AALBORG UNIVERSITY
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# Effect of orthoses on lower extremity biomechanics associated with patellofemoral pain during running gait

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## Abstract

Orthoses are commonly prescribed in clinical treatment of various running-related injuries. However, the underlying mechanisms of orthoses are poorly understood.

The purpose of the study was to determine the effect of anti-pronation orthoses on biomechanical parameters associated with development of patellofemoral pain during running.

Eight healthy recreational runners participated in a cross over study. Each subject was instructed to run on a predefined track in six different configurations of an orthotic running shoe, containing adjustable medial wedge support, adjustable medial longitudinal arch support and adjustable midsole cushioning. Kinematic and kinetic data were obtained from motion capture and force plate system. A subject-specific lower extremity muskuloskeletal model was constructed based on functional joint trials. Inverse dynamics was applied to compute external moments and forces.

The results obtained from the model displayed that anti-pronation orthoses significantly increased foot inversion moment, increased internal foot rotation moment, increased internal knee rotation moment, reduced hip adduction moment and reduced lateral knee shear force during stance phase in running.

These findings supports the clinical application of orthoses as a prophylactic tool against development of patellofemoral pain. However, the orthotic effect was distally oriented with only small or no effect on local and proximal parameters, suggesting only subgroups with distal risk factors may benefit from anti-pronation orthoses.

**Keywords:** Running, PFP, orthoses, inverse dynamics, wedge, arch support, cushion, risk factors.

## Introduction

The popularity of running as a recreational activity has increased throughout recent years in Denmark. Danish Institute for Sports Studies (2011) estimated that 31 percent of the adult Danish population engage in recreational running activities on a regular basis. Numerous health-related benefits from recreational running has been established, including prevention or offset of cardiovascular diseases, cancer, obesity, diabetes and osteoporosis (Warburton et al., 2006). However, engaging in recreational running also possesses an increased risk of sustaining a running-related injury (Taunton et al., 2002).

The prevalence of running-related injuries are high and may induce great socio-economical and personal consequences. Epidemiological studies have reported incident rates of 37% to 56% in recreational runners (Mechelen, 1992). The knee joint is the most exposed injury site, with affiliation to 42.1% of all running-related injuries (Taunton et al., 2002). Patellofemoral pain (PFP) syndrome represents the single most frequent running-related injury, with PFP constituting 39.3% of all knee joint injuries, equivalent to 16.5% of all running-related injuries (Taunton et al., 2002).

A broadly accepted definition of PFP is presented by Juhn (1999) as retropatellar or peripatellar pain resulting from physical and biochemical changes in the patellofemoral joint. PFP is believed to be caused be abnormal patellar tracking and/or patellar malalignment (Grana and Kriegshauser, 1985; Sanchis-Alfonso et al., 1998). However, the underlying risk factors are multifactorial with both proximal, distal and local parameters affecting patellar tracking and malalignment (Powers et al., 2012).

The interface provided by running shoes and cohering orthoses provides the sole interface between the runner and the surrounding environment. During prolonged running, large and repetitive forces are distributed through this interface (Cavanagh and Lafortune, 1980). The design of running shoes and cohering orthoses have the potential to influence this interface and, thereby, alter biomechanical parameters associated with PFP (Nawoczenski et al., 1995; Butler et al., 2007; Lack et al., 2013).

The primary relation between distal biomechanical parameters and the development of PFP are considered to be caused by the tibiocalcaneal coupling. Increased subtalar eversion are believed to cause increased tibial internal rotation (TIR) (Hintermann et al., 1994). Excessive TIR have been proposed as one of the most important etiological factors causing PFP (Tiberio, 1987; Lee et al., 2003). Previous studies have reported that TIR can be affected both by shoe characteristics (Butler et al., 2007) and orthoses (Nawoczenski et al., 1995; Lack et al., 2013).

Anti-pronation orthoses are believed to inhibit excessive subtalar eversion and consequently affecting patellofemoral joint mechanics through the tibiocalcaneal coupling. The clinical application of orthoses have been displayed beneficial in numerous studies (Sutlive et al., 2004; Johnston and Gross, 2004; Collins et al., 2008). However, the underlying mechanism is still not fully understood.

Furthermore, moment and forces acting within the knee joint may also be affected by changes in footwear configuration (Mündermann et al., 2003; Shelburne et al., 2008). Excessive moment and force in both the frontal and transverse plane have been associated with development of PFP (Stefanyshyn et al., 1999; Myer et al., 2014).

This study aims to investigate the effect of commonly used anti-pronation orthoses on biomechanical parameters related to development of PFP during running gait.

It is hypothesized that orthoses primarily affect distally oriented PFP risk factors.

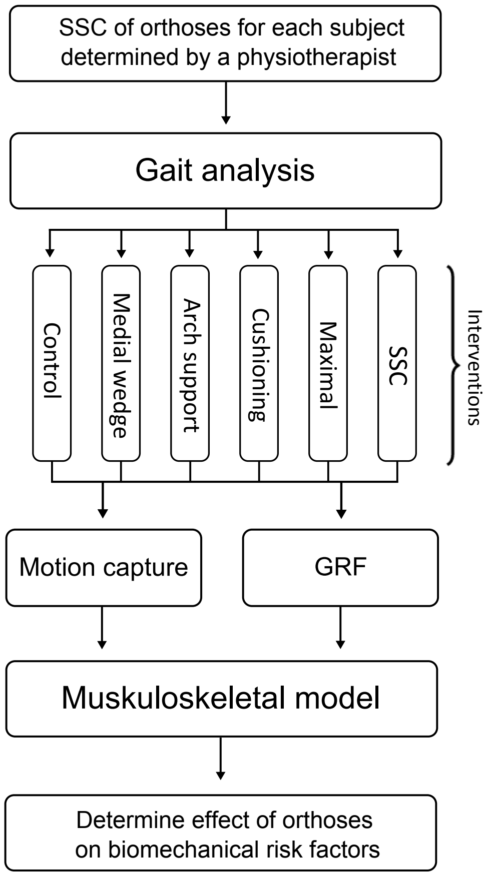


Figure 1: A flowchart representing the general outline of the study. *SSC: Subject-specific configuration.

# Methods

Eight male subjects participated in this study (age: 26.6±1.5 years, mass: 85.9±8.9 kg, height: 181.5±5.4 cm)(mean±SD) and were measured on both extremities. All subjects were recreational runners (17.5±7.9 km/week) with neutral to pronated foot posture (foot posture index: 4.4±2.7) and without lower extremity injuries at the time of the study.

All standards of the Declaration of Helsinki were accommodated and a written consent was obtained from all subjects. Power calculations were based on Bates et al. (1979) and displayed that a minimum of five subjects, measured on both extremities, were required in order to obtain a power of 0.8 and an $\alpha$-value of 0.05.

Prior to measurements, each subject underwent a running style analysis performed by a physiotherapist in order to identify subject-specific requirements for running shoes and cohering orthoses. All subjects exhibited a heel-to-toe running style.

## Orthoses

The orthoses used in this study are part of an adjustable running shoe system named F.E.A.T (Newline A/S, Denmark). The system provides insoles with three levels of longitudinal arch support, medial wedges with three heights and adjustable midsole with three levels of cushioning in the posterolateral and anteriomedial part.

The orthoses were all designed to inhibit excessive pronation trough different pathways.

| Intervention | Abbr. | Description |
|---|---|---|
| Control insole | Control | A standard flat insole with no orthotic effect. |
| Medial wedge | Wedge | A 4 mm medial wedge placed beneath a standard flat insole. |
| Medial arch support | Arch | An insole with embedded medial longitudinal arch support. |
| Midsole cushion | Cushion | Soft midsole cushioning placed posterolateral and hard cushioning placed anteromedial. |
| Maximal anti-pronation | Max | A combination of both wedge, arch and cushion. |
| Subject-specific configuration | SSC | Orthoses configuration based on running style analysis to fit subject-specific requirements. |

Table 1: Overview and description of the orthoses used as interventions in this study.


Figure 2: Displays the orthoses used in this study: (a) the control insole, (b) the insole with arch support, (c) the wedge and (d) the midsole cushion seen from dorsal view.

## Marker protocol

Retro-reflective skin markers were placed on the lower extremities of the subjects according to the Vicon Plug-in Gait protocol (Tabakin, 2007), with additional markers from the uOttawa marker set (Robertson, 2006) to identify the fifth metatarsal joint, medial malleolus and medial epicondyle. Furthermore, two additional markers were placed on the proximal and distal part of the thigh and shank, respectively, and one on patella. Markers identifying first metatarsal joint, fifth metatarsal joint and calcaneus were placed on the outside of the running shoes.

## Test protocol

The subjects were allowed a 10 minutes warm-up to familiarize with the environment and measurement system. Each subject was instructed to run on a 12 m predefined track at a self-selected speed in six randomized conditions (see Table 1). Each condition was repeated ten times on each leg to account for variability. Sufficient time for restitution were allowed between trials in order to eliminate fatigue.

## Experimental setup

Kinematic and kinetic data were recorded using eight infrared cameras (Oqus 300/310, Qualisys AB, Sweden) sampling at 256 Hz. Ground reaction forces (GRF) were measured using a force platform (AMTI OR 6-6, Advanced Mechanical Technology Inc., Massachusetts, USA) sampling at 1000 Hz. Data from infrared cameras and force platform were synchronized and managed using Qualisys Track Manager 2.9 (Qualisys AB, Sweden).

## Subject-specific model

A static reference and dynamic functional trials were recorded, following the method described by Lund et al. (2011), in order to determine subject-specific joint centers and axis directions of the lower extremities.

A subject-specific inverse dynamics model was constructed of the lower extremities for each individual subject by imposing joint parameters onto a cadaver model. The knee, subtalar and ankle articulations were defined as revolute joints. The hip articulation was defined as a spherical joint. The model hold a total of 18 degress of freedom. (Lund et al., 2011)

## Data analysis

For all trials gap-filling, marker labeling and cropping were performed in Qualisys Track Manager 2.9, marker trajectories and GRF were exported to C3D-files. A zero phase fourth order low pass Butterworth filter with a cut off frequency of 35

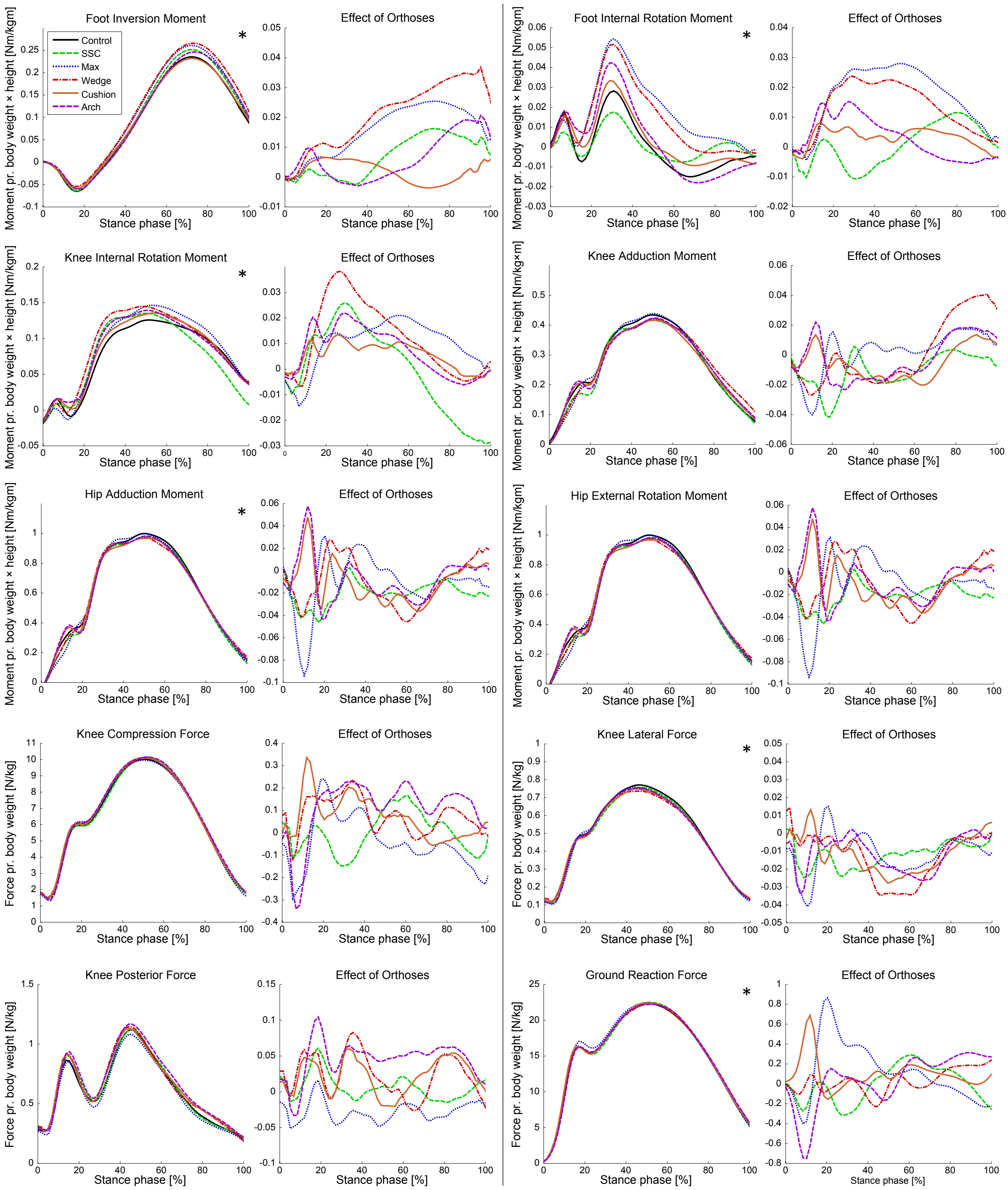


Figure 3: Group mean values for selected output parameters during stance phase for all six interventions. The "Effect of Orthoses" graphs represent the difference between individual interventions and the control condition. In graphs marked with an ∗ at least one condition is significantly different from control condition.

Hz was applied to the kinematic data. Kinematic and kinetic data were used to drive subject-specific inverse dynamics models in AnyBody Modeling System (AMS) v.6.0.3 (AnyBody Technology A/S, Denmark). Subsequently, inverse dynamics data were exported to H5-files for further analysis in MATLAB R2013b (Math-Works, MA., USA). Data were categorized, manually inspected and stance phase were identified by onset and offset of GRF. External moments were normalized to body height multiplied by body mass and forces were normalized to body mass of each subject. Peak and mean values were computed for each parameter during stance phase in each trial and exported to SPSS

| | Peak values | Control | Wedge | Arch | Cushion | Max | SSC |
|---|---|---|---|---|---|---|---|
| Moment [Nm/kgm] | Foot inversion | 0.26±0.09 | 0.29±0.10* | 0.27±0.09 | 0.26±0.09 | 0.21±0.10* | 0.26±0.09 |
| | Foot eversion | 0.074±0.04 | 0.068±0.04 | 0.073±0.04 | 0.074±0.04 | 0.066±0.03* | 0.067±0.03* |
| | Foot int. rotation | 0.11±0.05 | 0.14±0.06* | 0.11±0.07 | 0.12±0.07 | 0.15±0.08* | 0.11±0.05 |
| | Knee adduction | 0.47±0.11 | 0.47±0.12 | 0.46±0.11 | 0.47±0.11 | 0.47±0.13 | 0.44±0.11 |
| | Knee int. rotation | 0.19±0.08 | 0.22±0.08* | 0.21±0.1 | 0.20±0.09 | 0.21±0.09* | 0.19±0.08 |
| | Hip ext. rotation | 0.47±0.12 | 0.46±0.13 | 0.45±0.12 | 0.46±0.14 | 0.45±0.14 | 0.48±0.14 |
| | Hip adduction | 1.02±0.15 | 1.03±0.15 | 1.02±0.16 | 1.02±0.17 | 1.01±0.15 | 1.01±0.14 |
| Force [N/kg] | Knee compression | 9.79±2.11 | 9.67±2.19 | 9.74±2.14 | 9.75±2.26 | 9.62±2.24 | 9.79±2.04 |
| | Knee lateral shear | 0.82±0.25 | 0.80±0.25 | 0.80±0.24 | 0.80±0.24 | 0.79±0.24* | 0.80±0.23 |
| | Knee post. shear | 1.11±0.35 | 1.10±0.36 | 1.13±0.37 | 1.10±0.38 | 1.07±0.38 | 1.12±0.38 |
| | vGRF | 22.36±2.04 | 22.42±2.09 | 22.44±2.13 | 22.51±2.13 | 22.37±2.07 | 22.28±1.48 |
| | Impact vGRF | 16.63±1.37 | 16.49±2.26 | 16.85±1.72 | 16.88±2.25 | 17.37±1.42* | 16.51±1.58 |

Table 2: Table presenting group peak values for select output parameters with cohering standard deviation for all interventions. Significant from control condition are displayed with an *.

