyn	0.1	0.0	0.0	0.1	9.0
	supi	0.1	0.4	0.0	0.1	6.7
	pron	0.0	0.1	0.3	0.3	14.5
19	comp	1.4	1.4	2.1	1.8	87.1
	dyn	0.7	0.6	0.6	0.9	100.9
	supi	0.9	0.1	0.8	1.5	115.3
	pron	0.5	1.5	1.2	1.4	33.4
22	comp	0.3	3.4	1.4	1.5	20.3
	dyn	0.3	1.7	0.5	0.9	14.4
	supi	0.1	0.3	0.7	0.3	27.3
	pron	0.3	3.1	0.7	1.9	6.7
25	comp	0.3	0.0	0.4	0.6	10.5
	dyn	0.1	0.2	0.2	0.2	40.6
	supi	0.0	1.6	0.6	0.4	98.9
	pron	0.2	1.6	1.0	1.7	37.6
	mean	0.4	1.0	0.7	0.9	39.0
	sd	0.4	1.1	0.5	0.7	38.8

Table A2.13

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - right leg. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

		DIFFERENCE BETWEEN DAYS				
	RIGHT	Range of motion (°)			angle of axis (°)	
SUBJ	**HEEL**	**Frt**	**Trn**	**Sag**	**Trn**	**Sag**
9	**comp**	0.4	0.4	0.4	1.5	0.9
	dyn	0.2	0.1	0.1	2.8	1.5
	supi	0.3	0.4	0.1	4.2	0.5
	pron	0.1	0.8	0.3	2.1	3.2
19	**comp**	2.6	1.3	2.9	0.5	15.6
	dyn	1.6	0.9	0.4	3.7	9.6
	supi	1.6	0.2	0.5	6.8	9.0
	pron	1.0	1.0	2.4	4.3	18.3
22	**comp**	1.2	0.8	0.0	4.4	5.0
	dyn	1.3	0.6	0.1	8.2	7.8
	supi	0.5	0.8	0.1	0.6	1.3
	pron	0.7	0.0	0.1	9.0	43.5
25	**comp**	1.3	0.4	0.7	2.3	5.4
	dyn	1.1	0.2	0.4	4.4	6.4
	supi	0.2	0.9	0.5	5.5	5.7
	pron	1.1	1.3	0.2	0.3	5.4
	mean	0.9	0.6	0.6	3.8	8.7
	sd	0.7	0.4	0.8	2.6	10.5

Table A2.14

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - right heel. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

SUBJ	RIGHT FORFT	DIFFERENCE BETWEEN DAYS Range of motion (°)			angle of axis (°)	
		Frt	Trn	Sag	Trn	Sag
9	comp	1.0	0.0	0.6	0.4	3.9
	dyn	0.6	0.0	0.2	0.3	2.6
	supi	0.7	0.1	0.3	1.1	3.2
	pron	0.2	0.2	0.2	2.0	4.9
19	comp	0.5	0.4	0.5	0.9	1.1
	dyn	1.2	0.0	3.3	0.4	17.5
	supi	1.6	0.3	1.3	0.4	5.4
	pron	2.1	0.7	1.7	2.9	8.0
22	comp	0.8	0.9	1.0	3.5	4.5
	dyn	0.1	0.4	1.0	2.7	6.1
	supi	0.8	0.3	0.8	1.8	5.9
	pron	0.0	0.6	0.2	5.3	2.0
25	comp	1.4	0.5	2.0	2.0	5.4
	dyn	1.4	0.7	1.0	5.2	8.1
	supi	1.3	2.4	0.7	10.2	4.1
	pron	2.8	1.9	1.4	6.9	10.0
	mean	1.0	0.6	1.0	2.9	5.8
	sd	0.7	0.7	0.8	2.8	3.9

Table A2.15

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - right forefoot. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

