BACHELOR THESIS

Valgus Collapse and Gender

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Preface

This study is the product of a bachelor thesis. It is the last threshold to step over before the student receives a diploma in physiotherapy and can enter the working life as a physiotherapist. The students can choose whether to do a literature review or an experimental study. The school suggests some topics for the students but the individual student is also free to choose, within the spectrum of physiotherapy, a topic of own choice. In my opinion it is easier to strive towards a goal when it is self motivated. I therefore wanted to come up with a topic of my own. The process of finding a topic was not easy. I have, for unknown reasons, always been interested in differences across gender. Perhaps is it because there are many speculations about gender differences, of physical and non-physical nature. Some of the speculations are merely opinions without any concrete evidence as support. I believe that we need to investigate this topic to separate opinion from fact. After several options had been explored, it came down to the idea of testing gender differences in ranges of motion in a gait lab by using the one leg squat, which is a test I have personal experiences with in relation to physiotherapy. The topic of this thesis was decided to be: valgus collapse and gender.
The gait laboratory in school provides the student with good tools for testing kinematics. Little was known about whether the system would be sufficient for testing a one leg squat but some literature and a pilot study proved that it was possible.

Now that I am in the end of the process I am glad that I chose an experimental approach. Being of practically oriented nature, I liked the variety of recruiting subjects, testing in the gait lab and using statistical software in addition to the basic writing of the report. Being the first time of writing a scientific article, much was unclear and new. Some almost forgotten aspects had to be relearned from previous education about statistics and writing. Challenges were encountered along the way, but overcome through useful discussions with fellow students and teachers. The product is this experimental report about the valgus collapse and the influence of gender on its components.

The report follows the normal structure of a research report with an introduction where the epidemiology and background is introduced as well as information about the valgus collapse and the one leg squat, followed by a method section that explains the instrumentation and experimental procedure in detail. Following, the results are presented and finally a discussion comparing the results to other literature with a conclusion in the end.

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Abstract

Background: Women have an increased risk of ACL injuries and patellofemoral complaints. Literature has speculated that this might be due to difference in kinematics across gender. Components of a dynamic valgus collapse has been associated with the above mentioned knee complaints.

Research question: What is the influence of gender on 3D kinematics of the knee during a one leg squat in healthy subjects?

Goal: The purpose of this study is to observe the differences between men and women performing a one leg squat and to see if the outcomes show a gender trend in relation to valgus collapse.

Hypothesis: It is expected that a difference can be found between gender in degrees of movement in the frontal and the horizontal plane where women are thought to show more hip adduction and hip internal rotation as well as more knee abduction and knee external rotation

Research methods: The Codamotion Analysis system was used to analyse degrees of range of motion of 10 males and 10 females performing a one leg squat. Hip and knee ranges from all the three movement planes were extracted and compared by statistical analysis.

Results: Women showed more knee abduction than men. None of the other components of valgus collapse were significant different across gender.

Conclusion: Apart from knee abduction, the other components of the hypothesis were rejected. Future research should include greater sample sizes.

Key words: gender, one leg squat, valgus collapse.

Table of content

Introduction

Lower extremity complaints are a common problem in today's society(1). The functional disability in daily life and work makes lower extremity complaints a serious problem(1). Among lower extremity complaints in the Dutch population, problems of the knee make up the highest incidence of consultation rates(2). In a German clinic, 39,8 % of all sport injuries over a period of 10 years were reported to involve the knee(3). 20,3 % of these were anterior cruciate ligament (ACL) injuries.

Among knee complaints there seems to be a higher prevalence within the female population(2,4). The risk for ACL injuries for example is more than two times higher in women than in men(5–7). Females are also twice as likely to develop patellofemoral complaints than males(8).

Resent research has attempted to explore the epidemiology behind the higher rate of ACL injuries in women and many contributing factors have been suggested. One popular theory is that women perform activities in a manner that is different to men and this predisposes them to risk of injury. Quatman et al. suggested a sex specific mechanism where women tear their ACL due to a valgus collapse while men get the same injury from a primarily sagittal mechanism(7).