(IBM Corporation, New York, USA) for statistical analysis.

All output parameters were computed according to joint coordinate recommendations of the International Society of Biomechanics (Wu and Cavanagh, 1995; Wu et al., 2002).

### Statistics

Statistical analysis was performed with the statistical software SPSS (IBM Corporation, New York, USA). One-way repeated measure analysis of variance was used to detect differences between interventions. Fisher's least significant difference test was applied to conduct pairwise comparison between control condition and interventions. The statistical analysis was conducted at 95% confidence level and a p-value $< 0.05$ was considered statistical significant.

## Results

Mean group graphs for selected parameters are displayed in Figure 3 with a graphical presentation of the effect of orthoses compared with control condition. Peak and mean values for selected parameters are displayed in Table 2 and Table 3 respectively.

### Wedge

The wedge condition significantly increased peak foot inversion moment (13.1%, $p = 0.04$), increased peak foot internal rotation moment (23.9%, $p = 0.002$), increased mean foot internal rotation moment (316.7%, $p < 0.001$), increased peak internal knee rotational moment (10.9%, $p = 0.006$) and increased mean internal knee rotational moment (12.4%, $p = 0.04$).

### Arch support

No significant effect was induced by the arch support condition. However, the arch support condition trended similar behavior as the other conditions.

### Cushion

No significant effect was induced by the cushion condition.

### Maximal Anti-pronation

The max condition significantly decreased peak foot inversion moment (20.4%, $p = 0.01$), decreased peak foot eversion moment (11.2%, $p = 0.03$), increased mean foot inversion moment (17.1%, $p = 0.01$), increased peak foot internal rotation moment (28%, $p = 0.003$), increased mean foot internal rotation moment (271.9%, $p = 0.001$), increased peak knee internal rotation moment (9.5%, $p = 0.05$), increased mean knee internal rotation moment (12.6%, $p = 0.02$), decreased peak lateral shear knee force (3.5%, $p = 0.003$), decreased mean lateral shear knee force (2.2%, $p = 0.003$), decreased mean hip adduction moment (HAM) (1.8%, $p = 0.03$) and increased vertical ground reaction force (vGRF) at impact (4.4%, $p = 0.008$).

### SSC

The subject-specific configuration (SSC) condition significantly decreased peak foot eversion moment (9.9%, $p = 0.009$) and increased mean foot inversion moment (14.7%, $p = 0.005$). Two subjects did not complete the SSC intervention.

| | Mean values | Control | Wedge | Arch | Cushion | Max | SSC |
|---|---|---|---|---|---|---|---|
| Moment [$Nm/kgm$] | Foot inversion | 0.093±0.06 | 0.107±0.07 | 0.094±0.06 | 0.090±0.06 | 0.109±0.06* | 0.107±0.05* |
| | Foot int. rotation | 0.007±0.04 | 0.030±0.04* | 0.012±0.05 | 0.009±0.05 | 0.027±0.04* | 0.011±0.04 |
| | Knee adduction | 0.27±0.07 | 0.27±0.07 | 0.27±0.07 | 0.26±0.07 | 0.27±0.07 | 0.27±0.07 |
| | Knee int. rotation | 0.076±0.05 | 0.086±0.06* | 0.081±0.07 | 0.080±0.06 | 0.086±0.06* | 0.074±0.06 |
| | Hip ext. rotation | 0.17±0.05 | 0.17±0.06 | 0.17±0.06 | 0.17±0.06 | 0.17±0.06 | 0.18±0.06 |
| | Hip adduction | 0.59±0.08 | 0.58±0.08 | 0.58±0.09 | 0.58±0.08 | 0.57±0.08* | 0.58±0.09 |
| Force [$N/kg$] | Knee compression | 6.01±1.21 | 5.98±1.19 | 6.04±1.15 | 6.00±1.16 | 5.96±1.23 | 6.01±1.23 |
| | Knee lateral shear | 0.51±0.16 | 0.50±0.16 | 0.50±0.16 | 0.50±0.16 | 0.49±0.16* | 0.50±0.15 |
| | Knee post. shear | 0.59±0.20 | 0.58±0.21 | 0.60±0.21 | 0.58±0.21 | 0.56±0.20 | 0.59±0.21 |
| | vGRF | 15.00±0.80 | 14.88±1.05 | 15.02±0.77 | 15.05±0.84 | 15.08±0.90 | 15.00±0.90 |

Table 3: Table presenting group mean values for select output parameters with cohering standard deviation for all interventions. Significant from control condition are displayed with an *.

# Discussion

This study aimed to investigate the effect of anti-pronation orthoses on biomechanical parameters assosiated with PFP during running gait. The main effect from the orthoses was observed in ankle joint complex moments and transversal knee joint moments. However, small but significant effects were observed in the frontal hip moments and mediolateral knee joint shear forces. The hypothesis that the effect of orthoses are distally oriented was confirmed by the results.

## Medial Wedge

The medial wedge, max and SSC condition significantly increased foot inversion moment. Similar response have previously been reported by Nester et al. (2003). McClay (2000) proposed that increased foot inversion moment may be linked to a decrease in foot eversion. This observation suggests that the orthoses may be able to inhibited excessive pronation.

In both the wedge and max condition a significant effect on internal foot rotation moment was observed. Foot rotation have been linked to changes in mediolateral knee shear forces and knee adduction moments during gait (Lynn et al., 2008). However, no study have yet investigated the relation between internal foot rotation moment and foot rotation. Conclusion based on findings obtained regarding internal foot rotation moment are not possible at this given point.

Is was expected that a medial wedge would affect the knee adduction moment (KAM). However, this was not the case in this study. KAM have previously been suggested as a risk factor associated with PFP (Stefanyshyn et al., 2006). Studies by MacLean et al. (2006) and Mündermann et al. (2003) also found no change in peak KAM as a response to orthoses, however the latter study did find a change in the timing of the peak KAM. Controversially, Williams et al. (2003) did find that orthoses reduced KAM significantly in runners.

The wedge and max condition did display significant changes in the internal knee rotation moment. This observation further supports the tibiocalcaneal coupling as important when assessing orthotic effects. Mündermann et al. (2003) displayed that an increased knee internal rotation moment is closely correlated to a decrease in TIR. This correlation suggest that a medial wedge may provide a decrease in TIR and therefore provide a prophylactic effect related to PFP.

However, Stefanyshyn et al. (1999) reported that increased internal knee rotation moment may be a contributing factor to development of PFP. It can be speculated that this observation was a compensatory effect induced by subjects in order to run pain free.

## Arch support

The arch support condition displayed no significant effect on the biomechanical parameters investigated in this study. However, the arch support induced similar but smaller effect to most parameters compared with the wedge and max condition. This may indicate that the orthotic effect of arch support are small. Furthermore, the effectiveness of medial arch support depends on the individuals degree of dynamic navicular drop (Boozer et al., 2001). Unpublished data by Pedersen (2014b) displayed that the specific arch support orthoses used in this study did affect center of pressure and peak plantar pressure during treadmill running, suggesting that small biomechanical alterations induced by the arch support may not be detectable with the method applied in this study.

Another determinant that may be affecting the applicability of arch support is fatigue. This study was specifically designed to test the subjects in a non-fatigued state. However, previous studies have displayed that the navicular drop increases during prolonged running where fatigue is induced (Headlee et al., 2008). This indicates that arch support orthoses may provide a greater prophylactic effect during prolonged exercise, than expressed in this study.

## Cushion

The orthotic effect of placing soft midsole cushioning posterolateral and hard cushioning anteromedial was not measurable in this current study. Similar findings was also presented by Heidenfelder et al. (2010).

The cushion intervention may not induce a measurable kinetic or kinematic effect, however, previously unpublished data by Pedersen (2014a) displayed significant changes in local peak plantar pressure.

Introduction of advanced foot models incorporating plantar pressure data may provide insight in what mechanisms may be affected by midsole modifications (Oosterwaal et al., 2011).

## Maximal Anti-pronation

The maximal anti-pronation intervention displayed the largest effect on lower extremity biomechanics of all the interventions.

The combination of three different orthoses, that constituted the max condition, significantly increased the foot inversion moment and increased the internal knee rotational moment. Furthermore, this intervention was the only one producing local knee adaptions by significantly reducing lateral knee shear forces. The relation between lateral knee shear forces and PFP have, to this authors knowledge, not been described in the literature, however it can be speculated that diminution of mediolateral and anteroposterior shear forces may cause less stress on soft tissue and retention of normal alignment.

Furthermore, the max condition displayed a small but significant reduction in HAM. A study by Ireland et al. (2003) suggest that strength deficits in the hip musculature of PFP patients may provide inadequate response to external HAM during running, causing excessive knee valgus and malalignment. Orthoses may moderate the required hip strength to maintain healthy lower extremity alignment.

The max condition significantly increased the vertical ground reaction force at impact, which displays the shock absorption capabilities of foot pronation. An important consideration rises when controlling foot motion, because pronation acts as a double-edged sword. Too much pronation may cause increased TIR resulting in PFP, alternatively too little pronation may cause increased impact forces accelerating articular cartilage degeneration, which consequently may lead to osteoarthritis (Syed and Davis, 2000). It is therefore recommended that healthy individuals demonstrate a conservative approach to pronation control.

## SSC

The SSC condition was a subject-specific configuration of multiple orthoses. The SSC condition generally displayed similar, but less distinct impact on investigated parameters compared with the max condition. This observation is generally in agreement with what was expected, because the SSC condition induced an intervention that mechanically was positioned between the control and maximal condition. Furthermore, it must be expected that a prophylactic approach is conservative by default in order not to trigger an undesirable biomechanical response e.g. excessive inhibition of natural pronation.

Based on this current study no evidence suggest that an orthoses configuration performed by an physiotherapist is superior compared with standard configurations. However, several factors such as proprioception, comfort and long term use was not addressed in this study, which may affect the prophylactic effect.

## The Model

A subject-specific model was used in this study in order to increase the validity compared with standard inverse dynamics models. However, the model is still based on various assumptions and simplifications, which may affect the outcome. Therefore, further attention should be directed towards validation, before this specific model is applied in clinical application. If the model is found valid, it may provide a useful method for applying subject-specific inverse dynamics in large scale clinical studies, where detailed subject-specific inverse dynamics models based on magnetic resonance imaging or computed tomography may be too expensive or time consuming.

A test-retest was applied to the model prior to the study. The test-retest was applied to both feet of one subject tested one week apart. Results displayed that most parameters (75%) had a correlation coefficient value above 0.95. Some parameters (16%), on the other hand, displayed poor values below 0.80. The test-retest indicate acceptable reliability, however more studies are needed to verify these results.

## Subject-specific Response

Previously studies have reported large interindividual variability in the response to orthoses (Stacoff et al., 2000; Nigg et al., 2003). One possible explanation for this, may be due to the individual foot posture of the subjects. In this study the subject (nr. 7) with the lowest FPI score of +1, indicating a borderlining neutral to subinated foot posture, displayed an opposing foot inversion moment compared with the group mean. This may indicate that only subjects with a certain degree of pronation will benefit from anti-pronation orthoses.

Furthermore, several subjects expressed that the perception and comfort greatly varied between conditions, suggesting that increased motor control may be invoked in unfamiliar conditions, and diminish during longer exposure.

In all interventions the orthoses displayed the greatest effect on distal parameters and small on local and proximal parameters. Intuitively, this was expected as the intervention was applied distally. This observation suggests that only individuals displaying distal risk factors associated with PFP may benefit from orthoses during running. Alternative prophylactic measures may be required for PFP subgroups displaying proximal risk factors.

# Conclusion

The findings of this study displays that anti-pronation orthoses significantly affect foot, knee and hip joint moments associated with development of patellofemoral pain. This supports the clinical application of anti-pronation orthoses as a prophylactic tool. The primary effect of orthoses was distally oriented suggesting that subjects with distal risk factors may benefit in a greater extend from foot orthoses compared with other risk groups.

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**Title:**

**Effect of orthoses on lower extremity biomechanics associated with patellofemoral pain during running gait**

**Topic:**

Master thesis

**Project period:**

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**Project group:**

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**Participant:**

Dennis Pedersen

**Supervisors:** Christian Gammelgaard Olesen

Michael Skipper Andersen

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**Synopsis:**

Orthoses are commonly prescribed in clinical treatment of various running-related injuries. However, the underlying mechanisms of orthoses are poorly understood.

The purpose of the study was to determine the effect of anti-pronation orthoses on biomechanical parameters associated with development of patellofemoral pain during running.

Eight healthy recreational runners participated in a cross over study. Each subject was instructed to run on a predefined track in six different configurations of an orthotic running shoe, containing adjustable medial wedge support, adjustable medial longitudinal arch support and adjustable midsole cushioning. Kinematic and kinetic data were obtained from motion capture and force plate system. A subject-specific lower extremity muskuloskeletal model was constructed based on functional joint trials. Inverse dynamics was applied to compute external moments and forces.

The results obtained from the model displayed that anti-pronation orthoses significantly increased foot inversion moment, increased internal foot rotation moment, increased internal knee rotation moment, reduced hip adduction moment and reduced lateral knee shear force during stance phase in running.

These findings supports the clinical application of orthoses as a prophylactic tool against development of patellofemoral pain. However, the orthotic effect was distally oriented with only small or no effect on local and proximal parameters, suggesting only subgroups with distal risk factors may benefit from anti-pronation orthoses.

# Preface

The succeeding worksheets are supplementary reading to the main article and should not be considered and independent rapport. Documentation and related material addressed to individuals seeking to investigate similar matters can also be found in the following chapters.

# Contents

# 1 Danish Summary

Dette speciale er en del af et samarbejde med virksomheden Newline A/S. Formålet var at undersøge og kvantificere effekten af deres nylanceret konfigurerbare løbesko med tilhørende ortoser.

Der er en udbredt klinisk opfattelse, at ortoser og ændringer af skodesign kan reducerer både smerte og forekomst af løberelateret skader (Sutlive et al., 2004; Johnston and Gross, 2004; Collins et al., 2008). Den underliggende forklaring på ortosers skadesforebyggende effekt er dog ikke i tilstrækkelig grad forstået.

En case kontrol undersøgelse blev effektueret, for at klarlægge den biomekaniske effekt af anti-pronations ortoser på risikofaktorer associeret med den hyppigste løberelateret skade, patellofemoral smertesyndrom (PFPS) (Taunton et al., 2002).

Otte raske løbere blev rekrutteret til undersøgelsen. Deltagerne blev instrueret til at løbe på en prædefineret bane med seks forskellige sko- og ortose konfigurering: 1. control, 2. 4 mm medial kile, 3. svangstøtte, 4. midtersål med blødt materiale placeret posterolateral og hårdt materiale anteromedial, 5. en kombination af medial kile, svangstøtte og ændret midtersål, 6. en bruger specifik konfigurering af ortoser baseret på løbestilsanalyse.

