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BSc (Hons) Podiatry

School of Health and Social Sciences

Final Year Project

An Investigation into the Reliability of Quintic Biomechanics Software, when used to Measure Transverse Plane Tibial Rotation through the use of a Tibial Pointer.

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Dissertation submitted in part fulfilment of the requirements of the University of Wales Institute, Cardiff, for the degree of Bachelor of Science.

In submitting this report, I confirm that this is my own work and has not been submitted for any other degree or for publication.

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My thanks to those without whom the road would have been rockier:

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Abstract

Much evidence supporting the use of orthoses remains anecdotal (Landorf, 2000) and in part, this is due to the difficulties of measuring foot motion inside footwear. The relationship between transverse plane tibial rotation and frontal plane motion in the foot is well established and can be exploited to make inferences about foot motion through measurement of tibial rotation. McPoil and Corwall (1995) developed the tibial pointer device to enable tibial rotation to be measured using 2D video analysis thus bringing the technique within range of clinical research projects. The development of "off the peg" video motion analysis software provides an opportunity to further simplify the technique. The purpose of this study was to determine the suitability and reliability of Quintic Biomechanics software, when used to analyse transverse plane tibial rotation, via 2D video analysis of a tibial pointer device attached to the tibial tuberosity. Additionally reliability of measurement of frontal plane rearfoot motion and of correlation of rearfoot with tibial motion was assessed. Markers on the tibial pointer and rearfoot were digitised for single strides from 10 subjects (7 women 3 men) on two different occasions and the resulting co-ordinates used to calculate the respective motion patterns. Intraclass correlation coefficients (ICC) were used to assess the test retest reliability of the technique and 7 of the 10 subjects returned ICCs of greater than 0.7 for measurement of tibial rotation, suggesting good reliability. ICCs for measurement of rearfoot motion were less consistent and it was considered that the method adopted for this measurement was unreliable. Consistency of correlation between the two motion patterns was found to be poor and this was attributed to inconsistent measurement of rearfoot angle. The study concluded that Quintic Biomechanics software was reliable when used with the adopted method to measure transverse plane tibial rotation.

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1 Introduction

From ten to twelve hours of uninterrupted activity was often necessary (for data collection on a single subject) since preparing the experimental subject required the utmost care. The calculations involved were voluminous and required continuous work for several months. Unfortunately, Professor Braune was unable to enjoy the results of the research…. Death took him away in the middle of his work, even before the measurement of the coordinates on all the photographic plates was finished.

(Braune and Fischer in Cavanagh, 1993)

Traditionally assessment of foot pathologies has consisted of static assessment of foot type in either open or closed kinetic chain, coupled with visual observation of gait. Since its beginnings towards the end of the 19th centaury when Eadweard Muybridges work culminated in publication of *Animals in Motion* and *The Human Figure in Motion* (Curran, 2005), photographic or video kinematics has evolved to the point where it may commonly be seen track side, at sports training facilities. Increasingly, with advancing computational power, instrumented gait analysis is playing a more predominant role in both the clinical and research settings. Curran (2005) describes its advantages over pure observational techniques, in its ability to "*identify the fast, simultaneous motions that occur during walking that cannot be seen with the naked eye*". Modern systems utilise either a 3dimensional approach with 2 or more cameras which offers great accuracy, at the expense of long setup times and great cost, or a 2 dimensional approach with a single camera. The 2 dimensional (2D) approach with its simplicity and low costs is very attractive for clinical applications or for clinical based research, however for any degree of accuracy to be achieved the motion of interest must be tangential to the cameras optical axis. When that motion of interest is transverse plane rotation in the tibia, obvious difficulties exist in finding a suitable camera angle. Utilisation of trigonometric laws to analyses motion via a 2D system were described by Sutherland (1972), who used the difference between apparent and actual separation of markers placed on the hips, when viewed from the front, to make measurements of pelvic rotation. Cornwall (1995) adapted the technique, through the development of the tibial pointer device, to enable measurements of tibial rotation to be made via a 2D video gait analysis system. Their work aimed to fill a gap in the literature by providing a technique for assessing the in shoe effect of functional foot orthoses. With any medical intervention having to justify its funding and use, through scientific evidence of its efficacy, the need for hard evidence supporting the use of foot orthoses is paramount. A review of the literature supporting the use of foot orthoses was conducted by Landorf (2000), who summarised that while many authors had produced results which were generally quite supportive of foot orthoses, many studies were inconclusive or produced negative results. The difficulty encountered with any investigation into how differing types of orthoses function when in use, lies in taking measurements from the foot, in shoe. Measurements of force and pressure can be made inshoe via systems such as the Pedar inshoe pressure measurement system (Novel, Gmbh, Munich Germany), but direct kinematic measurements have proved difficult. Cornwall's (1995) technique exploits the established relationship between transverse plane lower limb rotations and frontal plane motions in the foot (Inman 1981), to provide data on the latter via measurements made of the former.

As can be seen from the work of Braune and Fischer, video gait analysis can be a time consuming process. It is hoped that the development of user-friendly motion analysis software such as the Quintic Biomechanics package will further speed up and simplify the technique encouraging more researchers and clinicians to adopt it, and apply it to a wider range of trials. The aim of this study is to investigate the reliability of Quintic Biomechanics software when used with the tibial pointer device developed by Cornwall to measure tibial rotation.

2 Literature Review

2.1 Functional Anatomy

The human ambulatory system is complex and heavily interdependent; to consider a part in isolation with out consideration to the effects upon and by the remainder is to be misled. This fact applies not only to the rigid mechanical linkages (bones) but also to soft tissue structures, muscle, and ligaments. However, only those segments bearing specific relation to the translation of movement between the leg and foot will be discussed here.

Triplaner motions occur between the leg and foot during both the open and closed kinetic chain phases of gait and this motion occurs predominantly through the combined actions of the ankle and subtalar joint. As Michaud (1997) points out, while definition of the axis of joints might be attempted, human joints are rarely axial in nature, rather achieving motion through a combination of linear and angular motion. Consequently, where the location of an axis is referred to, it should be borne in mind that this is an approximation and that the true axis will vary about this position.

2.1.1 Ankle Joint

Comprised of the articulation between the distal tibia and fibular, and the talar trochlea, the ankle or talocrural joint has an axis lying approximately 8° to the transverse plane and 20-30° to the frontal plane (Michaud 1997). This permits large amounts of sagital plane motion and comprises the ankle rocker that enables forward progression during the period of full foot contact (Perry 1992). The axis is considered by Michaud (1997) to constantly reposition as the ankle is moved and this has been confirmed by in vivo Roentgen stereophotogrammetric investigations by Lundberg (1989). This technique involves the introduction of radio opaque tantalum beads into sites of interest with in the foot of a volunteer. Stereo radiographs are then taken with the foot placed in a sequence of load bearing positions. The stereo pairs permit three-dimensional co-ordinates to be generated for each of the marker beads enabling the motion patterns of bones within a living subjects foot to be truly examined, rather than postulated from a combination of cadaveric study and external observation of the motion patterns of the foot. Inman (1981, p18) points out that since the ankle joint axis is inclined laterally in the frontal plane, transverse plane internal rotation of the lower leg will occur as the leg "rocks" over the joint. If this were to be taken in isolation it would suggest that the tibia was internally rotating from the start of full foot load to heel lift (see Figure 2-1), where as it is in fact externally rotating (see Figure 2-2). This paradox serves to highlight the folly of considering joints in isolation as in this instance the mechanism serves as an amplification system assisting in the re supination of the subtalar joint, providing the well documented transition from mobile adapter to ridged lever (Root 1977, Michaud 1997).

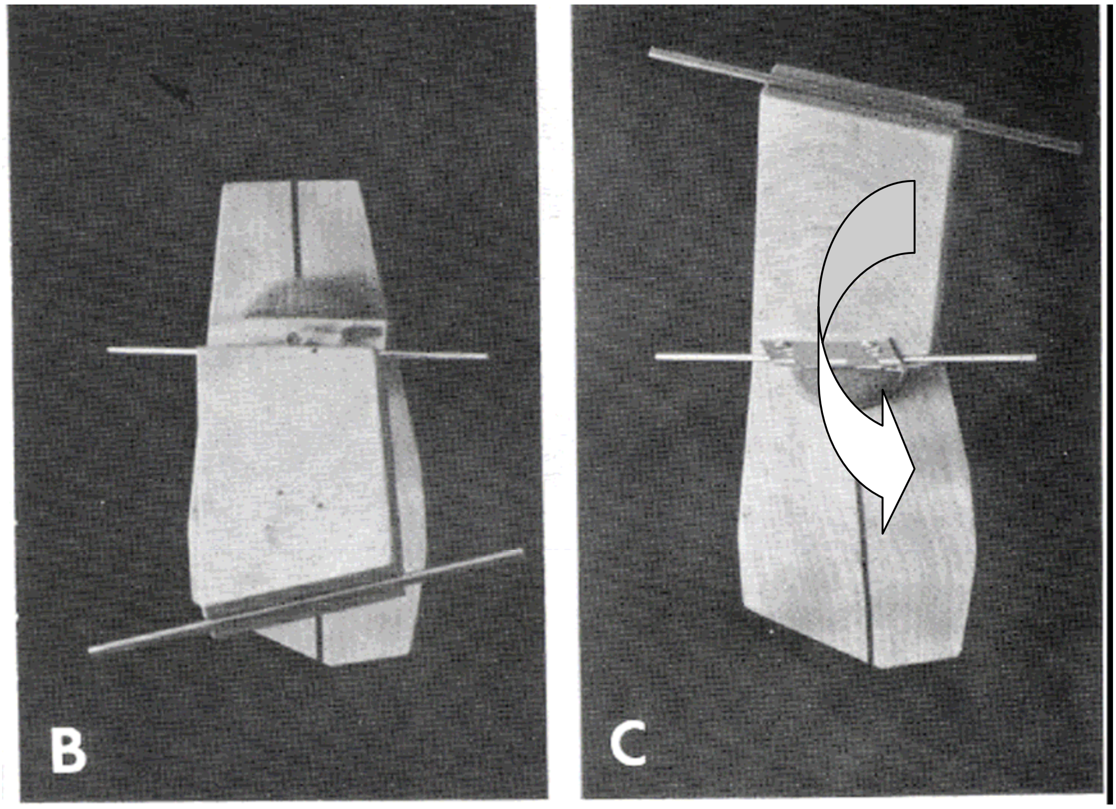
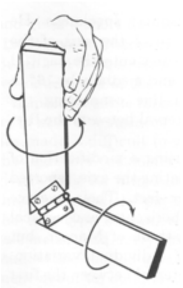


Figure 2-1 Axial model of the ankle joint showing internal tibial rotation with relative dorsiflexion. (Inman 1981)

2.1.2 Subtalar Joint



The subtalar joint (talocalcaneal joint) comprises the articulation between the inferior surface of the talus and the superior surface of the calcaneus. It is identified with the translation of lower limb transverse plane rotation into frontal plane rotation in the foot with Inman (1976) comparing it to a mitered hinge. A cadaveric study of 16 feet in 1941 by Manter established the spatial location of the average subtalar joint axis as 42° from the transverse plane and 16° from the sagittal plane, running inferior posterolateral to superior anteromedial (in Kirby 2001). This work was confirmed by Root (1977) and Inman (1976). The resultant triplaner motion in the foot is described as pronation (eversion, abduction and dorsiflexion) and supination (inversion, adduction and planter flexion) (Root et. al. 1977). More recently, examination of subtalar joint motion has been conducted through the utilisation of roentgen stereophotogrametry in separate investigations by Van Langelaan, Benink (in Kirby 2001), and Lundberg and Svensson (1989). These studies have demonstrated that subtalar joint axis location, changes with subtalar joint rotational position and that thus it cannot be described as a single axis, rather as a bundle of axes passing through the talocalcaneal joint. Specifically with increasing subtalar joint pronation, the axis location internally rotates and deviates medially while with supination the reverse occurs.

2.1.3 Midtarsal Joint

The mid tarsal joint comprises articulations between the talus and navicular, and between the calcaneus and cuboid. This joint is not generally discussed in relation to the translation of transverse to frontal plane motion, but it should be mentioned here due to the degree of inter-relatedness it shares with the subtalar joint (Michaud 1997). Kidd (2000) describes this, pointing out that in closed kinetic chain, motion cannot occur at the subtalar joint with out effecting the midtarsal joint and vice versa.

2.2 Biomechanics

2.2.1 Lower Kinetic Chain Rotation.

Inman (1981) outlines the hypothesis that the human body will integrate a pattern of motion of the various segments such that energy expenditure is minimized. He demonstrates how each of these motion patterns acts to reduce the deviation of the center of mass away from the line of progression. Known as the determinants of gait these movement patterns include transverse plane rotations of the hip and lower limb and frontal plane rotations of the foot.

On average 4° of pelvic rotation, either side of a central axis is seen with gait of normal stride length and cadence and this has the effect of increasing stride length and reducing the rise and fall of the body center of mass with each stride. This rotation rather than being attenuated at the hip joint actually increases progressively from pelvis to femur to tibia, with the tibia rotating on average three times as much as the pelvis (see Figure 2-2).

The pattern of rotation involves the swing limb internally rotating from the beginning of swing phase and continuing after heel strike until about 15 – 20% of stance phase when the motion is reversed into external rotation which continues until toe off Inman, 1981).

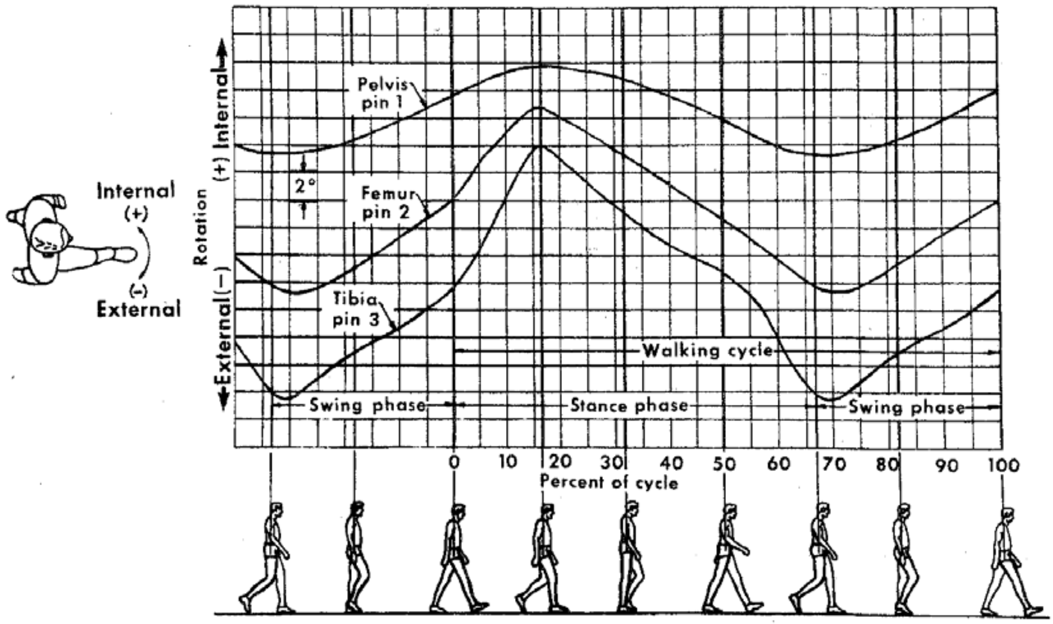


Figure 2-2Rotations of the pelvis, femur and tibia in the transverse plane. (Inman 1981)

2.2.2 Muscular Control of Subtalar Joint Pronation/Supination and Internal/External Leg Rotation.

Muscles have three functions;

i. Stabilize

ii. Accelerate

iii. Decelerate

(Root et al 1977)

These activities are achieved by synergistic and antagonistic cooperation of muscles (Grabowski, 2003). Due to the torque converting action of the subtalar joint pronatory/supinatory forces or motions in the foot are translated into internal/external forces or motions in the leg and vice versa as described in section 2.1.2. Thus the leg is internally rotating at heel strike, and continues to do so until the onset of mid-stance (Root 1977). According to Perry (1992), control is provided by tibialis posterior, tibialis anterior, flexor digitorum longus, flexor hallucis longus, and soleus in order of inverting leverage. Following this external rotation of the leg with re-supination of the subtalar joint is assisted by tibialis posterior, flexor digitorum longus, flexor hallucis longus, and soleus (Perry 1992).

2.2.3 Frontal Plane Rearfoot Motion during Stance Phase

According to Michaud(1997), while the leg undergoes an initial period of rapid internal rotation followed immediately by a more gradual period of external rotation, the subtalar joint remains maximally pronated until shortly before heel lift. Figure 2-3 shows the relation ship between the two motion patterns which suggest that there is a period during full foot contact when the tibia is continuing to rotate while the sub talar joint remains at a constant degree of pronation.

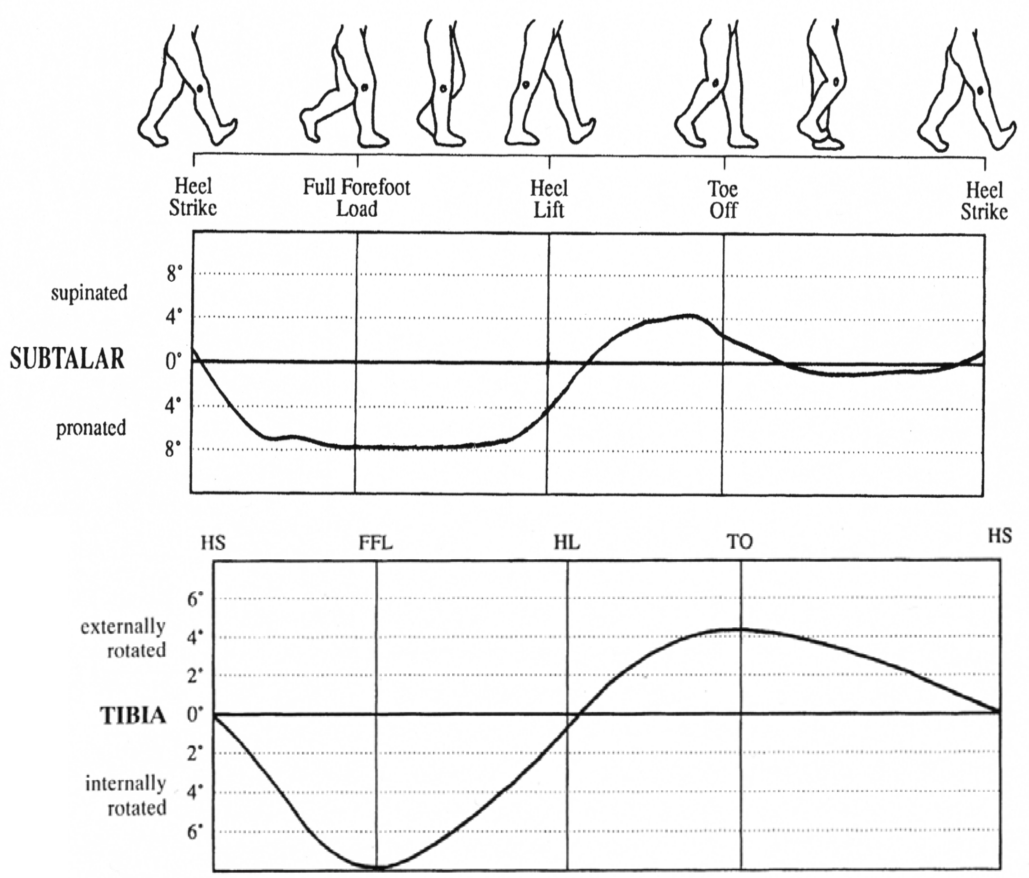


Figure 2-3 Comparison of frontal plane subtalar joint motion and transverse plane tibial rotation (Michaud, 1997)

2.2.4 Planal Dominance

The location of the subtalar joint axis has been shown by numerous authors (Green, Manter, Root, in Michaud, 1997) to vary considerably between individuals, ranging from 20° to 68.5° from the transverse plane and 4° to 47° from the sagital plane. Green (1984) and Michaud (1997) discuss the significance of this with respect to the ratio of transverse plane tibial rotation to frontal plane rotation of the foot permitted by the subtalar joint. Both authors suggest that an axis inclined more steeply than 45° in the sagital plane will result in increased tibial rotation relative to inversion/eversion, with the relationship being geometrically defined such that an axis angle inclined two-thirds of the way up from the transverse plane at 60° would result in twice as much transverse plane motion as frontal plane. Conversely, those with a subtalar joint axis inclined at less than 45° will have a higher ratio of frontal plane to transverse plane motion.

2.3 Video Gait Analysis

2.3.1 Historical

The era of photographic analysis of gait began in 1872 with American photographer, Eadweard Muybridge's successful attempt to demonstrate that a galloping horse has all four feet clear of the ground at once, thus winning a substantial bet for his employer. His equipment utilized electrical switches to activate sequentially, the shutters on a linear array of cameras, a technique he called *chronophotography* which he went on to apply to the study of human motion (Cavanagh, 1993).

2.3.2 Modern Techniques

The ever increasing speed and reducing price of micro processors, both in computers and in data capture equipment such as video cameras, has greatly simplified and speeded up the process of quantitating motion patterns. Video cameras now record data in digital format directly and as such, it can be easily down loaded to a computer for analysis. Software evolves rapidly and while some systems still require manual digitization of marker locations, some, such as APAS gait, (ARIEL dynamics Ltd) are able to undertake this automatically based on marker colour, size, and shape.

2.3.2.1 2 Dimensional (2D) versus 3 Dimensional (3D) Techniques

Video gait analysis may utilize a single camera to record motion parallel to the focal plane (2D analysis) or combine the data from two or more cameras to create a 3D digital model able to describe motion in any plane (Fuller, 1996). Curran (2005) outlines the major advantages and disadvantages of these systems pointing out that in general, 2D systems are simpler and faster to implement and considerably cheaper than 3D systems. They are however, more limited in the nature of the data that they can capture, in that the motion of interest must remain parallel to the camera focal plane. Despite this, 2D systems remain of more interest in the clinical setting and for most aspects of research (Curran, 2005).

2.4 Quintic Biomechanical Software

The Quintic Biomechanics software (Quintic consultancy limited) is marketed as a trackside, sports science performance analysis programme. It provides a suit of functions that permit detailed analysis and comparison of 2D digital video clips. Of particular interest within the context of kinesiology and of this study, is the ability to synchronise two video clips, and to then create spatially calibrated two-dimensional digital models of markers placed on the subject. This enables the generation of co-ordinates representing the marker locations on a frame-by-frame basis. These can subsequently be used to calculate distances and angles between the markers providing quantitative kinematic data (Quintic Tutorials, 2005). This software provides an attractive and cost effective clinical or research tool with an intuitive front end and Windows™ simplicity, enabling the basics of 2D video analysis to quickly and easily put into practice. To date however there has been little published research conducted using this software (searches on Pub Med and Google Scholar returned no relevant results).