	RIGHT	DIFFERENCE BETWEEN DAYS				
		Range of motion (^{0})			angle of axis (^{0})	
SUBJ	Ank/Stj	Frt	Trn	Sag	Trn	Sag
9	comp	0.8	0.7	0.7	2.8	6.7
	dyn	0.3	0.1	0.1	1.2	1.8
	supi	0.4	0.0	0.1	1.5	0.3
	pron	0.1	0.7	0.6	4.4	10.3
19	comp	4.0	2.7	0.8	7.2	10.6
	dyn	2.3	0.4	0.2	9.8	8.2
	supi	2.5	0.1	0.4	8.9	6.8
	pron	1.5	2.6	1.2	6.2	12.3
22	comp	1.5	2.6	1.4	2.4	13.5
	dyn	1.5	1.1	0.4	4.6	8.5
	supi	0.5	0.5	0.6	1.9	8.8
	pron	1.0	3.1	0.8	3.7	21.2
25	comp	1.1	0.4	1.1	1.8	8.2
	dyn	1.2	0.1	0.2	4.9	4.7
	supi	0.2	0.7	0.0	1.6	0.1
	pron	0.9	0.3	1.1	2.4	21.9
	mean	1.2	1.0	0.6	4.1	9.0
	sd	1.0	1.1	0.4	2.7	6.2

Table A2.16

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - right ankle/sub talar complex. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

		DIFFERENCE BETWEEN DAYS				
	RIGHT	Range of motion (°)			angle of axis (°)	
SUBJ	MTJ	Frt	Trn	Sag	Trn	Sag
9	comp	0.6	0.4	0.2	0.9	2.3
	dyn	0.3	0.2	0.1	1.5	2.3
	supi	0.4	0.3	0.2	2.2	2.9
	pron	0.2	0.7	0.0	5.4	1.2
19	comp	3.1	0.9	3.3	8.3	12.6
	dyn	0.4	0.9	3.6	5.4	39.3
	supi	0.0	0.5	0.8	0.5	6.5
	pron	3.1	0.3	4.1	8.2	31.1
22	comp	2.0	0.1	1.0	2.2	8.4
	dyn	1.3	1.1	1.0	6.8	13.5
	supi	1.3	0.5	0.9	4.5	11.0
	pron	0.7	0.6	0.2	2.7	5.0
25	comp	0.1	0.9	1.4	3.4	6.4
	dyn	0.3	0.5	1.5	4.0	23.0
	supi	1.6	1.5	0.2	17.2	5.6
	pron	1.7	0.6	1.2	9.4	13.0
	mean	1.1	0.6	1.2	5.2	11.5
	sd	1.0	0.4	1.3	4.2	10.9

Table A2.17

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - right mid tarsal joint. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

		DIFFERENCE BETWEEN DAYS				
	RIGHT	Range of motion (°)			angle of axis (°)	
SUBJ	RFC	Frt	Trn	Sag	Trn	Sag
9	comp	1.4	0.3	0.9	1.2	6.5
	dyn	0.6	0.1	0.2	1.5	2.8
	supi	0.8	0.3	0.3	1.8	3.4
	pron	0.2	0.0	0.6	2.2	7.4
19	comp	0.9	1.8	2.5	2.3	5.0
	dyn	1.9	0.5	3.8	5.7	19.7
	supi	2.5	0.4	0.4	4.8	1.6
	pron	1.6	2.3	3.0	1.9	11.5
22	comp	0.5	2.5	2.4	1.0	7.9
	dyn	0.2	2.1	1.4	0.6	7.1
	supi	0.8	0.0	1.5	0.8	8.6
	pron	0.3	2.5	0.9	1.1	5.1
25	comp	1.2	0.5	1.6	0.9	4.7
	dyn	1.5	0.4	1.2	5.0	9.7
	supi	1.4	0.8	0.1	4.4	1.2
	pron	2.5	0.3	2.3	5.6	16.0
	mean	1.1	0.9	1.5	2.6	7.4
	sd	0.7	0.9	1.1	1.9	5.0

Table A2.18

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - right rearfoot complex. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

