Reliability of Joint Kinetics using different Subject Calibration Techniques

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by

Barbara Safarovic

University of Applied Sciences Upper Austria

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Department of Kinesiology

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Department of Biomedical Engineering

Supervised by

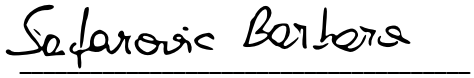
Dr. Thomas Haslwanter

Kristian O´Connor, PH.D

Declaration of academic honesty

I hereby declare and confirm that this is entirely the result of my own work. If other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere.

Milwaukee, February 20th 2016



Barbara Safarovic

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Executive Summary

Video-based motion analysis systems are being used more and more frequently to study body segmental and joint kinematics during movements such as gait. It is the most common activity performed by humans. An impairment of gait may have a profound impact on a person´s quality of life.

Repeatability is affected by the ability to accurately locate anatomical landmarks and to define joint centres. The purpose of this study was to compare the reliability of lower extremity kinematic and kinetic data with two testers using a few different subject calibration models based on functional and anatomical landmark models. The data got collected with the use of a single camera system on two different days and two examiners. For each subject ten walking trials got recorded.

The hypothesis was that the reliability would get improved with the use of the functional method. Repeatability got compared between days with one tester and between testers on one day. Results suggest that the repeatability between testers are fairly equally compared with between days where the effect of marker displacement gets visible.

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1 Introduction

Gait analysis deals with the human locomotion like any kind of motion used for many of the activities of daily living from the biomechanical perspective. Assessment of gait function is an important component of the examination of patients with neuromuscular, orthopedic and cardiopulmonary conditions.

It gets commonly used in sports medicine to help the athletics to improve their performance. But also in lots of clinical practices that engage with the basis of many interventions used in rehabilitation. Specifically, clinical gait analysis can be used to achieve one of four goals: diagnosis between diseases, assessment of the severity of the disease, monitoring of progress or prediction of the outcome of interventions.

Although the reliability of observational gait analysis can be improved when video recordings are used, this approach limits the ability to assess the three-dimensional (3D) aspect of gait.

1.1 Statement of Problem

The assessment of gait analysis can be influence by several sources, resulting in a systematic instrumental error or random systematic instrumental error (Chiari, Croce, Leardini, Cappozzo, Chiari, Croce, Cappozzo, et al. 2005a). The literature has shown, that soft tissue artifacts like skin deformation (Chiari, Croce, Leardini, Cappozzo, Chiari, Croce, Cappozzo, et al. 2005b) and maker displacement (Chiari, Croce, Leardini, Cappozzo, Chiari, Croce, and Cappozzo 2005; Gorton, Hebert, and Gannotti 2009) causes an greater error than the instrumental error. In this research the most critical sources of error is the result of the misplacement of anatomical landmarks.

1.2 Statement of Purpose

The purpose of this study is to validate and to prepare a single-camera 3D tracking system for clinical introduction. Retro-grade reflectors are a new non-invasive method for 3D motion capturing with only a single camera (Weinhandl et al. 2010).

Retrograde reflectors get fixed on body segments like the pelvis, shank, thigh and on the food. Anatomical Landmarks get detected with a flexible marker. Joint centers may also be found were one bone is in contact with another. By tracking the motion of markers on one body segment relative to the other, the joint center can be estimated as the point on the segment that moves the least (O'Brien et al. 2000). This leads to the calculation of the hip-, knee- and ankle joint centers by different approaches such as the functional approach (Ehrig et al. 2006; Bell, Pedersen, and Brand 1990) or the anatomical landmark method.

To eliminate the problems mentioned before, different calibrations and different joint determinations were performed. For this inter-tester and inter-sessions (Schwartz, Trost, and Wervey 2004; Gorton, Hebert, and Gannotti 2009) were used.

The main goal of this research study is to compare the reliability of different methods of subject calibration on 3D walking patterns.

1.3 Questions

Given the purpose of this research and the current literature on this topic, the following questions were formed:

1.3.1 Primary question

How does the functional knee method influence the knee and ankle moment?

1.3.2 Secondary question

How does the three hip methods affect the moment?

2 Theoretical Background

2.1 Anatomical Background

For every joint calculation, it is important to mark and to palpate the anatomical landmarks in the correct way. Therefore it is necessary to have the anatomical knowledge of the lower body.

Figure 1 shows the anatomical landmarks (marked and labeled in red), bones (labeled in black), joint centers (labeled in blue) and body segments (labeled in grey) of the lower body, which are needed for our trials.

To determine the lower limb joint centres, different anatomical landmarks are needed.

Three of them are located on the hip: *Anterior Superior Iliac Spine* (ASIS), *Posterior Superior Iliac Spine* (PSIS) and *Sacrum* (SACR). In combination with the *Greater Trochanter* (GT) it is possible to define and to calculate the *Hip Joint Center* (HJC). For the data analysis three different approaches were used (described in capture 3.3.2.1) to calculate the HJC.

The *Lateral Epicondyle* (LE) and the *Medial Epicondyle* (ME) are located on the lower end of the femur. Similar to the HJC, the *Knee Joint Center* (KJC) gets calculated (described in capture 3.3.2.2) by these two anatomical landmarks.

The *Ankle Joint Center* (AJC) is estimated between the *Lateral Malleolus* (LM), which is located at the lower end of the fibula and the *Medial Malleolus* (MM), which is located at the lower end of the tibia. The calculation of the AJC gets described in capture 3.3.2.3.

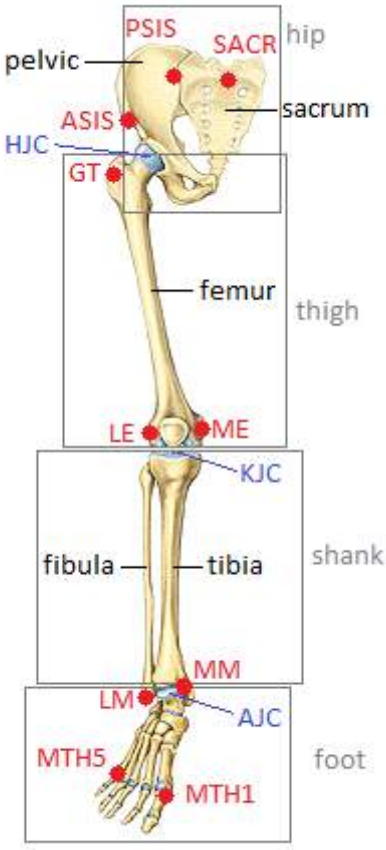

Figure 1: Anatomical landmarks, bones, joint centres and body segments of the lower body

Also for the description of the body segments (hip, thigh, shank and foot) the anatomical landmarks are needed.

With the landmarks of the Right and Left ASIS, Right and Left PSIS and the SACR it is possible to reconstruct the hip. To rebuild the thigh a line got drawn from the GT to the midpoint of the LE and the ME or the KJC. Similar to that, the shank is supposed to be described as a line between the KJC and the midpoint of the LM and MM. The foot gets presented as a triangle with the corners by the midpoint of the First Metatarsal Head (MTH1) and the Fifth Metatarsal Head (MTH5) and the AJC.

2.2 Clinical Gait Analysis

Gait (walking and running) is the most common activity performed by humans. An impairment of gait can have a profound impact on a person´s quality of life.

There is no single unifying concept that explains the motion of the body during gait. Instead, each approach to gait analysis tends on its own pattern (Kirtley 2006).

2.2.1 Gait Cycle

One gait cycle is completed when two steps have been taken. It is defined as the time interval between two successive occurrences of one of the same event of walking. One gait cycle contains the following terms: Initial Contact, Opposite toe off, Heel rise, Opposite initial contact, Toe off, Feet adjacent and Tibia vertical (Figure 2)(Whittle 2007).