Kinematik og kinetik blev registreret med et motion-capture og kraftplatforms system. Efterfølgende blev en patient-specifik muskuloskeletal model konstrueret, baseret på funktionelle led øvelser udført af den enkelte participant (Lund et al., 2011). Invers dynamik blev anvendt til at beregne eksterne momenter og kræfter, associeret med PFPS, under stand fase i løb.

Resultaterne fra undersøgelsen viste at svangstøtte (3) og midtersål (4) interventionerne alene ikke influerede de undersøgte parametre signifikant. Brugerspecifik ortose konfiguration (6), medial kile (2) og en kombination af alle orthoser (5) viste at have signifikant indflydelse på en række biomekaniske parametre. Herunder øget inversionsmoment i fodleddet, øget intern rotationsmoment i fodleddet, øget intern rotationsmoment i knæleddet, reduceret adduktionsmoment i hofteleddet og reduceret laterale forskydningskræfter i knæleddet.

Resultaterne fra undersøgelsen understøtter den kliniske anvendelse af anti-pronations ortoser, som instrument i forebyggelse og behandling af PFPS. Det skal dog bemærkes at den inducerede effekt fra ortoserne var distalt orienteret, med kun ringe eller ingen effekt på lokale og proksimale risikofaktorer. Dette antyder at hovedsageligt undergrupper med patologiske fødder vil have gavn af anti-pronations ortoser.

# Foot Function 2

This chapter has previously been presented in Pedersen (2014) and will briefly describe and discuss the function and complication regarding pronation and supination of the foot.

## 2.1 Pronation

Pronation is inward rotation of the foot and is defined as calcaneal eversion, abduction and dorsiflexion, see fig. 2.1. Pronation is a normal function of the lower extremity and is utilized in order to provide shock absorption. Furthermore, the metatarsal joints unlocks during pronation allowing increased mobility in the foot in order to compensate for uneven terrain (Pamela K. Levangie, 2011).
There is still a lot of controversy about the relationship between pronation and running related injuries. However, a recent meta-analysis found a weak, but significant, correlation between excessive pronation and overuse injuries (Tong and Kong, 2013).
Some evidence suggest a connection between pronation and internal axial tibial rotation. Therefore, excessive pronation may lead to excessive internal rotation of tibia. This may cause misalignment of the patellofemoral joint leading to complications like patellofemoral pain syndrome. (Tiberio, 1986)

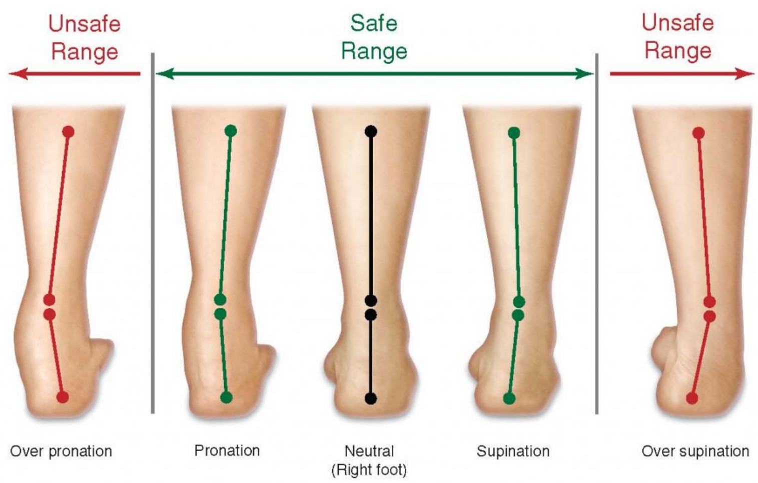



*Figure 2.1: Illustration of a right foot in different ranges of pronation and supination. (BodyScientific, 2013)*

## 2.2 Supination

Supination is outward rotation of the foot and is defined as calcaneal inversion, adduction and plantar flexion, see fig. 2.1 (Pamela K. Levangie, 2011).
Supination normally occur during late stance phase where prolusion is initiated. Supination locks the metatarsal joints providing a rigid lever arm in order to provide maximal propulsive force. (Bolgla and Malone, 2004)
Hypersupination is far less common than hyperpronation and is therefore of less prophylactic interest. Hypersupination may cause injuries like shin splints, plantar fasciitis and stress fractures due to the decreased shock absorption during supination (Pamela K. Levangie, 2011).

# Orthoses 3

This chapter will describe the most commonly used orthoses and the theoretical background behind these. Furthermore, current literature investigating the effect of those orthoses will be discussed. Section 3.1 and 3.2 has previously been presented in Pedersen (2014).

## 3.1 Arch support

It have been established that the height of the medial longitudinal arch of the foot, see fig. 3.1, are related to different injury patterns. Runners with a high arch have a higher incidence rate of ankle injuries, bony injuries and lateral injuries. Whereas runners with a low arch are more likely to exhibit knee injuries, soft tissue injuries and medial injuries (Williams et al., 2001). By posting excessive material in the compartment underneath the medial arch, orthoses hinders it from collapsing and thereby remains in an anatomically normal position. The underlying mechanism behind the correlation between arch height and running related injuries are not fully understood. One theoretical explanation to the importance of the arch height has been its connection to pronation.
A study by Boozer et al. (2002) displayed that there exist a relationship between arch height and calcaneal eversion during running. Furthermore, a study by Nigg et al. (1993) found the arch height to influence the kinematic coupling at the angle joint complex. The study displayed that the arch height affected the transfer of foot eversion to tibial rotation in some degree (Nigg et al., 1993). Both studies indicate that arch height is an important factor when assessing running related injuries.

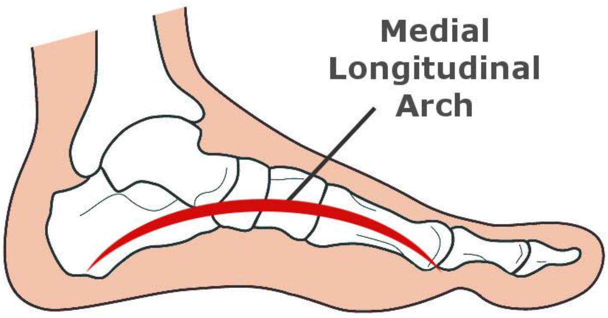



*Figure 3.1: Illustration of the medial longitudinal arch in medial view. (Natural Running Center, 2013)*

## 3.2 Wedge

The therapeutic effect of wedges are believed to lie in its ability to control calcaneal eversion-inversion. Lateral wedges increase eversion and decrease inversion, contrary a medial wedge that increase inversion and decrease eversion.

Lateral wedge are the most applied type of wedges. The primary usage for lateral wedges are in patients with knee osteoarthritis. A previous study by Kakihana et al. (2005) displayed that lateral wedge decrease the abduction moment in the knee. Studies investigating the effect of medial wedges are sparse, however, one study by Perry and Lafortune (1995) displayed that medial wedges decrease calcaneal eversion. The study also revealed that medial wedges increase the impact peak during running.

It is believed that a medial wedge can decrease the loading in the lateral compartment of the knee. Furthermore, a decrease in calcaneal eversion is linked to a decrease in pronation. Therefore, medial wedges may also be beneficial for subjects with excessive pronation.

*Figure 3.2: Illustration of medial wedge support in posterior view. (BodyScientific, 2013)*

## 3.3 Cushion

Anti-pronation cushioning is designed with a softer material in the posterolateral part of the midsole (also known as a crash pad) and a harder material in the anteriomedial part.

The theory behind this midsole construction is that during heel strike the posterolateral cushioning will deform and decelerate the rearfoot eversion. Hardening of the anteriomedial midsole will reduce the inward motion of the forefoot by increasing the deceleration.

Heidenfelder et al. (2010) displayed that increased crash pad thickness reduces the impact forces, without affecting the rearfoot stability. Furthermore, Sterzing et al. (2013) displayed that rearfoot cushioning hardness affected impact forces and that forefoot cushioning did not affect reaction forces.

Pedersen (2014) have previously found that the cushioning method investigated in this study significantly reduces plantar pressure in the posterolateral part of the foot and increases in the anteriomedial part, see fig. 3.3.

However, no studies have investigated the proposed anti-pronation abilities of the anti-pronation midsole construction.

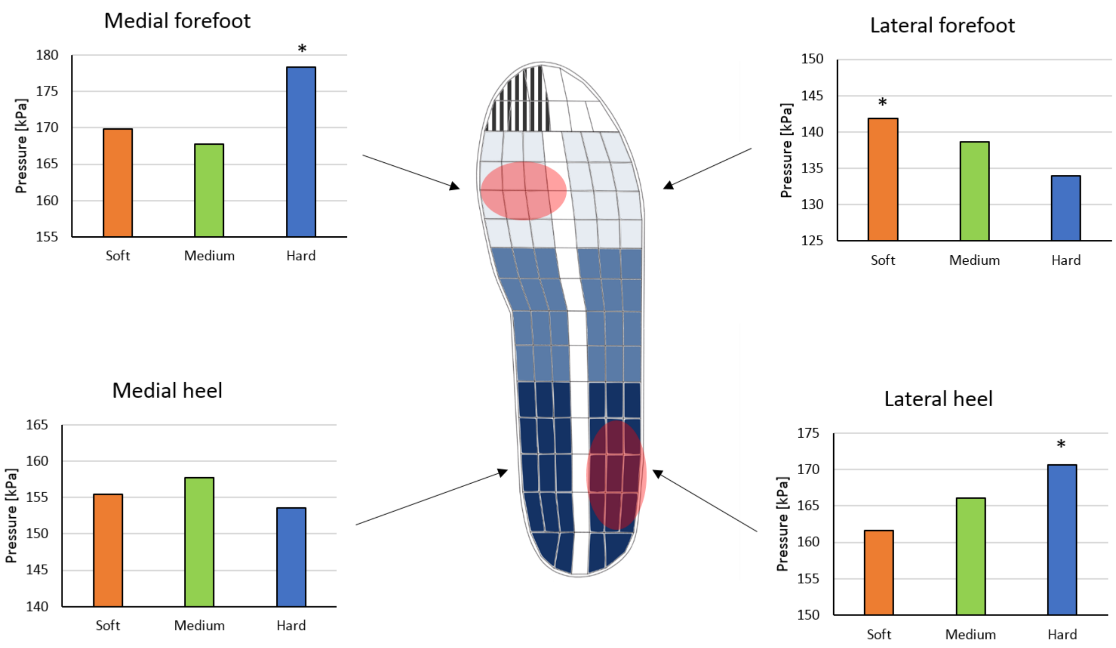



*Figure 3.3: Illustration of previously unpublished data by Pedersen (2014), displaying plantar pressure induced by changes to midsole cushion. Conditions marked with an * are significantly different from the other conditions ($p < 0.05$).*

# Running Shoes 4

The type of running shoe for each subject were prescribed by a physiotherapist based on a running style analysis. The physiotherapist had a selection of seven different running shoes. Only two different running shoes were prescribed since the subjects displayed similar amount of pronation and heel-to-toe running.

| | Pacemaker 3.0 | Runaissance 3.0 |
|---|---|---|
| Type | Neutral | Neutral |
| Weight | 310 gr. | 342 gr. |
| Drop | 12 mm | 4 mm |

*Table 4.1: Comparison of features displayed by the two running shoes applied in this study.*


(a) Pacemaker 3.0


(b) Runaissance 3.0

*Figure 4.1: Pictures of the two applied running shoes.*

# Shoe Configuration 5

A running style analysis was performed on each subject by a physiotherapist in order to determine the optimal configuration of the shoes and cohering orthoses. The running style analysis was performed on a treadmill and analyzed trough slow motion recordings of the subjects. The physiotherapist prescribed the shoe type and configured the orthoses based on current clinical and industrial recommendations. In table 5.1 the individual subject specific configuration (SSC) for each subject can be found.

| | Shoe type* | Foot | Arch support | Wedge | Sole inserts |
|---|---|---|---|---|---|
| Subject 1 | Runassistence 3.0 | Left | High | Low | Medium |
| | | Right | High | Low | Medium |
| Subject 2 | Runassistence 3.0 | Left | Medium | Medium | Medium |
| | | Right | Medium | High | Medium |
| Subject 3 | Pacemaker 3.0 | Left | High | Low | Hard |
| | | Right | Medium | Low | Hard |
| Subject 4 | Pacemaker 3.0 | Left | High | High | Medium |
| | | Right | High | Medium | Medium |
| Subject 5 | Runassistence 3.0 | Left | High | Low | Medium |
| | | Right | High | Low | Medium |
| Subject 6 | Pacemaker 3.0 | - | - | - | - |
| | | - | - | - | - |
| Subject 7 | Pacemaker 3.0 | - | - | - | - |
| | | - | - | - | - |
| Subject 8 | Pacemaker 3.0 | Left | High | Low | Medium |
| | | Right | High | High | Medium |

*Table 5.1: Individual configuration of the running shoes and the cohering orthoses for each subject. Subject 6 and 7 did not perform a running style analysis. *For more information about the different shoe types see chapter 4.*

# 6 Subjects

In table 6.1, presented below, characteristics of the individual subjects that participated in the study can be found. It can be noted that the group is highly homogeneous in relation to age and shoe size. However, outliners are present when investigating mass and height distribution of the group.

| | Age [years] | Mass [kg] | Height [cm] | Shoe size [eu] | Level [km/week] |
|---|---|---|---|---|---|
| Subject 1 | 29 | 74 | 1.82 | 44.5 | 30 |
| Subject 2 | 27 | 75 | 1.75 | 42 | 15 |
| Subject 3 | 24 | 86 | 1.93 | 45.5 | 15 |
| Subject 4 | 26 | 85 | 1.81 | 44 | 10 |
| Subject 5 | 27 | 73 | 1.76 | 42.5 | 30 |
| Subject 6 | 28 | 91 | 1.78 | 44 | 20 |
| Subject 7 | 28 | 102 | 1.81 | 44.5 | 10 |
| Subject 8 | 25 | 88 | 1.85 | 43 | 10 |
| Mean | 26.6 | 85.9 | 181.5 | 43.9 | 17.5 |
| Standard deviation | 1.5 | 8.9 | 5.4 | 1.1 | 7.9 |

*Table 6.1: Characteristics of the individual subjects that participated in this study. Mean and standard deviation are displayed at the bottom of the table.*

# 7 Foot Posture Index

Foot Posture Index (FPI) was developed to quantify standing foot posture (Redmond et al., 2006). FPI consists of six anatomical measures and produces a score that can help identify whether a subject have pronated, neutral or supinated foot posture. A study by Redmond et al. (2008) found the mean FPI score for a normal healthy population to be +4. A common interpretation of the FPI score are displayed in table 7.1.

| Highly supinated | Supinated | Neutral | Pronated | Highly pronated |
|---|---|---|---|---|
| < −3 | −3 to +1 | +1 to +7 | +7 to +10 | +10 < |

*Table 7.1: Normative FPI score values. (Redmond et al., 2008)*

The score for each of the six underlying test and the final FPI score for each subject in this study can be found in table 7.2.

| Subject | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Talar head palpation | Left | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| | Right | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| Lateral malleolar curves | Left | 1 | 0 | 1 | 0 | 1 | 2 | 0 | 0 |
| | Right | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 0 |
| Inv/eversion of calcaneus | Left | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 |
| | Right | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 |
| Talonavicular joint prominence | Left | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Right | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Congruence of medial longitudinal arch | Left | 2 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| | Right | 2 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| Abd/adduction of forefoot | Left | 2 | 1 | 0 | 0 | 1 | 1 | -1 | 0 |
| | Right | 2 | 0 | 0 | 1 | 0 | 1 | -1 | 0 |
| FPI Score | Left | 10 | 4 | 4 | 3 | 6 | 6 | 1 | 2 |
| | Right | 10 | 3 | 3 | 4 | 5 | 6 | 1 | 2 |

*Table 7.2: The table display that all subjects, except subject 1, have a FPI score within the normal range. Subject 1 have en FPI score that indicate a pronated to highly pronated foot posture that potentially may be pathological.*

# Marker Protocol 8

The marker protocol used in this study is a combination of protocols suggested by Tabakin (2007), Robertson (2006) and Lund et al. (2011).