Abnormal hip and knee kinematics have also been associated with patellofemoral complaints in women(9–12). The abnormal kinematics include increased amount of hip adduction and knee abduction which places the knee in a position of valgus or 'medial collapse'(10,11). A valgus position of the knee, whether it is a fixed joint position or dynamically caused by faulty lower extremity movement, would result in lateral mal-tracking of the patella and thus an increase in lateral shearing forces(11–15).

Hence, a dynamic valgus position might be a factor worthwhile considering to explain the reported gender differences in occurrence of both patellofemoral complaints and ACL injuries.

If there is a gender specific valgus trait related to movement, this is not only important in explaining the gender differences in knee complaints, but can also be of importance in rehabilitation and prevention of these injuries.

To know what components of the movement pattern are important to analyze, it is necessary to specify the definition of valgus. 'Knee valgus' refers mainly to the outwards angulation of the tibia in relation to the femur(7). The term 'valgus collapse' however, also includes rotation components of the femur and tibia during a movement, namely hip internal rotation and knee external rotation(7,16). Thus the complex movement of a valgus collapse happens not only in the frontal plane but also in the horizontal plane. It is important to look at all the components of the valgus collapse in order to get the overall picture of compensation mechanisms.

Many researchers have investigated the dynamic alignment of the lower extremity of men and women during functional tasks like walking, landing from a jump or squatting(17–21). Some studies have investigated the three dimensional (3D) kinematics of the lower extremities during a one leg squat (3D kinematics, meaning the characteristics of motion displayed in degrees, measured in three movement planes). Gracia et al.(22), Zeller et al.(23) and Dwyer et al.(17) are 3 studies that also looked at gender differences in 3D kinematics. Most of the research done on the subject point towards a gender difference in the frontal plane, whereby women show more hip adduction and knee abduction(9,23–26), which are components of valgus collapse. Differences in the horizontal plane have, however, not been clearly identified. The results of Zeller et al.(23)

for example showed that women had more hip external rotation than men whereas the definition of valgus collapse involves internal rotation of the hip. In addition, few studies have included rotation of the knee and the ones that have are showing contradicting results(24,27).

Hence, there is still no definite consensus about sex related differences of lower limb kinematics in functional tasks. In order to quantify information and provide more insight into the topic, more research is needed.

To do research on this topic, a challenging activity for the knee has to be simulated. Looking at ACL injuries, they often happen during non-contact closed chain movements such as landing and cutting/pivoting (changing moving direction) where most of the body weight is placed on one leg(27). It can therefore be useful to examine the dynamic alignment of the leg with an exercise done in a closed chain and loaded position. The one leg squat has been chosen for this study, as it is an exercise that fulfils these criteria. It is used as a clinical test and a method used by physiotherapists in assessment of the lower limb to clinically identify abnormal movement patterns(28). It is a dynamic, loaded movement that can be compared to functional activities such as landing and running(29).

The purpose of this study is to observe the differences between men and women performing a one leg squat and to see if the outcomes show a gender trend in relation to valgus collapse. All three movement planes are important to look at as movement in one plane influences the whole kinetic chain. This leads to the research question: “What is the influence of gender on 3D kinematics of the knee during a one leg squat in healthy subjects?”

It is expected that a difference can be found between gender in degrees of movement in the frontal and the horizontal plane where women are thought to show more hip adduction and hip internal rotation as well as more knee abduction and knee external rotation.

Method

Study design

This study was designed to investigate a hypothesis of kinematic differences across gender by performing measurements in a laboratory and is therefore an experimental study. Subjects were informed that the aim of the study was to explore gender differences in relation to lower extremity kinematics but were not informed about the hypothesis of the outcomes in case of possible bias.