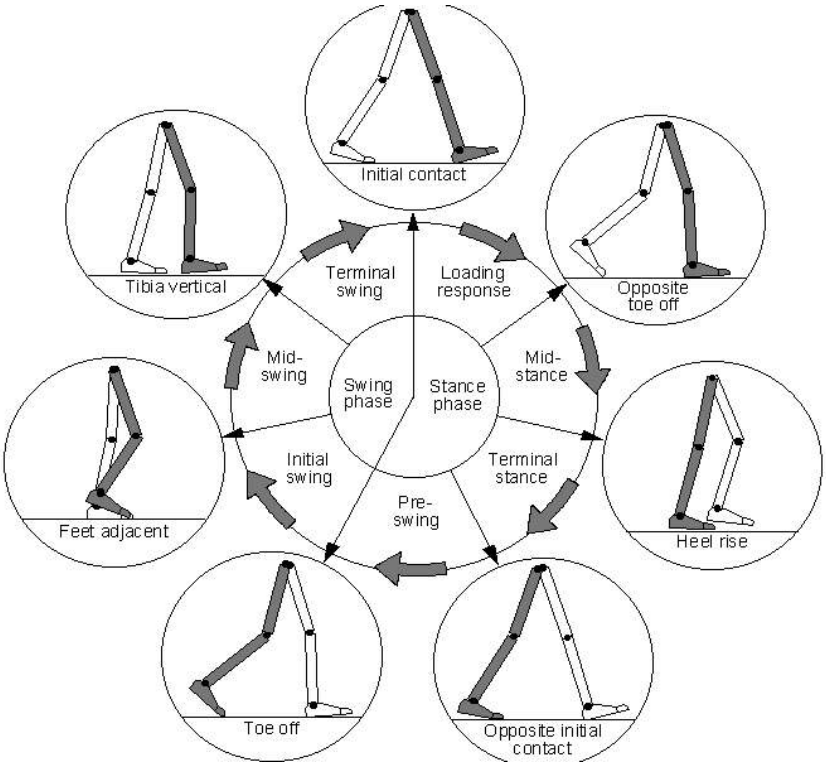

Figure 2: Position of the legs during one gait cycle (Whittle 2007)

It can be subdivided into the 'stance phase' and 'swing phase'. Normally the stance phase takes longer than the swing phase (60% to 40%). The stance phase starts with the Initial Contact and ends with the Toe-off of the same foot. The Toe-off is the start of the swing phase, which ends with the Initial contact (Figure 3).

During normal both feet are on the ground for a short time. This phase is called: 'double support phase'. Depending on the speed, it takes about 10% of the time (both 20%) of a gait cycle. If the participant is running, the double support phase changes into a flight phase (Whittle 2007; Kirtley 2006).

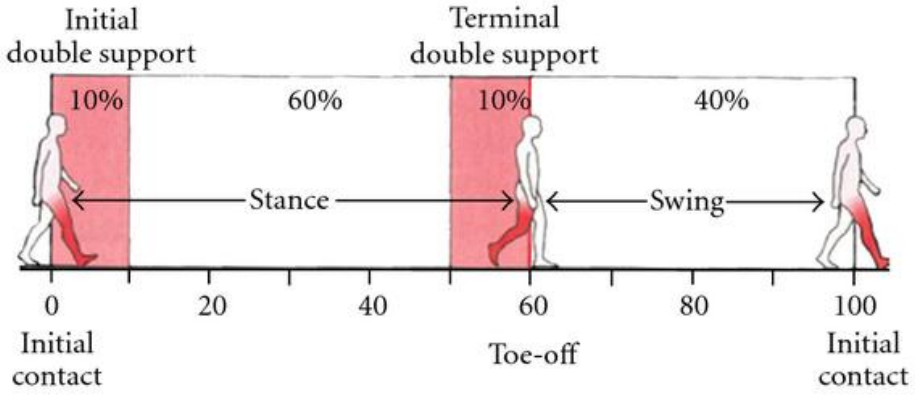

Figure 3: Gait cycle, divided into 'stance phase', 'swing phase' and 'double support phase' (Kirtley 2006)

2.2.2 Source of errors

Reliability is one of the main important issues in clinical gait analysis. For that it is necessary to know that gait analysis can be influenced by several sources of errors like: systematic instrumental errors, random instrumental errors, soft tissue artifacts or anatomical landmark misplacements. Furthermore, such perturbations are difficult to remove.

With the use of the Moire Phase Tracking System, the instrumental errors can be neglected. Therefore this chapter deals only with the soft tissue artifacts and the anatomical misplacements.

2.2.2.1 Soft tissue artifacts

Skin deformation and displacements can cause one of the most critical sources of error in human movement analysis. In 2005 Leardini (Chiari, Croce, Leardini, Cappozzo, Chiari, Croce, Cappozzo, et al. 2005b) pointed out a few methods to minimize these artifacts. Methods like the "solidification" procedure (Chèze, Fregly, and Dimnet 1995) or the multiple anatomical landmark calibration (Cappozzo et al. 1995). As a result, to avoid these errors retro-flective markers are placed on the lateral and medial sides of the joints and marker clusters get fixed on each body segment.

2.2.2.2 Anatomical landmark misplacement

A major issue in human movement analysis is the identification of *anatomical landmarks* (AL) and the reconstruction of their position in a selected set of axes. The incorrect location of the AL can be caused by three main factors: (1) the palpable ALs are not points but surfaces; (2) a soft tissue layer covers the ALs; (3) the identification of the location of the ALs depends on which palpation procedure was used (Chiari, Croce, Leardini, Cappozzo, Chiari, Croce, and Cappozzo 2005).

In 2006, R. Stagini developed a new method (double calibration) to keep misplacement errors as low as possible. The double calibration technique can improve the reliability of the acquired kinematic data, without increasing the duration and complexity of the acquisition and processing procedures (Stagni, Fantozzi, and Cappello 2006).

2.3 Definition of Joint centres

There are a lot of different approaches to estimate the joint centres for the hip, knee and ankle. For this study the following shown in Figure 4 got used.

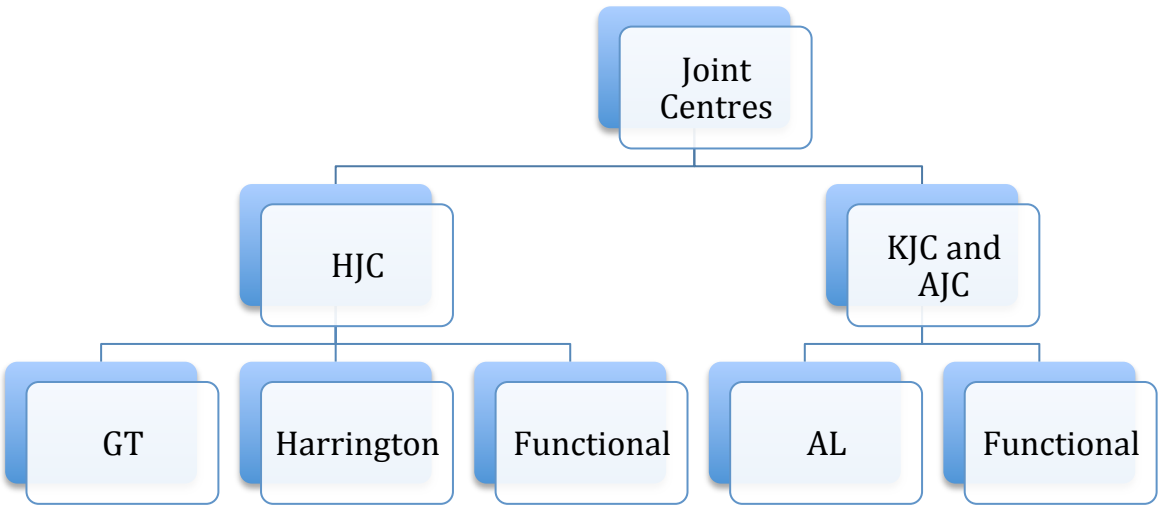

Figure 4: Different methods to estimate the joint centres

2.3.1 Hip Joint Centre

Greater Trochanter Method

This approach based on the palpation of the right and left greater trochanter. Draw a line between these two anatomical landmarks and the HJC is placed at a one quarter distance of these two landmarks (Weinhandl and O'Connor 2010).

Harrington Method

Another alternative predictive method uses the palpation of the right and left ASIS and PSIS to get the pelvis width. With a regression equation processed by Harrington in 2007 (Harrington et al. 2007), using an approach of Bell in 1990 (Bell, Pedersen, and Brand 1990) it is possible to estimate the HJC.

Functional Method

For this study the functional method of the symmetrical axis of rotation, called SARA was taken. This approach to determine the HJC is a natural extension of the axis transformation technique that is capable to consider the rotational movement of two segments independently, by including a rotation and transformation term for the second segment (Ehrig et al. 2006). For that the subjects were asked to perform a star motion with their right foot.

2.3.2 Knee Joint Centre

Anatomical Landmark

This approach for the KJC estimation needs the palpation of the lateral and medial epicondyle (LE and ME). The midpoint between these two landmarks represents the KJC.

Functional Method

Similar to the functional HJC the functional approach for the KJC uses the symmetrical axis of rotation (SARA) (Ehrig et al. 2006). For that the subjects were asked to flex their knee with their right foot.