		DIFFERENCE BETWEEN DAYS				
	LEFT	Range of motion (^{o})			angle of axis (^{o})	
SUBJ	LEG	Frt	Trn	Sag	Trn	Sag
9	comp	0.8	2.1	0.0	1.2	25.5
	dyn	0.2	0.1	0.5	0.4	34.5
	supi	0.6	0.2	0.1	0.8	29.1
	pron	0.2	2.3	0.1	1.5	6.3
19	comp	0.2	2.7	0.2	0.0	5.3
	dyn	0.6	0.2	0.3	2.8	9.9
	supi	0.3	0.2	0.7	0.9	20.7
	pron	0.5	2.9	1.0	1.4	24.9
22	comp	0.2	2.9	1.3	1.7	20.8
	dyn	0.3	0.2	0.2	0.7	13.1
	supi	0.7	0.1	0.3	1.1	32.1
	pron	0.5	2.9	1.6	2.4	54.2
25	comp	0.6	1.2	1.4	2.2	1.0
	dyn	0.0	0.6	0.1	0.7	3.5
	supi	0.6	0.2	1.0	3.2	3.1
	pron	0.0	1.0	0.4	1.2	7.1
	mean	0.4	1.2	0.6	1.4	18.2
	sd	0.2	1.2	0.5	0.9	14.7

Table A2.19

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - left leg. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

		DIFFERENCE BETWEEN DAYS				
	LEFT	Range of motion (^{0})			angle of axis (^{0})	
SUBJ	**HEEL**	**Frt**	**Trn**	**Sag**	**Trn**	**Sag**
9	**comp**	1.2	1.0	0.1	4.5	8.9
	dyn	0.4	0.4	0.3	4.4	16.4
	supi	1.0	0.3	0.6	4.1	23.9
	pron	0.3	1.3	0.7	6.2	41.1
19	**comp**	1.3	0.2	0.8	3.0	3.6
	dyn	0.2	0.3	0.6	2.3	7.5
	supi	0.2	0.2	0.2	1.6	1.9
	pron	1.0	0.0	0.7	4.1	4.3
22	**comp**	1.1	0.0	0.8	4.3	13.9
	dyn	0.5	0.2	0.1	7.3	12.2
	supi	1.1	0.2	0.8	6.2	15.8
	pron	0.1	0.1	0.1	1.0	15.1
25	**comp**	0.4	2.0	1.8	3.2	21.3
	dyn	0.9	0.4	0.3	12.9	16.7
	supi	0.7	0.7	1.6	5.9	24.6
	pron	1.2	1.3	0.2	14.0	10.4
	mean	0.7	0.5	0.6	5.3	14.9
	sd	0.4	0.6	0.5	3.6	9.8

Table A2.20

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - left heel. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

		DIFFERENCE BETWEEN DAYS				
	LEFT	Range of motion (°)			angle of axis (°)	
SUBJ	FORFT	Frt	Trn	Sag	Trn	Sag
9	comp	2.2	0.4	0.4	0.1	11.0
	dyn	0.0	0.1	0.2	2.4	3.3
	supi	0.6	0.1	1.0	1.3	13.3
	pron	1.6	0.4	0.6	1.3	5.3
19	comp	0.2	2.6	2.0	5.7	4.3
	dyn	0.9	0.9	0.2	6.8	3.2
	supi	0.3	1.7	1.0	8.9	5.8
	pron	0.5	1.0	3.0	3.3	10.8
22	comp	0.6	0.4	0.5	1.6	0.5
	dyn	0.1	1.1	0.3	8.0	1.9
	supi	1.4	0.2	1.0	0.5	0.6
	pron	0.8	0.6	0.5	9.0	0.8
25	comp	0.0	0.1	1.5	0.3	4.5
	dyn	1.5	0.4	0.3	8.3	2.9
	supi	1.2	0.4	0.5	3.9	3.7
	pron	1.2	0.4	1.0	4.5	6.9
	mean	0.8	0.7	0.9	4.1	4.9
	sd	0.6	0.7	0.8	3.3	3.9

Table A2.21

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - left forefoot. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