Participants

All physiotherapy students studying at Fontys University of Applied Sciences in Eindhoven were invited to participate in this study by mail. Based on a time schedule, ten male and ten female subjects were included to participate, aged 21-30. The subjects were all active young people involved in recreational sport activity of different types. Anthropometric measures can be found in table 1. The measures are displayed in mean and standard deviation to give an overall representation of the average of the two groups.
Subjects were excluded if they reported a history of ACL injury or surgery, any lower extremity injury or surgery during the last six months. Further exclusion criteria were current lower extremity or balance complaints that could affect their self-perceived manner of standing on one leg or do a one leg squat. No limitations for the age range of participants were set. See table 2 for list of inclusion criteria.

Table 1: Anthropometric measurements, n=10 male subjects, n=10 female subjects.

	Age (years)		**Weight (kg)**		**Height (cm)**		**H_activity***		**I_activity***	
	m*	f*	m	f	m	f	m	f	m	f
Mean	24,90	24,00	77,90	59,10	179,90	167,50	6,25	5,05	13,1	12,45
±SD*	±2,88	±2,54	±12,68	±7,87	±3,87	±4,81	±2,52	±2,49	±3,48	±1,92

*m=male, f=female, H_activity: reported hours of activity every week. I_activity: reported intensity of activity on a scale from 0-20. SD= Standard deviation

Table 2: Inclusion Criteria

-student at Fontys University of Applied Science, the year 2012/2013. -no history of ACL injury/surgery. -no injury or surgery of the dominant landing leg during the last 6 months. -no current LEC* or other complaints that can affect standing on one leg. -no current LEC or other complaints that can affect the manner of doing a one leg squat (subjectively determined). -no LEC with a VAS-scale of >3 in daily life.

*LEC: Lower Extremity Complaints

Setting

The experiment was conducted in the gait lab of Fontys University of Applied Sciences, Eindhoven. Men and women were tested on different days; women were tested two days after the men. For time efficiency, three people were conducting the experiments (principal investigator and two assistants).

Instrumentation

The 3D analysis system of Codamotion (Codamotion Analysis, Charnwood Dynamics Ltd, type CX1) was used for the measurements. Of the equipment, cameras were used as well as markers and frames (see figure 1). The accuracy of Codamotion is 0,05mm for the horizontal (z) and frontal plane (x) and 0,3mm for the sagittal plane (y) at 3m range.(42) The frames with markers define segments for every joint from which movements in the three planes are calculated. The pelvis movements are measured with respect to the laboratory and the lower extremity joint movements are measured with respect to their proximal segments (see figure 2).
Dual DriveBoxes and markers were placed with straps and double sided tape according to Codamotion protocol (see appendix I) on the pelvis, lower portion of femur, upper portion of tibia, lateral femoral condyle of the knee, lateral malleolus and the lateral heel and lateral fifth metatarsal of the foot (see figure 1). The markers were placed on both legs with exception of the foot markers which were placed only on the dominant stance leg. Cameras were placed within a range of 3 meters from the subject. The sample frequency was 206/s.