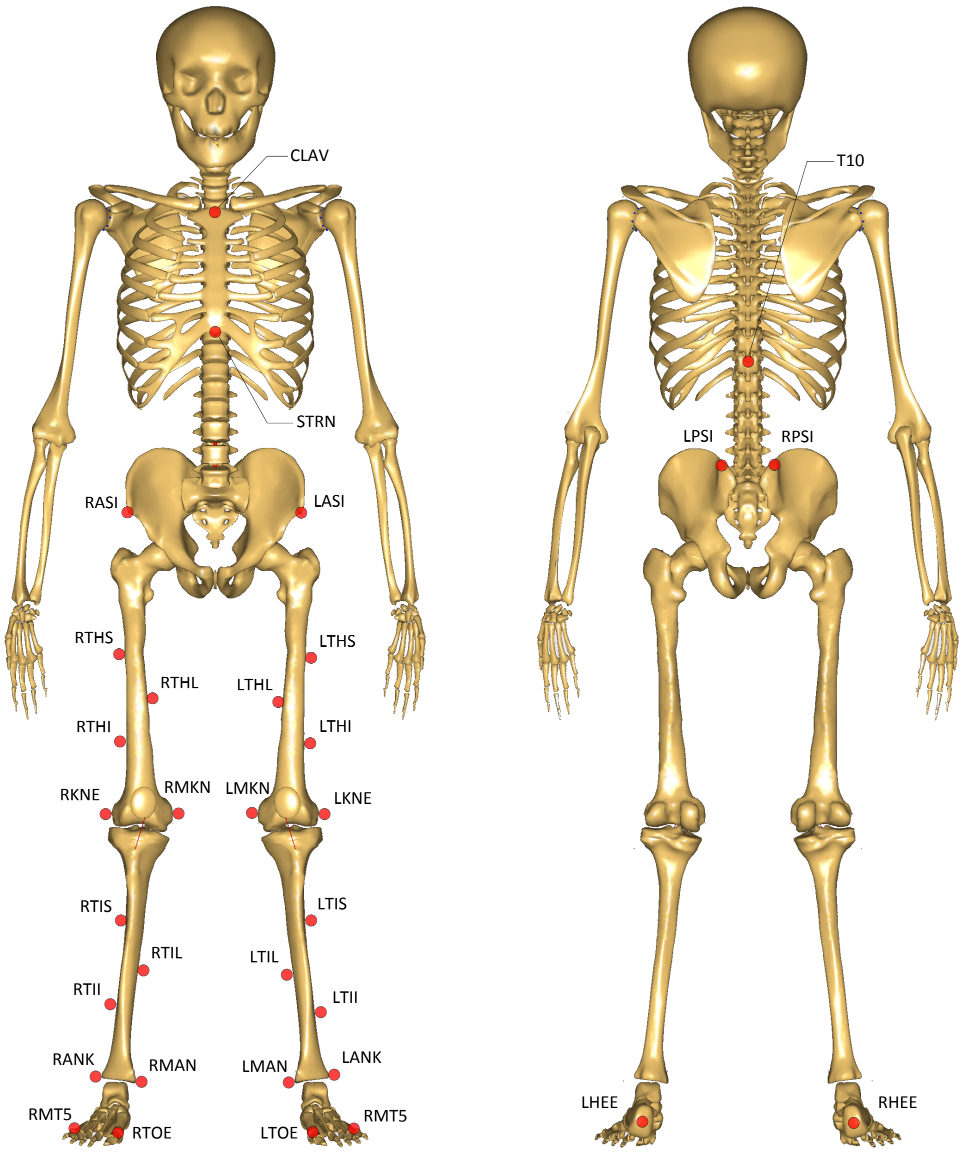



*Figure 8.1: Illustration of marker protocol applied in this study.*

# Experimental Setup 9

The experimental setup of the study consisted of a 12 m predefined track. A force plate (AMTI OR 6-6, Advanced Mechanical Technology Inc., Massachusetts, USA) was embedded in the ground and eight infrared cameras (Oqus 300/310, Qualisys AB, Sweden) surrounded the track.

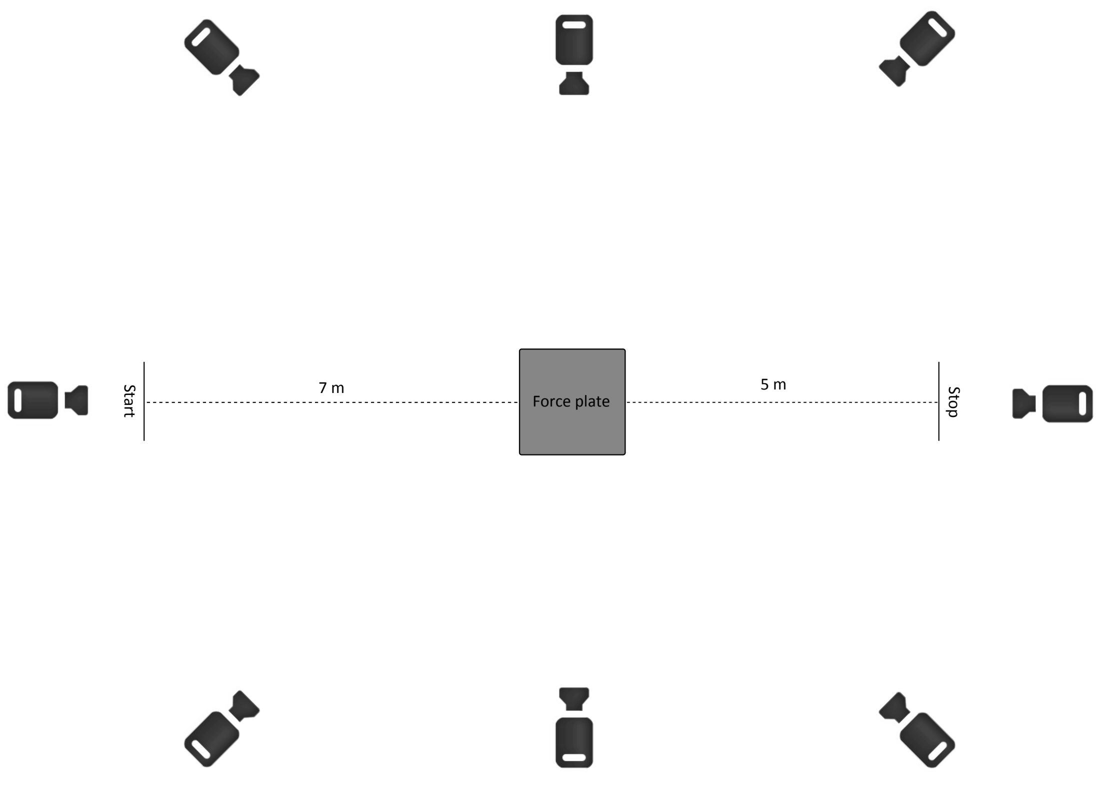



*Figure 9.1: Illustration of the experimental setup used in this study, displaying camera and force plate placement.*

# Musculoskeletal model 10

The musculoskeletal model applied in this study was developed by Lund et al. (2011) and is designed to incorporate subject-specific joint information based on a static and functional trials. The model positions itself between standard musculoskeletal models applying linear scaling, and the highly subject-specific musculoskeletal models applying magnetic resonance imaging or computed tomography. This position allows for musculoskeletal models to be applied in large clinical studies, because of its time efficiency and inexpensiveness nature, while still utilizing subject-specific information.

The model applies one standing reference trial to identify segment lengths and three dynamic trials to identify joint centers and axis directions of the ankle complex, knee and hip, see fig. 10.1. A subject-specific kinematic model is optimized based on the trials. The obtained segment and joint information is then imposed onto a cadaver model by nonlinear transformation. Kinematic and kinetic data can then be used to drive the model to obtain inverse dynamics computed moments and forces.

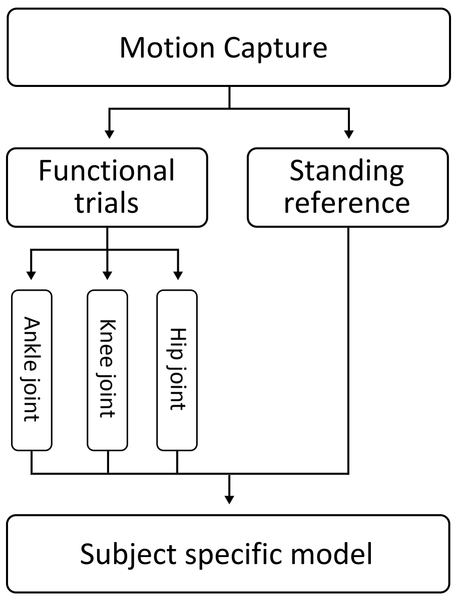



*Figure 10.1: Simplified flow chart representing the required tasks to construct the subject-specific model applied in this study.*

The model possesses the inherent assumptions and limitations of inverse dynamics as rigid segments, frictionless joints, no co-contraction and mass distribution (Buchanan et al., 2005; Riemer et al., 2008). Furthermore, this models also uses idealized revolute (knee, subtalar and ankle) and spherical joints (hip). This simplification of the human body may have serious effect on the computed output parameters. Due to this limitation, investigation of condylar loading changes cannot be conducted. This could have provided useful information when assessing orthotic treatment in relation to patellofemoral pain.

The model needs further validation before it can be applied in clinical application. This can be done by either in-vivo measurements, indirect electromyographical validation or comparison with higher-level subject-specific models (Lund et al., 2012).

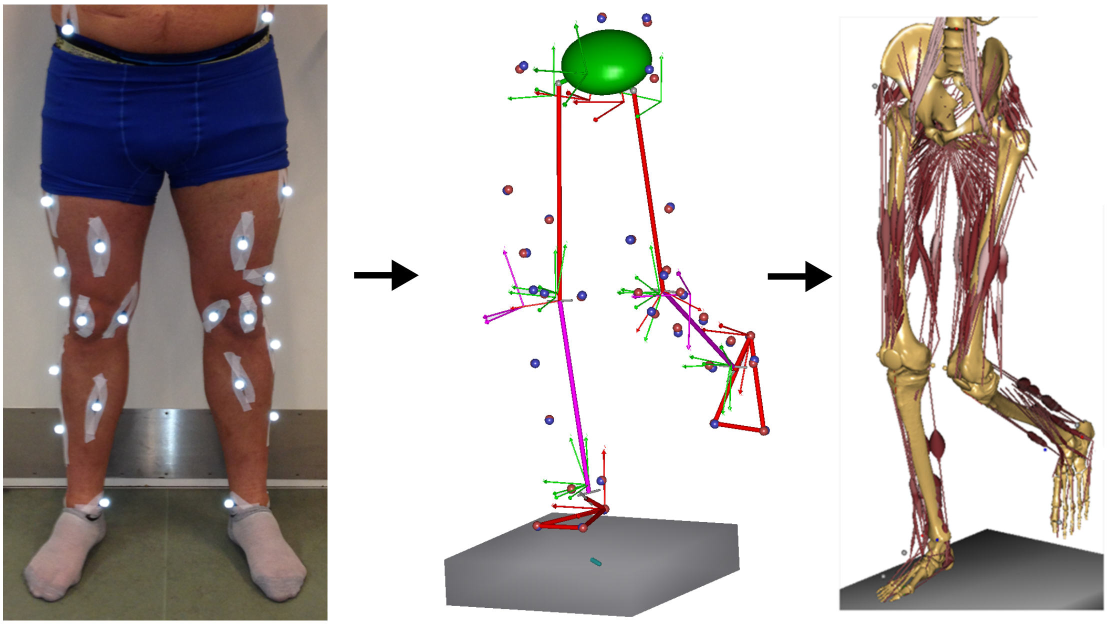


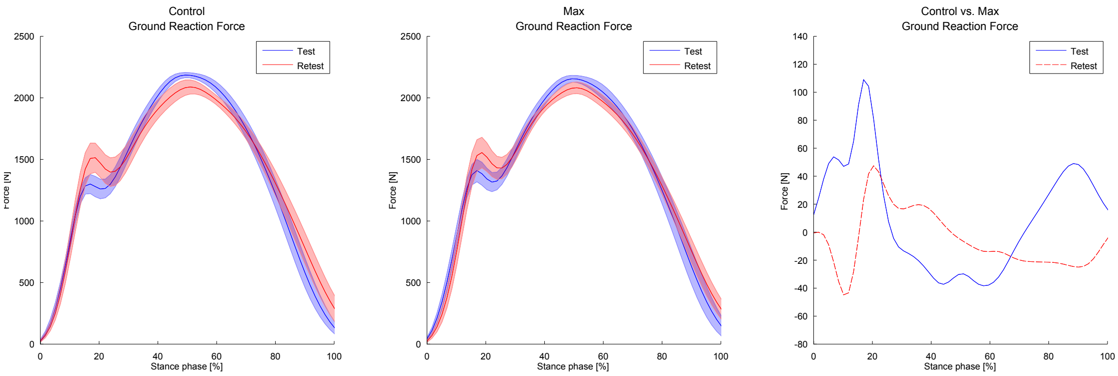
*Figure 10.2: Overview of the different stages in the model from the motion-capture to a kinematic model to a inverse dynamics model.*

# Test-Retest Reliability 11

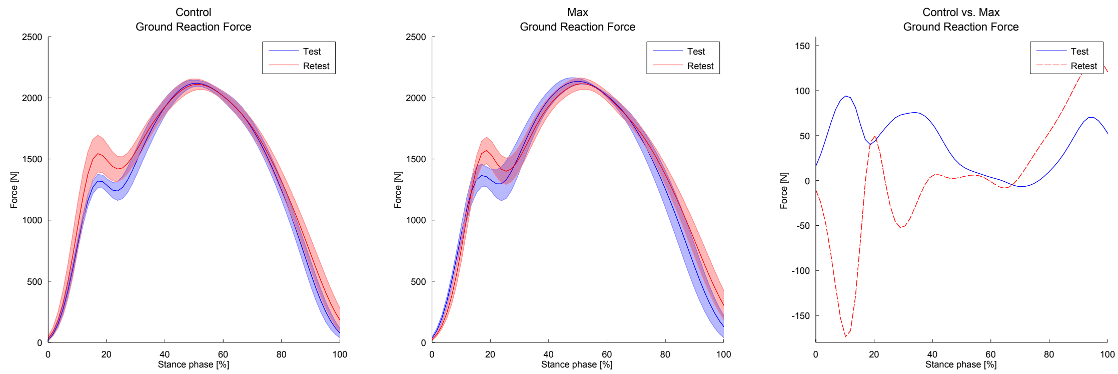
In order to test the reliability of the setup a test-retest was performed on both feet of one subject. The test-retest was performed six day apart. Subject-specific joint centers trials were performed on both occasions and two independent models were constructed. The test-retest was performed in both the control condition and the maximal anti-pronation condition (Max). Correlation coefficient values for outcome measures can be found in table 11.1. Furthermore, a graphical comparison of the test-retest, with cohering floating standard deviation, are displayed in fig. 11.1 to 11.8.