2.3.3 Ankle Joint Centre

Anatomical Landmark

Similar to the KJC, this approach uses the anatomical landmarks of the lateral and medial malleolus (LM and MM). Draw a line between these two landmarks and the midpoint of this line is assumed to be the AJC.

Using the KJC

In this case the AJC get calculated in the same way described above. The only difference is the recalculation of the lateral and medial malleolus. For the functional knee method was taken to estimate the new anatomical landmarks. The idea behind this is to remove the cross talk between the frontal and sagittal plane.

2.4 3D Motion capturing

In general clinical setting, the 3D gait analysis system not only must be reliable, valid and able to distinguish between normal from abnormal gait. It must also be easy to use by a clinician with a moderate level of training and must be relatively inexpensive.

2.4.1 Stereophotogrammetry

To reconstruct 3D images, images from two or more cameras are needed. The cameras get positioned in the right angle (Figure 6) and after the calibration they shouldn´t get moved anymore. Without calibration it is impossible to measure distances accurately.

With the use of reflective markers it is possible to detect the limb segments and to identify their positions and orientations. When the subject moves in front of the cameras, only the markers are captured by the system (Figure 5).

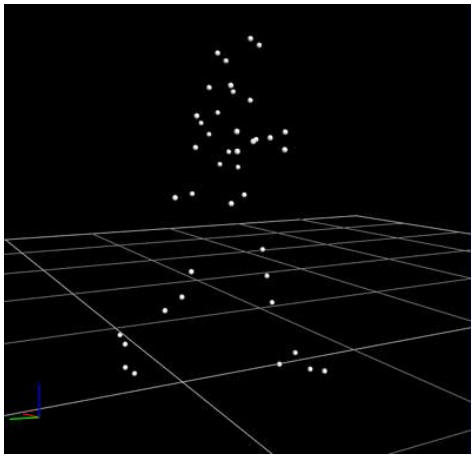

Figure 5: Captured data from a camera based system

A computer software is used to calculate the relationship between the known three-dimensional positions of markers on the calibration object and the two

dimensional positions of those markers in the fields of view of the different cameras. (Whittle 2007; Kirtley 2006)

A disadvantage of this system is, that lots of cameras are needed and the marker must always get captured by at least two or more cameras. An example for this kind of motion capturing is the VICON system.

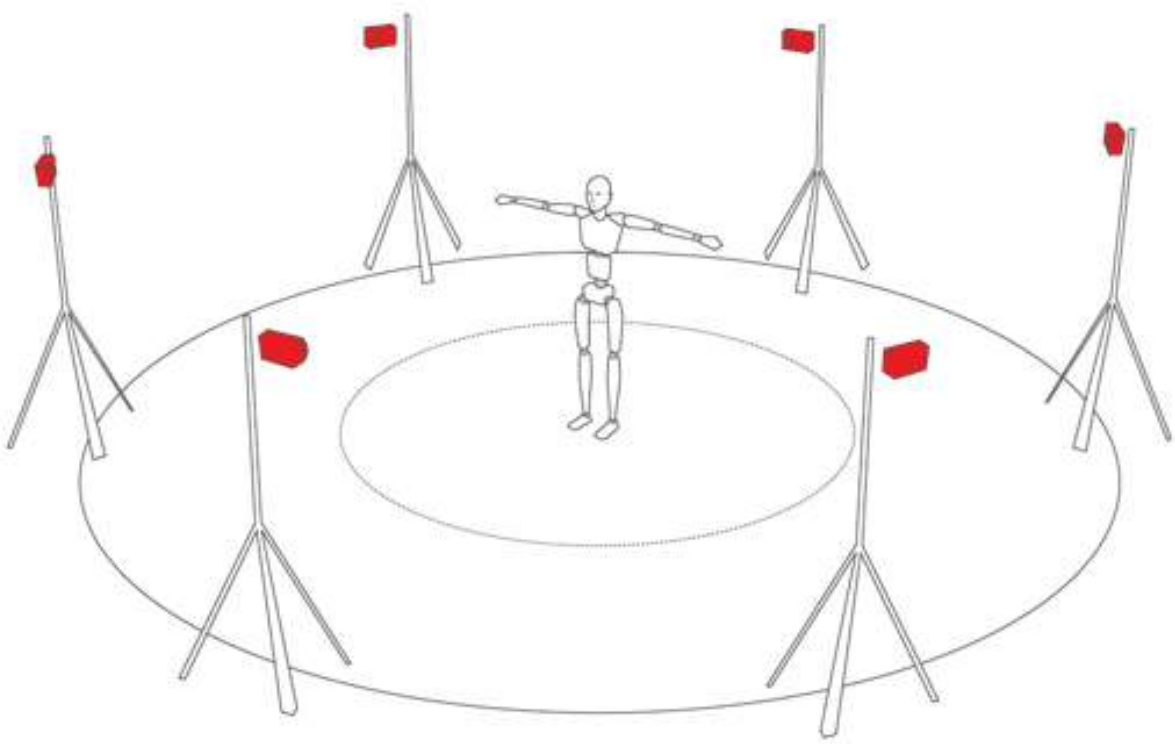

Figure 6: 3D Motion capture system - Stereophotogrammetry (http://technabob.com/blog/2007/08/06/arena-motion-capture-for-the-masses/)

2.4.2 Moiré Phase Tracking System

The Moiré Phase Tracking System meets all requirements mentioned before.

Similar to the Stereophotogrammetry, the subject gets marked up with special reflective markers (Figure 7) and only these markers get captured by the camera (Figure 8).

An advantage of this system is, that only one camera is necessary to create a 3D image.

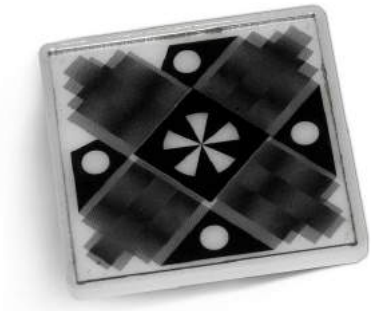

Figure 7: Moire Phase Tracking markers

A single camera system can accurately measure only X, Y and Z direction, the in-plane translation and rotation. The system can track over a 2x2x2 meter volume with 360° rotation about the camera-marker line-of-sight, and ±60° out-of-plane rotations. With the accurate capturing of 3-axis orientation, the known tilt, the actual size of the marker in the image and the full 6 *Degree of Freedom* (DoF) 3D pose of the marker in camera coordinates it is possible to determine distance of the camera-marker.

Due to unique id´s of each marker, the system is able to track up to 256 makers simultaneously.

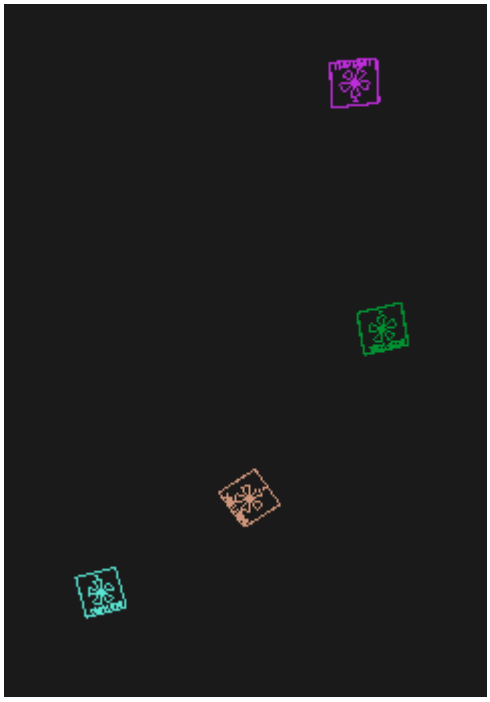

Figure 8: MPT marker capturing

3 Methods

3.1 Subjects

Ten healthy volunteers participated in the study (Table 1). An informed form was read and signed by all volunteers prior to the beginning of the data collection. Volunteers were accepted in the study if they:

(1) don´t have a medical condition that may impair their walking ability;

(2) don´t take any medications or drugs that may make them dizzy or tired;

(3) are currently free of lower extremity pain or injuries;

(4) are not pregnant.

The data was collected on two different days.

The protocol was approved by the university Institutional Review Board.

Table 1: gender, age, height and weight of the subjects

Subject	Gender	Age	Height (cm)	Weight (kg)
1	Male	44	180	77
2	Male	28	190,5	93,44
3	Male	25	177,8	79,38
4	Female	29	167,6	65,77
5	Female	36	162,6	68
6	Male	29	178	62
7	Female	26	171	66,5
8	Female	36	175,26	63,5
9	Male	23	188	82
10	Male	33	177,80	68,04
Mean		**30,9**	**176,86**	**72,56**

3.2 Materials and Equipment

Data collection took place during two testing session in the Neuromechanics Laboratory at the University of Wisconsin-Milwaukee.