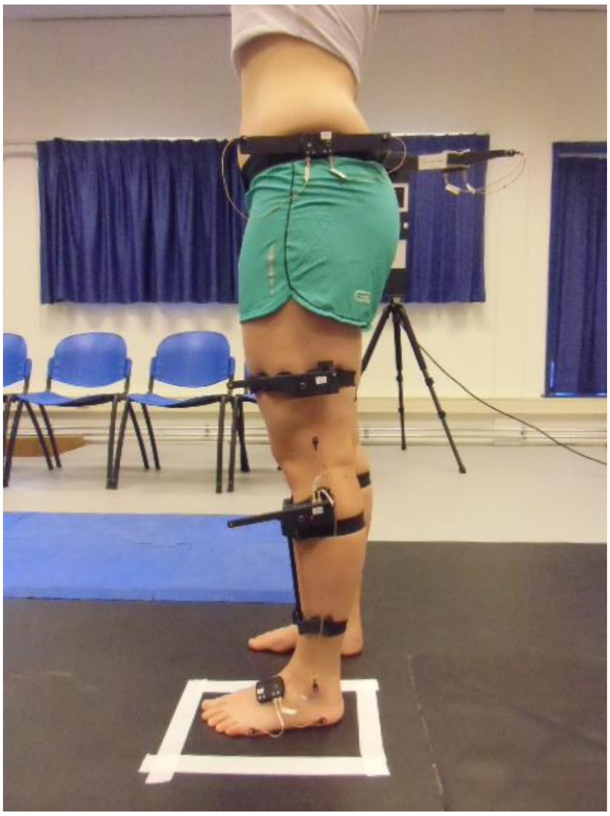

Figure 1: Marker placement

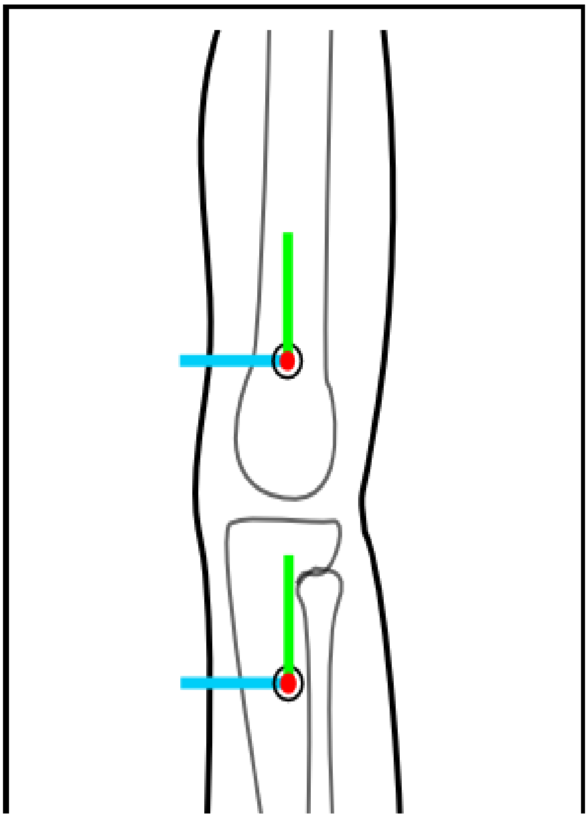

Figure 2: Figure illustrating coordinate system and axes. Blue lines: x-axis, green lines: z-axis, red line (seen from a vertical view): y-axis. The movement of the distal segment (tibia) is calculated as sequential rotations around the axis of the coordinate system of the proximal segment (femur).

Outcome measures

Parameters of interest were, in accordance with the hypothesis, ranges of hip adduction and hip internal rotation as well as knee abduction and knee external rotation. Hip and knee flexion data was also gathered in order to get information from all the three planes. Movements were calculated as degrees of adduction/abduction in the frontal plane (x), internal/external rotation in the horizontal plane (z) and flexion/extension in the sagittal plane (y). See Figure 3 for illustration of movement directions in the horizontal (z) and frontal (x) planes.

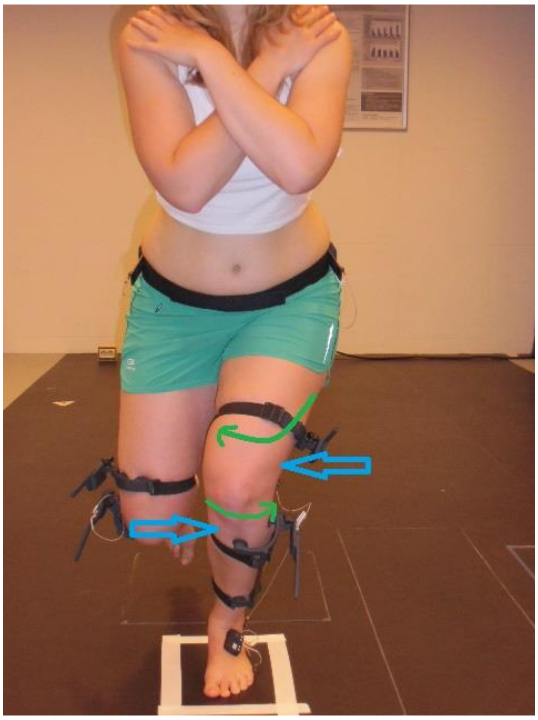

Figure 3: Movements during a one leg squat in relation to the hypothesis. Blue arrows indicate movement directions in frontal plane (x) and green arrows indicate movement directions in horizontal plane (z).