2.5 Measurement of Tibial Rotation – The Tibial Pointer

Functional Foot Orthoses are widely used for the control of pathological motion in the foot during gait and in particular the control of excessive pronation. However much of the evidence supporting their use remains anecdotal (Landorf, 2000), a factor which is in part due to the difficulties of measuring foot motion inside the subjects shoe (Cornwall, 1995). The relationship between transverse plane tibial rotation and frontal plane rearfoot motion documented by many authors (Inman, 1976; Root 1977) provides a mechanism for remotely collecting data on foot function without resorting to modifications to the subject's footwear. Sutherland (1972), details techniques for quantitative motion analysis through the application of trigonometric theory to measurements collected from photographic images. Cornwall and McPoil (1995) adapted and applied these using the Tibial Pointer device (see **Error! Reference source not found.**) to provide a technique for 2D video analysis of tibial rotation. This permitted them to establish the ratio of tibial to rearfoot motion in subjects walking barefoot, and to then apply this to assess the degree of control provided by foot orthoses introduced into the subject shoes. Investigation was conducted into the reliability (Cornwall, 1995) and validity (Sawert, 1995) of the technique. Between trial Intra Class Correlation (ICC) Values were calculated for a number of parameters (see Table 2-1) with results ranging from 0.832 to 0.965 indicating good reliability.

Variable	ICC

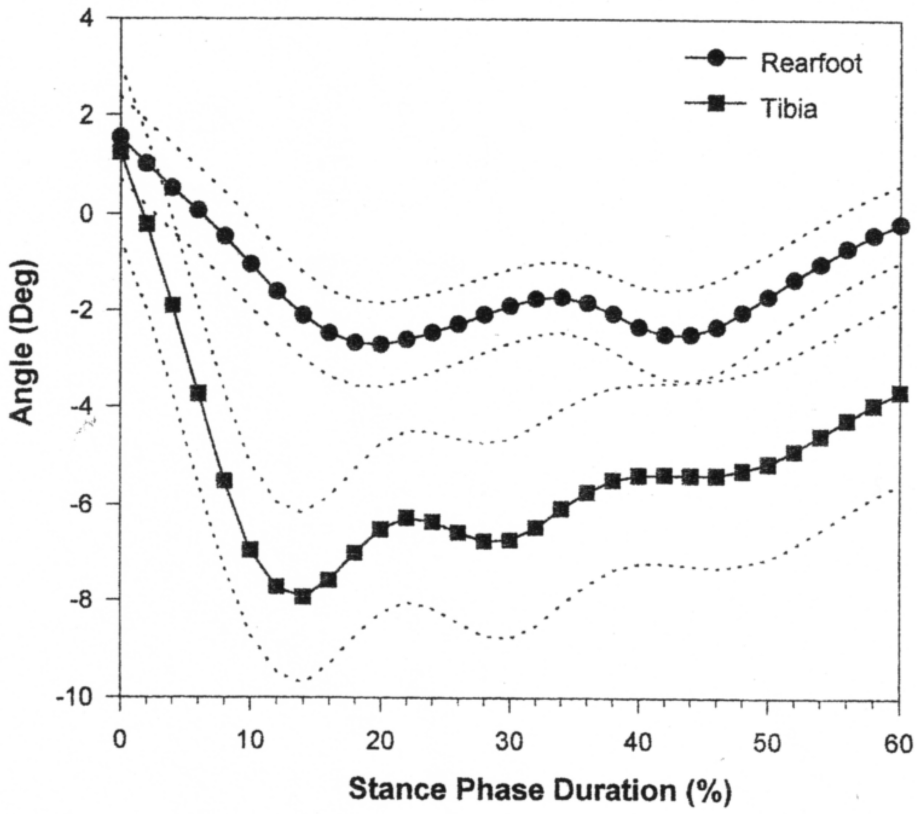
Tibial rotation angle at heel strike	0.936
Rearfoot angle at heel strike	0.916
Maximum internal rotation angle	0.919
Maximum rearfoot eversion angle	0.868
Time to maximum rearfoot angle	0.965
Time to maximum internal tibial rotation angle	0.832

Table 2-1 Between Trial ICC Values (Cornwall, 1995)

Validity of the technique was established through the comparison of results obtained via 2D and 3D analysis of video data collected using a four-camera set up. Peak performance automated analysis software (Peak Performance Technologies) was utilised to digitise the video data from all cameras for the tibial pointer markers and for additional markers required for 3D analysis. Apparent separations of the tibial pointer markers were then calculated and used to derive tibial rotation via 2D analysis. Three-dimensional co-ordinates were generated from the two-dimensional co-ordinates using software, (QLDT, Cardinal Software) and three dimensional tibial rotation values were obtained. The degree of association between the overall mean transverse tibial rotation movement patterns was investigated via Pearson's product moment correlation with $r=0.845$, indicating significant correlation.

In the second part of their initial study Cornwall et al (1995) attempted to demonstrate that the measurement of transverse plane tibial rotation through the tibial pointer device was sufficiently sensitive to detect alterations to frontal plane rearfoot motion induced through the wearing or absence of shoes, and through the introduction of orthotic devices. They found that maximum transverse tibial rotation is reduced compared with barefoot walking when shoes or orthotic devices are worn, as measured with the tibial pointer device.

Through this work Cornwall et al (1995) have shown the tibial pointer to be capable of producing repeatable and valid results, to be a practical method for investigating the in-shoe motion patterns of the foot during gait and to be sufficiently sensitive to detect the alteration in these motion patterns brought about by the introduction of orthoses.



Graph 2-1 Cornwall's (1995) overall time motion results averaged for all participants (note, in this instance –ve values have been chosen to denote internal rotation and eversion)

2.6 Influence of Treadmills and Treadmill design on Gait

The use of treadmills to conduct video gait analysis relies on the assumption that treadmill walking simulates over-ground walking sufficiently closely that experimental validity remains uncompromised. This was investigated by Lemke et al (1995), using 2D analysis of markers attached to the lower leg and calcaneus of subjects videoed while walking over-ground and on a treadmill to examine differences in rearfoot motion. They concluded that treadmill walking is similar but not identical to over-ground walking and considered that;

> *"If the clinician is primarily interested in the amplitude of tibial, calcaneal and rearfoot motion, a treadmill may be substituted for over-ground walking."*

Pierrynowski and Sajko (2005) argued that treadmill width will affect base of gait, with narrow treadmills leading to an increase in pronation/supination owing to a longer lever arm system and that, a hard surface will increase pronation/supination during weight acceptance because of a stiffer lever arm system. They compared narrow/hard (34.5cm wide) and wide/soft (50.5cm wide) treadmills utilizing 3D analysis to measure pronation/supination about each subjects estimated subtalar joint axis at three different walking speeds. Results indicated statistically different rearfoot kinematics between the two treadmill designs and the authors concluded that if clinical decisions depended on small rearfoot angular changes, then treadmill effects should be noted.

2.7 Assessment of Reliability

The tibial pointer and the Quintic Biomechanical video analysis software are measurement tools. Polgar (2000) states that measurement tools should have properties of reliability, validity, applicability, and practicability. The properties of applicability (how suitable the tool is) and practicability (how easy it is to use) can be assessed subjectively. The tibial pointer was designed to measure tibial rotation (therefore applicability is built in) in a more practical manner than the alternative, which in this case is the more expensive, and time consuming 3D analysis. The Quintic software was selected to compliment the tibial pointer, to provide a practical, applicable technique for measuring tibial rotation. This leaves the properties of reliability and validity, assessment of which is better undertaken by objective means. When assessing the validity of a technique the following equation is useful:

$$\text{Observed value} = \text{true value} \pm \text{error}$$

Thus for a completely valid technique the error will equal zero. The predicament comes however, in knowing the true value, against which to compare your observed value in order to ascertain the error (Polgar, 2000). Usually new techniques are measured against the current “gold standard” in order to assess their validity. In this instance, the “gold standard” would be 3D analysis of tibial rotation using equipment such as the Vicon motion analysis system (Oxford Metrics Ltd). This however was impracticable but some indication of the validity of the technique can be obtained through comparison with the findings of Cornwall et al (1995) whose techniques were validated against 3-dimensional analysis.

Reliability or reproducibility can relate to a number of different concepts. Intra-observer reliability is the consistency with which the same observer can reproduce the results on different occasions and inter-observer reliability concerns the consistency of results between two or more observers conducting the same test.

2.8 Summary

The literature reviewed above provides evidence to support the following statements:

- A relationship exists between transverse plane tibial rotation and frontal plane rearfoot motion.
- The tibial pointer has been demonstrated to be capable of measuring transverse plane tibial rotation with sufficient sensitivity to detect changes in rearfoot motion.
- 2D video analysis can provide valid and reliable results as measured against 3D video analysis when used to assess tibial rotation with a tibial pointer device or to assess rearfoot motion.
- Treadmills provide good simulation of over-ground walking when used to assess the amplitude of tibial, calcaneal or rearfoot motion.

2.9 Aims

2.9.1 Primary Aim

This study aims to investigate the reliability and suitability of the Quintic Biomechanical software when used to measure transverse plane tibial rotation with the tibial pointer device, and to measure frontal plane rearfoot motion.

2.9.2 Secondary Aim

The study will also investigate the relationship between transverse plane tibial rotation and frontal plane rearfoot motion.

2.10 Hypotheses

This study will test three hypotheses:

1. Analysis of tibial rotation utilising the tibial pointer and Quintic Biomechanical video analysis software demonstrates good test-retest reliability.

2. Analysis of rearfoot motion using Quintic Biomechanical video analysis software demonstrates good test-retest reliability.
3. Comparison of tibial rotation to rearfoot motion using the tibial pointer and Quintic Biomechanical software demonstrates a significant correlation.

The null hypotheses are:

1. Analysis of tibial rotation utilising the tibial pointer and Quintic Biomechanical video analysis software does not demonstrate good test-retest reliability.
2. Analysis of rearfoot motion using Quintic Biomechanical video analysis software does not demonstrate good test-retest reliability.
3. Comparison of tibial rotation to rearfoot motion using the tibial pointer and Quintic Biomechanical software does not demonstrate a significant correlation.

3 Method

3.1 Introduction

A convenience sample of ten podiatry students was selected. With the tibial pointer and rearfoot markings applied, participants were asked to walk for five minutes at 3km/h on a treadmill (Powerjog E10, belt width 0.43m) and following this simultaneous digital video was collected from the anterior and posterior facing cameras. A time reference marker (the switching on of a filming light) visible to both cameras was included to enable subsequent synchronisation of the video.

Using Quintic Biomechanical analysis software (Quintic Biomechanics V9.03a, Quintic Consultancy Ltd), the two video clips were then viewed simultaneously and synchronised. A sequence from the synchronised files, beginning two frames before heel strike and ending two frames after heel lift, was digitised. This enabled the generation of co-ordinates representing the position of each marker on the tibial pointer to be collected on a frame-by-frame basis. Data collected for the rearfoot was in the form of the angle from vertical to the tibia, and to the calcaneus at each frame. Processing of this data established the degree of tibial rotation and the rearfoot angle at each frame. Analysis of correlation of the two motion patterns was then conducted. The process was then repeated for each participant at a later date, enabling reliability of the system to be assessed.

3.2 Pilot Study

A series of rolling pilot studies were utilised to problem solve the various technical difficulties that arose and to test the resulting solutions. Initially it was hoped that a tibial pointer design could be developed that was viewable from the rear. This would allow a single camera approach to be employed, reducing further technical difficulties and associated sources of error inherent from the deployment of two cameras, and the synchronisation of their footage. Ultimately manufacturing difficulties curtailed this development and a two-camera set-up was adopted along with an adaptation of McPoil's original tibial pointer design. Alongside the development of the mechanical aspects of experimental design, investigation was conducted into the various software tools provided in the Quintic Biomechanics package and their merits regarding the required data generation.

3.2.1 Tibial Pointer Design

While initially appearing an attractive solution to the difficulties associated with two camera set-ups, the rear-facing tibial pointer was unable to provide sufficient amplification of tibial rotation, unless the arms were extended to such a degree that they interfered with contra lateral limb function. This was due to the attachment point being located on the opposite side of the rotational axis to the tips of the pointer. Designs were considered based on a semicircular strip of plastic extending around the lateral side of the limb only, but no method of manufacturing such a device was discovered with in the project time constraints.

Three variations of tibial pointer design were investigated, with differing arm lengths of 160mm, 100mm and 70mm respectively. Pointers with a long arm length provide good magnification of tibial rotation at the expense of increased vibration of the pointer and hence increased signal noise. A pointer with 100mm arms was adopted as this appeared significantly more stable than the 160mm version, and still gave good motion amplification. During the digitisation process, difficulty was occasionally encountered identifying the marker beads against similarly coloured backgrounds; shiny silver beads were found to be easily identifiable in all lighting conditions.

3.2.2 Software Tools

The Quintic biomechanics software package offers a number of tools for measuring angles, velocity, and acceleration in moving subjects. It has however, been designed primarily as a tool for analysing and enhancing performance in sporting activities rather than as an instrument of research. As such, there is not always a straightforward technique for extracting the requisite data and this proved to be the case with regards both measurement of the apparent separation of the tibial pointer markers, and the measurement of the rearfoot angle.

3.2.2.1 Tibial Rotation

In order to calculate the degree of internal or external rotation present in any video frame a measurement of the apparent separation of the markers on the tibial pointer is required and two possible techniques were considered. Once the video file has been calibrated so that on screen measurements relate to real-world distances, measurement of the horizontal separation of the pointer markers is possible by constructing vertical lines through the markers and then tracing a horizontal line between them (see Figure 3-1). This technique could be utilised to obtain snapshots of maximum internal or external rotation, but would be susceptible to random errors induced by vibration of the pointer and inaccurate onscreen measurement. Conversely the adopted technique involving digitisation of the marker position for each frame from heel strike to heel lift provides a detailed picture of the entire motion pattern. The digitisation process produces co-ordinates for the on screen location of the markers from which the apparent separation can be derived. This technique also allows for some reduction of the effect of random errors through the technique of data smoothing.

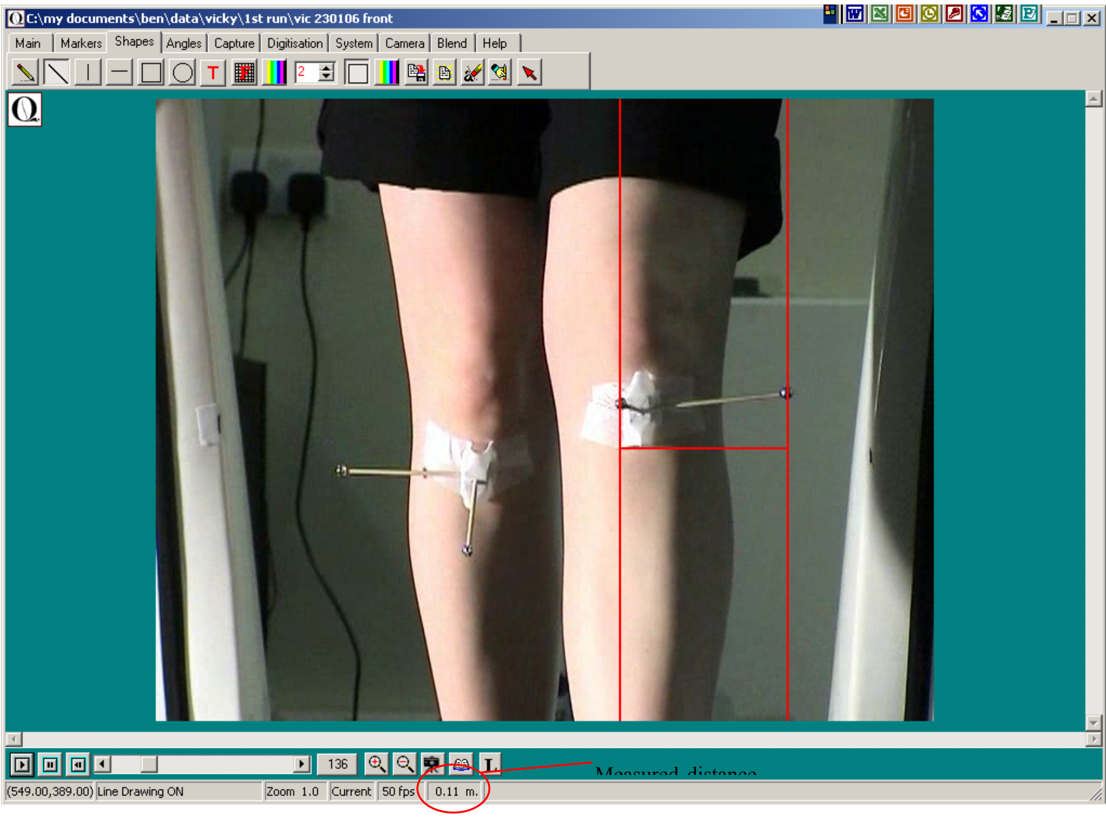


Figure 3-1 onscreen measurement of apparent separation

3.2.2.2 Rearfoot Angle

Measurement of the rearfoot angle proved to be far more problematic than measurement of tibial rotation. Initially techniques utilising the angles function were investigated (see Figure 3-2). This involved clicking on three points on the image to generate two lines, the angle between which is automatically calculated. However, with this technique the central point is located on that portion of the Tendo Achilles proximal to its calcaneal insertion, which bowstrings with frontal plane calcaneal motion. As such, the locating of the point becomes very subjective as the operator attempts to extrapolate two straight lines to their intersection.

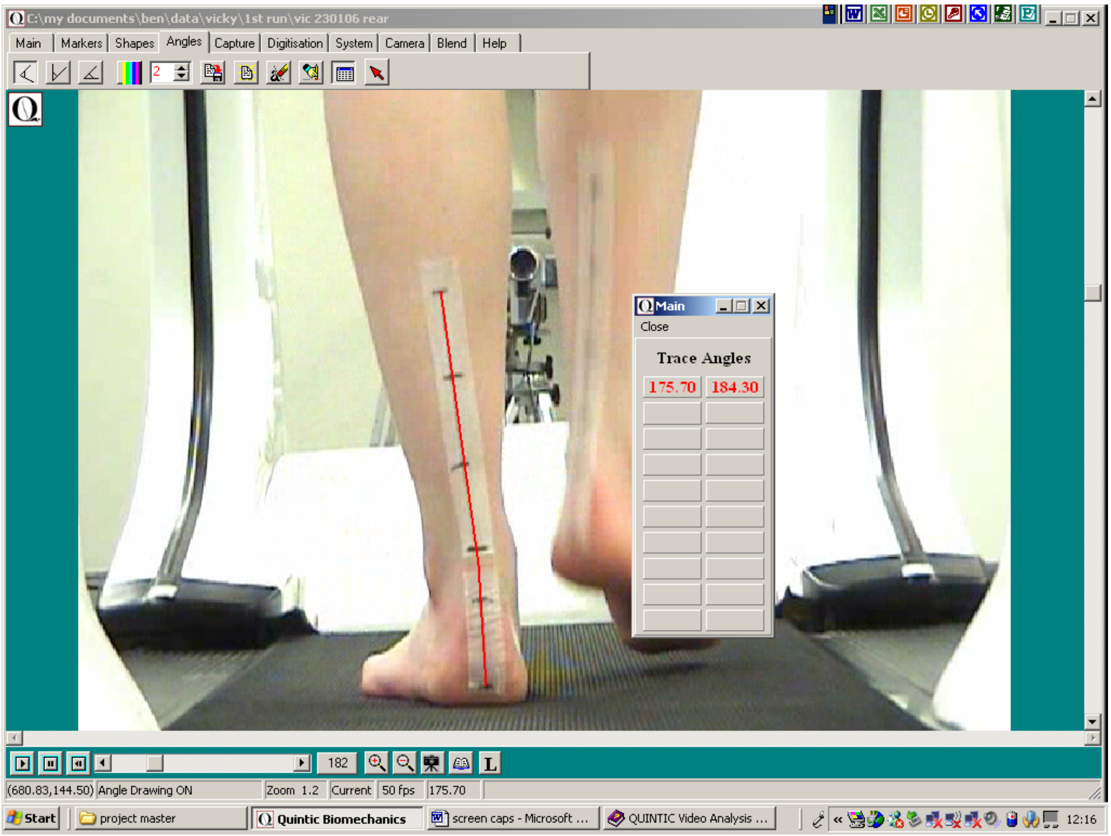


Figure 3-2 The Angles Function used to measure Rearfoot Angle

3.2.3 Synchronisation

This apparently simple task proved surprisingly difficult and was never solved satisfactorily. The camera records at a rate of 50 frames per second (fps) so the time lapse between frames is 0.02 seconds. However, the duration for which information is actually recorded for each frame is a function of the shutter speed, and as this is a component of exposure it is probably varied with light intensity but will lie in the range of 1/100th to 1/1000th of a second. The problem is to have a discrete event that is noticeably recorded on a single frame only, but on both cameras simultaneously. Initially a camera flash fired at the subject from the side where it would be visible to both cameras was tried. This was completely unsuccessful as camera flash has duration of between 1/10,000th and 1/30,000th of a second (Howes, 1997) and thus failed to record in any frames at all. The switching on of a filming light that was finally adopted worked because the change in light intensity took place over several frames enabling synchronisation to be achieved by looking for the first frame in which a change in light intensity took place. Other approaches included setting a shorter focal length on the lens, so that heel strike could be viewed from both cameras, but this reduced magnification of the markers making digitisation difficult and inaccurate. Moving a hand through both camera fields of view was partially successful but tended to affect the gait of the subject and was less reliable than the filming light.

3.2.4 Data Smoothing.

Examination of the initial results during the Pilot Study revealed that data from the tibial pointer relating to tibial rotation was affected by noise, as a consequence of vibration of the pointer device and errors introduced during digitisation. Low pass filters are a form of digital filter employed when high frequency interference or noise needs to be separated from the underlying low frequency signal (Robertson 2004). These filters can be very sophisticated and complex but the simplest form was adopted here, the moving average filter, in order to reduce the effects of unwanted noise. Moving average filters take the average over several input values, the least of which would be three, one either side of the value in question. Three versions were trailed, 3-point, 5-point, and 2 x 3-point (2 passes of the three point filter). The results for one subject are displayed in Graph 4-13 and the 5-point filter was subsequently applied to all data.

3.3 Sample Selection

Ten subjects were selected on a convenience basis, the only exclusion criteria being injury or surgery in the preceding year, recovery from which might lead to changes in gait pattern between the two sampling sessions. No assessment of foot function, mobility or deformity was undertaken since the purpose of the trial was to test reliability across the range of foot types that would be encountered in the normal population. A detail sheet containing age, sex, history of trauma, surgery or congenital deformity and treadmill experience, was completed for each subject.