| | | Control | Max | Effect |
|---|---|---|---|---|
| Ground Reaction Force | Left | 0.99 | 0.99 | 0.04 |
| | Right | 0.99 | 0.99 | 0.28 |
| Foot Inversion Moment | Left | 0.97 | 0.99 | 0.32 |
| | Right | 0.99 | 0.99 | 0.71 |
| Knee Int. Rot. Moment | Left | 0.83 | 0.97 | 0.12 |
| | Right | -0.76 | -0.88 | 0.80 |
| Hip Int. Rot. Moment | Left | 0.96 | 0.95 | 0.26 |
| | Right | 0.94 | 0.96 | 0.89 |
| Knee Adduction Moment | Left | 0.97 | 0.97 | 0.50 |
| | Right | 0.96 | 0.99 | 0.54 |
| Knee Compression Force | Left | 0.98 | 0.99 | 0.26 |
| | Right | 0.96 | 0.98 | -0.36 |
| Knee Anterior Shear Force | Left | 0.61 | 0.81 | 0.57 |
| | Right | 0.03 | 0.35 | 0.01 |
| Knee Medial Shear Force | Left | 0.97 | 0.98 | 0.11 |
| | Right | 0.95 | 0.98 | -0.06 |
| Mean values | Left | 0.91 | 0.97 | 0.27 |
| | Right | 0.63 | 0.67 | 0.35 |

*Table 11.1: Correlation coefficient values for selected outputs for both feet of one subject performing a test-retest with two interventions. Effect is the correlation coefficient of the difference between the Max intervention and the Control intervention.*