Table 2 shows the used equipment for the data collection.

Table 2: Materials and Equipment

Force plate	Name:	FP4060-NC
	Manufacturer:	Bertec Corporation
Single-Camera-System	Name:	Camera Basler A404k MC 40280 Moire Phase Tracking System
	Model:	MPT-S2CLU180
	Manufacturer:	Metria Innovation Inc.
Tracking Program	Name:	Moire Phase Tracking- Series 2- GUI V3.2.4
Other	Retro reflective markers:	Plates made of plastic (7cm x 7cm)

Kinematic data were collected with the single camera system with a sampling rate of 180Hz and kinetic data were recorded at 9000 Hz. The participants wear lab shoes and spandex for standardization purposes.

3.3 Experimental Protocol

Gait analyses were performed on each subject on two different days. Two examiners pointed out the anatomical landmarks. On both testing days the data collection for stance, flex, star and walking trial was the same.

For the analog data, the calibration of the force plate and the camera was necessary. For that, four images are needed. The first one was without any pressure or marker on the force plate. The last pictures were taken with the marker stick, putting some pressure on three different points on the force plate (Figure 9). The use of only one force plate (FP1) made the calibration easier.

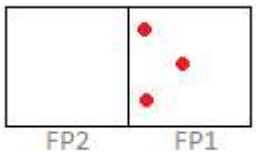

Figure 9: Force plate calibration

To determine the 3D position and orientation of each lower limb segment, retro-reflective markers (Figure 7) were placed to one side of the subject´s pelvis, thigh, shank and foot (Figure 10).

Figure 10: Marker set

First, a standing calibration was recorded. The participants were asked to place their feet as close as possible to the edge of the force plate and their arms crossed the chest. Moreover both tester had to point with a marker fixed on a stick on following anatomical landmarks: right and left ASIS, right and left PSIS, sacrum, GT, LE, ME, LM, MM, MTH1 and MTH5.

The functional approach for the determination of the HJC required a special motion. For that the subjects were asked to draw a star with her or her right/left foot (depends on the chosen side). To avoid a bad data collection, this motion got repeated for three times.

For the functional approach of the KJC the subject had to flex his or her knee five times. To avoid errors and mistakes every trial was repeated for at least three times. The last task was a simple walking trial. For that the subjects were pleased to start at a defined point and to walk with self-selected speed. The starting point was for both days and for every walking trail the same. This helped to eliminate as many variable influences as possible. Subjects performed ten successful walking trials. A successful trial was defined as when right leg initial contact and toe-off occurred on the force plate.

3.4 Data Processing

During the standing calibration the anatomical coordinate systems were established for the pelvis, thigh, shank and foot. The x-axis pointed laterally, the y-axis pointed anteriorly and the z-axis pointed superiorly. The pelvis anatomical system was defined by the right and left ASIS and PSIS. The thigh segment was defined two ways. One was based on palpation of the anatomical landmarks and the other on the functional approach. The hip joint center was defined three ways, GTR, Harrington, functional. Then knee joint center was defined two ways. One was also based on the anatomical landmarks and the other on the functional model. The ankle joint center was defined as the midpoint between the malleoli.

For the walking trials, the kinematic data were filtered using a 4^{th} order, recursive Butterworth filter with a cutoff at 8Hz. The kinetic data were filtered with a recursive low pass filter with sampling rate of 9000Hz. Joint angles were calculated using a joint coordinate system approach (Grood and Suntay 1983). The net joint moments were calculated using an inverse dynamics approach. Only the stance phase was analyzed, which was defined as when the ground reaction force exceeded 10 N. All kinematic data were time normalized to 100% of stance phase.

Initial contact (IC) angles, and the range of motion (RoM) during stance were extracted in all panes for each joint (Figure 11). Peak moments were extracted from the kinetic data (Figure 12). All data processing was performed with an existing customized Matlab program.

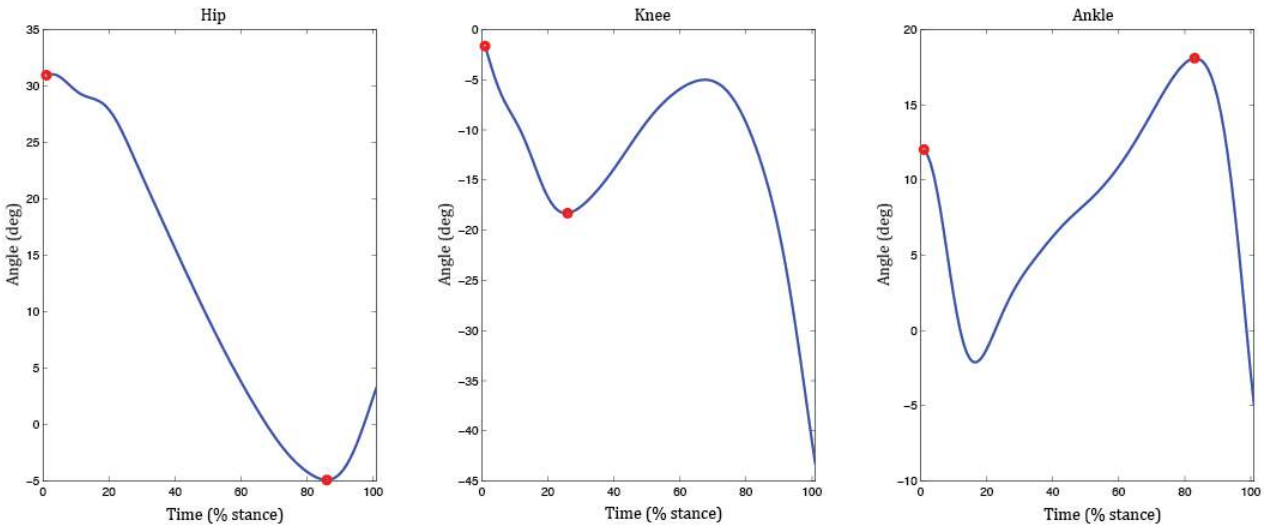

Figure 11: RoM for every joint in the sagittal plane. Blue line represents the angles; the range between the red points (o) describes the RoM