3.4 Tibial Pointer

The tibial pointers consist of ethylene vinyl acetate (EVA) foam cubes (sides 1cm) with two wooden rods set at 90° to each other (see Figure 3-7). Silver plastic beads set on each rod at 100mm from the apex provide makers for digitisation. The silver beads proved to be visible in varying light conditions and didn't become lost against the background, a problem encountered with white beads.

Double-sided sticky foam pads and strips of mefix were used to attach the pointer to the tibial tuberosity, such that one arm pointed directly forward and the second was directed laterally. The laterally projecting arm provided the distance reference for video file calibration.

3.5 Rearfoot Markings

With the subject lying in the prone position, strips of mefix were applied to the posterior of the calcaneus and to the lower third of the lower leg. A 50mm bar bisecting the calcaneus and a 150mm bar bisecting the lower ⅓ of the leg were then drawn onto the mefix and these provided both the markers for digitisation and for video file calibration (see Figure 3-3).

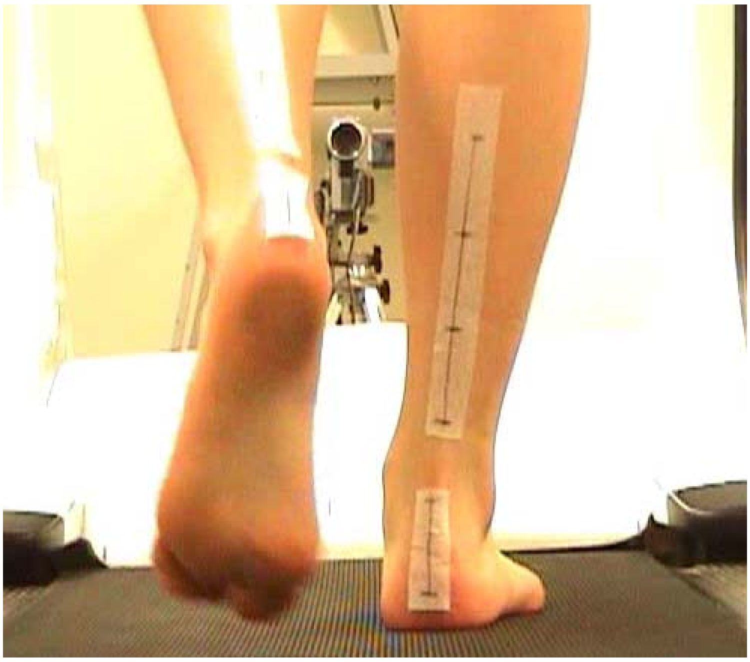


Figure 3-3 Rearfoot Markings

3.6 Camera Positions and Set-up

Two digital video cameras were used one filming the tibial pointer and one the rearfoot markings.

The anterior camera (Sony Handycam DCR-PC120E), filming the tibial pointer was set centrally 3m from the subject with the optical axis 0.41m above the level of the walking platform. The posterior camera (Sony Handycam DCR-HC30E) was set 2.5m centrally from the subject with an optical axis height 0.13m above the walking platform. The sports programme mode was selected as this gives the fastest shutter speed, and focus was set to auto-focus as this greatly speeded-up set-up and always gave good results. Both cameras were set in the sagittal plane relative to the subject, and levelled prior to filming. The lens focal length adjusted to frame markers placed on the running machine to give consistent magnification and perspective. Positions for both cameras and the treadmill were marked on the ground in order to ensure between trial consistency. Markers were also placed on the handrails of the treadmill to standardise the subject position. The posterior camera was connected directly to the computer (Sony VIOS), via a firewire cable allowing direct control of the camera from with in the Quintic Biomechanics software and storage of the data-stream directly in the computer. The anterior camera was independent of the computer and video data was recorded onto cassette.

3.7 Quintic Software Setup

Little set-up of the software was necessary except for adjustment of the video capture settings to ensure maximum quality. These were set to those suggested for maximum image quality by Quintic Consultancy (see Figure 3-4) (Quintic Tutorials, 2005).

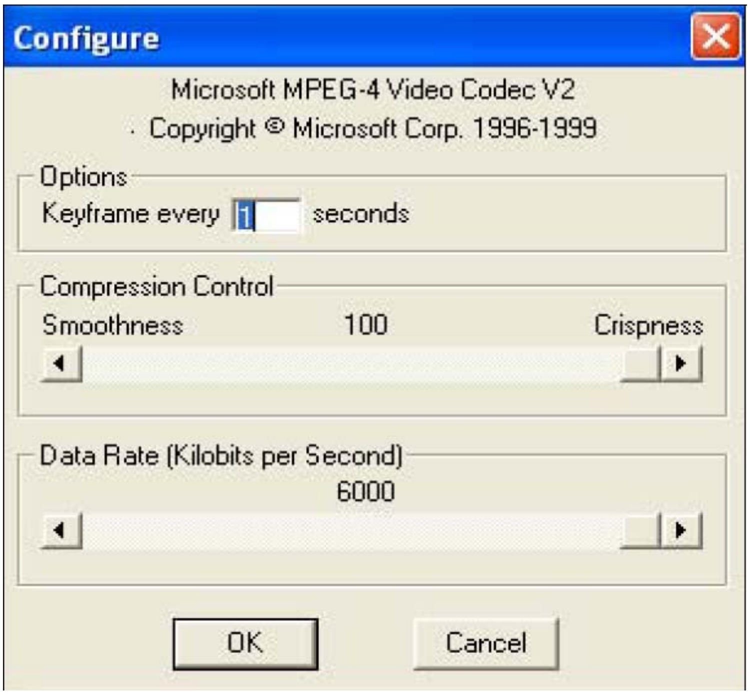


Figure 3-4 Video Capture Settings

3.8 Filming Procedure

With all markings and equipment in position, the subject was asked to begin walking at 3km/h. A period of five minutes was allowed for the subject to relax into a normal gait pattern and at the end of this time both video cameras were switched on. With both cameras running, a filming light was switched on to provide a time reference point visible on both cameras to allow subsequent synchronisation of the video clips. Approximately 15seconds of video were collected representing around 10 full gait cycles.

Following filming, video from the posterior camera was replayed, checked for quality, focus, visibility of the synchronisation marker and any unnecessary frames from the start or finished were clipped out. The file was then compressed and stored in "Avi" format by the Quintic software. The anterior camera was subsequently connected to the computer, the video data downloaded and the same procedure followed as for the posterior camera. On a subsequent date, the procedure was repeated for each subject.

3.9 Digitisation

Digitisation of the markers on the tibial pointer and the rearfoot, generated numerical data in the form of co-ordinates, which permitted the calculation of the rotational position of the tibia and the rearfoot angle for each frame. Each pair of video clips was opened simultaneously, one in the Main window and one in the Best window. The synchronisation marker (point at which the filming light was switched on) was located in each clip and the two clips were synchronised. A suitable stride was then identified from the synchronised clips and frame numbers relating to heel strike and heel lift were noted. Criteria considered when selecting a stride were;

1) Visibility of reference markers. (Not obscured by contralateral limb and adequately lit)
2) Visual assessment of the stride as typical, i.e. no evidence of direction change due to balance or other abnormal motion pattern.

Each file was then opened in turn, calibrated for distance, and digitised using the appropriate template.

3.9.1 Calibration

Calibration provides information on how distances measured on the screen relate to actual distance on the subject (Quintic Tutorials 2005). It requires that a line be traced on the screen along a maker of known length in the plane of motion; the length of the marker is then entered.

For the anterior video files the lateral arm of the tibial pointer (length 100mm) was used. To do this a frame was selected where the pointer arm could be seen to be truly perpendicular to the camera in order to avoid parallax errors, and the "calibrate horizontal line only" option was selected. With this option, the calibration coefficient used for the horizontal axis is also used for the vertical axis and since all measurements taken are primarily in the horizontal plane this is the most relevant and accurate calibration technique.

For the posterior video files the 150mm line marked along the lower ⅓ was utilised, using the "calibrate vertical line only" option. Since the heel is moving towards the camera during the course of the stride, a frame was picked mid-stride to minimise perspective errors.

3.9.2 Model Templates

Templates define the number of points that will be digitised in each frame and how the points are linked together.

For the anterior files two unlinked points per frame were digitised, representing the two markers on the tibial pointer (see Figure 3-5).

For the posterior files, four points were digitised; 1 and 2 were linked representing the top and bottom of the line bisecting the tibia, and 3 and 4 were linked representing the top and bottom of the line bisecting the calcaneus (see Figure 3-6).

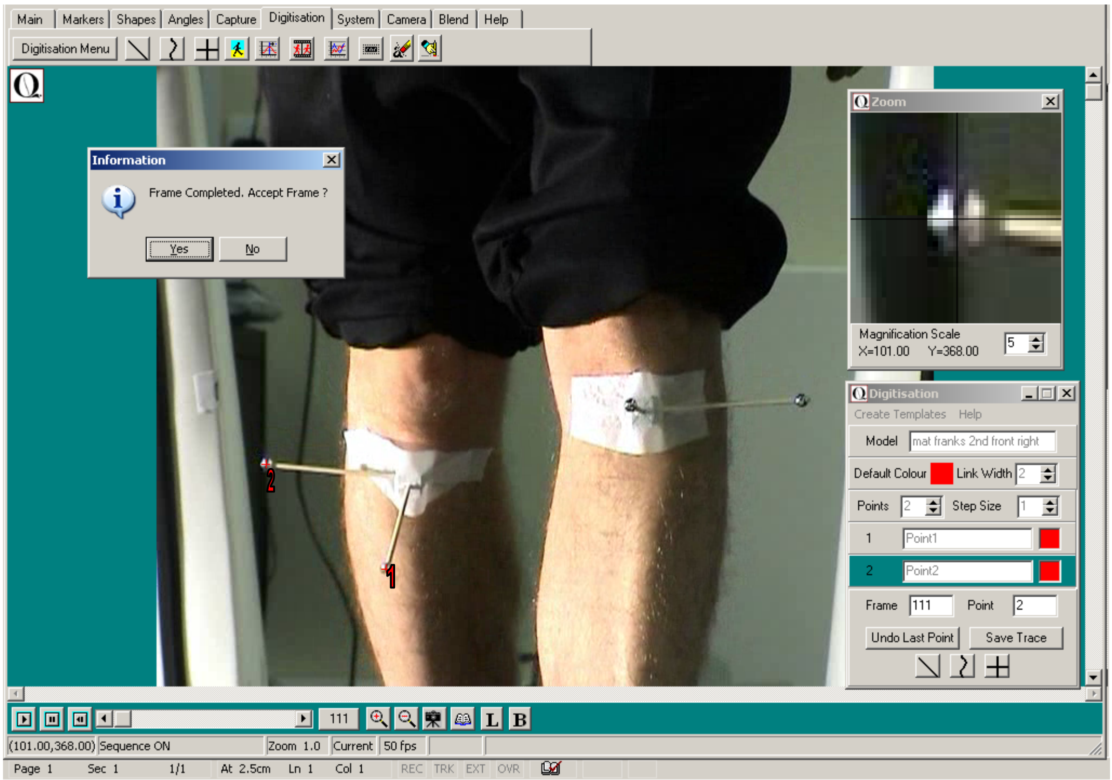


Figure 3-5 Quintic window showing digitisation of tibial pointer.

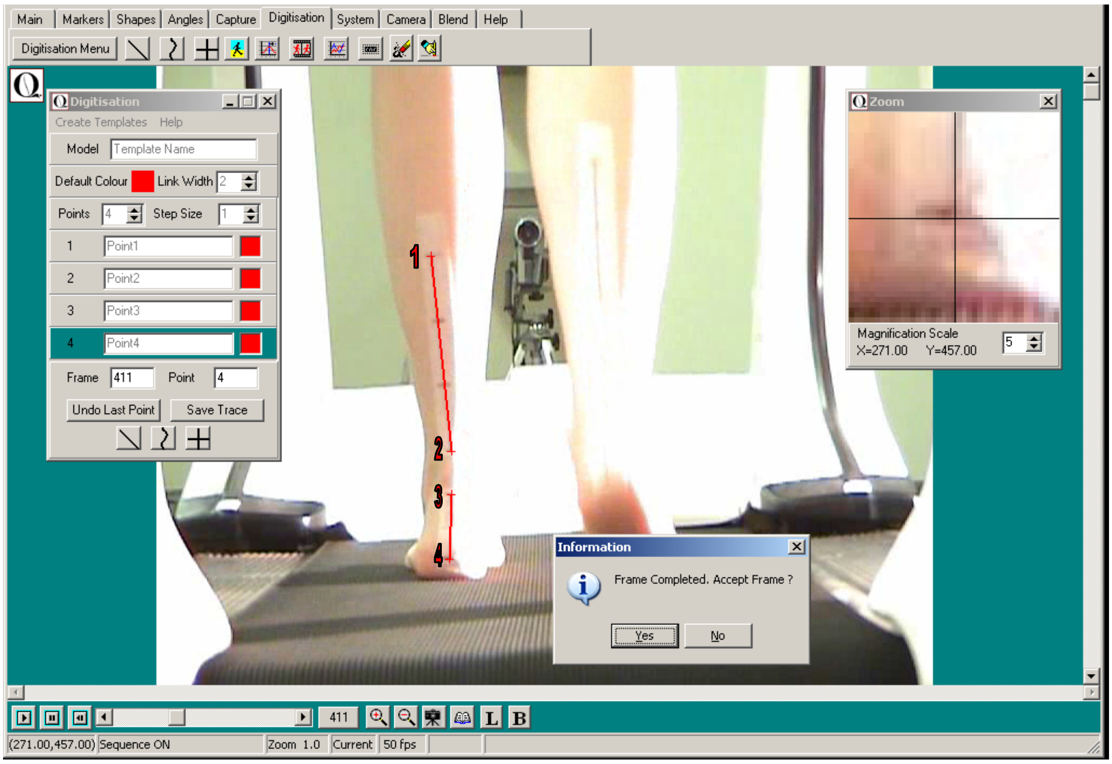


Figure 3-6 Quintic window showing digitisation of rearfoot markings.

3.9.3 Digitisation and Data Output

Each file was digitised from at least two frames before heel strike to two frames after heel lift. For the anterior files data was outputted as an excel file containing co-ordinates for points 1 and 2 for each frame. For the posterior files the Quintic software was used to calculate the angle from vertical for the tibial marker, line 1 to 2 and for the calcaneal marker, line 3 to 4. These were outputted as two excel files, one for tibial angle and one for calcaneal angle.

3.10 Data processing

Since all output files from Quintic were in excel format, no manual data entry was required, eliminating this key source of errors. All data processing was conducted in excel (see Figure 3-9) to produce tibial rotation and rearfoot angle. A moving average filter was then applied to reduce the effect of noise due to digitisation errors and vibration of the tibial pointer. Finally, analysis of tibial rotation to rearfoot motion and of intrarater reliability was conducted (see

Figure 3-10)

3.10.1 Calculation of Tibial Rotation

Tibial rotation was calculated in four stages;

1. Calculation of the calibration coefficient
2. Calculation of the apparent distance between the markers on the tibial pointer.
3. Trigonometric calculation of tibial rotation.
4. Moving average data smoothing.

The calibration coefficient C_{coef}**,** is derived:

$$C_{coef} = \frac{L \times 1000}{(X_1 - X_2)}$$

Where:

L (in metres) is the measured length of the calibration marker entered during calibration of the video file.

$X_1 - X_2$ Is the difference between the X Co-ordinate for either end of the calibration marker.

The apparent distance D_{app} is derived:

$$D_{app} = (X_{l\arg er} - X_{smaller}) \times C_{coef}$$

Where:

$X_{l\arg er}$ and $X_{smaller}$ are which ever is larger or smaller of the X coordinate from points 1 and 2 on the tibial pointer (this is determined by whether a left or right leg has been selected).

C_{coef} is as derived above.

The tibial rotation is derived:

$$45 - Cos^{-1}\left(\frac{D_{app}}{D_{act}}\right)$$

Where:

D_{app} is as derived above.

D_{act} is the actual distance between the two markers on the tibial pointer (141mm)

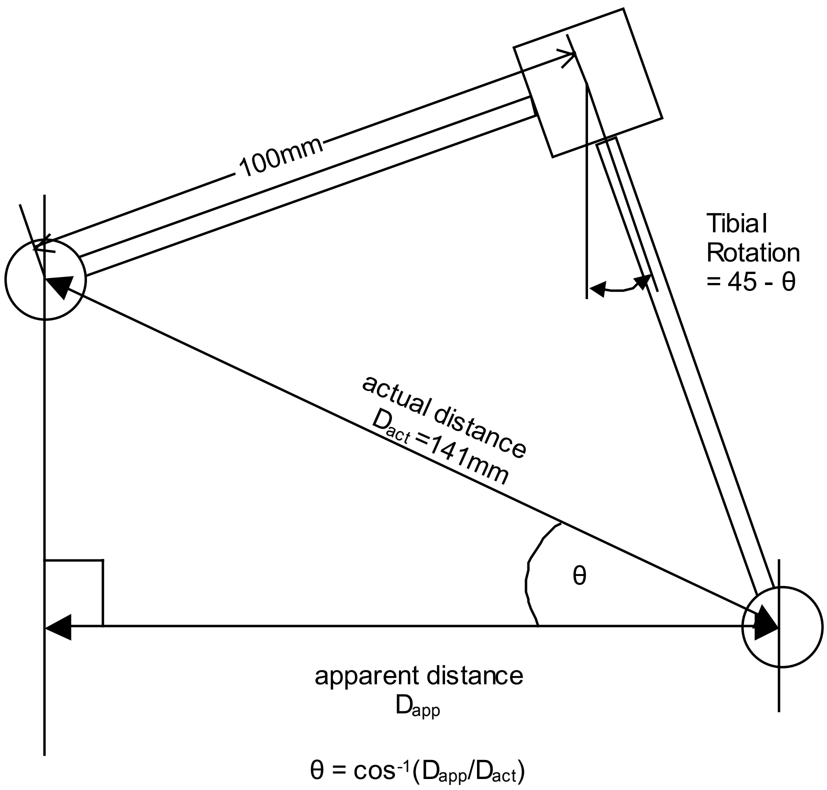


Figure 3-7 superior view of pointer showing basis of trigonometric calculations

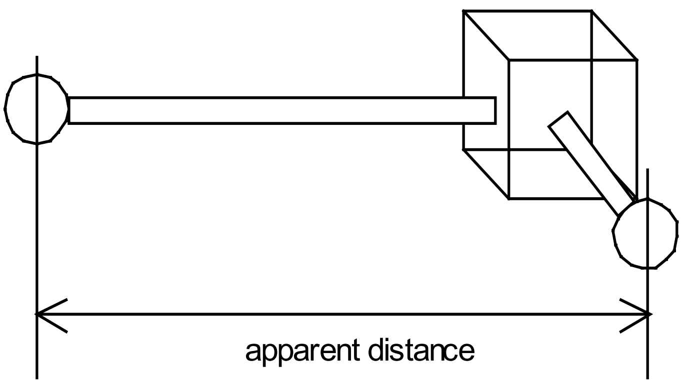
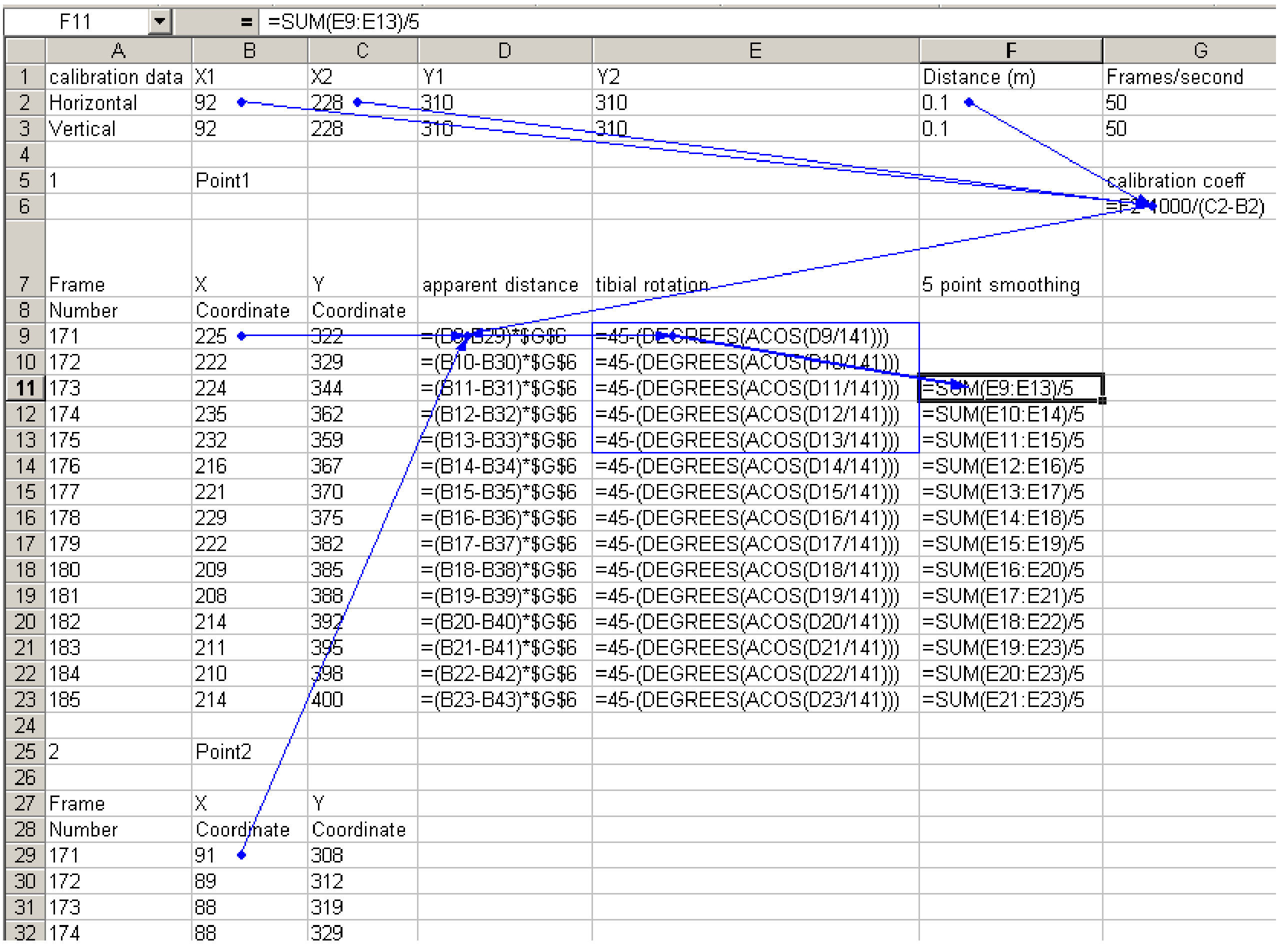


Figure 3-8 Anterior view showing apparent distance as viewed by the camera



F11	=	=SUM(E9:E13)/5					
	A	B	C	D	E	F	G
1	calibration data	X1	X2	Y1	Y2	Distance (m)	Frames/second
2	Horizontal	92	228	310	310	0.1	50
3	Vertical	92	228	310	310	0.1	50
4							
5	1	Point1					calibration coeff
6							=F2*1000/(C2-B2)
7	Frame	X	Y	apparent distance	tibial rotation	5 point smoothing	
8	Number	Coordinate	Coordinate				
9	171	225	322	=(B9-B29)*G6	=45-(DEGREES(ACOS(D9/141)))		
10	172	222	329	=(B10-B30)*G6	=45-(DEGREES(ACOS(D10/141)))		
11	173	224	344	=(B11-B31)*G6	=45-(DEGREES(ACOS(D11/141)))	=SUM(E9:E13)/5	
12	174	235	362	=(B12-B32)*G6	=45-(DEGREES(ACOS(D12/141)))	=SUM(E10:E14)/5	
13	175	232	359	=(B13-B33)*G6	=45-(DEGREES(ACOS(D13/141)))	=SUM(E11:E15)/5	
14	176	216	367	=(B14-B34)*G6	=45-(DEGREES(ACOS(D14/141)))	=SUM(E12:E16)/5	
15	177	221	370	=(B15-B35)*G6	=45-(DEGREES(ACOS(D15/141)))	=SUM(E13:E17)/5	
16	178	229	375	=(B16-B36)*G6	=45-(DEGREES(ACOS(D16/141)))	=SUM(E14:E18)/5	
17	179	222	382	=(B17-B37)*G6	=45-(DEGREES(ACOS(D17/141)))	=SUM(E15:E19)/5	
18	180	209	385	=(B18-B38)*G6	=45-(DEGREES(ACOS(D18/141)))	=SUM(E16:E20)/5	
19	181	208	388	=(B19-B39)*G6	=45-(DEGREES(ACOS(D19/141)))	=SUM(E17:E21)/5	
20	182	214	392	=(B20-B40)*G6	=45-(DEGREES(ACOS(D20/141)))	=SUM(E18:E22)/5	
21	183	211	395	=(B21-B41)*G6	=45-(DEGREES(ACOS(D21/141)))	=SUM(E19:E23)/5	
22	184	210	398	=(B22-B42)*G6	=45-(DEGREES(ACOS(D22/141)))	=SUM(E20:E23)/5	
23	185	214	400	=(B23-B43)*G6	=45-(DEGREES(ACOS(D23/141)))	=SUM(E21:E23)/5	
24							
25	2	Point2					
26							
27	Frame	X	Y				
28	Number	Coordinate	Coordinate				
29	171	91	308				
30	172	89	312				
31	173	88	319				
32	174	88	329				

Figure 3-9 Microsoft Excel worksheet showing data flow for calculation of tibial rotation.