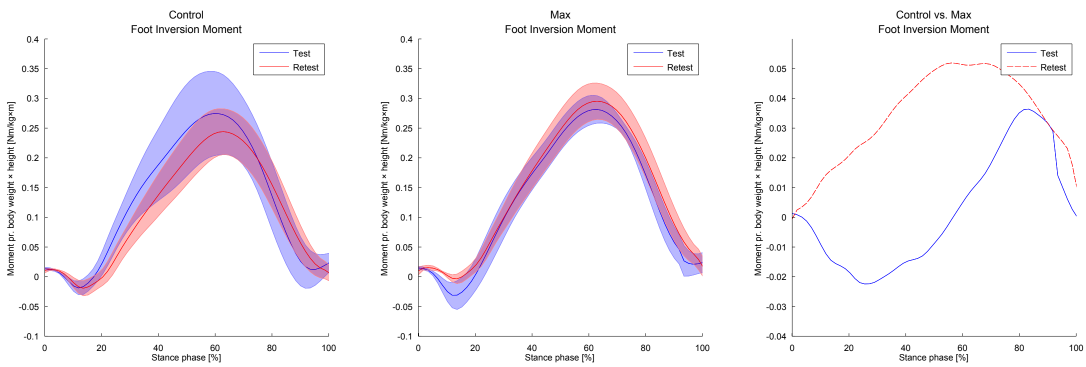



(a) Left

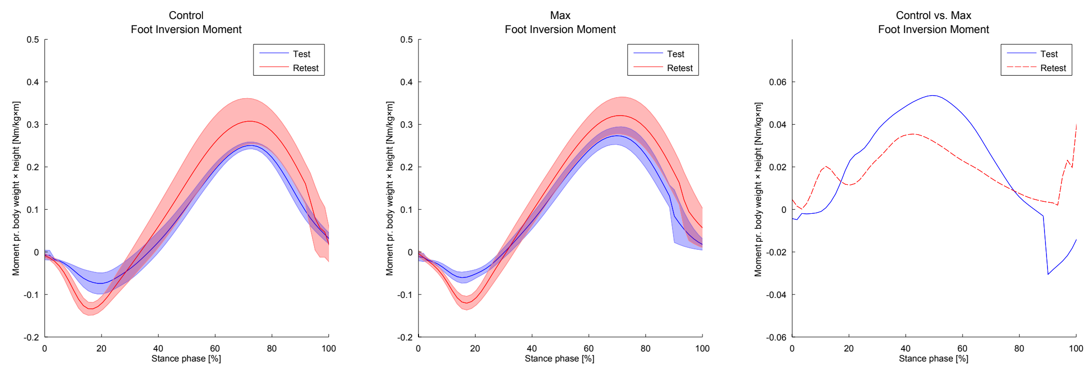



(b) Right

*Figure 11.1: Test-Retest comparison of ground reaction force*

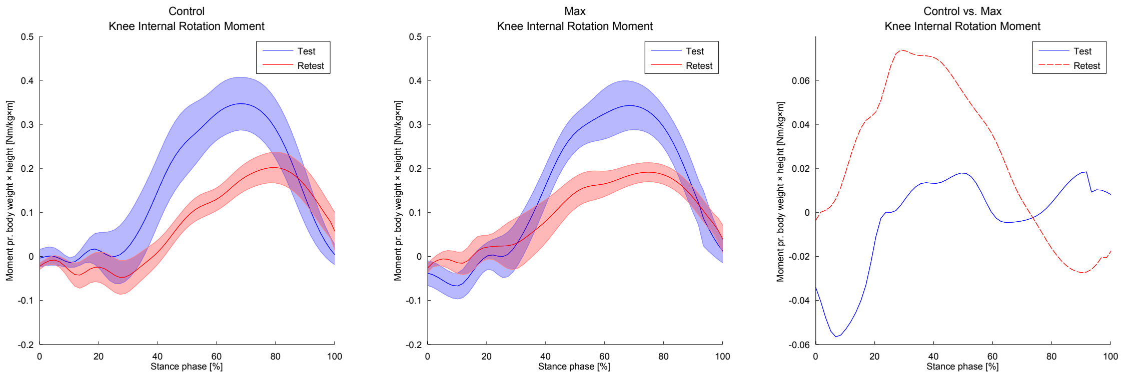



(a) Left

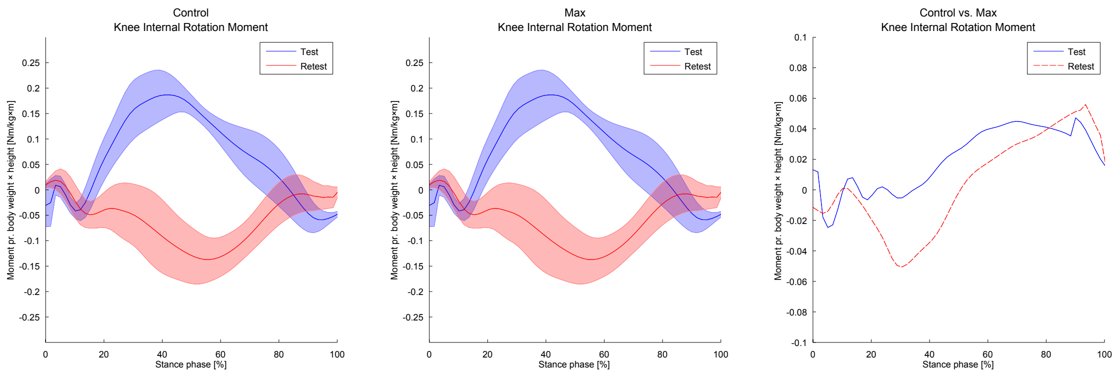



(b) Right

*Figure 11.2: Test-Retest comparison of foot inversion moment*

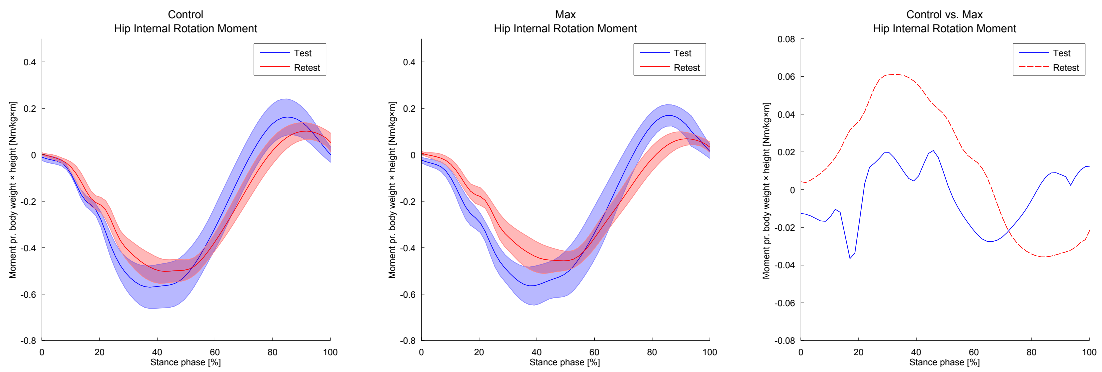



(a) Left

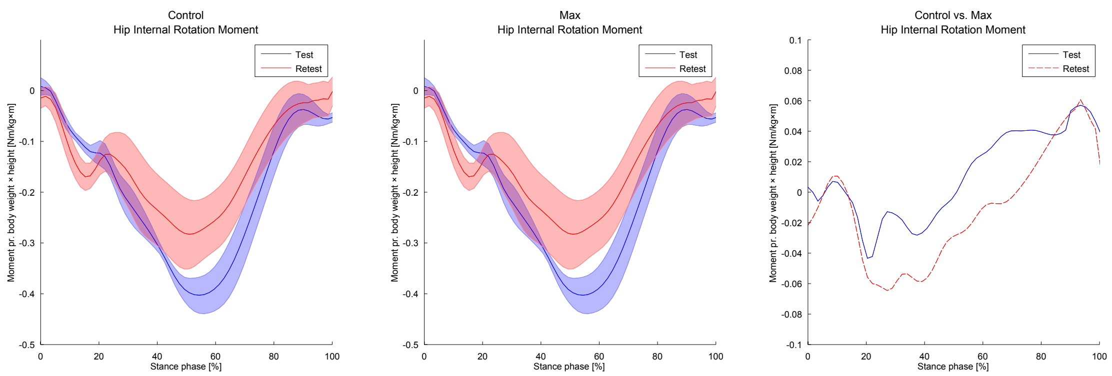



(b) Right

*Figure 11.3: Test-Retest comparison of internal knee rotation moment*

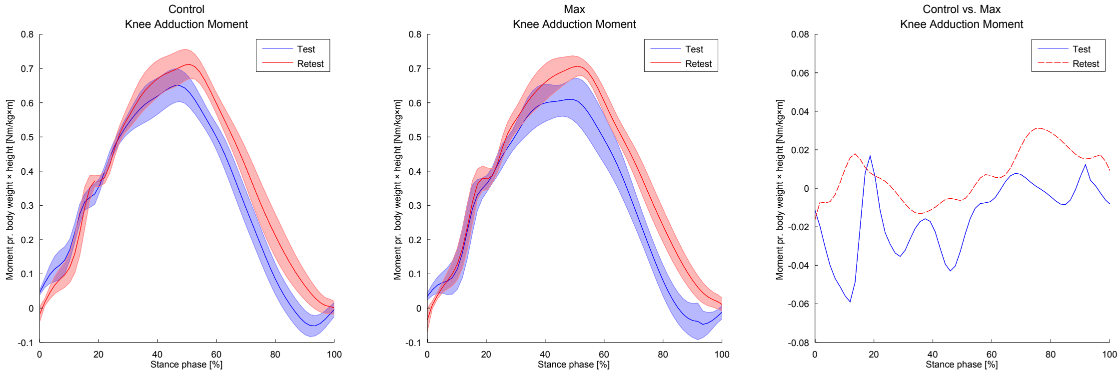



(a) Left

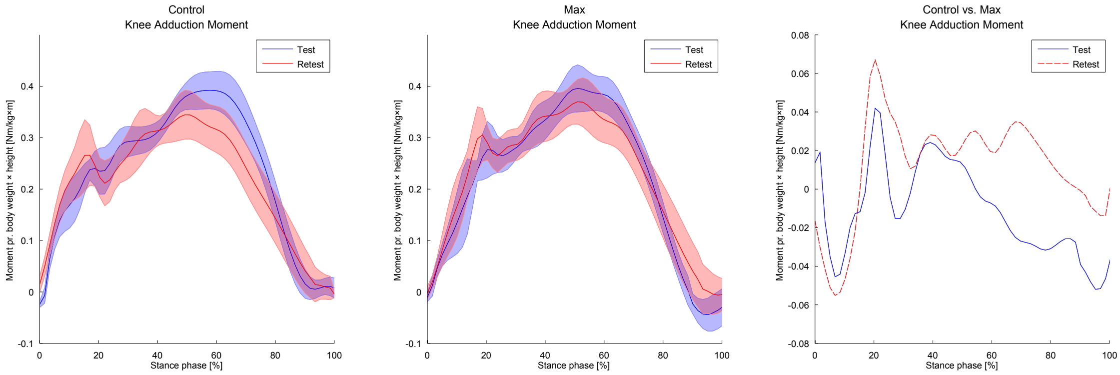



(b) Right

*Figure 11.4: Test-Retest comparison of internal hip rotation moment*

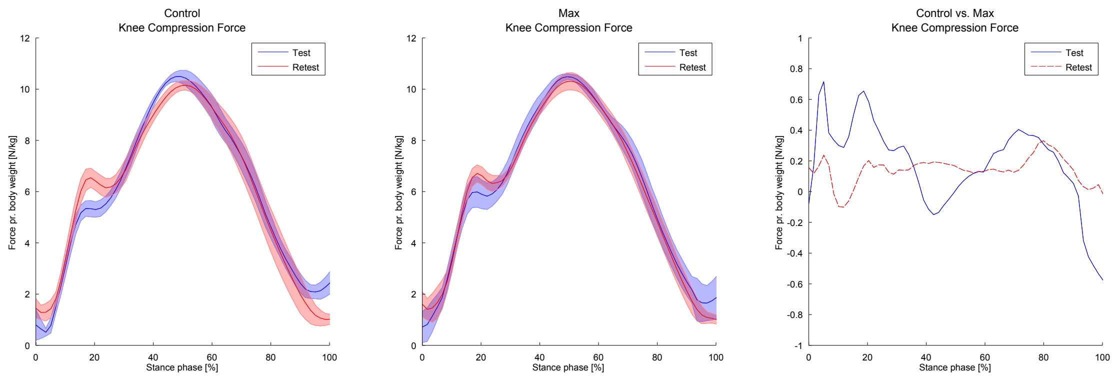



(a) Left

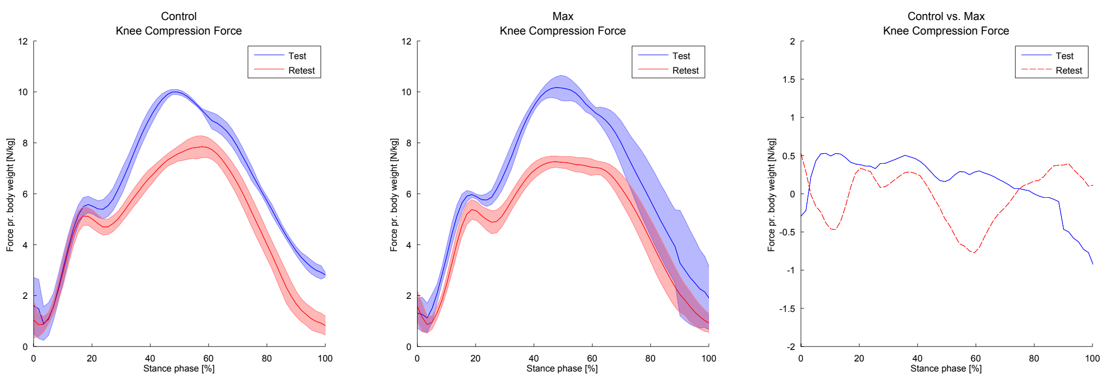



(b) Right

*Figure 11.5: Test-Retest comparison of knee adduction moment*

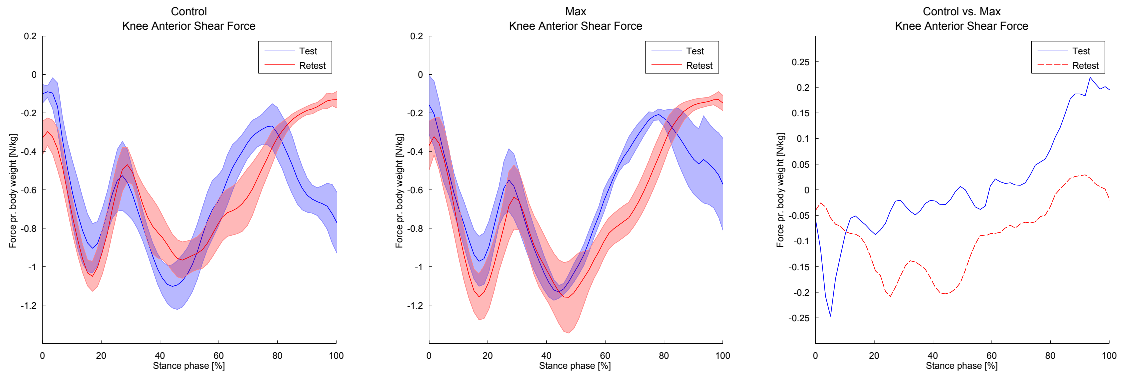



(a) Left

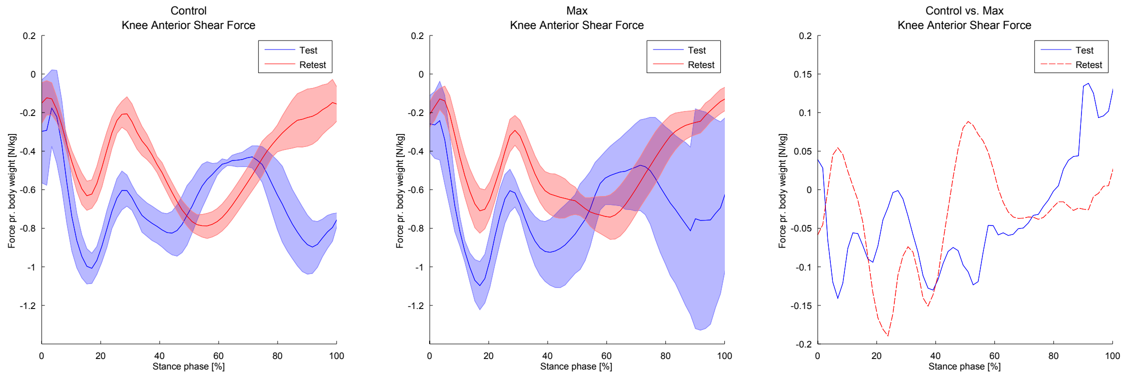



(b) Right

*Figure 11.6: Test-Retest comparison of compressive knee force*

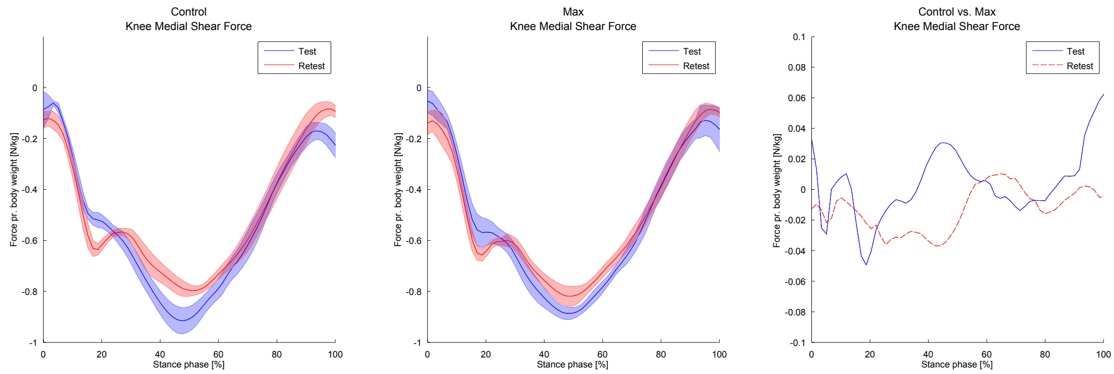



(a) Left

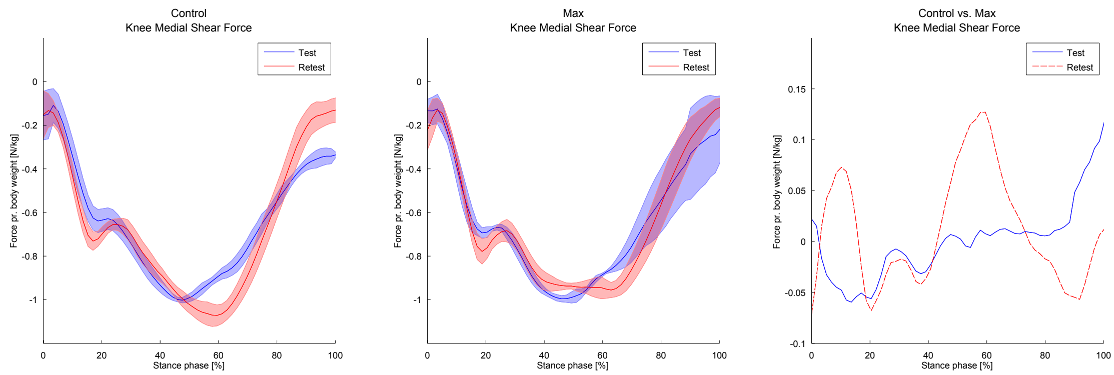



(b) Right

*Figure 11.7: Test-Retest comparison of anterior knee shear force*




(a) Left




(b) Right

*Figure 11.8: Test-Retest comparison of medial knee shear force*

# 12 Foot Marker Protocol

Prior to the main study a preliminary study was conducted in order to identify the differences between utilising shoe marker and skin marker when capturing rearfoot motion.

Generally, three different methods are described in the literature for registration of rearfoot motion: shoe markers, skin markers and bone markers. Bone markers are considered the "golden standard", however, due the invasive nature of this method it is very seldom used in studies including multiple subjects (Stacoff et al., 2001). Bone markers are inconvenient and fragile during dynamic task. Furthermore, local anesthesia are necessary when mounting the markers, which may impair natural movement. Shoe markers on the other hand are easily mounted and non-invasively placed directly on the shoe. This method, however, does not account for in-shoe motion, and may therefore not be representing true rearfoot motion (Fiedler et al., 2011). Using skin markers imply that markers are places directly on the skin, which requires cutting windows in the shoe to provide visual access. Removing material from the shoe may reduce the structural integrity of the shoe and affect the function of the orthoses.

No optimal marker method for registration rearfoot motion have been presented, and the selection of method is therefore an assessment of tradeoffs.

To investigate if shoe markers and skin markers produced comparable results, a single subject study was conducted. Differences in measured parameters between a model constructed with rearfoot shoe markers and a model constructed with rearfoot skin marker from the same subject is presented in tabel 12.1. The test was performed in both the control condition and the maximal anti-pronation condition (Max). Correlation coefficient values for outcome measures can also be found in table 12.1.

Furthermore, a graphical comparison of the comparison, with cohering floating standard deviation, are displayed in fig. 12.1 and 12.2.

| | Control | Max | Effect |
|---|---|---|---|
| Ground Reaction Force | 0.99 | 0.98 | 0.55 |
| Foot Inversion Moment | 0.95 | 0.98 | 0.35 |
| Knee Int. Rot. Moment | 0.92 | 0.83 | -0.31 |
| Hip Int. Rot. Moment | 0.99 | 0.68 | 0.29 |
| Knee Adduction Moment | 0.97 | 0.82 | -0.24 |
| Knee Compression Force | 0.98 | 0.90 | 0.27 |
| Knee Anterior Shear Force | 0.73 | 0.36 | 0.41 |
| Knee Medial Shear Force | -0.91 | -0.83 | -0.04 |
| Mean values | 0.70 | 0.59 | 0.16 |

*Table 12.1: Correlation coefficient values for selected outputs for one foot of one subject performing two interventions, with both a skin marker setup and a shoe marker setup. Effect is the correlation coefficient of the difference between the Max intervention and the Control intervention.*

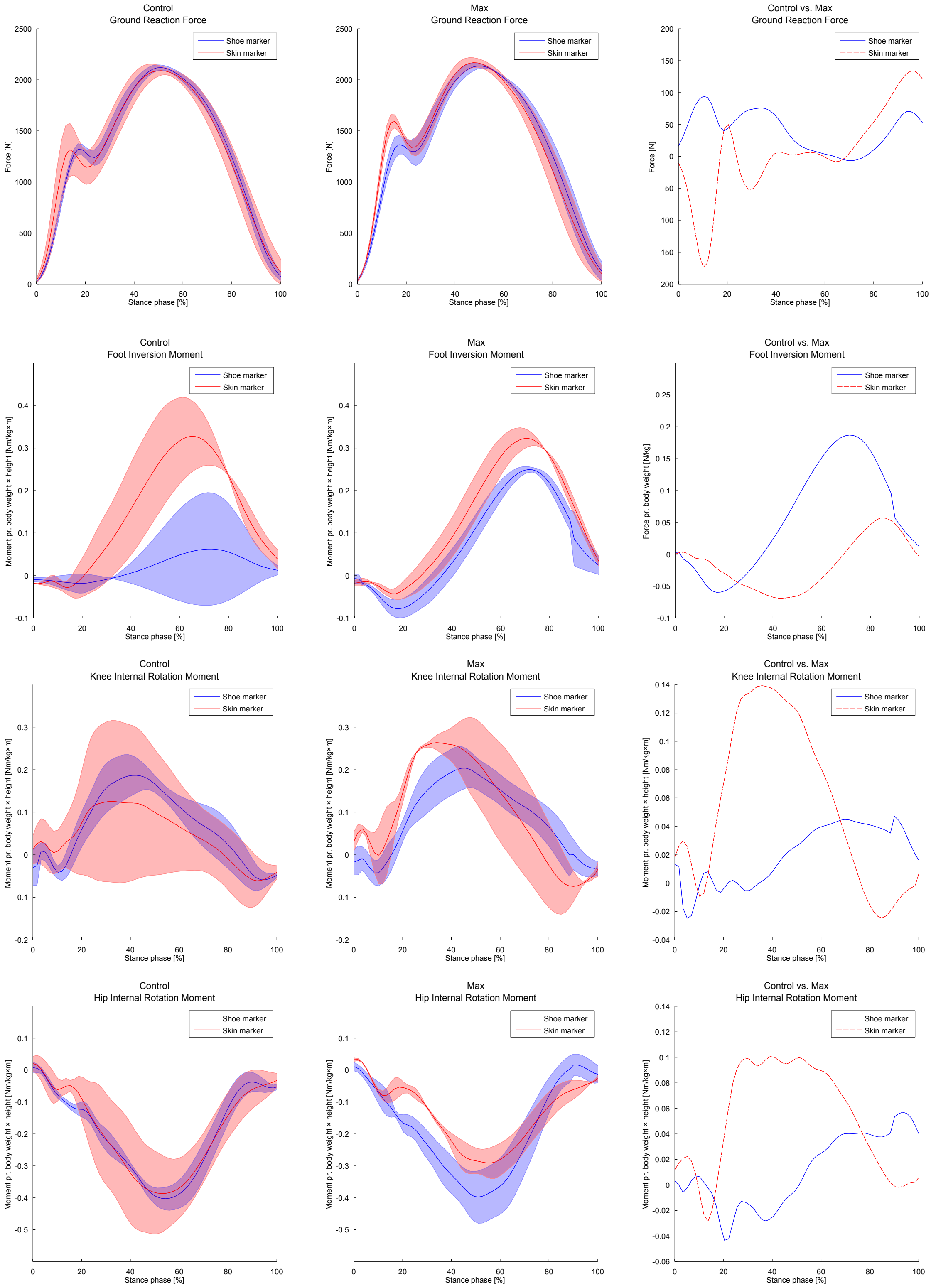



*Figure 12.1: Comparison between selected parameters constructed with shoe and skin markers respectively.*

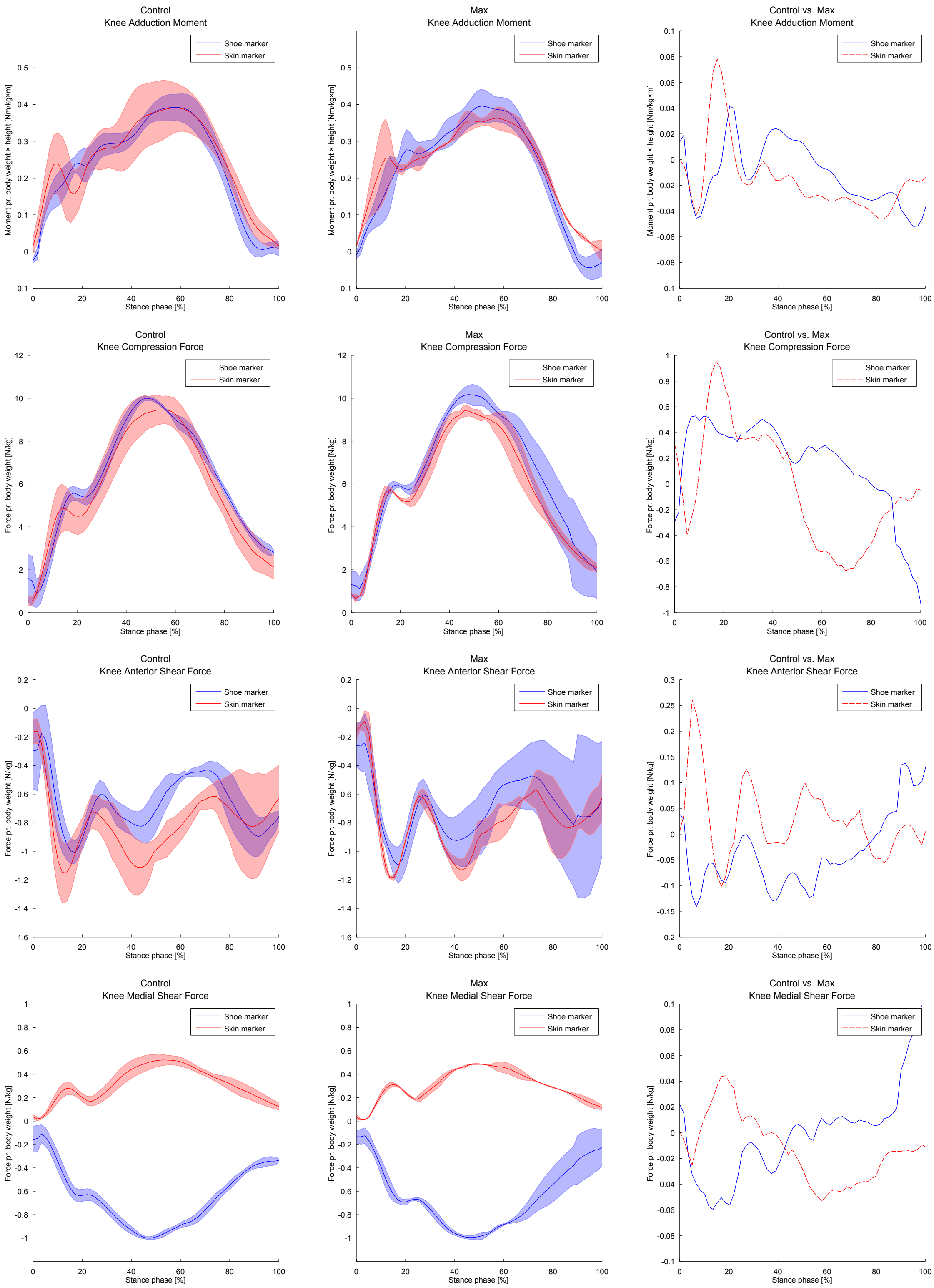



*Figure 12.2: Comparison between selected parameters constructed with shoe and skin markers respectively.*

# 13 Subject-Specific Results

In this chapter subject-specific results are displayed for selected biomechanical parameters investigated in this study. One important observation is that subject 7 displays opposing response to the interventions when comparing peak foot eversion moment across the group. This could be linked to either body mass or foot posture index of the subject that stand out from the group mean. Furthermore, it can be noted that large interindividual variation is present and caution should therefore be warranted, when prescribing orthoses, without assessing individual characteristics.