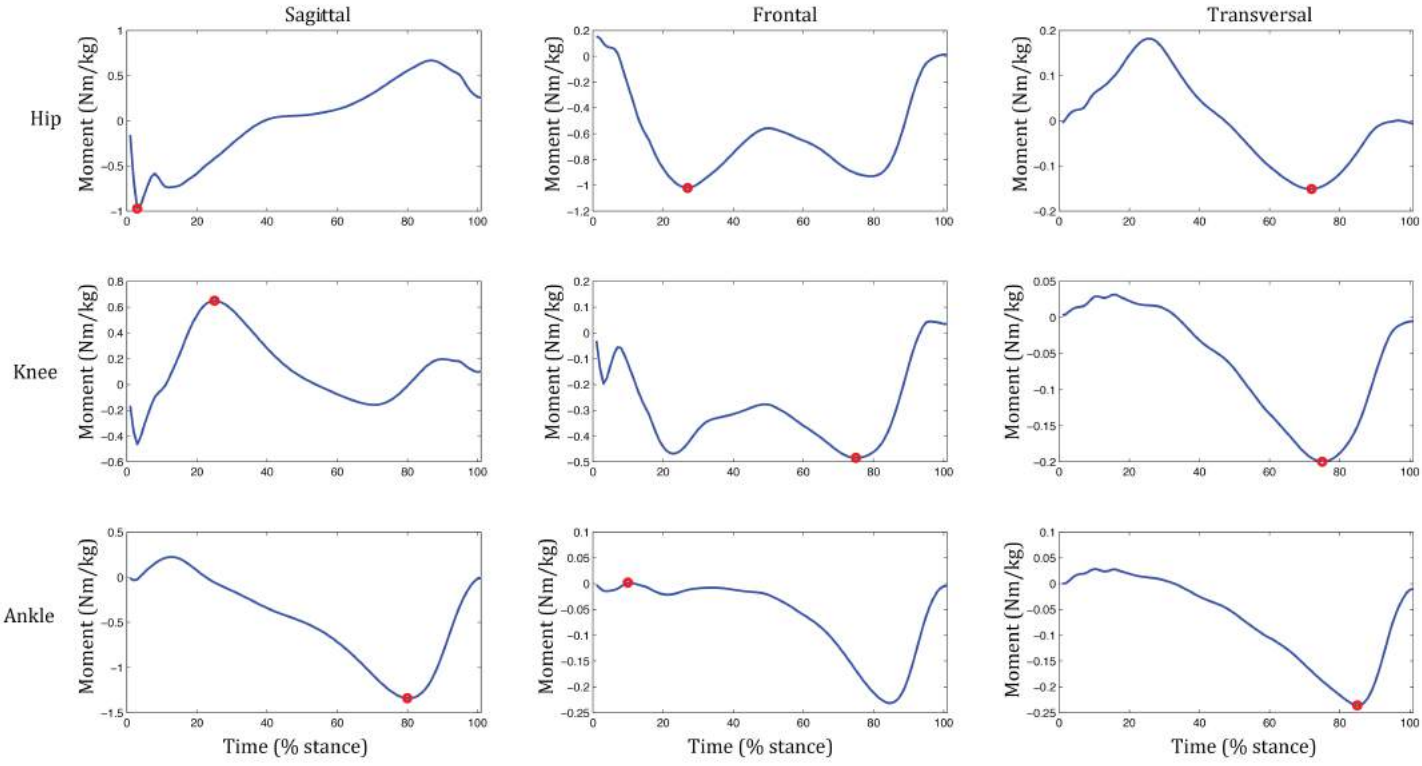

Figure 12: Used peak moments to estimate the reliability for the kinetics

3.5 Statistical Analysis

Focus was to investigate the reliability of the results either between two examiners on the same testing day or between testing days with the same examiner. Figure 13 shows an example for a good and bad coefficient of determination (r^2) between examiners on the first day.

The goal was to determine the influence in the joint centres using different subject calibrations techniques(Figure 4).

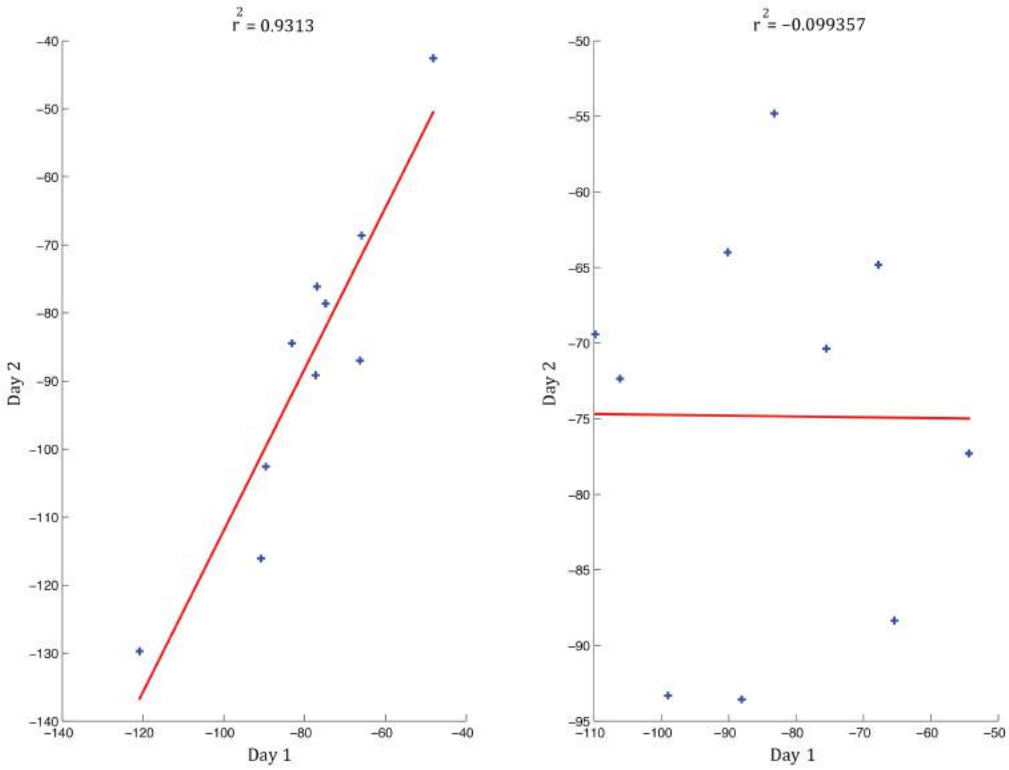

Figure 13: Good and bad correlation (r2 = 0.9313 and r2=-0.099357) between days

4 Results

This research examined the effects of marker displacement on within days and within testers. To reduce as many variable influences the protocol for the data collection was always the same.

For the ankle, knee and hip the mean joint moments (Figure 15) and angles (Figure 14) in the sagittal, frontal and transversal plane of all trials and all subjects were plotted as a function of time. This figures shows a comparison between tree different calculations for the joint centres of the lower limb.

These data were collected and used to determine the correlation within days and testers and to create a plot to show them.

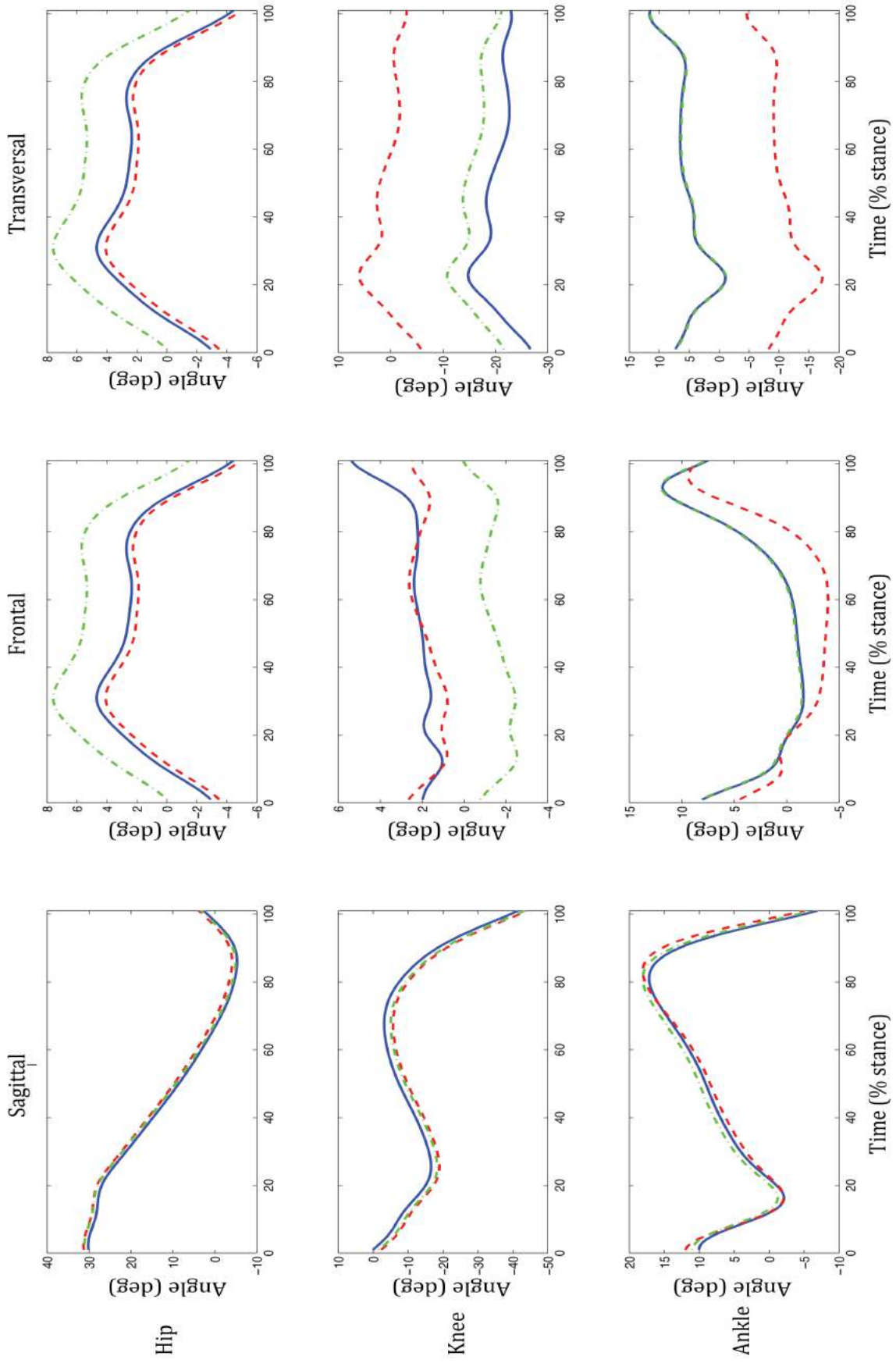

Figure 14. Mean joint angles with three different calculations for the joint centres: (1)Harrington method for the hip, anatomical landmark for the knee and ankle (solid blue line (-)); (2) Greater Trochanter method for the hip, functional approach for the knee and ankle (dashed red line (--)); (3) Functional approach for the hip and knee and anatomical landmarks for the ankle (dashed green line (-.))