3.10.2 Calculation of Rearfoot Angle

The excel files containing tibial and calcaneal angles were combined and the rearfoot angle derived:

Rearfoot angle = calcaneal angle – tibial angle.

Dependent on the motion pattern present in each case Quintic reported either acute or obtuse angles. Consequently, it was sometimes necessary to subtract 360° from the results in order to maintain consistency.

3.10.3 Data Smoothing

A five point moving average filter was applied to both anterior and posterior data, this takes the form:

$$y(n) = \frac{[x(n-2) + x(n-1) + x(n) + x(n+1) + x(n+2)]}{5}$$

Where:

y is the averaged value

x is the original value

n is the frame at *X*

3.11 Data Analysis

3.11.1 Intra-Observer Reliability

Analysis of intra observer reliability was conducted by calculating Intraclass Correlation Coefficients (ICC's) using SPSS. ICC's are more appropriate than Pearson's *r* or Spearman's *rho* when investigating trial repeatability because they take into account the linear relationship of the two data sets as well as the variance. This can be seen by analysing the relationships $x = y$ and $x = 10y$. Pearson's will return a value of 1 for both relationships where as the ICC's are 1.0 and 0.198 respectively. This is more meaningful as a test of repeatability since $x = y$ represents the ideal relationship between the two data sets, while $x = 10y$ could be regarded as a poor result. In effect, ICC's approximate what would be the average value of Pearson's *r*, for all combinations of the pairs of data that make up the data set. If the two data sets are identical a value of 1 will be returned, but with increasing variance between the pairs of data this value trends to zero (Lowry, 2006).

NB. It is meaningless to average correlation coefficients, as the value of the correlation coefficient is not a linear function of the magnitude of the relation between the variables. Thus, the average of the correlation coefficients does not represent the average correlation for all the subjects (StatSoft, 2006). However, the square of the correlation coefficient is linear and so provides a true indication of the magnitude of correlation but no indication of the direction of correlation (-ve or +ve). Usefully this value may be quoted as a percentage of maximum possible correlation.

3.11.2 Tibial Rotation to Rearfoot Motion Correlation

As the data is non-parametric, Spearman's rank correlation coefficient, a non parametric alternative to Pearson's product moment correlation, was used to analyse the degree of correlation between transverse plane tibial rotation and frontal plane rearfoot motion (.Petrie A, 2005)

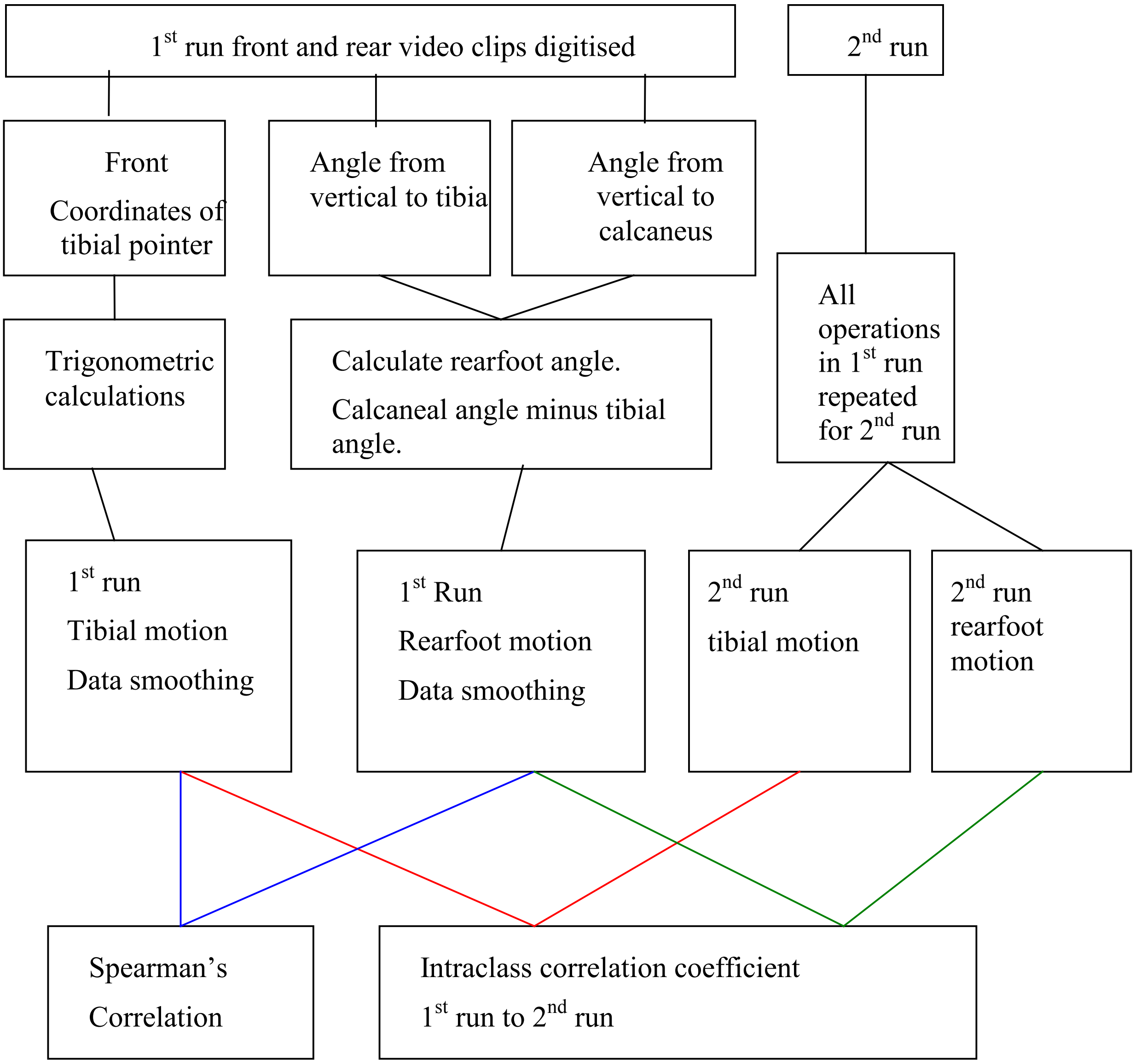


Figure 3-10 Data Processing Pathway

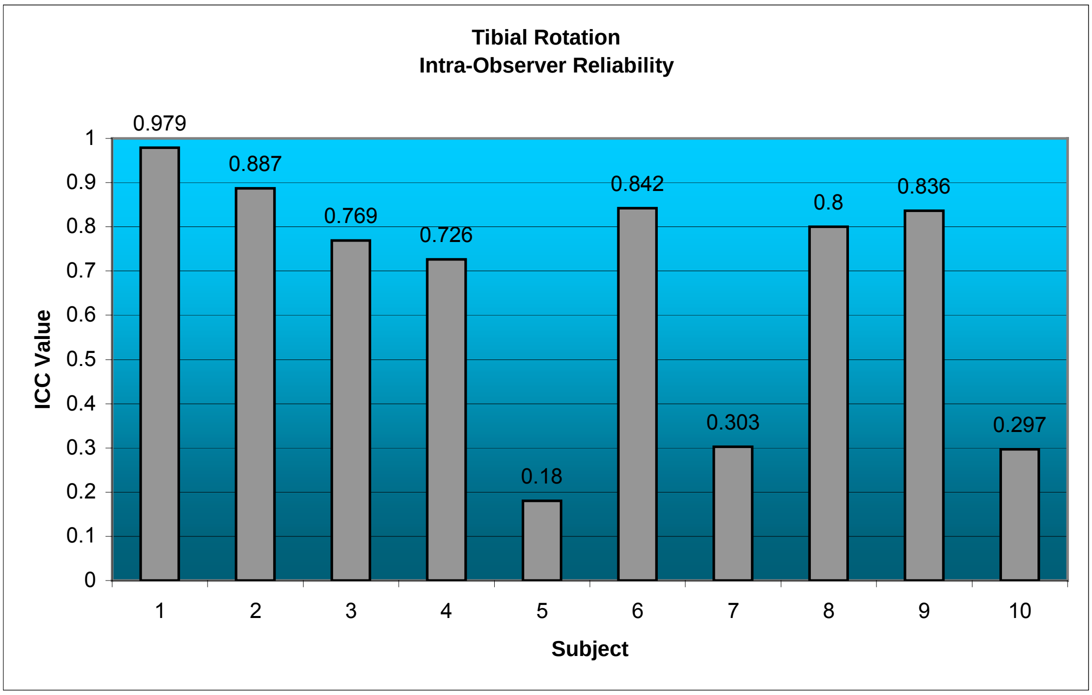
4 Results

4.1 Sample Demographics

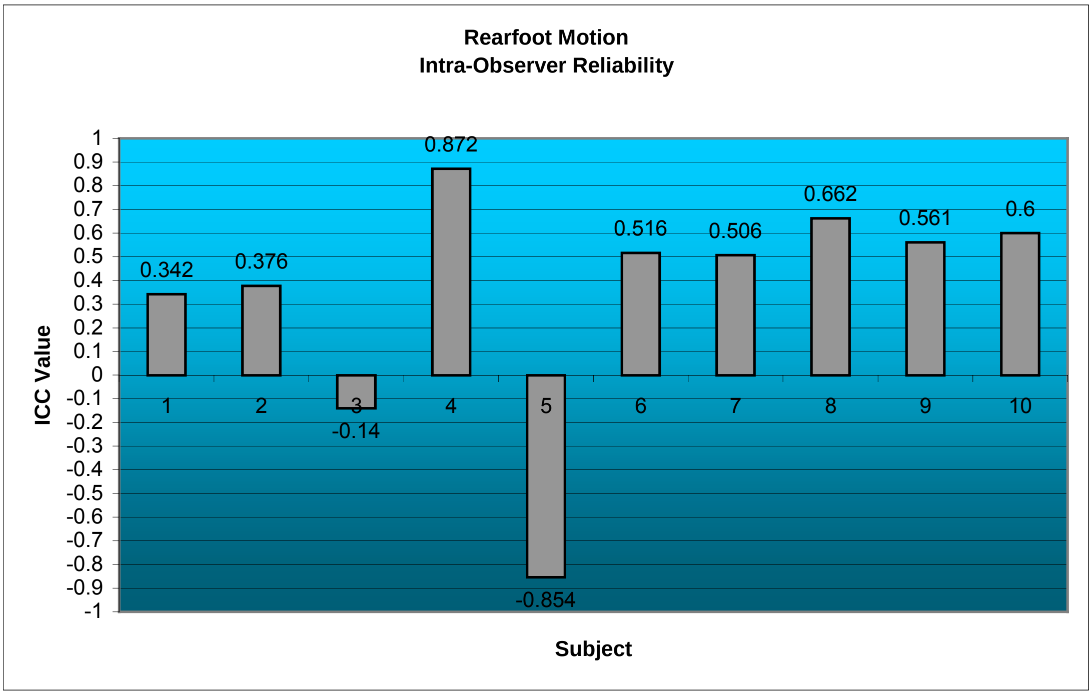
The sample of 10 comprised 3 men 7 women ages ranging from 19 to 41 (mean 27 SD 9). Two subject reported congenital conditions (subject 8 clubfoot & ligamentous laxity, subject 9 internally rotated hips), and one reported trauma and surgery (subject 3 broken right leg, pinned more than three years ago). Three subjects reported that they currently, regularly use treadmills (subjects 5, 6 and 8).

4.2 Intraobserver Reliability

The ICC values for Intra observer reliability are presented in Graph 4-1 for tibial rotation and Graph 4-2 for rearfoot motion.



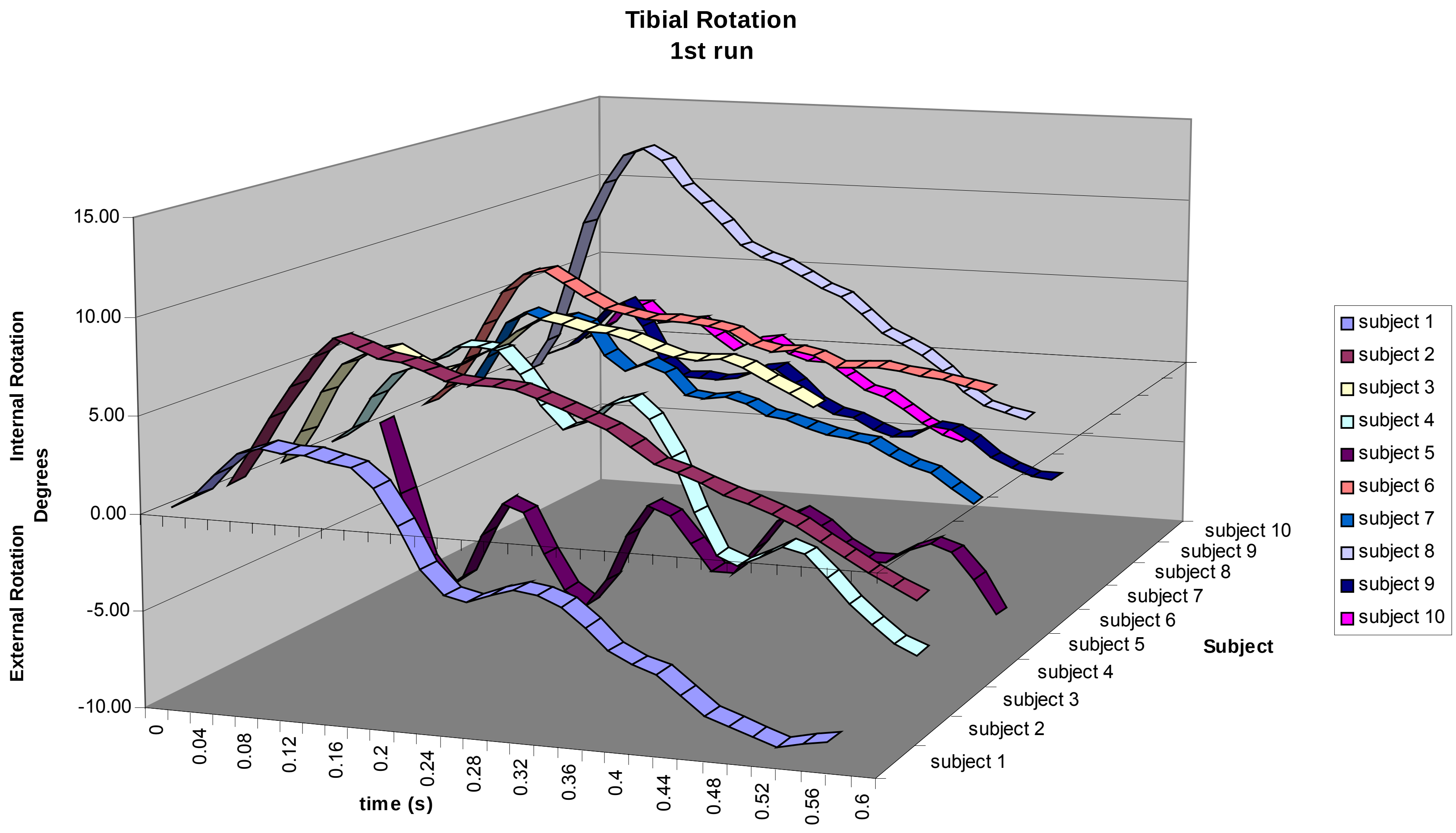
Graph 4-1 Tibial rotation ICC values



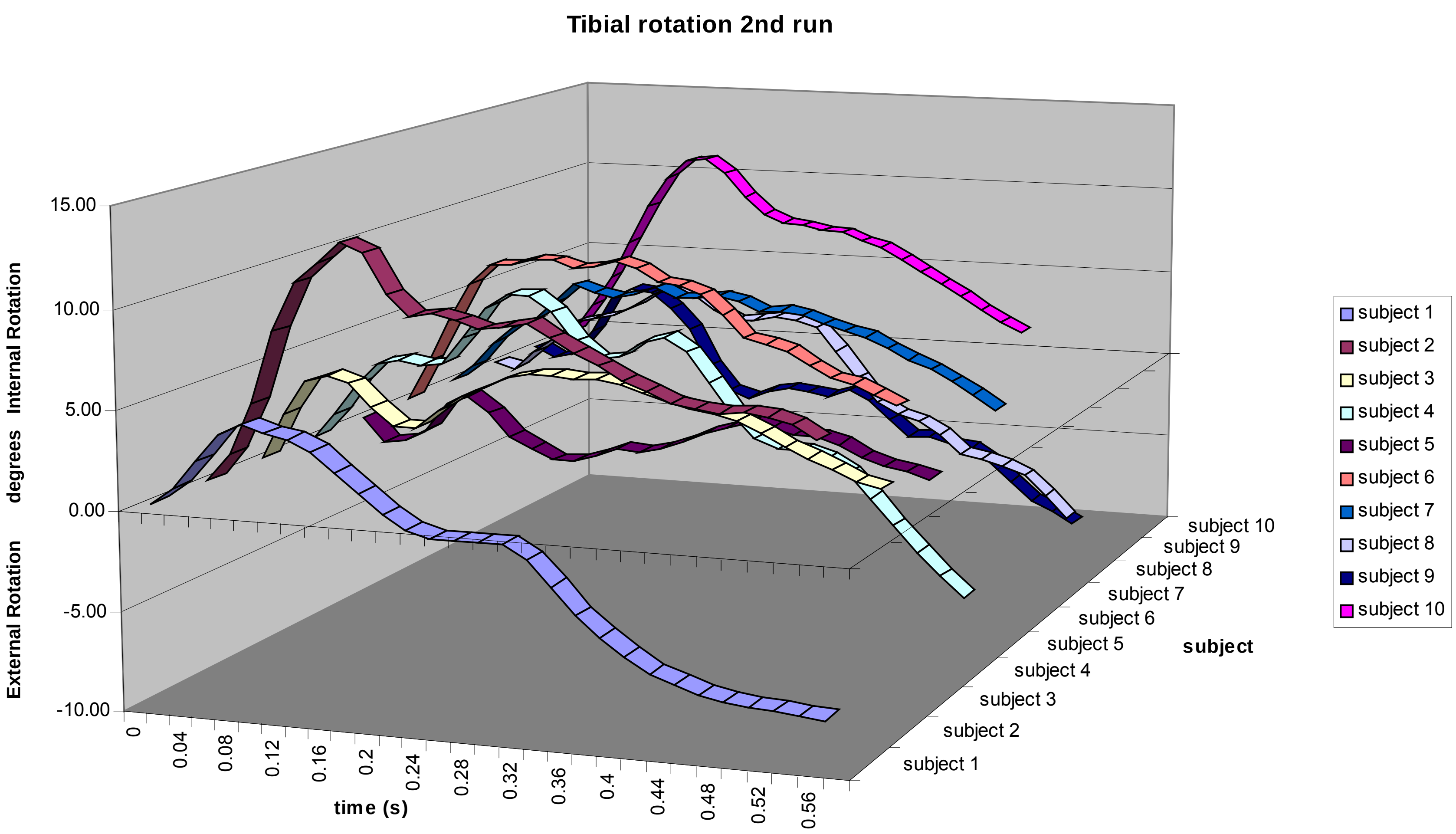
Graph 4-2 Rearfoot Motion ICC Values

4.3 Motion Patterns

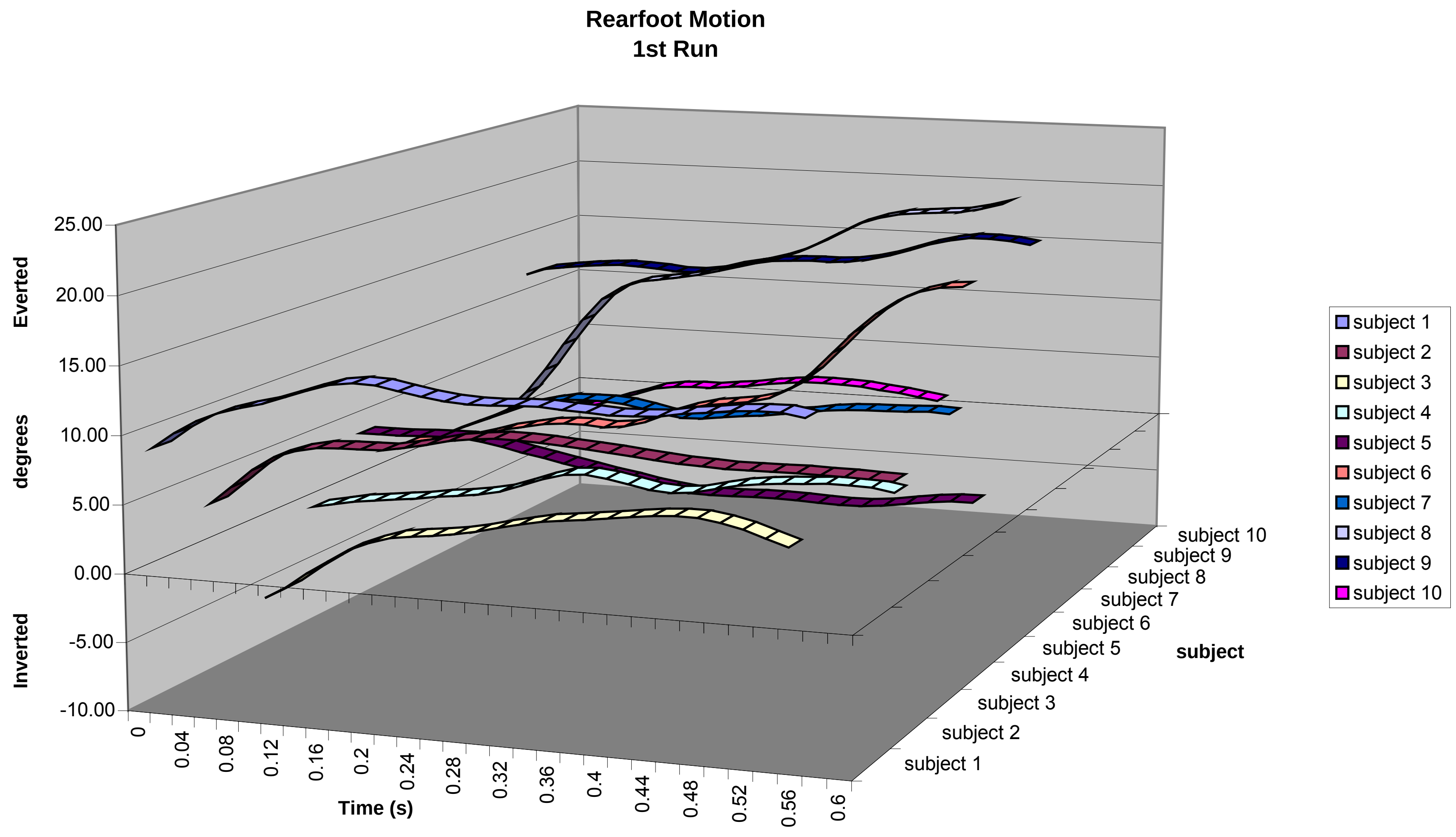
After application of the moving average filter, a good impression of tibial rotation was gained and can be seen in Graph 4-3 and Graph 4-4. Graph 4-5 and Graph 4-6 show the motion patterns for the rearfoot on the 1st and 2nd runs respectively.