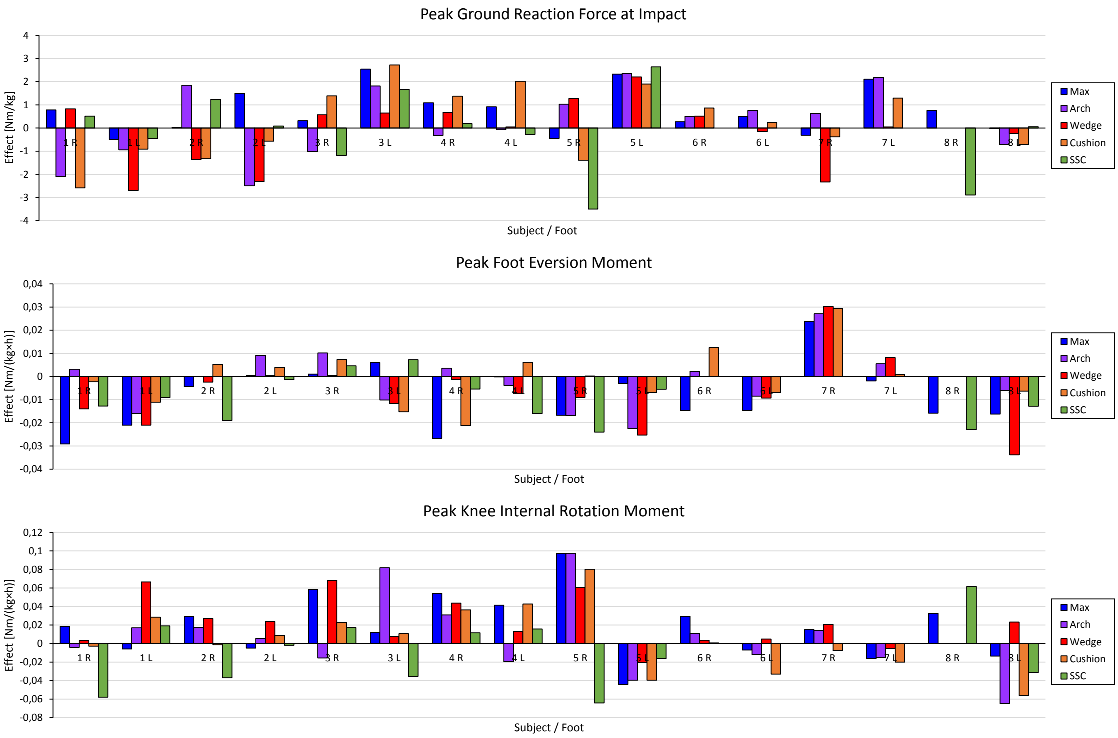



*Figure 13.1: Subject-specific results for selected outputs. The graphs display the difference between the interventions and the control condition. *Subject 6 and 7 did not complete the Optimal intervention. **Subject 8R did not complete Arch, Wedge and Cushion intervention. (R: right foot, L: left foot).*

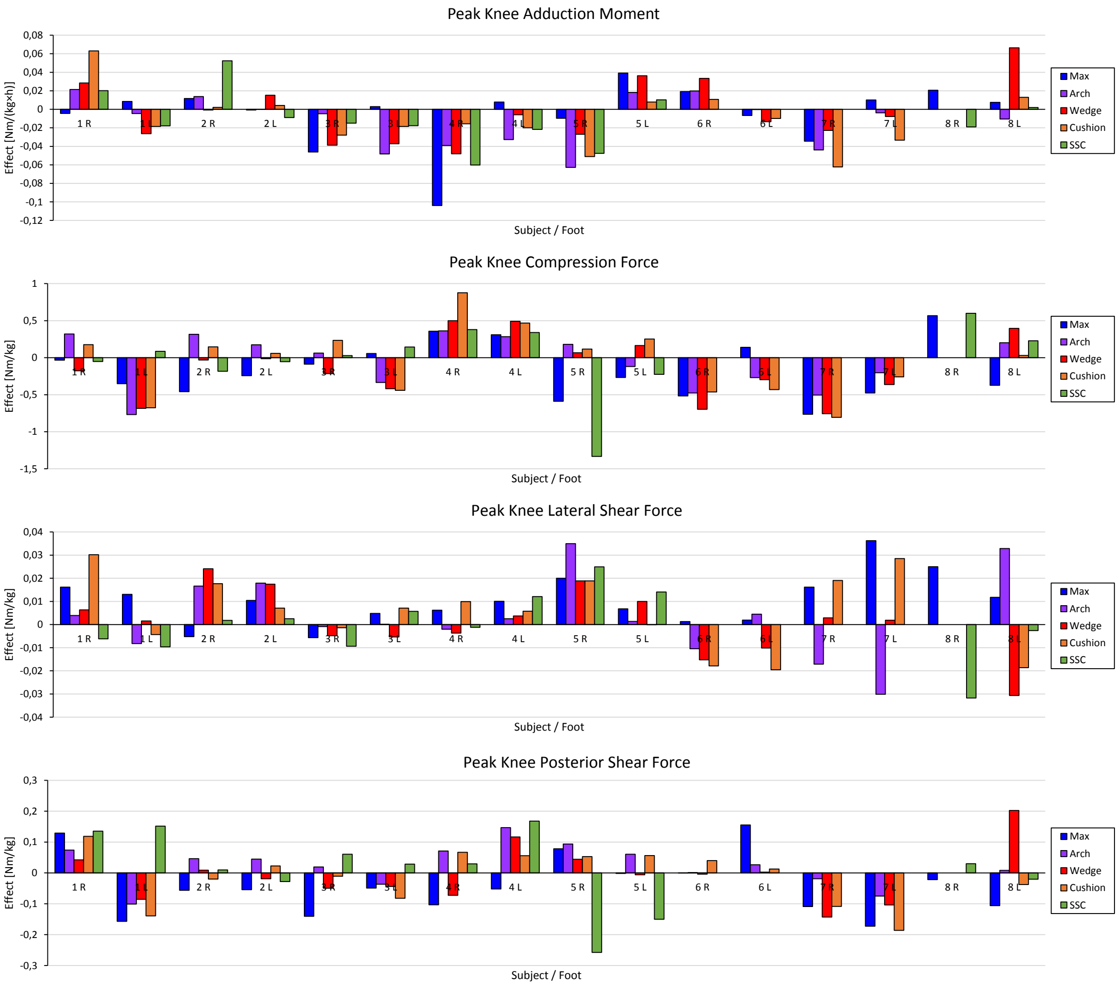



*Figure 13.2: Subject-specific results for selected outputs. The graphs display the difference between the interventions and the control condition. *Subject 6 and 7 did not complete the Optimal intervention. **Subject 8R did not complete Arch, Wedge and Cushion intervention. (R: right foot, L: left foot).*

# Written Consent 14

## Informeret samtykke til deltagelse i et biomekanisk forskningsprojekt

### Forskningsprojektets titel:

Løbeskosdesigns effekt på biomekaniske risikofaktorer for løbeskader.

### Erklæring fra forsøgspersonen:

Jeg har fået skriftlig og mundtlig information og jeg ved nok om formål, metode, fordele og ulemper til at sige ja til at deltage. Jeg ved, at det er frivilligt at deltage, og at jeg altid kan trække mit samtykke tilbage uden at miste mine nuværende eller fremtidige rettigheder til behandling. Jeg erklærer at jeg ikke kan holde forsøgsansvarlig eller AAU ansvarlig for eventuelle skader pådraget i forbindelse med forsøget. Jeg giver samtykke til, at deltage i forskningsprojektet og har fået en kopi af dette samtykkeark samt en kopi af den skriftlige information om projektet til eget brug.

Forsøgspersonens navn: ____________________________________________________________

Dato: ________________ Underskrift: _________________________________________________

### Erklæring fra den forsøgsansvarlige:

Jeg erklærer, at der er givet mundtlig information om projektet, udleveret skriftlig information og der foreligger et samtykke til, at forsøgspersonen kan deltage.

Den forsøgsansvarliges navn:_________________________________________________________

Dato: ________________ Underskrift: _________________________________________________

# 15 Information to Subjects

## Information vedrørende biomekanisk forskningsprojekt

### Forskningsprojektets titel

"Løbeskosdesigns effekt på biomekaniske risikofaktorer for løbeskader."

### Formål

Bestemme effekten af ændringer i løbeskoens design i forhold til biomekaniske risikofaktorer, der er forbundet med løbeskader.

### Forløb

En løbestilsanalyse bliver foretaget af en fysioterapeut, hvor et par løbesko med F.E.A.T systemet bliver tilpasset til din løbestil. Efterfølgende foretages en udvidede løbestilsanalyse med motion capture, tryksensor såler og kraftplatforme. Du vil blive udstyret med måleinstrumenter og specielt tøj. Du vil i forsøget skulle løbe med en konstant hastighed på en prædefineret bane gentagende gange. Undervejs vil skoens design blive konfigureret forskelligt.

### Tid

En halv time til løbestilsanalysen ved fysioterapeuten.
Tre timer til den udvidede løbestilsanalyse.

### Krav

For at kunne deltage i forsøget kræver det at du er erfaren løber (min. 10 km/ugen). Du må desuden ikke have nogen skader eller forhold, der påvirker din løbestil.

### Ubehag

Under normale forhold vil der ingen ubehag eller smerte være forbundet med at deltage i forsøget.

### Hvor

Arkadens fysioterapi, John F. Kenndys Plads 1R, 9000 Aalborg

Aalborg Universitet, Frederik Bajers Vej 7b, 9220 Aalborg Øst

# 16 Matlab Code

## Import data

```
% Import data from H5-file

 filePattern = fullfile('X:\dir\H5', '*.h5');
CZCS = dir(filePattern);

  for k = 1:length(CZCS)
    baseFileName = CZCS(k).name;
    fullFileName = fullfile('X:\dir\H5', baseFileName);
    f = h5info(fullFileName);
    onoff{k} = h5read(CZCS(k).name, '/Output/EnvironmentModel/ForcePlate1/OnOff');
    tstart{k} = find(onoff{k},1);
    tend{k} = find(onoff{k},1,'last');

   %Select Output

   KAMR{k} =h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Right/KneeAdduction/M_Projected');
   KAML{k} =h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Left/KneeAdduction/M_Projected');

   KIRMR{k} = h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Right/KneeInternalRotation/M_Projected');
   KIRML{k} = h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Left/KneeInternalRotation/M_Projected');

   AIRMR{k} = h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Right/AnkleInternalRotation/M_Projected');
   AIRML{k} = h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Left/AnkleInternalRotation/
```

```
    M_Projected');

    STJMR{k} = h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Right/AnkleInversion/M_Projected');
    STJML{k} = h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Left/AnkleInversion/M_Projected');

    HIRMR{k} = h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Right/HipInternalRotation/M_Projected');
    HIRML{k} = h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Left/HipInternalRotation/M_Projected');

    HAMR{k} = h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Right/HipAdduction/M_Projected');
    HAML{k} = h5read(CZCS(k).name, '/Output/JointAnglesAndMoments/Left/HipAdduction/M_Projected');

    KFR{k} = h5read(CZCS(k).name, '/Output/JointReactionForces/RightKneeForceInShankCoordinateSystemPerBodyWeight');
    KFL{k} = h5read(CZCS(k).name, '/Output/JointReactionForces/LeftKneeForceInShankCoordinateSystemPerBodyWeight');
    KFRX{k} = transpose(KFR{1,k}(1,:));
    KFLX{k} = transpose(KFL{1,k}(1,:));
    KFRY{k} = transpose(KFR{1,k}(2,:));
    KFLY{k} = transpose(KFL{1,k}(2,:));
    KFRZ{k} = transpose(KFR{1,k}(3,:));
    KFLZ{k} = -transpose(KFL{1,k}(3,:));

    Fz{k} = h5read(CZCS(k).name, '/Output/EnvironmentModel/ForcePlate1/FzTotal');
    Fz{k} = -Fz{k};

end
```

### Crop data

```
% Organize variable in subject matrices
% Cropping data to stance phase
% Right foot trials

var = KIRM; %Variable

%%
Subject1_Right_Control = strfind(name(:,1), '
    Subject1_Right_Control');
Subject1_Right_Control = transpose(find(~cellfun(@isempty,
    Subject1_Right_Control)));

k = Subject1_Right_Control;

for ii = 1:size(k,2)
 x = (squeeze(var{1,k(ii)}(tstart{1,k(ii)}:tstart{1,k(ii)}+
     lenght)));
var2(ii,:) =x;
end
clear Subject1_Right_Control;
Subject1_Right_Control = transpose(var2);
clear var2;
%%
Subject1_Right_Max = strfind(name(:,1), 'Subject1_Right_Max');
Subject1_Right_Max = transpose(find(~cellfun(@isempty,
    Subject1_Right_Max)));

k = Subject1_Right_Max;

for ii = 1:size(k,2)
 x = (squeeze(var{1,k(ii)}(tstart{1,k(ii)}:tstart{1,k(ii)}+
     lenght)));
var2(ii,:) =x;
end
clear Subject1_Right_Max;
Subject1_Right_Max = transpose(var2);
clear var2;
%%
Subject1_Right_Midsole = strfind(name(:,1), '
    Subject1_Right_Midsole');
Subject1_Right_Midsole = transpose(find(~cellfun(@isempty,
    Subject1_Right_Midsole)));

k = Subject1_Right_Midsole;

for ii = 1:size(k,2)
```

```
 x = (squeeze(var{1,k(ii)}(tstart{1,k(ii)}:tstart{1,k(ii)}+lenght)));
var2(ii,:) =x;
end
clear Subject1_Right_Midsole;
Subject1_Right_Midsole = transpose(var2);
clear var2;
%%
Subject1_Right_Wedge = strfind(name(:,1), 'Subject1_Right_Wedge');
Subject1_Right_Wedge = transpose(find(~cellfun(@isempty,Subject1_Right_Wedge)));

k = Subject1_Right_Wedge;

for ii = 1:size(k,2)
 x = (squeeze(var{1,k(ii)}(tstart{1,k(ii)}:tstart{1,k(ii)}+lenght)));
var2(ii,:) =x;
end
clear Subject1_Right_Wedge;
Subject1_Right_Wedge = transpose(var2);
clear var2;
%%
Subject1_Right_HighArch = strfind(name(:,1), 'Subject1_Right_HighArch');
Subject1_Right_HighArch = transpose(find(~cellfun(@isempty,Subject1_Right_HighArch)));

%...continues to line 576
```