		DIFFERENCE BETWEEN DAYS				
	LEFT	Range of motion (^{0})			angle of axis (^{0})	
SUBJ	Ank/Stj	Frt	Trn	Sag	Trn	Sag
9	comp	2.0	1.2	0.1	4.7	15.0
	dyn	0.1	0.6	0.2	0.4	18.8
	supi	1.5	0.2	0.7	2.7	50.5
	pron	0.5	1.0	0.8	1.3	59.5
19	comp	1.1	2.5	1.0	3.6	3.6
	dyn	0.4	0.5	0.2	3.4	2.2
	supi	0.6	0.4	0.6	1.0	4.8
	pron	0.5	2.9	1.6	5.3	9.9
22	comp	0.8	2.8	0.5	2.4	6.5
	dyn	0.9	0.4	0.1	0.6	148.8
	supi	0.4	0.2	1.1	1.1	17.9
	pron	0.4	3.1	1.6	4.0	58.9
25	comp	0.1	3.2	0.4	1.3	3.7
	dyn	0.9	1.0	0.2	3.8	2.4
	supi	1.3	1.0	0.6	5.6	12.2
	pron	1.2	2.3	0.2	2.2	15.2
	mean	0.8	1.4	0.6	2.7	26.9
	sd	0.5	1.1	0.5	1.7	38.0

Table A2.22

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - left ankle/sub talar complex. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

		DIFFERENCE BETWEEN DAYS				
	LEFT	Range of motion (°)			angle of axis (°)	
SUBJ	MTJ	Frt	Trn	Sag	Trn	Sag
9	comp	0.9	0.6	0.4	0.3	11.2
	dyn	0.4	0.3	0.1	1.0	4.1
	supi	0.3	0.4	1.6	0.9	12.9
	pron	1.3	1.0	1.2	12.8	4.8
19	comp	1.1	2.4	2.8	8.8	7.1
	dyn	1.1	1.2	0.4	1.5	6.0
	supi	0.5	1.5	0.9	2.7	9.3
	pron	0.6	0.9	3.7	9.9	21.0
22	comp	0.5	0.4	0.3	0.3	0.4
	dyn	0.6	0.9	0.1	6.7	4.3
	supi	0.3	0.1	0.2	0.6	0.6
	pron	0.7	0.5	0.4	0.7	0.1
25	comp	0.4	1.9	0.3	6.2	0.9
	dyn	0.6	0.0	0.1	2.5	0.5
	supi	0.5	1.1	1.1	6.3	6.4
	pron	0.0	0.8	0.8	5.6	6.3
	mean	0.6	0.9	0.9	4.2	6.0
	sd	0.3	0.7	1.0	3.9	5.6

Table A2.23

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - left mid tarsal. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.

		DIFFERENCE BETWEEN DAYS				
	LEFT	Range of motion (°)			angle of axis (°)	
SUBJ	RFC	Frt	Trn	Sag	Trn	Sag
9	comp	3.0	1.7	0.5	3.9	14.1
	dyn	0.3	0.3	0.3	1.9	1.7
	supi	1.2	0.3	0.9	1.8	15.0
	pron	1.8	2.0	0.4	8.9	10.7
19	comp	0.1	0.0	1.8	0.5	3.3
	dyn	1.5	0.7	0.2	2.7	2.0
	supi	0.0	1.9	0.3	1.8	1.2
	pron	0.1	1.9	2.1	1.4	6.5
22	comp	0.4	3.2	0.8	1.5	3.4
	dyn	0.2	1.3	0.0	0.5	1.2
	supi	0.7	0.3	1.2	2.1	3.6
	pron	0.3	3.5	2.1	1.4	31.6
25	comp	0.5	1.3	0.1	1.6	0.4
	dyn	1.5	1.0	0.2	3.5	0.1
	supi	1.8	0.1	0.5	4.1	0.2
	pron	1.2	1.5	0.6	1.3	2.9
	mean	0.9	1.3	0.7	2.4	6.1
	sd	0.8	1.1	0.7	2.0	8.3

Table A2.24

The difference between days in the ranges of motion and angulation of axes of rotation to the sagittal and transverse planes - left rearfoot complex. Frt = frontal plane, Trn = transverse plane, Sag = sagittal plane.