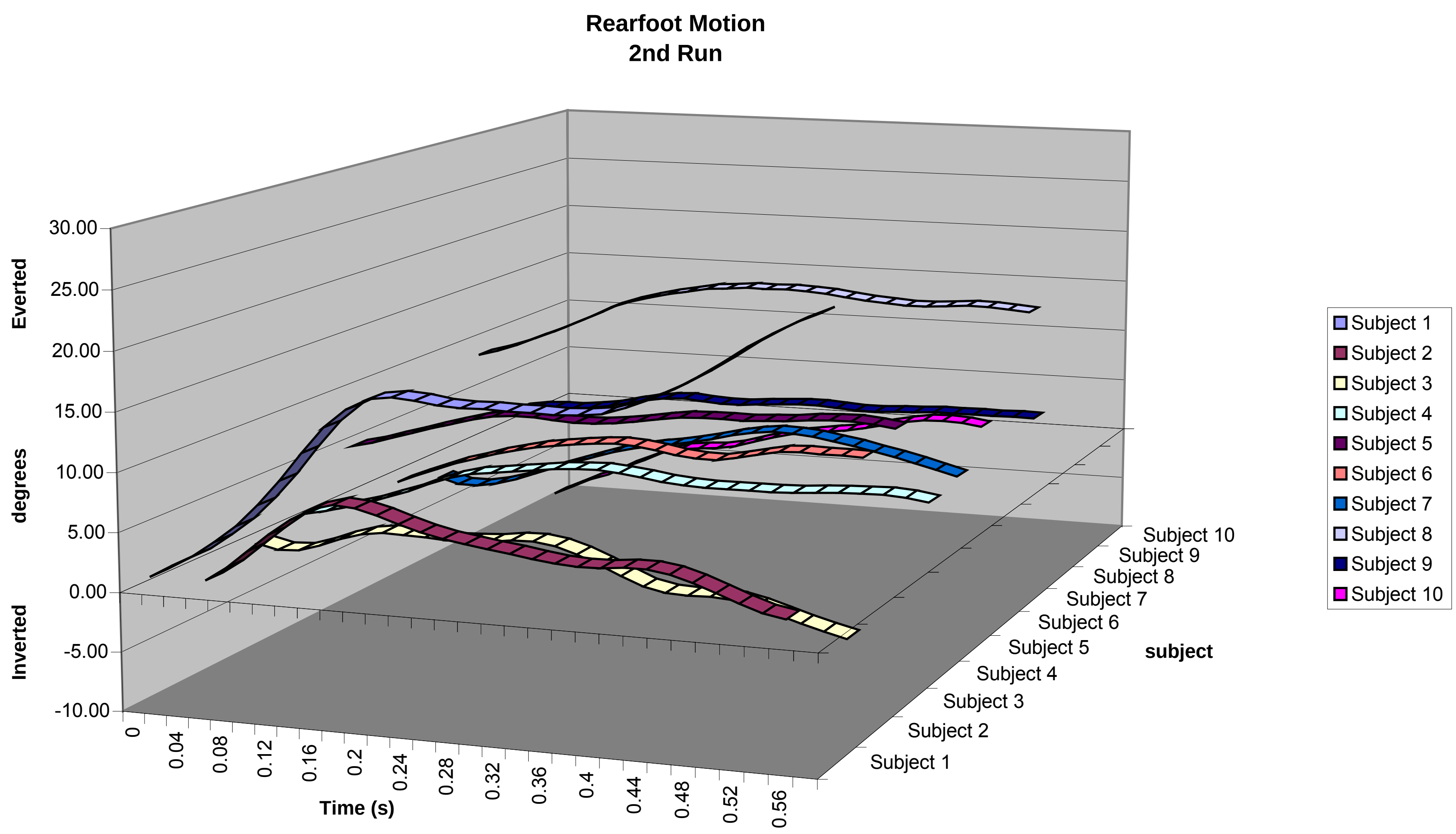
Graph 4-3 Tibial Rotation 1st Run



Graph 4-4 Tibial Rotation 2nd Run



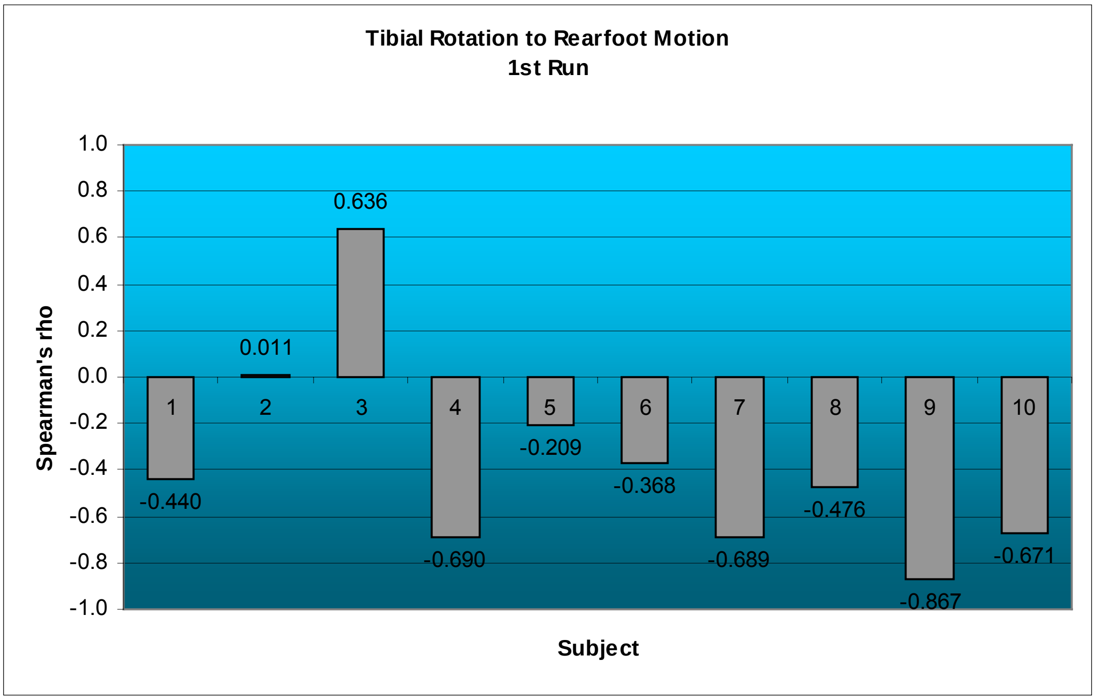
Graph 4-5 Rearfoot Motion 1st Run



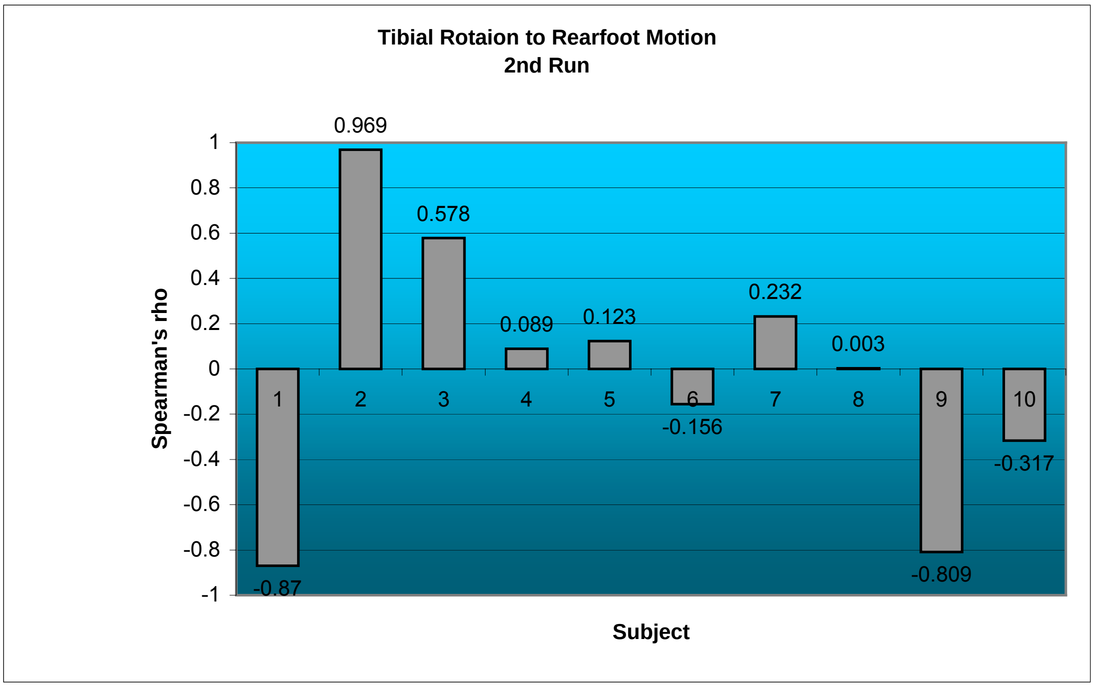
Graph 4-6 rearfoot motion

4.4 Tibial Rotation to Rearfoot Motion Correlation.

The values of Spearman's rho calculated for tibial rotation with rearfoot motion for the 1st and 2nd runs are presented in Graph 4-7 and Graph 4-8.



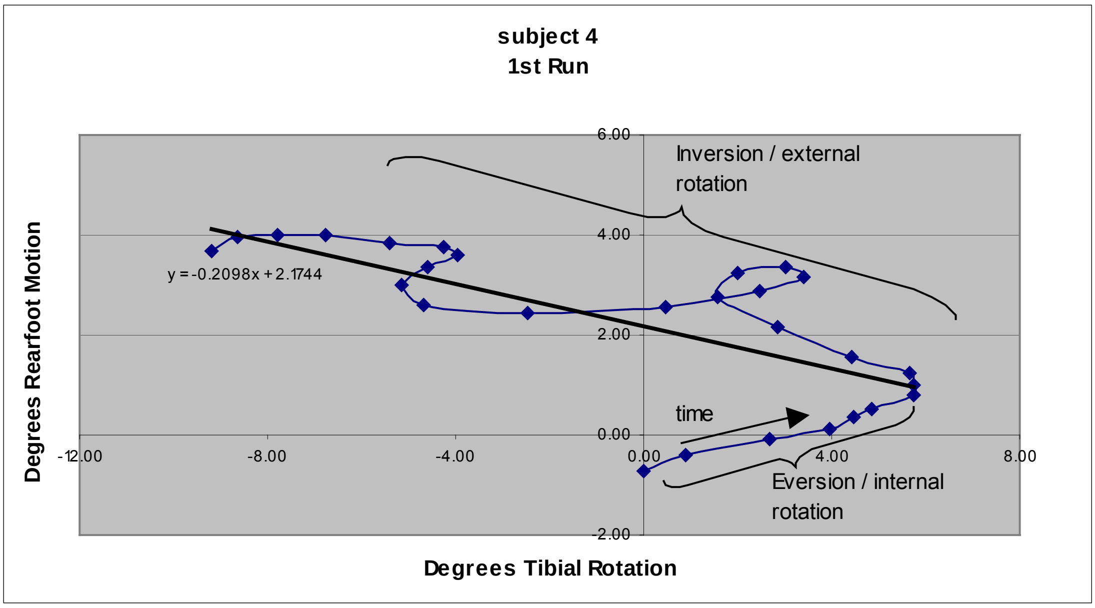
Graph 4-7 Tibial Rotation to Rearfoot Motion Correlation.



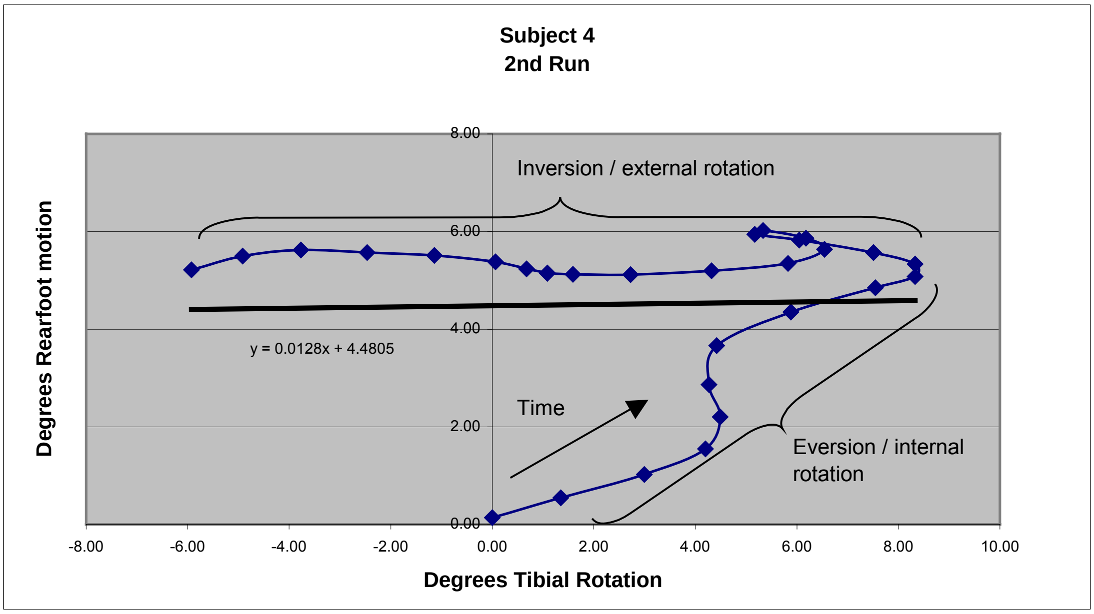
Graph 4-8 Tibial Rotation to Rearfoot Motion Correlation.

4.5 Scatter plots of Tibial Rotation with Rearfoot Motion

Scatter-plots of tibial rotation with rearfoot motion for subject 4 are provided to illustrate the non-linearity of the relationship. Subject 4 showed good between trial reliability for both tibial rotation and rearfoot motion. The linear trend-line fitted to these graphs illustrates the line of best fit (regression line) about which variance of the data is calculated in order to generate values for Spearman's rho. The slope of this line determines whether the value returned is positive or negative. Comparison of the two graphs shows how the duration of the initial period of internal rotation affects this slope.



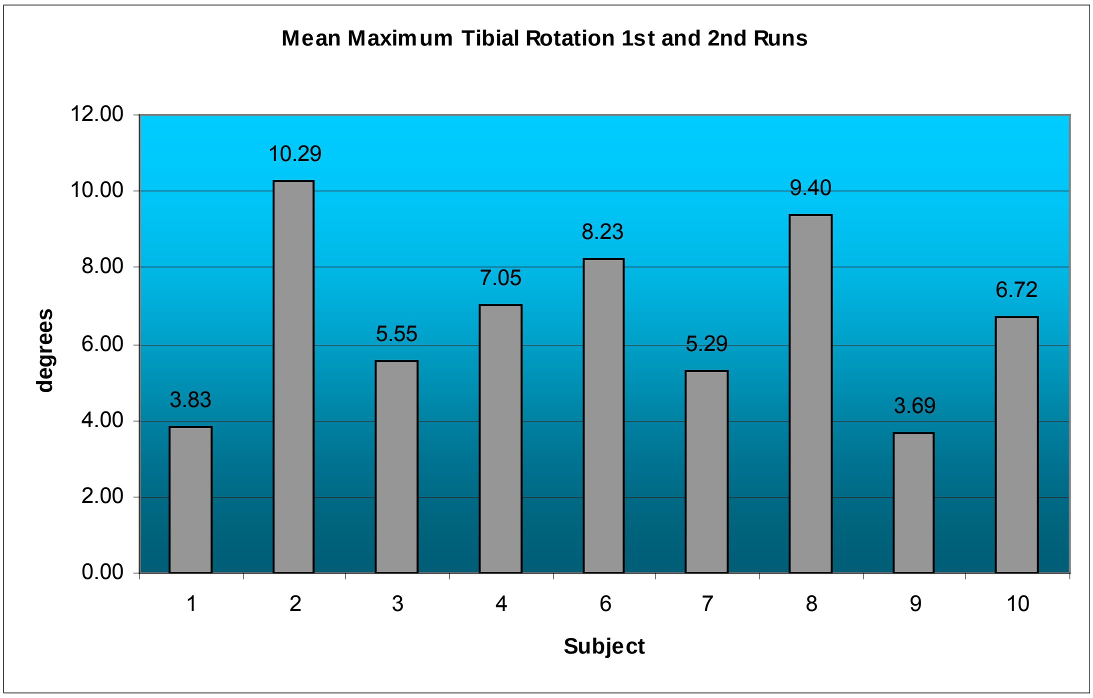
Graph 4-9 Example of the non-linear relation ship between tibial and rearfoot motion.



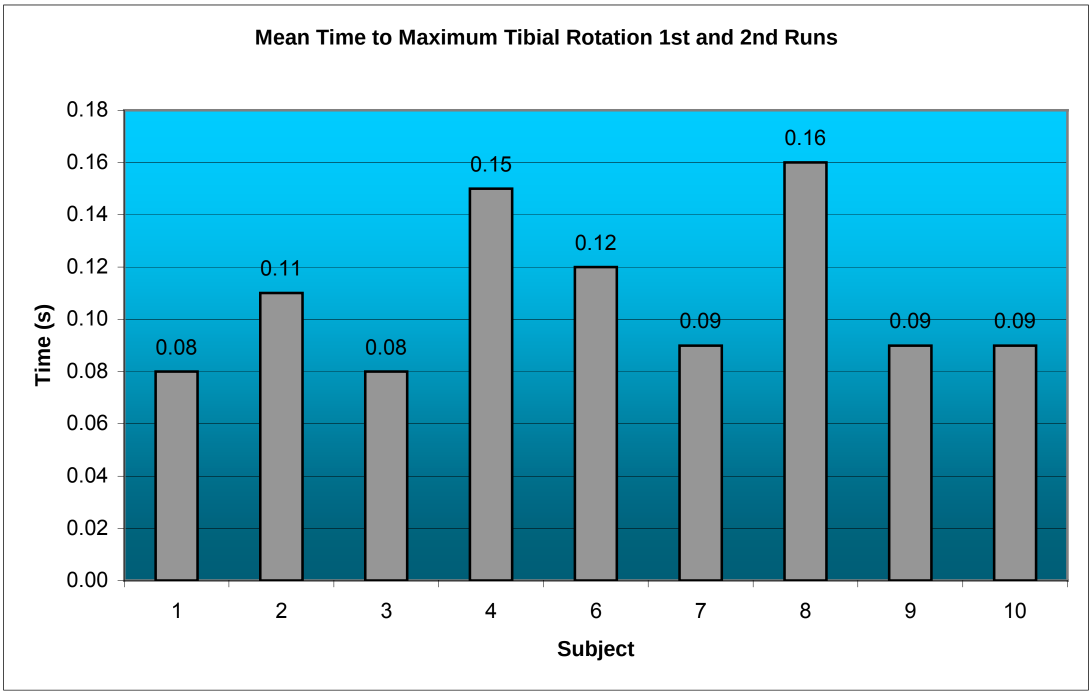
Graph 4-10 As above but showing how the regression line changes with an increased period of internal rotation.

4.6 Time to Maximum Tibial Rotation

The mean maximum internal tibial rotation for both runs by subject is presented in Graph 4-11 and the mean time to maximum internal rotation in Graph 4-12. Where the subject displays two peaks for internal rotation (Subject 3,6 and 7), the first peak has been recorded as being a better indicator of the end of the shock absorption phase of stance. Subject 5 did not display a conventional motion pattern and this measurement could not be recorded in this case.