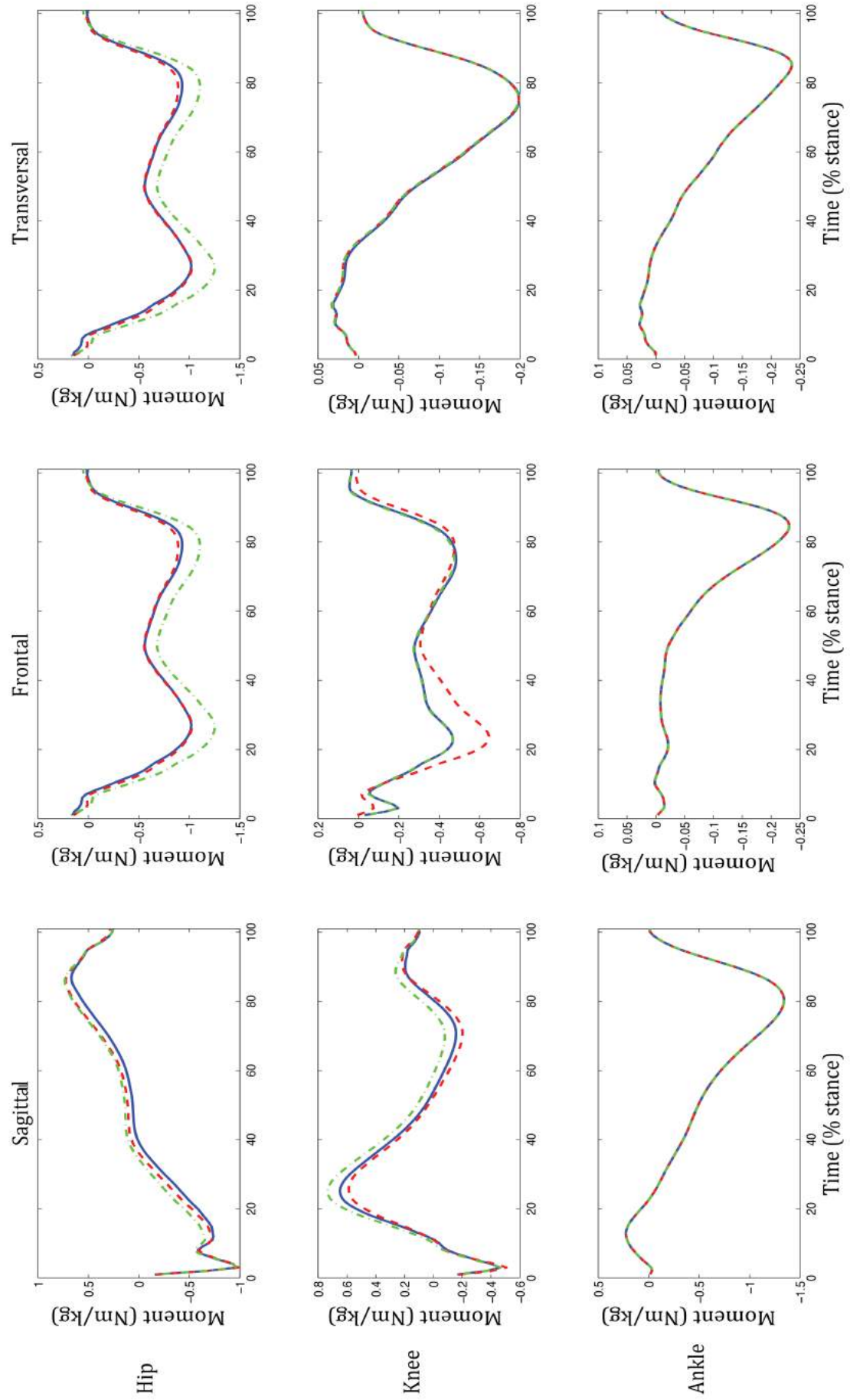

Figure 15: Mean joint moments with three different calculations for the joint centres: (1)Harrington method for the hip, anatomical landmark for the knee and ankle (solid blue line (-)); (2) Greater Trochanter method for the hip, functional approach for the knee and ankle (dashed red line (--)); (3) Functional approach for the hip and knee and anatomical landmarks for the ankle (dashed green line (-.))

Question 1: How does the functional knee method influence the knee and ankle moment?

For this question the calculation of the Greater Trochanter method for the hip and the anatomical landmarks for the ankle were used. For the knee the functional approach and the anatomical landmarks got used.

Basically in the kinematic data the methods didn´t affect the results between examiners. The functional method shows only some improvements for the IC in the sagittal plane for the knee and hip and in the transversal plan for the hip. A huge improvement can be found in the frontal plane for the RoM. In sum both models shows a pretty high reliability between examiners (Table 3).

Reliability between days is nearly based zero in half of the shown planes in Table 3. Only in the frontal plane for the hip, RoM shows a significant improvement for the AL model (Table 3).

Table 3: Repeatability of the kinematics (IC and RoM) between examiners and days

		Ankle		**Knee**		**Hip**	
	Knee Method	IC	RoM	IC	RoM	IC	RoM
Between examiners on the first day							
Sagittal	Anatomical Landmark	1.00	1.00	0.89	0.96	0.71	0.99
	Functional	1.00	1.00	0.97	0.97	0.96	0.99
Frontal	Anatomical Landmark	1.00	1.00	0.92	0.98	0.96	0.50
	Functional	1.00	1.00	0.90	0.98	0.92	0.99
Transversal	Anatomical Landmark	1.00	1.00	0.62	0.99	0.42	0.99
	Functional	1.00	1.00	0.67	0.99	0.83	0.99
Between days with tester 1							
Sagittal	Anatomical Landmark	-0.27	0.46	0.90	0.40	0.29	0.92
	Functional	-0.27	0.46	0.89	0.39	0.15	0.93
Frontal	Anatomical Landmark	0.84	0.97	-0.18	0.80	0.37	0.62
	Functional	0.84	0.97	-0.20	0.81	0.24	-0.01
Transversal	Anatomical Landmark	0.96	0.21	0.24	0.64	0.19	0.85
	Functional	0.96	0.21	0.22	0.64	0.25	0.84

Generally also in the kinetic data the models didn´t affect the moments between examiners. The results suggest a high reliability for the ankle and the knee joint in all of the planes.

The functional model improves the reliability between days only in the sagittal plane for the knee. Reliability in the frontal plane for knee and ankle are nearly based zero.

Table 4: Repeatability of the kinetics between examiners and days

	Sagittal		**Frontal**		**Transversal**	
Knee Method	Ankle	Knee	Ankle	Knee	Ankle	Knee
Between examiners on the first day						
AL	0.99	0.97	0.97	0.79	0.99	0.95
Functional	0.99	0.97	0.97	0.80	0.99	0.95
Between days with tester 1						
AL	0.94	0.69	-0.40	-0.03	0.81	0.56
Functional	0.94	0.87	-0.40	0.05	0.81	0.60

Question 2: How does the three hip methods affect the moment?

For the second question the functional approach for the ankle and knee were used. To answer the question and to see the difference in the data, all three methods (greater trochanter method, Harrington method and functional approach) for the hip are shown.

Table 5 presents the results of the kinematics for the knee between days and examiners. Between examiners, a small improvement for the functional model can be found in the frontal and sagittal plane for the hip for the IC angle. Although the results suggest a high repeatability in all planes for knee and hip, in sum the models didn´t affect the results between examiners.
In principle the models didn´t affect the kinematic results between days. Only in the frontal plane the functional model achieved better reliability results.