## Save variable

```
%Save variable to Struct

Subjects.Subject1_Right.KAM = struct('Control', Subject1_Right_Control, 'Max',Subject1_Right_Max', 'Midsole', Subject1_Right_Midsole, 'Wedge', Subject1_Right_Wedge, 'HighArch', Subject1_Right_HighArch, 'Optimal', Subject1_Right_Optimal);

Subjects.Subject1_Left.KAM = struct('Control', Subject1_Left_Control, 'Max',Subject1_Left_Max', 'Midsole', Subject1_Left_Midsole, 'Wedge', Subject1_Left_Wedge, 'HighArch', Subject1_Left_HighArch, 'Optimal', Subject1_Left_Optimal);

Subjects.Subject2_Right.KAM = struct('Control', Subject2_Right_Control, 'Max',Subject2_Right_Max', 'Midsole', Subject2_Right_Midsole, 'Wedge', Subject2_Right_Wedge, 'HighArch', Subject2_Right_HighArch, 'Optimal', Subject2_Right_Optimal);

Subjects.Subject2_Left.KAM = struct('Control', Subject2_Left_Control, 'Max',Subject2_Left_Max', 'Midsole', Subject2_Left_Midsole, 'Wedge', Subject2_Left_Wedge, 'HighArch', Subject2_Left_HighArch, 'Optimal', Subject2_Left_Optimal);

Subjects.Subject3_Right.KAM = struct('Control', Subject3_Right_Control, 'Max',Subject3_Right_Max', 'Midsole', Subject3_Right_Midsole, 'Wedge', Subject3_Right_Wedge, 'HighArch', Subject3_Right_HighArch);

Subjects.Subject3_Left.KAM = struct('Control', Subject3_Left_Control, 'Max',Subject3_Left_Max', 'Midsole', Subject3_Left_Midsole, 'Wedge', Subject3_Left_Wedge, 'HighArch', Subject3_Left_HighArch);

Subjects.Subject4_Right.KAM = struct('Control', Subject4_Right_Control, 'Max',Subject4_Right_Max', 'Midsole', Subject4_Right_Midsole, 'Wedge', Subject4_Right_Wedge, 'HighArch', Subject4_Right_HighArch, 'Optimal', Subject4_Right_Optimal);

Subjects.Subject4_Left.KAM = struct('Control', Subject4_Left_Control, 'Max',Subject4_Left_Max', 'Midsole', Subject4_Left_Midsole, 'Wedge', Subject4_Left_Wedge, 'HighArch', Subject4_Left_HighArch, 'Optimal',
```

```
    Subject4_Left_Optimal);

Subjects.Subject5_Right.KAM = struct('Control',
    Subject5_Right_Control,'Max',Subject5_Right_Max','Midsole',
    Subject5_Right_Midsole,'Wedge', Subject5_Right_Wedge, '
    HighArch', Subject5_Right_HighArch,'Optimal',
    Subject5_Right_Optimal);

Subjects.Subject5_Left.KAM = struct('Control',
    Subject5_Left_Control,'Max',Subject5_Left_Max','Midsole',
    Subject5_Left_Midsole,'Wedge', Subject5_Left_Wedge, '
    HighArch', Subject5_Left_HighArch,'Optimal',
    Subject5_Left_Optimal);

Subjects.Subject6_Right.KAM = struct('Control',
    Subject6_Right_Control,'Max',Subject6_Right_Max','Midsole',
    Subject6_Right_Midsole,'Wedge', Subject6_Right_Wedge, '
    HighArch', Subject6_Right_HighArch,'Optimal',
    Subject6_Right_Optimal);

Subjects.Subject6_Left.KAM = struct('Control',
    Subject6_Left_Control,'Max',Subject6_Left_Max','Midsole',
    Subject6_Left_Midsole,'Wedge', Subject6_Left_Wedge, '
    HighArch', Subject6_Left_HighArch,'Optimal',
    Subject6_Left_Optimal);

Subjects.Subject7_Right.KAM = struct('Control',
    Subject7_Right_Control,'Max',Subject7_Right_Max','Midsole',
    Subject7_Right_Midsole,'Wedge', Subject7_Right_Wedge, '
    HighArch', Subject7_Right_HighArch,'Optimal',
    Subject7_Right_Optimal);

Subjects.Subject7_Left.KAM = struct('Control',
    Subject7_Left_Control,'Max',Subject7_Left_Max','Midsole',
    Subject7_Left_Midsole,'Wedge', Subject7_Left_Wedge, '
    HighArch', Subject7_Left_HighArch,'Optimal',
    Subject7_Left_Optimal);

%...continues to line 35
```

### Calculate mean and peak values

```
%Calculate mean and peak values for each condition in each subject

Subjects.Subject1_Right.KAM.Max = transpose(Subjects.Subject1_Right.KAM.Max)

Subjects.Subject1_Right.KAM.ControlMean = transpose(mean(Subjects.Subject1_Right.KAM.Control));
Subjects.Subject1_Right.KAM.ControlPeak = transpose(max(Subjects.Subject1_Right.KAM.Control));
Subjects.Subject1_Right.KAM.ControlMin = transpose(min(Subjects.Subject1_Right.KAM.Control));
Subjects.Subject1_Right.KAM.ControlTrapz = transpose(trapz(Subjects.Subject1_Right.KAM.Control));

Subjects.Subject1_Right.KAM.MaxMean = transpose(mean(Subjects.Subject1_Right.KAM.Max));
Subjects.Subject1_Right.KAM.MaxPeak = transpose(max(Subjects.Subject1_Right.KAM.Max));
Subjects.Subject1_Right.KAM.MaxMin = transpose(min(Subjects.Subject1_Right.KAM.Max));
Subjects.Subject1_Right.KAM.MaxTrapz = transpose(trapz(Subjects.Subject1_Right.KAM.Max));

Subjects.Subject1_Right.KAM.MidsoleMean = transpose(mean(Subjects.Subject1_Right.KAM.Midsole));
Subjects.Subject1_Right.KAM.MidsolePeak = transpose(max(Subjects.Subject1_Right.KAM.Midsole));
Subjects.Subject1_Right.KAM.MidsoleMin = transpose(min(Subjects.Subject1_Right.KAM.Midsole));
Subjects.Subject1_Right.KAM.MidsoleTrapz = transpose(trapz(Subjects.Subject1_Right.KAM.Midsole));

Subjects.Subject1_Right.KAM.WedgeMean = transpose(mean(Subjects.Subject1_Right.KAM.Wedge));
Subjects.Subject1_Right.KAM.WedgePeak = transpose(max(Subjects.Subject1_Right.KAM.Wedge));
Subjects.Subject1_Right.KAM.WedgeMin = transpose(min(Subjects.Subject1_Right.KAM.Wedge));
Subjects.Subject1_Right.KAM.WedgeTrapz = transpose(trapz(Subjects.Subject1_Right.KAM.Wedge));

Subjects.Subject1_Right.KAM.HighArchMean = transpose(mean(Subjects.Subject1_Right.KAM.HighArch));
Subjects.Subject1_Right.KAM.HighArchPeak = transpose(max(Subjects.Subject1_Right.KAM.HighArch));
```

```
Subjects.Subject1_Right.KAM.HighArchMin = transpose(min(
    Subjects.Subject1_Right.KAM.HighArch));
Subjects.Subject1_Right.KAM.HighArchTrapz = transpose(trapz(
    Subjects.Subject1_Right.KAM.HighArch));

Subjects.Subject1_Right.KAM.OptimalMean = transpose(mean(
    Subjects.Subject1_Right.KAM.Optimal));
Subjects.Subject1_Right.KAM.OptimalPeak = transpose(max(
    Subjects.Subject1_Right.KAM.Optimal));
Subjects.Subject1_Right.KAM.OptimalMin = transpose(min(Subjects
    .Subject1_Right.KAM.Optimal));
Subjects.Subject1_Right.KAM.OptimalTrapz = transpose(trapz(
    Subjects.Subject1_Right.KAM.Optimal));

Subjects.Subject2_Right.KAM.Max = transpose(Subjects.
    Subject2_Right.KAM.Max)

Subjects.Subject2_Right.KAM.ControlMean = transpose(mean(
    Subjects.Subject2_Right.KAM.Control));
Subjects.Subject2_Right.KAM.ControlPeak = transpose(max(
    Subjects.Subject2_Right.KAM.Control));
Subjects.Subject2_Right.KAM.ControlMin = transpose(min(Subjects
    .Subject2_Right.KAM.Control));
Subjects.Subject2_Right.KAM.ControlTrapz = transpose(trapz(
    Subjects.Subject2_Right.KAM.Control));

Subjects.Subject2_Right.KAM.MaxMean = transpose(mean(Subjects.
    Subject2_Right.KAM.Max));
Subjects.Subject2_Right.KAM.MaxPeak = transpose(max(Subjects.
    Subject2_Right.KAM.Max));
Subjects.Subject2_Right.KAM.MaxMin = transpose(min(Subjects.
    Subject2_Right.KAM.Max));
Subjects.Subject2_Right.KAM.MaxTrapz = transpose(trapz(Subjects
    .Subject2_Right.KAM.Max));

Subjects.Subject2_Right.KAM.MidsoleMean = transpose(mean(
    Subjects.Subject2_Right.KAM.Midsole));
Subjects.Subject2_Right.KAM.MidsolePeak = transpose(max(
    Subjects.Subject2_Right.KAM.Midsole));
Subjects.Subject2_Right.KAM.MidsoleMin = transpose(min(Subjects
    .Subject2_Right.KAM.Midsole));
Subjects.Subject2_Right.KAM.MidsoleTrapz = transpose(trapz(
    Subjects.Subject2_Right.KAM.Midsole));

%...continues to line 516
```

**Export**

```
%Prepare data in matrix for export to statistical analysis

dataANOVA(1,1) = Subjects.Subject1_Right.KAM.ControlMeanPeak ;
dataANOVA(1,2) = Subjects.Subject1_Right.KAM.MaxMeanPeak ;
dataANOVA(1,3) = Subjects.Subject1_Right.KAM.HighArchMeanPeak ;
dataANOVA(1,4) = Subjects.Subject1_Right.KAM.WedgeMeanPeak ;
dataANOVA(1,5) = Subjects.Subject1_Right.KAM.MidsoleMeanPeak ;
dataANOVA(1,6) = Subjects.Subject1_Right.KAM.OptimalMeanPeak ;

dataANOVA(2,1) = Subjects.Subject1_Left.KAM.ControlMeanPeak ;
dataANOVA(2,2) = Subjects.Subject1_Left.KAM.MaxMeanPeak ;
dataANOVA(2,3) = Subjects.Subject1_Left.KAM.HighArchMeanPeak ;
dataANOVA(2,4) = Subjects.Subject1_Left.KAM.WedgeMeanPeak ;
dataANOVA(2,5) = Subjects.Subject1_Left.KAM.MidsoleMeanPeak ;
dataANOVA(2,6) = Subjects.Subject1_Left.KAM.OptimalMeanPeak ;

dataANOVA(3,1) = Subjects.Subject2_Right.KAM.ControlMeanPeak ;
dataANOVA(3,2) = Subjects.Subject2_Right.KAM.MaxMeanPeak ;
dataANOVA(3,3) = Subjects.Subject2_Right.KAM.HighArchMeanPeak ;
dataANOVA(3,4) = Subjects.Subject2_Right.KAM.WedgeMeanPeak ;
dataANOVA(3,5) = Subjects.Subject2_Right.KAM.MidsoleMeanPeak ;
dataANOVA(3,6) = Subjects.Subject2_Right.KAM.OptimalMeanPeak ;

dataANOVA(4,1) = Subjects.Subject2_Left.KAM.ControlMeanPeak ;
dataANOVA(4,2) = Subjects.Subject2_Left.KAM.MaxMeanPeak ;
dataANOVA(4,3) = Subjects.Subject2_Left.KAM.HighArchMeanPeak ;
dataANOVA(4,4) = Subjects.Subject2_Left.KAM.WedgeMeanPeak ;
dataANOVA(4,5) = Subjects.Subject2_Left.KAM.MidsoleMeanPeak ;
dataANOVA(4,6) = Subjects.Subject2_Left.KAM.OptimalMeanPeak ;

dataANOVA(5,1) = Subjects.Subject3_Right.KAM.ControlMeanPeak ;
dataANOVA(5,2) = Subjects.Subject3_Right.KAM.MaxMeanPeak ;
dataANOVA(5,3) = Subjects.Subject3_Right.KAM.HighArchMeanPeak ;
dataANOVA(5,4) = Subjects.Subject3_Right.KAM.WedgeMeanPeak ;
dataANOVA(5,5) = Subjects.Subject3_Right.KAM.MidsoleMeanPeak ;
dataANOVA(5,6) = Subjects.Subject3_Right.KAM.OptimalMeanPeak ;

dataANOVA(6,1) = Subjects.Subject3_Left.KAM.ControlMeanPeak ;
dataANOVA(6,2) = Subjects.Subject3_Left.KAM.MaxMeanPeak ;
dataANOVA(6,3) = Subjects.Subject3_Left.KAM.HighArchMeanPeak ;
dataANOVA(6,4) = Subjects.Subject3_Left.KAM.WedgeMeanPeak ;
dataANOVA(6,5) = Subjects.Subject3_Left.KAM.MidsoleMeanPeak ;
dataANOVA(6,6) = Subjects.Subject3_Left.KAM.OptimalMeanPeak ;

dataANOVA(7,1) = Subjects.Subject4_Right.KAM.ControlMeanPeak ;
dataANOVA(7,2) = Subjects.Subject4_Right.KAM.MaxMeanPeak ;
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```
dataANOVA(7,3) = Subjects.Subject4_Right.KAM.HighArchMeanPeak ;
dataANOVA(7,4) = Subjects.Subject4_Right.KAM.WedgeMeanPeak ;
dataANOVA(7,5) = Subjects.Subject4_Right.KAM.MidsoleMeanPeak ;
dataANOVA(7,6) = Subjects.Subject4_Right.KAM.OptimalMeanPeak ;

dataANOVA(8,1) = Subjects.Subject4_Left.KAM.ControlMeanPeak ;
dataANOVA(8,2) = Subjects.Subject4_Left.KAM.MaxMeanPeak ;
dataANOVA(8,3) = Subjects.Subject4_Left.KAM.HighArchMeanPeak ;
dataANOVA(8,4) = Subjects.Subject4_Left.KAM.WedgeMeanPeak ;
dataANOVA(8,5) = Subjects.Subject4_Left.KAM.MidsoleMeanPeak ;
dataANOVA(8,6) = Subjects.Subject4_Left.KAM.OptimalMeanPeak ;

dataANOVA(9,1) = Subjects.Subject5_Right.KAM.ControlMeanPeak ;
dataANOVA(9,2) = Subjects.Subject5_Right.KAM.MaxMeanPeak ;
dataANOVA(9,3) = Subjects.Subject5_Right.KAM.HighArchMeanPeak ;
dataANOVA(9,4) = Subjects.Subject5_Right.KAM.WedgeMeanPeak ;
dataANOVA(9,5) = Subjects.Subject5_Right.KAM.MidsoleMeanPeak ;
dataANOVA(9,6) = Subjects.Subject5_Right.KAM.OptimalMeanPeak ;

dataANOVA(10,1) = Subjects.Subject5_Left.KAM.ControlMeanPeak ;
dataANOVA(10,2) = Subjects.Subject5_Left.KAM.MaxMeanPeak ;
dataANOVA(10,3) = Subjects.Subject5_Left.KAM.HighArchMeanPeak ;
dataANOVA(10,4) = Subjects.Subject5_Left.KAM.WedgeMeanPeak ;
dataANOVA(10,5) = Subjects.Subject5_Left.KAM.MidsoleMeanPeak ;
dataANOVA(10,6) = Subjects.Subject5_Left.KAM.OptimalMeanPeak ;

dataANOVA(11,1) = Subjects.Subject6_Right.KAM.ControlMeanPeak ;
dataANOVA(11,2) = Subjects.Subject6_Right.KAM.MaxMeanPeak ;
dataANOVA(11,3) = Subjects.Subject6_Right.KAM.HighArchMeanPeak ;
dataANOVA(11,4) = Subjects.Subject6_Right.KAM.WedgeMeanPeak ;
dataANOVA(11,5) = Subjects.Subject6_Right.KAM.MidsoleMeanPeak ;
dataANOVA(11,6) = Subjects.Subject6_Right.KAM.OptimalMeanPeak ;

dataANOVA(12,1) = Subjects.Subject6_Left.KAM.ControlMeanPeak ;
dataANOVA(12,2) = Subjects.Subject6_Left.KAM.MaxMeanPeak ;
dataANOVA(12,3) = Subjects.Subject6_Left.KAM.HighArchMeanPeak ;
dataANOVA(12,4) = Subjects.Subject6_Left.KAM.WedgeMeanPeak ;
dataANOVA(12,5) = Subjects.Subject6_Left.KAM.MidsoleMeanPeak ;
dataANOVA(12,6) = Subjects.Subject6_Left.KAM.OptimalMeanPeak ;

%... Continues to line 113
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