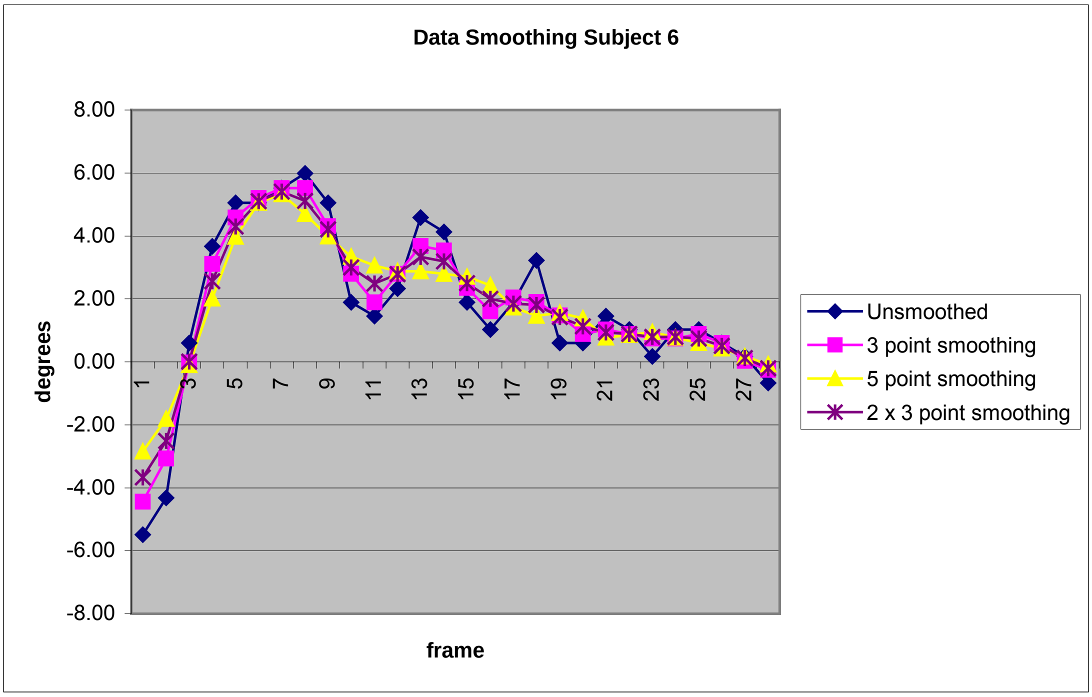
Graph 4-11 Mean Maximum Tibial Rotation



Graph 4-12 Mean Time to Maximum Rotation.

4.7 Data Smoothing

A graph comparing the product of the different moving average filters considered is included to demonstrate the effect of this technique on the data.



Graph 4-13 Comparison of moving average filters.

5 Discussion

The primary aim of this study was to assess the reliability of Quintic Biomechanical Software, when used to measure transverse plane tibial rotation using the tibial pointer device and when used to measure frontal plane rearfoot motion. The results suggest good between trial reliability for measurement of tibial rotation using the tibial pointer, and the null hypothesis that, analysis of tibial rotation utilising the tibial pointer and Quintic Biomechanical video analysis software does not demonstrate good test-retest reliability, was rejected. The results of analysis of between trial reliability for measurement of rearfoot motion were less consistent and the null hypothesis that, analysis of rearfoot motion using Quintic Biomechanical video analysis software does not demonstrate good test-retest reliability, is accepted. However, it is considered that this inconsistency is primarily attributable to specific problems associated with marking the rearfoot and that this could be addressed in future trials. The secondary aim of investigating the relation ship between transverse plane tibial rotation and frontal plane rearfoot motion produced very inconsistent results and the third null hypothesis that, comparison of tibial rotation to rearfoot motion using the tibial pointer and Quintic Biomechanical software does not demonstrate a significant correlation, was also accepted. This inconsistency is considered also partially attributable to rearfoot marking errors, and partially due to factors associated with analysing non-linear data using Spearman's *rho.*

5.1 Detail Sheet

None of the participants reported conditions that were likely to induce a consistent change between the trials, such as an injury from which they were recovering. One participant (subject 8) reported that she had ligamentous laxity, a condition that might have led to inconsistent change between trials. In the event, between trial ICC values for this subject showed good consistency.

5.2 Between Trial Reliability for Measurement of Tibial Rotation

Visual analysis of graphs of tibial rotation against time showed good agreement for most subjects with the exception of subjects five and ten. The ICC values supported this observation returning values greater than 7 for seven of the subjects while subjects 5, 7, and 10 returned values of three or less. The data from subject 5 suggested an unusual pattern of tibial rotation for both trials. No errors could be found in the data, and the pattern can be seen in the raw data and indeed when viewing the video clip and so it is likely that this subject actually does have an unusual gait pattern. Subject 10 was observed (when reviewing the video clips) to alter gait pattern between trials, narrowing the base of gait to the point that on the second trial it was difficult to digitise the rearfoot markers due to their being obscured by the opposite limb. No visual reason could be attributed to the discrepancy between trials for subject 7 but analysis of the graph of tibial motion reveals that the tibia remains internally rotated much longer into midstance on the second run than on the first.

5.3 Between Trial Reliability for Measurement of Rearfoot Angle.

Between trial agreements was visibly less for rearfoot motion with discrepancies of both magnitude and slope (of the motion time curve) being evident. Discrepancies of magnitude are likely to be due to inconsistent application of rearfoot markings while inconsistencies in the slope may be due to actual fluctuations in the motion pattern. Only a single stride was analysed per subject and so inconsistency due to fluctuation in gait pattern is to be expected. Results that are more consistent would probably be obtained by averaging three or more strides per subject. Exceptionally inconsistent results were obtained for subject 5 with an ICC of **–8.5** indicating that values were increasing in one trial while decreasing in the other a fact that is confirmed by the graph (Appendix 9.1).

5.3.1 Rearfoot Marking Technique

The technique for marking the centre of the calcaneus and tibia showed marked inconsistency between the trials. In the absence of suitable bony landmarks on which to site markers the procedure becomes subjective and variance in marker positioning was visible on the video files. With hindsight the solution to this, and that that was adopted by Cornwall (1995), is to measure the subjects resting calcaneal stance position as determined by the markers placed for the trial. Rearfoot motion can then be calculated relative to this, thus eliminating errors due to inconsistent marking. A simple and repeatable technique for achieving this to get the subjects to stand in a relaxed position on a sheet of paper on the stationary treadmill. A short video clip can then be collected and the position of their feet traced on to the paper enabling them to be accurately repositioned on the second trial. The rearfoot angle for resting calcaneal stance can be calculated via digitisation of the video clip and subtracted from the subsequent rearfoot angle recordings.

5.4 Analysis of Correlation between Transverse Plane Tibial Rotation and Frontal Plane Rearfoot Motion.

The results of Spearman's rank correlation coefficients for rearfoot motion with tibial rotation, showed a high degree of variation between the subjects. This is to be expected given the inconsistency in the results for between trial reliability for rearfoot motion. However, even those subjects returning ICC values of 5 or above for both tibial and rearfoot motion (subject 4,6,8,and 9) returned generally inconsistent values for spearman's *rho* for the two trials. Visual analysis of the time/ motion graphs for these subjects suggests that this inconsistency should not be a high as the Spearman's values would indicate. Although a non-parametric test, spearman's still requires that the two data sets are related in a linear fashion and plotting tibial against rearfoot motion (Graph 4-9) demonstrates that this is not the case. Comparing this with Graph 4-10, shows how the regression line (line of best fit) alters from negative to positive between the 1st and 2nd runs as the duration of the initial period of internal rotation increases.

Assessing correlation between variables related in a non-linear fashion is not straightforward; essentially, there are three options available.

- Transform the data to obtain a linear plot, for instance by plotting the log of one or both of the variables.
- Identify the Specific Function that best describes the relationship and test for "goodness of fit."
- Divide the data into sections that do approximate to a straight line and run an analysis of variance on these (Statsoft, 2005).

The final option would seem to offer the best chance of success in this case as the portions of data relating to internal and external rotation could be divided and treated independently.

5.5 Visual Analysis of Motion Patterns

5.5.1 Tibial Rotation

Time motion graphs of tibial rotation (see Graph 4-3 and appendix 9.1) demonstrated clearly defined motion patterns, which while varying between subjects, nether the less showed shared characteristics. Most subjects demonstrated rapid internal rotation from heel strike to a point of maximum internal rotations occurring on average 0.11s (SD 0.04s) after heel strike (see graph 4-12). This was followed by an overlying pattern of more gradual external rotation continuing until heel lift. Overall the motion pattern agreed well with that described by Cornwall (1995) (see Graph 2-1) and with Inman's observations (1981) (see Figure 2-2) A secondary peak or pronounced plateaux was noted in 8 subjects, suggesting that the tibia undergoes switching from internal to external rotation twice during stance phase. The effects of data smoothing should be considered here, since the applied five point moving average filter will act to reduce peaks generated by a small number of data points whether they are unwanted noise, or a genuine product of the subjects motion pattern. Since the secondary peak is the product of comparatively few values, its real magnitude will be greater than appears in the graphs. Of course, this may be an artefact of the tibial pointer design and use, caused by bounce following heel strike. However, Cornwall's (1995) results display similar properties achieved using a pointer of different dimensions, which might be expected to behave differently.

5.5.2 Rearfoot Motion

The time motion patterns for rear foot motion (Graph 4-5, Graph 4-6 and appendix 9.1) can be seen to be less consistent between individuals and between trials than those for tibial rotation. While less agreement is seen with Cornwall's findings, the most common pattern of motion seen is one of continued eversion until shortly before heel lift when the direction of motion changes to inversion. This is in line with the pattern of of pronation at the sub talar joint described by Michauds (1997).

5.6 Limitations

5.6.1 Standardisation of Data Strings

In order to average the motion patterns, either across all the trial subjects, or across several strides from the same subject, it is necessary to manipulate the data so that all data strings are directly comparable. When comparing strides, whether from the same or different subjects, each is of a slightly different duration and thus contains a different number of readings. The solution to obtaining a plot of the average motion pattern is to plot each reading against percentage of stance rather than against time. However, whilst the percentage of stance that is represented by each reading is easy to calculate, the position of the tibia or rearfoot at certain regular percentages of stance (say 5,10,15 20% etc) requires interpolation between the measured values and no technique was found that was applicable within the time constraints of this study. Essentially, it would be done by plotting each data string against percent of stance, and then manually reading off the required values, a total of 800 readings!

5.6.2 Strides Recorded per Subject

Due to time constraints, only a single stride per subject was digitised and consequently natural variations in motion pattern between strides affected the repeatability of the trial. Ideally, at least three strides per subject would be digitised and averaged but in order to do so it is necessary to standardise the resulting data strings as described above. Around 40 minutes were required to extract the raw data from a single stride (anterior and posterior video clips) so in total 13 to 15 hours were spent on this aspect of data collection. Thus, it can be seen that serious time implications are involved if this is to be undertaken, although hopefully the consequences would not be as dire as that befalling Professor Braune! If effective, software offering automated digitisation could make an important contribution to Video Gait Analysis, enabling much larger samples to be averaged providing a clearer picture of the underlying motion patterns.

5.6.3 Synchronisation

It proved difficult to find s suitable time marker visible to both cameras that allowed precise synchronisation of the two video clips. Switching on the filming light produced a change in light intensity that extended over five frames. Consequently, judgement was required on the part of the investigator based on when the light intensity started to change and the relative position and movement of the subjects limbs in the two clips. It is unlikely that any synchronisation error of greater than a single frame occurred because of this but with an average of 27 frames per subject this would have a small but measurable effect on the reliability.

5.6.4 Digitisation

This was very straightforward for the tibial pointer but some difficulties were encountered with respect to capturing the rearfoot angle. Ideally, three points would be marked, one at the top of the distal third of the tibia, one at the base of the calcaneus, and one representing the axis of frontal plane motion between the tibia and calcaneus. The problem lies in that this central point is situated over the Achilles tendon, and thus moves laterally and medially with tendon bowstringing, associated with rearfoot eversion and inversion. Consequently tibial and calcaneal angle were calculated relative to vertical requiring extra calculations to be carried out to establish the rearfoot angle. This was compounded by the manner in which the Quintic software reports angles. Namely a method has been adopted that avoids crossing between 0° and 359° such that if the first reading in a data string is say 359° and the following readings increase, they will be read as values greater than 360°, conversely if the first reading is 1° and subsequent readings decrease, negative values will be returned. This requires additional processing to be applied to some data strings adding to the risk of errors.

5.7 Further Studies

Further investigation into the relation ship between motion patterns in the transverse plane in the tibia and pronatory or supinatory motions in the foot should aim to include a measure of midfoot motion in addition to the calcaneal motion studied here.

For ideas on pointer devices that might be adapted to use with a 2D video system the reader is directed to Nestor (2002).

6 Conclusion

The reliability and suitability of Quintic Biomechanics software, when used to measure transverse plane tibial rotation through the utilisation of a tibial pointer device and when used to measure rearfoot motion was investigated and correlation between the two motion patterns was analysed. Between trial reliability for the measurement of tibial rotation was found to be good with 7 out of 10 subjects returning ICCs of greater than 0.7. Between trial reliability for the measurement of rearfoot motion as found to be inconsistent and specific problems relating to the marking technique for the rearfoot were highlighted, and a proposed solution identified. Analysis of the correlation of rearfoot motion and tibial rotation was compromised by the inconsistent reliability of the measurement of rearfoot motion and by the fact that the relationship is non-linear in nature and requires transformation of the data and the application of regression techniques which were beyond the time constraints of this investigation.

The Quintic Biomechanical Software was considered to simplify video analysis of motion, enhancing the techniques suitability as a clinical research tool. Further development of the software might include automated digitisation capabilities. By eliminating this time consuming aspect of data collection multiple strides could be processed and averaged, improving the picture gained of the underlying motion patterns.

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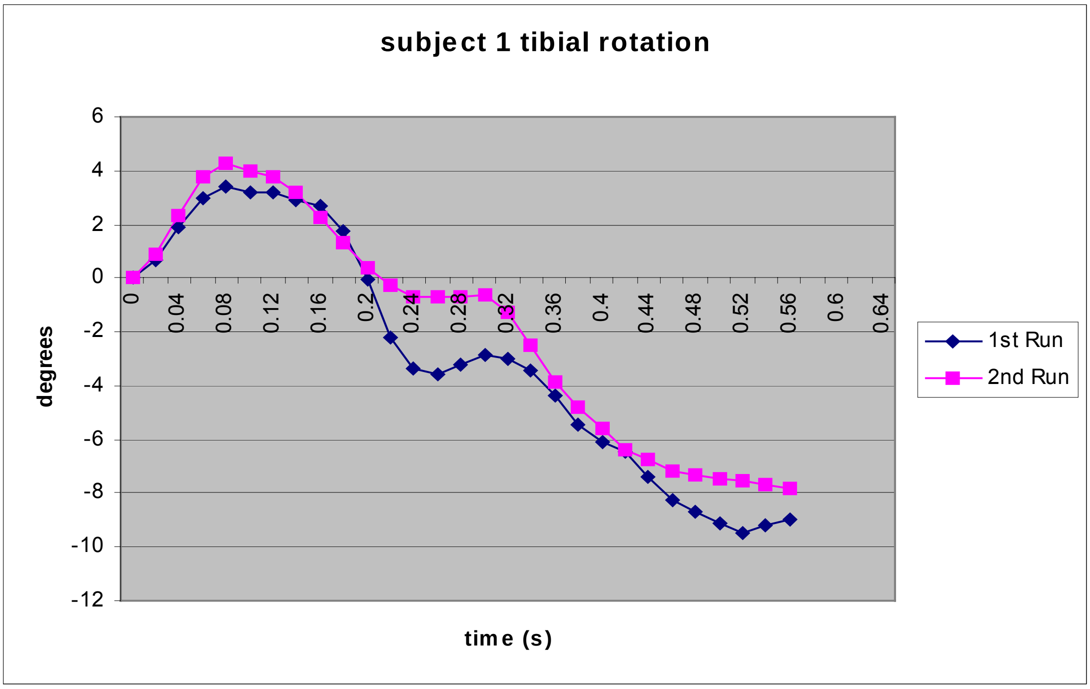
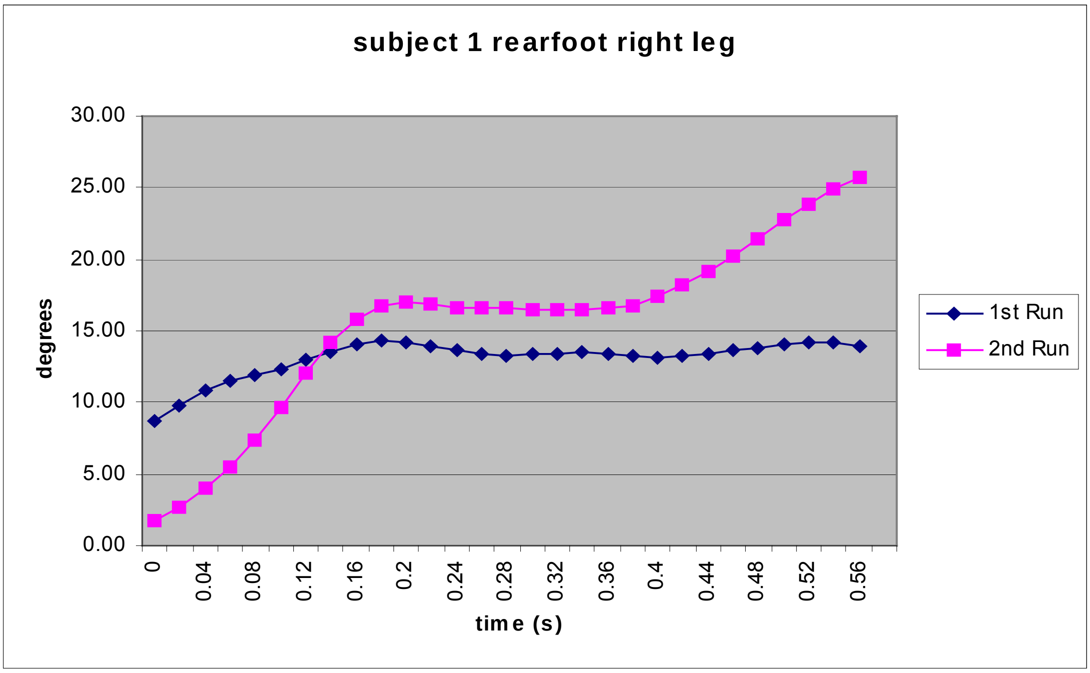
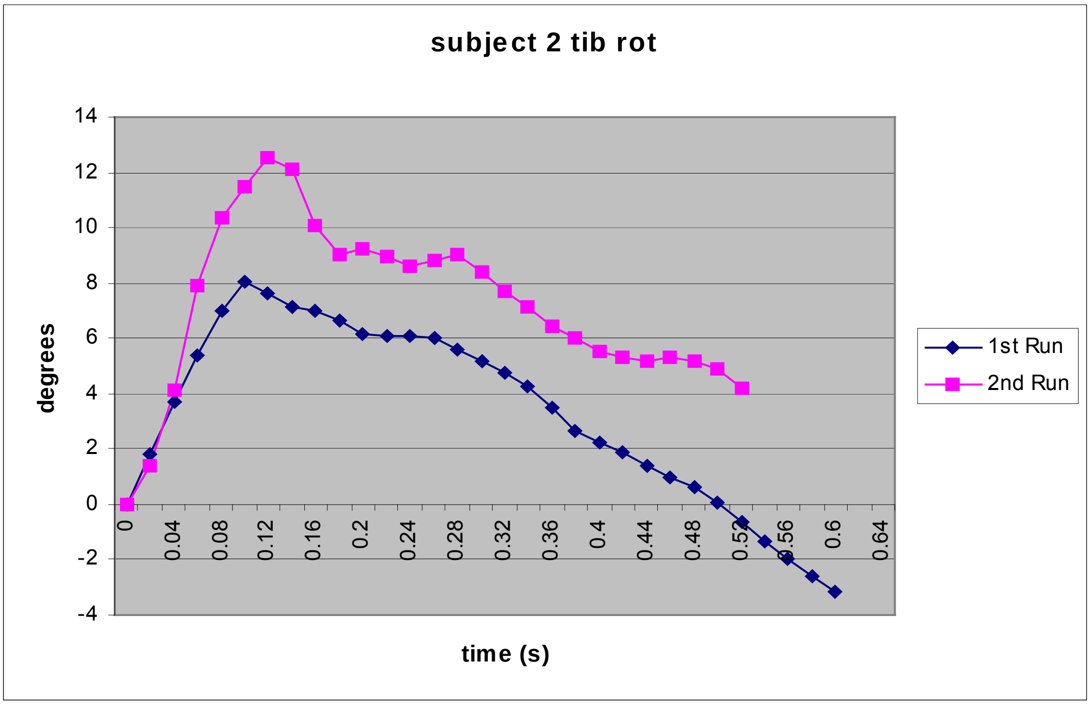
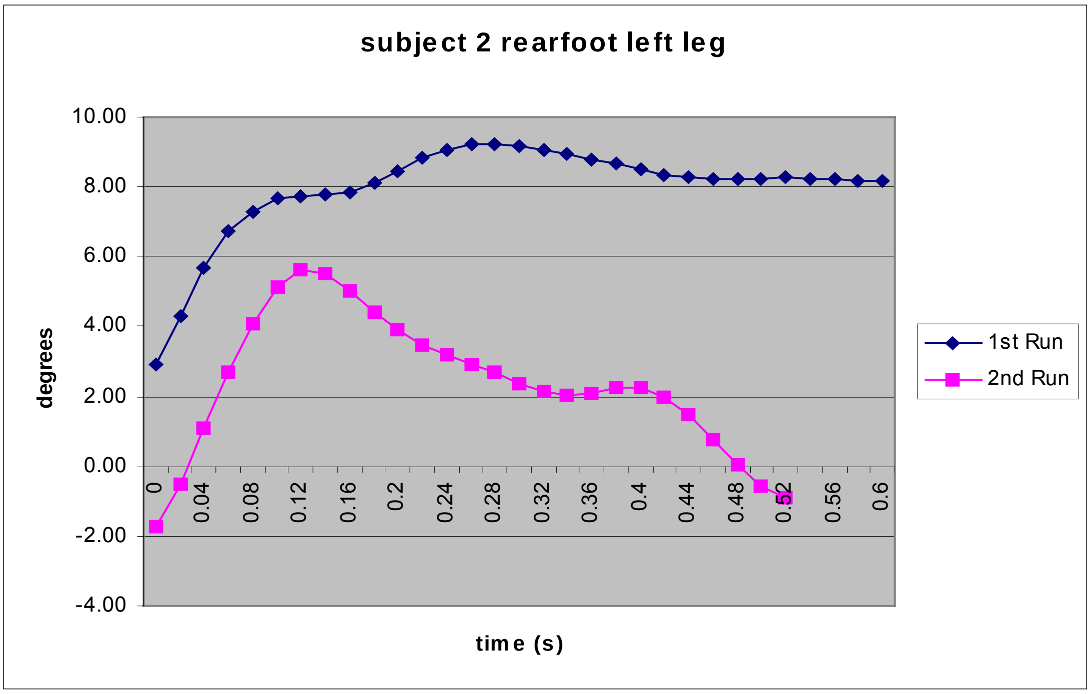
9 Appendices