Table 5: Reliability of the kinematics between examiners and days

		Knee		**Hip**	
	Hip Method	IC	RoM	IC	RoM
Between examiners on the first day					
	Functional	0.99	0.99	0.98	0.99
Sagittal	GTR	0.99	0.99	0.96	0.99
	Harrington	0.99	0.99	0.92	0.99
	Functional	0.96	1.00	0.94	0.99
Frontal	GTR	0.96	1.00	0.92	0.99
	Harrington	0.96	1.00	0.81	0.98
	Functional	0.98	0.99	0.99	0.99
Transversal	GTR	0.98	0.99	0.99	0.99
	Harrington	0.98	0.99	0.99	0.99
Between days with examiner 1					
	Functional	0.86	0.81	0.21	0.92
Sagittal	GTR	0.86	0.81	0.15	0.93
	Harrington	0.86	0.81	0.32	0.93
	Functional	0.15	0.82	0.41	0.20
Frontal	GTR	0.15	0.82	0.23	-0.01
	Harrington	0.15	0.82	0.27	0.08
	Functional	0.77	0.79	0.67	0.80
Transversal	GTR	0.77	0.79	0.64	0.84
	Harrington	0.77	0.79	0.65	0.81

Basically also in the kinematics the models didn't affect the results between examiners. The results suggest a high and good reliability for hip in all planes and models.

Overall the models affect the kinematic reliability between days. The functional approach shows a significant improvement in the frontal plane. Against the transversal plane the Harrington model achieved a better repeatability than the functional (Table 6).

Table 6: Reliability of the kinetics between examiners and days

Hip method	Sagittal Hip	Frontal Hip	Transversal Hip
Between examiners on the first day			
Functional	0.99	0.99	0.99
GTR	0.99	0.98	0.98
Harrington	0.99	0.89	0.95
Between days with examiner 1			
Functional	0.90	0.50	0.42
GTR	0.93	-0.09	0.33
Harrington	0.90	0.07	0.56

5 Discussion

The purpose of this study was to compare the reliability of lower extremity kinematic and kinetic data using a few different subject calibration models based on functional and anatomical landmark models. It was hypothesized that the functional description for the joint centers would improve the repeatability of the kinetic and kinematic data, compared with the anatomical landmark models (Pohl, Lloyd, and Ferber 2010; Weinhandl and O'Connor 2010; Besier et al. 2003). This assumption got tested using a few different models and only between testers on the first day and between days with one tester (Schwartz, Trost, and Wervey 2004).

All of the used models demonstrated a highly repeatable kinetic and kinematic waveform shapes. The functional model produced slightly more repeatable kinetics and kinematics results in between testers than the AL model. However, the differences between the models were not as predominant as expected. Compared with between testers, the results for between days are less or negative reliable. Main reason for such a low between days repeatability may be marker displacement (Chiari, Croce, Leardini, Cappozzo, Chiari, Croce, and Cappozzo 2005) or soft tissue artifacts (Chiari, Croce, Leardini, Cappozzo, Chiari, Croce, Cappozzo, et al. 2005b) described by Cappozzo, Groce, Leardini and Chiari in 2005. Although it was hypothesized that the functional model would produce a better reliability, the data suggest most of the time no improvement in kinematic and kinetic correlation compared with the AL model. A reason for that could be that all of the ten subjects in this study were healthy with minimal body fat, which would improve the ability to palpate the ALs. In subjects population where palpation of pelvis ALs becomes more difficult, the functional method would be expected to produce more repeatable gait data than the AL model. Therefore the functional approach might also produce more repeatable knee joint kinematics and kinetics than the ALs in subject who have bony deformities of the knee joint, where location of the epicondyles. This would explain the similar results between the models.

But even other several factors might explain the similarities between the models. Both examiners had the same knowledge in locating lower limb ALs such as Greater Trochanter or the ASIS of the hip. Compared with a recent study, where one of the

examiners was a trained physical therapist, the correlation values were surprisingly similar. Although the subjects started walking from the same spot, the walking speed may be different between the days. According to other research projects walking speed has an influence at the reliability and the human gait patterns (Winter 1984; Fortin, Nadeau, and Labelle 2008).

This report reveals some of the problems that may affects the reliability results. Basically the methods didn´t really affect the kinematic and kinetic reliability between examiners and days. Between examiners on one day the kinematic and kinetic results achieved a higher reliability, compared with between days. There most of the results were nearly based zero. As expected at the beginning and confirmed by the results within days, marker misplacement had the most impact beside other influences, like soft tissue artifacts.

The results explained in this report are therefore more of an overview because most of the collected data is still not analyzed to its full extend.

6 Table of figures and tables

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8 Appendix

Appendix A: Consent Form

UNIVERSITY OF WISCONSIN – MILWAUKEE
CONSENT TO PARTICIPATE IN RESEARCH

THIS CONSENT FORM HAS BEEN APPROVED BY THE IRB FOR A ONE YEAR PERIOD

1. General Information

Study title: Reliability of Joint Kinetics using different Subject Calibration Techniques
Person in Charge of Study (Principal Investigator):

- The Principal Investigator (PI) for this study is Kristian O'Connor, PhD., a faculty member in the Department of Kinesiology. The co-PI on this study is Barbara Safarovic, visiting scholar in the Department of Kinesiology.

2. Study Description

You are being asked to participate in a research study.
Your participation is completely voluntary.
You do not have to participate if you do not want to.

Study description:

- The purpose of this study is to compare the reliability of different methods of subject calibration on three-dimensional walking patterns
- This investigation may help with clinical decision making and rehabilitation after injuries.
- This investigation may also help determine clinically relevant measures of walking ability.
- The study is being done at UW Milwaukee, where there will be 10 participants.
- Participants will be tested during two 1 hour sessions across two days

3. Study Procedures

What will I be asked to do if I participate in the study?
If you agree to participate you will be asked to go to the Neuromechanics Laboratory at UW Milwaukee (Enderis Hall, Room 132) for two testing sessions across two days. You will be asked to wear clothing appropriate for physical activity; however, clean, tight-fitting shorts will be provided for you during the testing session.

The tasks you perform will include:

1. You will be given a questionnaire containing questions pertaining to previous lower extremity injuries and your recreational activity level. (10 minutes)
2. Based on answers to questionnaire inclusion and exclusion criteria for the study will be assessed. If you meet necessary criteria for the study testing will begin. If you do not meet criteria for the study you will be ineligible to participate.
3. You will be asked to provide basic demographic information regarding your height, weight, age, gender. (5 minutes)
4. You will be asked to put on tight-fitting shorts, which will be provided for the testing session. (5 minutes)

5. Markers will be applied to your pelvis and dominant leg at specific landmarks. The location of these markers will be recorded as you stand motionless on the force plate. You will also perform three distinct motions (knee, flexion / extension, hip flexion / extension and an arc movement of the hip. (10 minutes)
6. You will walk across the room at a comfortable walking speed five times. (10 minutes)

The tasks described in points 1 to 3 (above) will only be necessary on the first day of testing. Points 4 to 6 apply to both testing days.

The interval between testing day 1 and testing day 2 should be 1 to 5 days.

4. Risks and Minimizing Risks

What risks will I face by participating in this study?

Physical risks

- Muscle soreness as a result of the testing. (Unlikely)
- Injuries such as muscle strain or muscle tightness as a result of the testing session. (Unlikely)
- Minor skin irritation due to the spray tape adhesive or tape. (Unlikely)

Psychological, social, economic risks

- None

Protection of Physical Risks:

To reduce the above risks, practice trials will be performed prior to data collection to allow you to become familiar with each procedure prior to performing a maximal effort trial. If you feel any soreness or irritation while participating in this study, please tell the investigators as soon as possible. If you are injured while participating in this research study, you will initially be provided care by the investigator(s), who are all trained in first aid and CPR. Students will then be referred to the Norris Health Center for follow-up care. Non-students will be referred to their primary care physician and will be responsible for all expenses incurred.

Risks to Privacy and Confidentiality:

Since your private information will be collected for this study, there is always a risk of breach of confidentiality (Very unlikely).

Protection of Risks to Privacy and Confidentiality:

All data will be stored in a locked filing cabinet in a locked room. All data will be given a letter and number that is uniquely associated with you. This code will not contain any partial identifiers (i.e. last four digits of your SSN) and will be stored in a separate locked office in a locked filing cabinet. No identifiers will be stored with the research data. Only those individuals with an active role in this study will have access to the research data and only the PI and Co-PI will have access to identifying information. When all participants' have completed active participation in the study and data collection is completed, the code will be destroyed. All appropriate measures to protect your private information will be taken.

5. Benefits

Will I receive any benefit from my participation in this study?
There are no benefits to you other than to further research. The information which is obtained may be useful scientifically and possibly helpful to others.

6. Study Costs and Compensation

Will I be charged anything for participating in this study?
You will not be responsible for any of the costs from taking part in this research study. You are responsible for your own transportation to and from UWM and for any parking costs for the testing session.

Are subjects paid or given anything for being in the study?
There is no compensation for participating in this study.