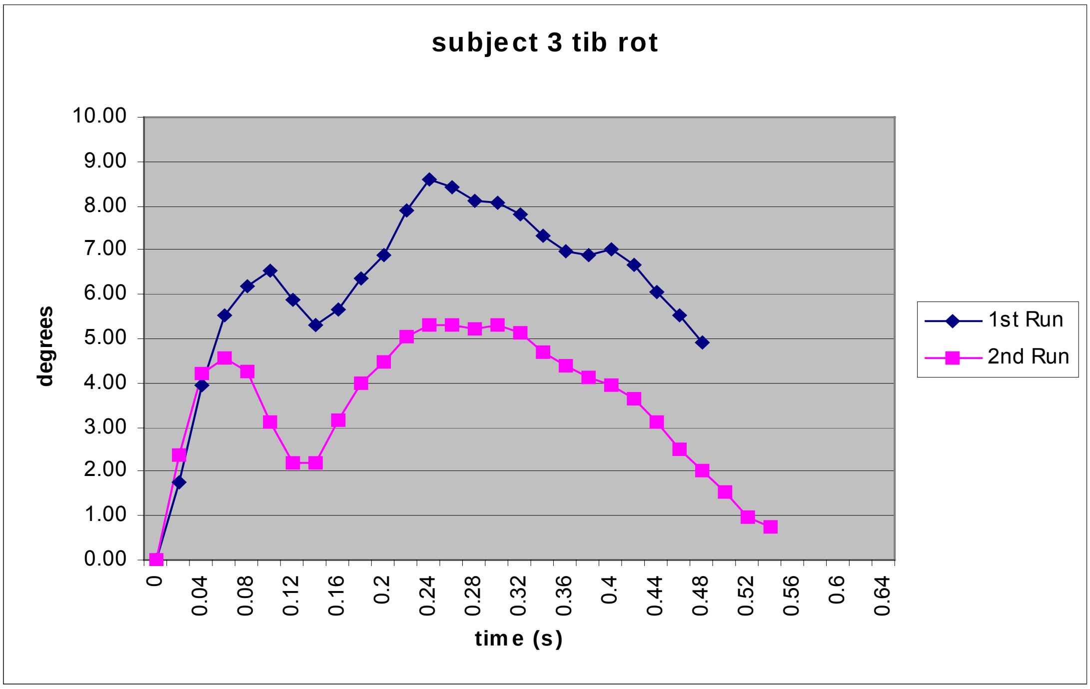
9.1 Time Motion Graphs for all Participants






subject 2 tib rot
degrees
time (s)
1st Run
2nd Run
14
12
10
8
6
4
2
0
-2
-4
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
0.6
0.64


subject 2 rearfoot left leg
degrees
time (s)
1st Run
2nd Run
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
0.6



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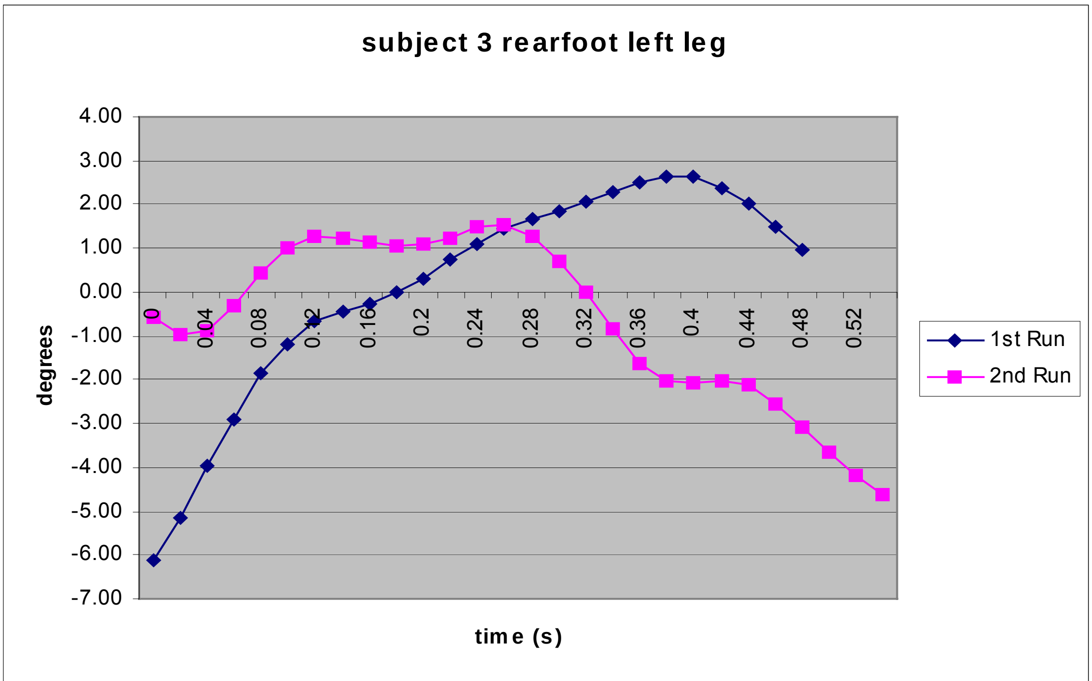
degrees
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
0.6
0.64
time (s)
1st Run
2nd Run



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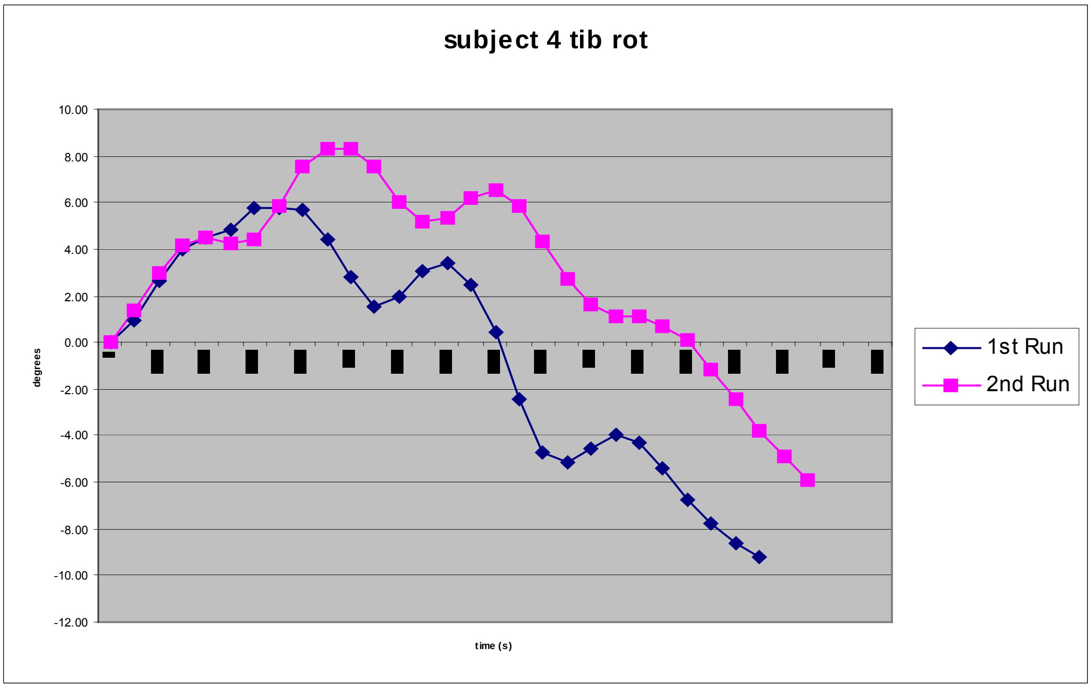
degrees
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
time (s)
1st Run
2nd Run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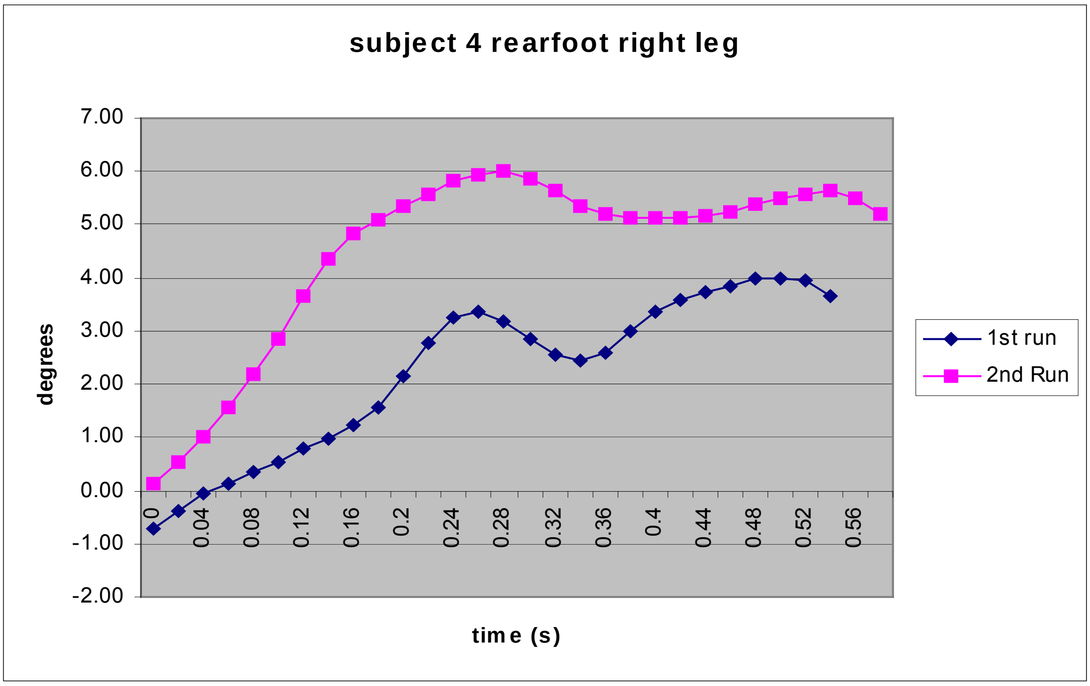
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
degrees
time (s)
1st Run
2nd Run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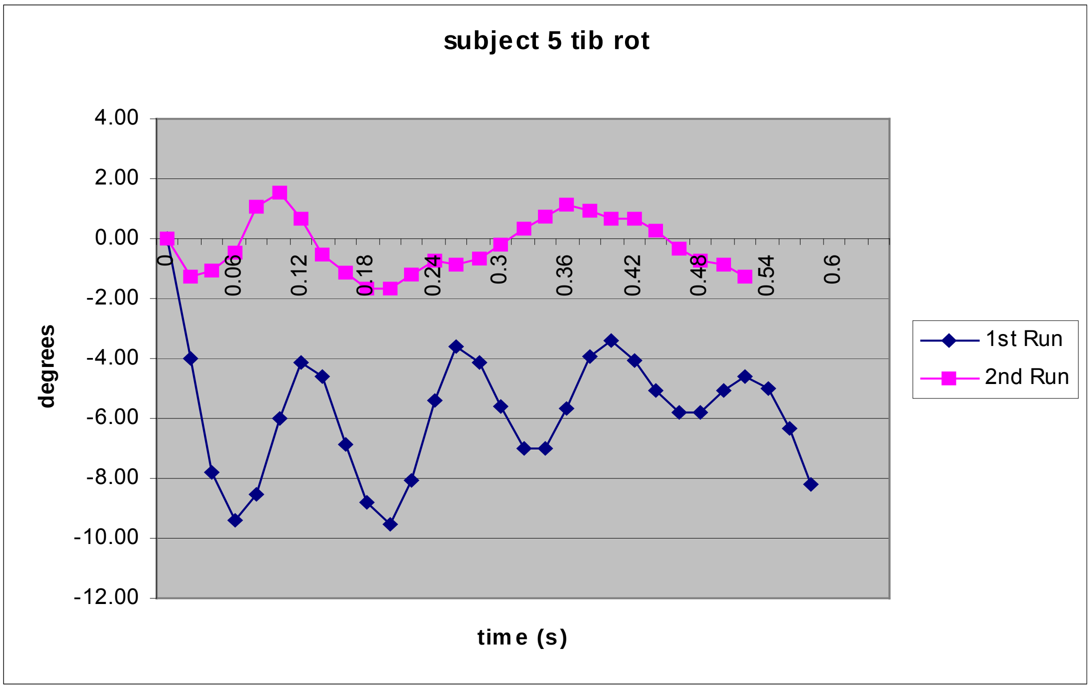
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
degrees
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
time (s)
1st run
2nd Run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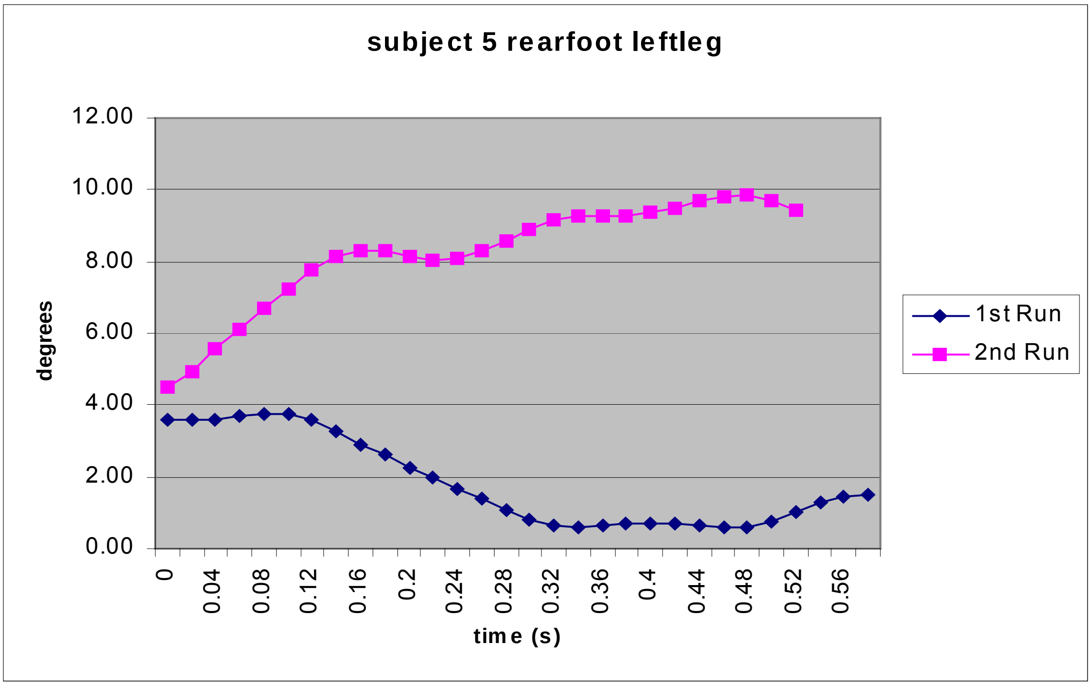
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
degrees
0
0.06
0.12
0.18
0.24
0.3
0.36
0.42
0.48
0.54
0.6
time (s)
1st Run
2nd Run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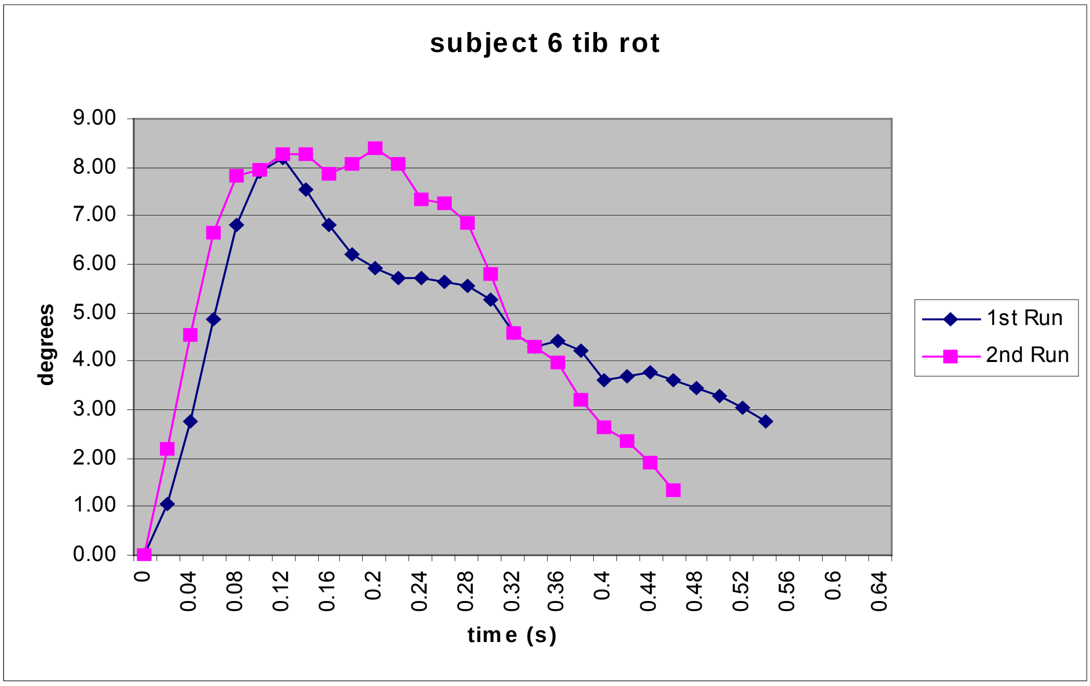
12.00
10.00
8.00
6.00
4.00
2.00
0.00
degrees
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
time (s)
1st Run
2nd Run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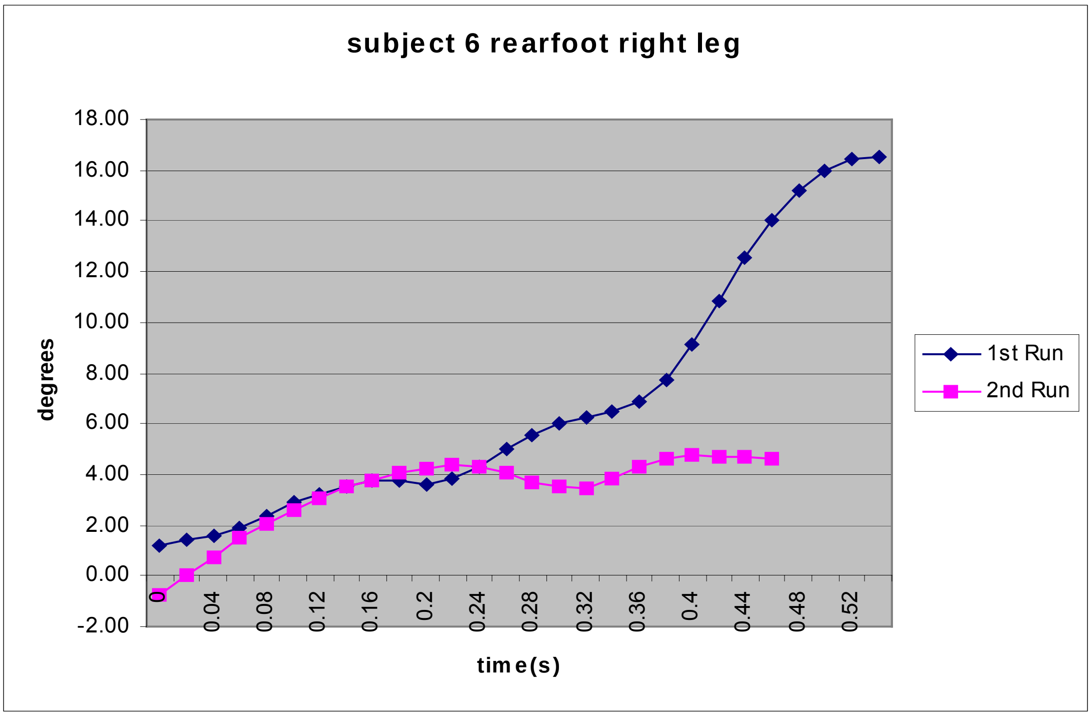
degrees
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
0.6
0.64
time (s)
1st Run
2nd Run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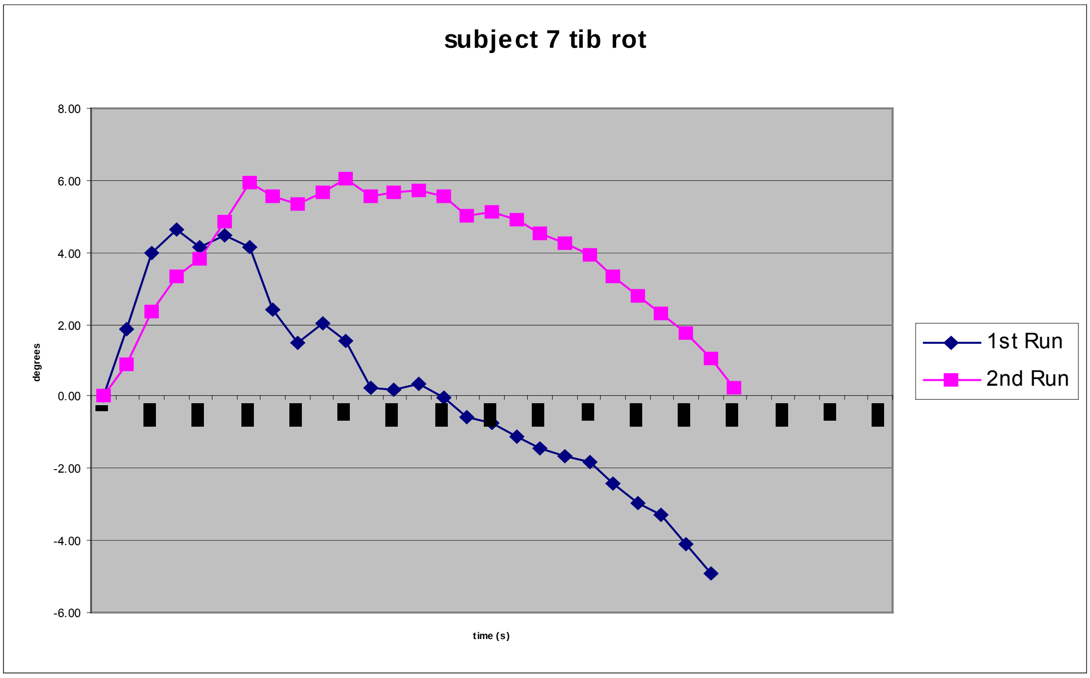
degrees
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
time(s)
1st Run
2nd Run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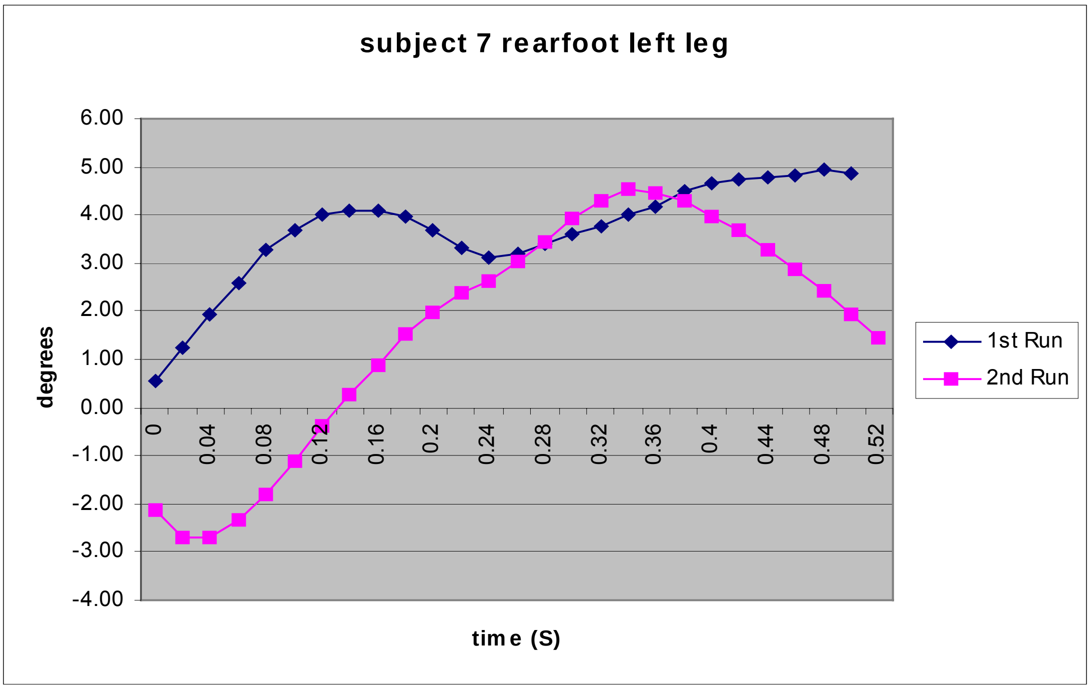
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
degrees
time (s)
1st Run
2nd Run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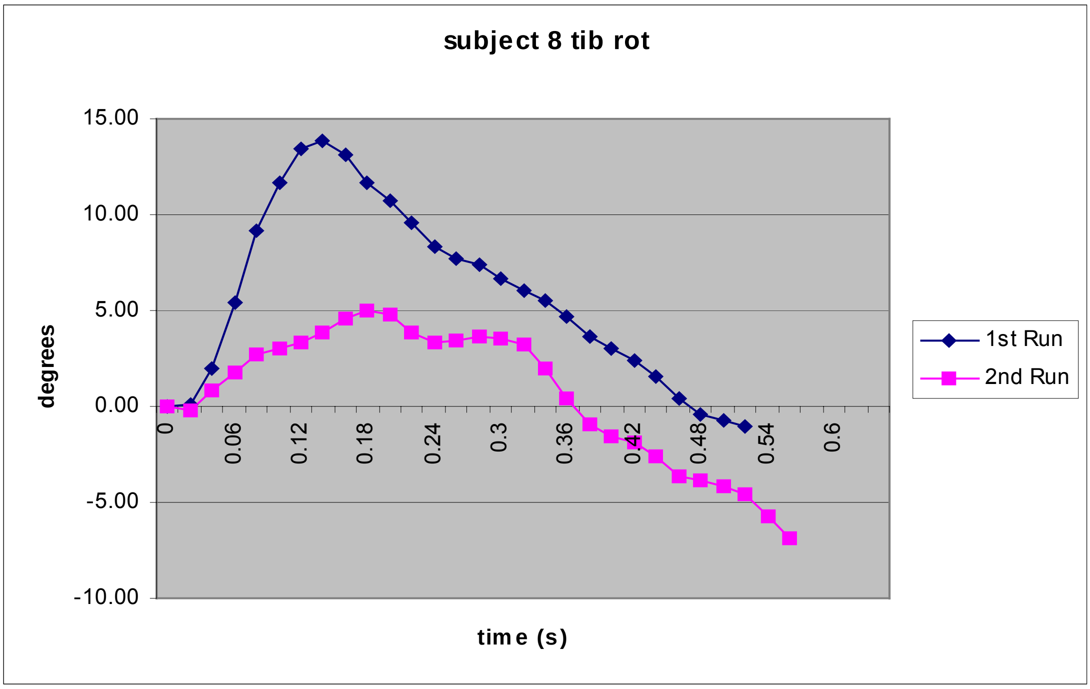
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
degrees
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
time (S)
1st Run
2nd Run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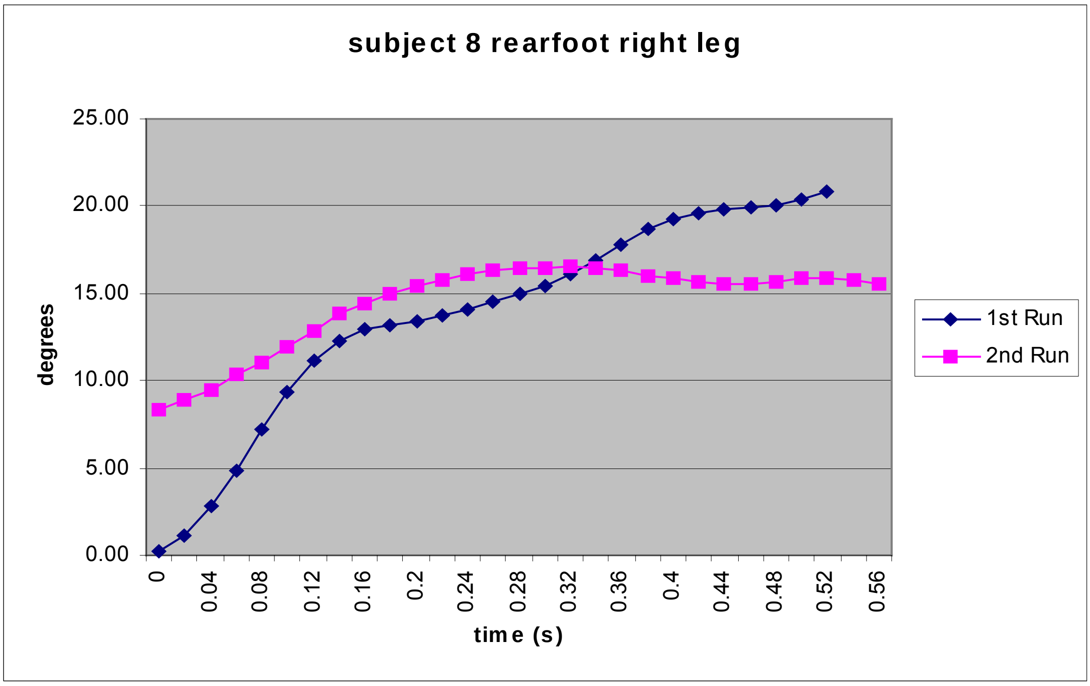
15.00
10.00
5.00
0.00
-5.00
-10.00
degrees
0
0.06
0.12
0.18
0.24
0.3
0.36
0.42
0.48
0.54
0.6
time (s)
1st Run
2nd Run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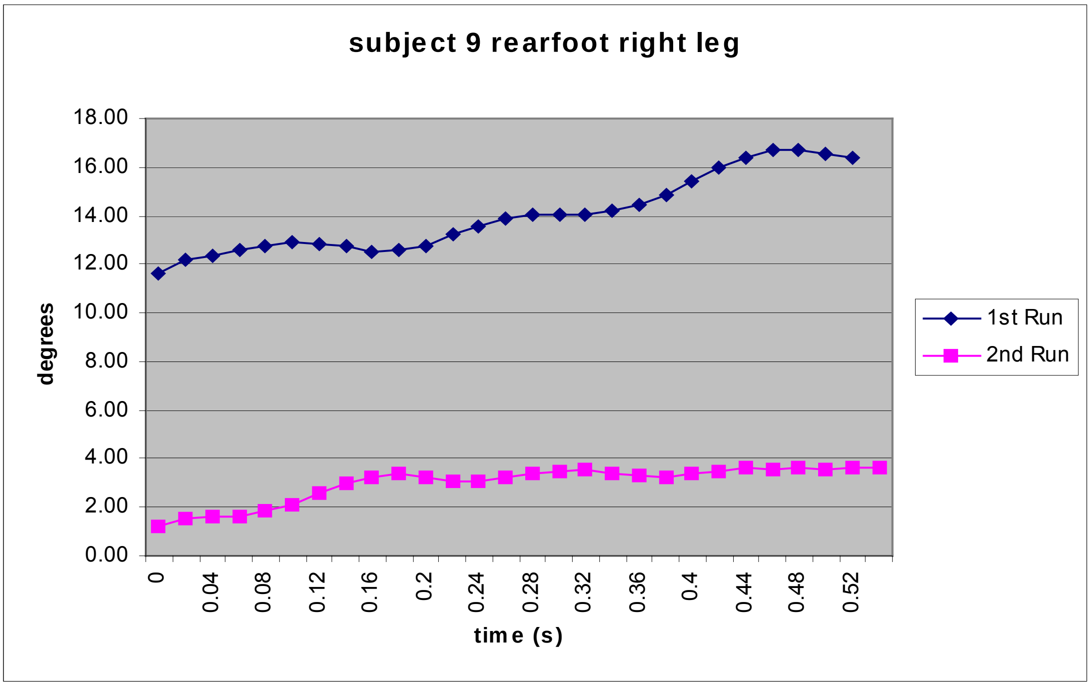
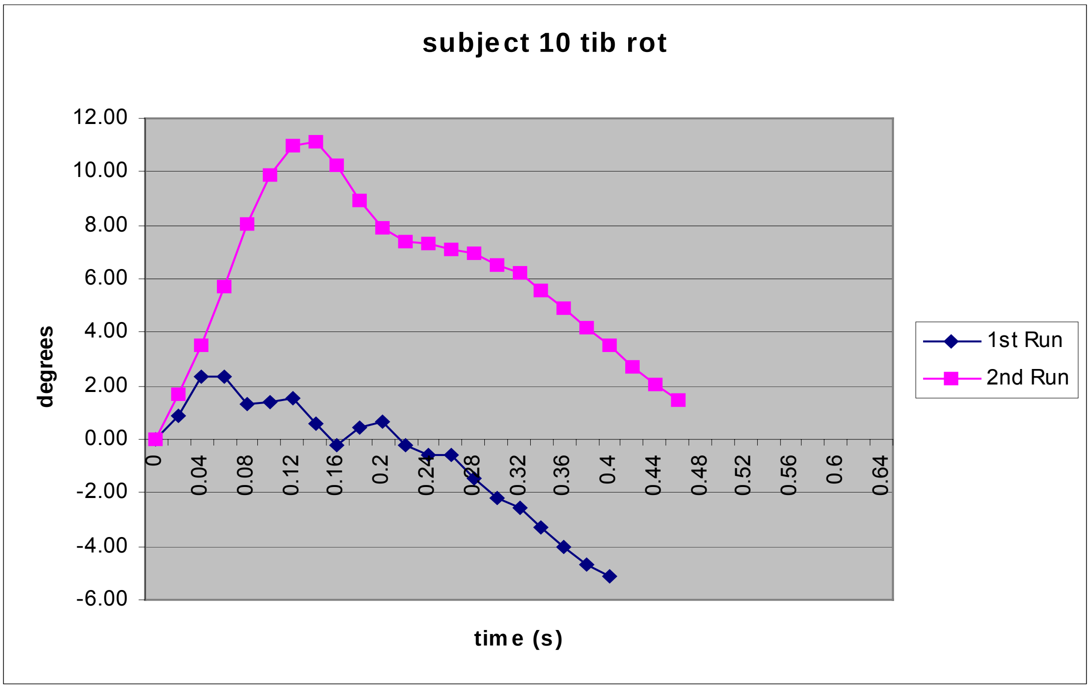
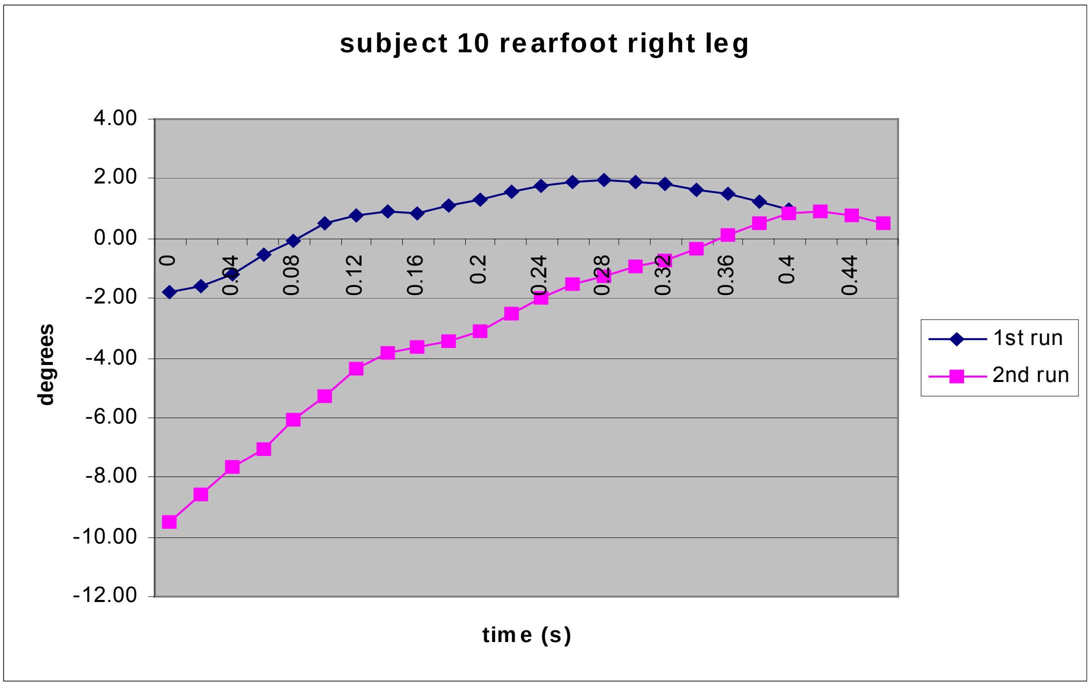
20.00
15.00
10.00
5.00
0.00
degrees
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
time (s)
1st Run
2nd Run


subject 9 tib rot
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
degrees
0
0.06
0.12
0.18
0.24
0.3
0.36
0.42
0.48
0.54
0.6
time (s)
1st Run
2nd Run


subject 9 rearfoot right leg
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
degrees
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
time (s)
1st Run
2nd Run


subject 10 tib rot
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
degrees
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
0.6
0.64
time (s)
1st Run
2nd Run


subject 10 rearfoot right leg
4.00
2.00
0.00
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-10.00
-12.00
degrees
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
time (s)
1st run
2nd run

9.2 Ethics Proposal

University of Wales Institute Cardiff

SCHOOL OF HEALTH AND SOCIAL SCIENCES ETHICS PANEL

Approval Form

Completion instructions:

1 *Maximum number of words allowed altogether 550, including headings. Longer submissions will be returned without consideration .*

2 *Use font size 10-12.*

Initial Submission Date :	**Resubmission Date(s) :**
Student :Ben Lovett	**Course :**BSc (Hons) Podiatry
Supervisor 1 : Sarah Curran	**Supervisor 2** :
Is this to be submitted to an LREC? YES NO **If Yes please name LREC :**	**Has a CRB check been sought?** **YES NO NOT APPLICABLE**

Title of Project:

An investigation of the reliability of the quintic biomechanical analysis software when used to measure the ratio of transverse tibial rotaion to frontal plane rearfoot motion when walking.

Background : The link between transverse rotation of the tibia and pronation/supination at the sub talor joint is well established and has been used by Cornwall and McPoil (1995) to develop a technique to quantifiably measure rearfoot frontal plane motion in subjects wearing shoes. Work by Sawert et al (1995) established that use of the tibial pointer device with 2D analysis provided a reliable and valid method of assessing transverse tibial rotation when compared to 3D analysis. Recent developments in digital videography and new analysis software "Quintic", has the potential to greatly simplify and speed up the techniqe increasing its attractivness as a research tool and rendering it useful in the clinical environment. To date no work has been published regarding the reliability of this technique using the Quintic software.

Aim: To establish whether the Quintic video gait analysis system permits the tibial pointer technique to be employed in a clinical setting to reliably measure frontal plane rearfoot motion via tibial rotation.

Sample Details (to include):-

- Inclusion criteria – No history of: congenital deformities to the lower

extremities,severe orthopaedic or neurological injuries to the lower extremities. ▪ Description of where and how the sample were recruited –20 Students at the Wales center for Podiatric studies. ▪ Confirmation of whether permission / informed consent has been obtained – all subjects to sign informed consent form. ▪ Details of the initial contact method – notice to be displayed on locker room board
Method to be used : The tibial pointer consists of a medium density EVA foam block to which are attached two 100mm rods perpendicular to each other. The foam block is attached to the tibial tuborosity via double sided sticky tape. The subject is videoed walking bare foot on a treadmill and the ratio of tibial rotation to pronation/supination calculated using the quintic software.
Potential discomfort or inconvenience to respondent : Time only; about 20mins to set up and video each subject.
Special points to note : gait lab to be booked to allow data collection.

References :

Cornwall M.W., McPoil T.G., 1995, Footwear and Foot Orthotic Effectiveness Research: A New Approach.

Sawert M.K., Cornwall M.C., McPoil T.G., 1995, Validation of two dimensional measurement of transverse tibial Rotation during walking using three dimensional motion analysis. Lower Extremity 2: 285, 1995; in Cornwall M.W., McPoil T.G., 2000, The effect of foot orthoses on transverse tibial rotation during walking, JAPMA 90(1) pp2-11.

Student's signature____________________________ Date:______________

(Supervisor signature required prior to submission)

I have checked this form and believe that all the necessary information is given.

Supervisor's signature____

9.3 Ethics Approval

to Ben Lovett
SC

Memo

from SCHOOL ETHICS PANEL

subject FINAL YEAR PROJECT

our ref A2
date 19 | 10 | 05

As you know your proposal was amongst those considered at the most recent meeting of the School Ethics Panel.

1 [✓] Your proposal was approved subject to the conditions listed below. You will also need to seek permission from Head of Centre.

2 [] Your proposal was approved in principle subject to the conditions listed below but the Panel request that you submit your questionnaire or interview schedule for scrutiny. This step is necessary as the subject of your research is potentially sensitive. You will also need to seek permission from

3 [] The information provided on the proposal is insufficient. You should submit a revised proposal after discussion with your supervisor. It is in your own interest to submit as soon as possible. After that you will also need to seek permission from

4 [] The Panel regrets it has reservations about your project and therefore cannot approve it in its present form. You are advised to submit a revised proposal for their further consideration. It is in your own interest to submit as soon as possible.

The Panel also draws your attention to the possibility that this study may require the approval of other ethics committees.

Conditions of approval

i) That any questionnaire and/or interview schedule which you intend to use, and any information or educational materials you intend to give to participants must be approved by your supervisor.

ii) That you check with your supervisor that the project is technically feasible.

iii) That your supervisor is satisfied that the measures that you intend to use are appropriate for you to use with intended sample

iv) That the consent of each subject is sought and recorded as appropriate, and these records stored and available for examination, if required, by the Panel until publication of the results of the Examining Board at which your project is considered.

v) That all raw data collected should be stored and be available for examination, if required, by the Panel until publication of the results of the Examining Board at which your project is considered. After this they should be destroyed unless prior consent has been obtained from all subjects for the data to be stored and used for teaching and research.

vi) That any substantive changes to the proposal as approved are referred to the Panel.

vii) That any untoward incident which occurs in connection with this proposal should be reported back to the Panel **without delay**.

[Nov 01]

UWIC

9.4 Communication with UWIC School of Podiatry.

SCHOOL OF HEALTH AND SOCIAL SCIENCES - WALES CENTRE FOR PODIATRIC STUDIES
YSGOL IECHYD A GWYDDORION CYMDEITHASOL - CANOLFAN ASTUDIAETHAU PODIATRIG CYMRU

UWIC

Mr Paul Frowen
Principal Lecturer
Wales Centre for Podiatric Studies
UWIC Llandaff Campus
Cardiff CF5 2YB

7 December 2005

Dear Mr Frowen

I am writing to request permission to use UWIC School of Podiatry facilities to collect data for my research project. This will involve use of the Gait Lab and the Quintic video gait analysis system to record video data of transverse tibial rotation and frontal plane calcaneal motion. Subjects (students) will be required to spend 5 minutes walking on treadmill on two separate occasions while a short video clip is recorded.

Yours sincerely

Ben Lovett
Final Year Student

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Cardiff's **metropolitan** university

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UNIVERSITY OF WALES INSTITUTE, CARDIFF   ATHROFA PRIFYSGOL CYMRU, CAERDYDD

SCHOOL OF HEALTH AND SOCIAL SCIENCES - WALES CENTRE FOR PODIATRIC STUDIES
YSGOL IECHYD A GWYDDORION CYMDEITHASOL - CANOLFAN ASTUDIAETHAU PODIATRIG CYMRU

UWIC

Mr Ben Lovett
Final Year Student
Wales Centre for Podiatric Studies
UWIC Llandaff Campus
Cardiff CF5 2YB

7 December 2005

Dear Ben

This letter confirms that you have my permission to use UWIC School of Podiatry facilities to collect data for your research project using the Gait Lab and the Quintic video gait analysis system.

Yours sincerely

Paul Frowen
Head of Centre
Wales Centre for Podiatric Studies

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9.5 Subject Consent Form

Quintic Biomechanics Software, Reliability Study

The Study

The study aims to investigate the reliability of Quintic Biomechanical analysis software, when used to measure transverse plane tibial rotation and frontal plane calcaneal inversion and eversion.

What's Required

To participate in this study you need to be available on **two separate occasions** for a period of about 20 minutes. On each occasion markers will be placed on your tibial tuberosity (the bony prominence at the top of your shin), and on the back of your heel.

You will then be asked to walk on a treadmill (running machine) for 5 minutes during which time digital video cameras will record the motion of the markers.

Participant Confidentiality

Each participant will only be identified during the course of the study by a number. At the end of the study all video files will be deleted.

I consent to take part in the above study:-………………………..Date……………