7. Confidentiality

What happens to the information collected?
All information collected about you during the course of this study will be kept confidential to the extent permitted by law. We may decide to present what we find to others, or publish our results in scientific journals or at scientific conferences. Only the PI and co-PI will have access to the information. However the Institutional Review Board at UW-Milwaukee or appropriate federal agencies like the Office for Human Research Protections may review this study's records. The confidentiality of your data and information will be safeguarded as outlined in "Risks & Minimizing Risks" section under the "Protection of Risks to Privacy and Confidentiality" header.

8. Alternatives

Are there alternatives to participating in the study?
There are no known alternatives available to you other than not taking part in this study.

9. Voluntary Participation and Withdrawal

What happens if I decide not to be in this study?
Your participation in this study is entirely voluntary. You may choose not to take part in this study. If you decide to take part, you can change your mind later and withdraw from the study. You are free to not answer any questions or withdraw at any time. Your decision will not change any present or future relationships with the University of Wisconsin Milwaukee. If you choose to withdraw, we will use the information collected about you to that point. If you are a student, your refusal to take part in the study will not affect your grade or class standing.

10. Questions

Who do I contact for questions about this study?
For more information about the study or the study procedures or treatments, or to withdraw from the study, contact:

Kristian O'Connor, PhD
Department of Kinesiology
Enderis 471
P.O. Box 413
Milwaukee, WI 53201
414-229-2680

Who do I contact for questions about my rights or complaints towards my treatment as a research subject?
The Institutional Review Board may ask your name, but all complaints are kept in confidence.

Institutional Review Board
Human Research Protection Program
Department of University Safety and Assurances
University of Wisconsin – Milwaukee
P.O. Box 413
Milwaukee, WI 53201
(414) 229-3173

11. Signatures

Research Subject's Consent to Participate in Research:
To voluntarily agree to take part in this study, you must sign on the line below. If you choose to take part in this study, you may withdraw at any time. You are not giving up any of your legal rights by signing this form. Your signature below indicates that you have read or had read to you this entire consent form, including the risks and benefits, and have had all of your questions answered, and that you are 18 years of age or older.

_____
Printed Name of Subject/ Legally Authorized Representative

_____ _____
Signature of Subject/Legally Authorized Representative Date

Principal Investigator (or Designee)
I have given this research subject information on the study that is accurate and sufficient for the subject to fully understand the nature, risks and benefits of the study.

_____ _____
Printed Name of Person Obtaining Consent Study Role

_____ _____
Signature of Person Obtaining Consent Date

Appendix B: Medical History & Physical Activity Questionnaire

Participant Code: ____
Date: _____

Medical History & Physical Activity Questionnaire

Screening Criteria

Please answer the following questions to the best of your ability. Eligible participants will answer "yes" to these questions.

☐ Yes ☐ No Are you between the ages of 18 and 45 years old?

Medical History Questionnaire

For your safety, a list of conditions that would make you unable to participate in this study has been prepared. Please read this list carefully and consider whether any of the conditions apply to you. If any of these conditions are true for you, you will not be able to participate in this study. For each condition, please indicate "yes" or "no" if this is true or not for you.

☐ Yes ☐ No Do you have a medical condition that may impair your walking ability (i.e. concussion, neurological impairments, orthopedic problems ,etc)?

☐ Yes ☐ No Are you taking medications/drugs that may make you dizzy or make you tired (i.e. cold medications, sleeping medications, muscle relaxants)?

☐ Yes ☐ No Do you currently have any lower extremity pain or injury(ies)?

☐ Yes ☐ No Are you pregnant or do you have reason to believe that you may be pregnant?

Comments/Notes: _____

_____

_____

_____

_____

_____

Appendix D: IRB Certificate

UNIVERSITY of WISCONSIN
UWMILWAUKEE
Department of University Safety & Assurances

Melissa Spadanuda
IRB Manager
Institutional Review Board
Engelmann 270
P. O. Box 413
Milwaukee, WI 53201-0413
(414) 229-3173 *phone*
(414) 229-6729 *fax*

http://www.irb.uwm.edu
spadanud@uwm.edu

New Study - Notice of IRB Expedited Approval

Date: November 17, 2015

To: Kristian O'Connor, PhD
Dept: Kinesiology

Cc: Barbara Safarovic

IRB#: 16.142
Title: Reliability of Joint Kinetics using different Subject Calibration Techniques

After review of your research protocol by the University of Wisconsin – Milwaukee Institutional Review Board, your protocol has been approved as minimal risk Expedited under Category 4 as governed by 45 CFR 46.110.

This protocol has been approved on **November 17, 2015** for one year. IRB approval will expire on **November 16, 2016**. If you plan to continue any research related activities (e.g., enrollment of subjects, study interventions, data analysis, etc.) past the date of IRB expiration, a continuation for IRB approval must be filed by the submission deadline. If the study is closed or completed before the IRB expiration date, please notify the IRB by completing and submitting the Continuing Review form found in IRBManager.

Any proposed changes to the protocol must be reviewed by the IRB before implementation, unless the change is specifically necessary to eliminate apparent immediate hazards to the subjects. It is the principal investigator's responsibility to adhere to the policies and guidelines set forth by the UWM IRB, maintain proper documentation of study records and promptly report to the IRB any adverse events which require reporting. The principal investigator is also responsible for ensuring that all study staff receive appropriate training in the ethical guidelines of conducting human subjects research.

As Principal Investigator, it is your responsibility to adhere to UWM and UW System Policies, and any applicable state and federal laws governing activities which are independent of IRB review/approval (e.g., FERPA, Radiation Safety, UWM Data Security, UW System policy on Prizes, Awards and Gifts, state gambling laws, etc.). When conducting research at institutions outside of UWM, be sure to obtain permission and/or approval as required by their policies.

Contact the IRB office if you have any further questions. Thank you for your cooperation and best wishes for a successful project.

Respectfully,
Melissa C Spadanuda
Melissa C. Spadanuda
IRB Manager

Appendix E: Naming Convention

Calibration

Naming Convention	Description
Cal_FP_01	Image without any pressure on the force plate
Cal_FP_02	Put some pressure on a special point the force plate
Cal_FP_03	Put some pressure on a special point the force plate
Cal_FP_04	Put some pressure on a special point the force plate

Subject Calibration

Naming Convention (Subject_Day_Tester_Side_Name_Number)	**Name**	**Description**
Sx_Dx_Tx_R_STANCE_xx	STANCE	Stand still with the arms across the chest
Sx_Dx_Tx_R_RASI_xx	RASI	Right anterior superior iliac spine
Sx_Dx_Tx_R_RPSI_xx	RPSI	Right posterior superior iliac spine
Sx_Dx_Tx_R_LASI_xx	LASI	Left ASIS
Sx_Dx_Tx_R_LPSI_xx	LPSI	Left posterior superior iliac spine
Sx_Dx_Tx_R_SACR_xx	SACR	Sacrum
Sx_Dx_Tx_R_RGTR_xx	RGTR	Right greater trochanter
Sx_Dx_Tx_R_LGTR_xx	LGTR	Left greater trochanter
Sx_Dx_Tx_R_LAKN_xx	LAKN	Lateral epicondyle
Sx_Dx_Tx_R_MEKN_xx	MEKN	Medial epicondyle
Sx_Dx_Tx_R_LAMA_xx	LAMA	Lateral malleolus
Sx_Dx_Tx_R_MEMA_xx	MEMA	Medial malleolus
Sx_Dx_Tx_R_MTH1_xx	MTH1	First metatarsal head
Sx_Dx_Tx_R_MTH5_xx	MTH5	Fifth metatarsal head

Subject Movement

Name	**Naming Convention** (Subject_Day_Side_Name_Number)	**Time** [seconds]	**Repeat**
Star Arc Movement	Sx_Dx_R_STAR_xx	10	3
Knee Flex Movement	Sx_Dx_R_FLEX_xx	7	3
Walking Trial	Sx_DxTx_R_WALK_xx	5	10

List of Abbreviations

Description	Abbreviation
Anterior Superior Iliac Spine	ASIS
Posterior Superior Iliac Spine	PSIS
Sacrum	SACR
Greater Trochanter	GT
Lateral Epicondyle	LE
Medial Epicondyle	ME
Lateral Malleolus	LM
Medial Malleolus	MM
First Metatarsal Head	MTH1
Fifth Metatarsal Head	MTH5
Hip Joint Center	HJC
Knee Joint Center	KJC
Ankle Joint Center	AJC
Symmetrical Axis of Rotation	SARA
Degree of Freedom	DoF
Initial contact	IC
Range of Motion	RoM
Anatomical landmark	AL