Experiment procedure

Before the experiment, subjects had to fill in a questionnaire concerning lower extremity complaints and general information such as weight, age, height and activity level on a scale from 0-20 (0 being no sports and 20 being very high intensity sports), as well as hours spent performing sports per week. See table 1 for outcomes of the questionnaire.

On the day of the experiment, the dominant stance leg of all subjects was determined by asking the participants to jump down from a 13cm high step with one leg and noting which leg they used for landing. This method was chosen as it represents a loaded movement such as the one leg squat and also because a lot of ACL injuries happen in deceleration moments such as landing from a jump(30).

Marker placement was done by the same two people each day of testing and the instructions for how to perform the one leg squat were given by the same person both days following a written protocol.
All subjects were barefoot for the marker placement and measuring. Male participants were wearing only shorts and the female subjects were wearing shorts and a rolled up T-shirt. Absence of clothing around the

iliac crest made it easier to place the pelvis frame and was also done in order to avoid possible sliding of the frame over the clothes.

The protocol used for the one leg squat is similar to the one of Dwyer et al.(17). In analogy with their study, the distance (or depth) of the one leg squat was not controlled in order to better simulate clinical setting conditions.
The starting position for the one leg squat was standing on the dominant stance leg with hands crossed over the chest, the standing leg extended and the non-standing leg bent to approximately 45 degrees of knee flexion (lower leg behind body) in order for it to not touch the floor. The participants were instructed to not make contact between the legs or between the non-standing leg and the floor at any time during the performance of the one leg squat and to look straight ahead during the whole movement. The task was to attempt to squat down as far as possible without losing balance and then returning to the starting position (see figure 2). The whole movement had to last a minimum of 3s. This was chosen in order to provoke compensations.

Figure 4: Performance of the one leg squat

Participants were allowed to practice the movement five times by themselves after receiving instructions. This number was chosen because it was thought to be sufficient for the participants to master the exercise without giving substantial fatigue to the muscles.

Before the recording, the marker placement, as well as the one leg squat performance of the test subject, was checked by the principal investigator.
Recording consisted of approximately 2s of start position followed by the one leg squat and the recording was stopped when the subject had returned to start position. Measurements where marker visibility was poor or the subject failed to follow the instructions were discarded and replaced with new recordings. For every test subject, the measurements were continued until a set of 4 sufficient recordings were obtained.

A retest was also done with two randomly chosen male subjects in order to see if there was any day to day difference of significance. The 2 male subjects were tested together with the female subjects two days later. This manner was chosen for time efficiency. The randomization was done on the testing day of the male group by letting them choose between ten envelopes where two of the envelopes included a retest note.

Data collection and statistical analysis

Data was collected from the first three measurements for every person and processed in Microsoft Excel 2010 (see figure 2 and 3 for examples of outcome measures displayed in graphs). If any measurements appeared faulty during the data collection (abnormal graphs or errors in recording time) they were replaced by the fourth measurement for that subject. Ranges were calculated from the difference between max/min values and mean start position. Mean starting position was calculated by using the average joint angles of

the first 300 samples (=approximately 1,5 s) of a recording when the person was standing still in starting position. This was done to get a more realistic measure of the start position than the first number from the recording was believed to present.
Significance value was set to p < 0,05. SPSS statistical software version 18 was used to compare the outcome parameters as well as anthropometric data between the two gender groups. The Mann Whitney U test for non-parametric independent samples was chosen to compare the groups.
A non-parametric related sample test (Wilcoxon Signed Ranks Test) was also done with the retest subjects to test the day to day variance.

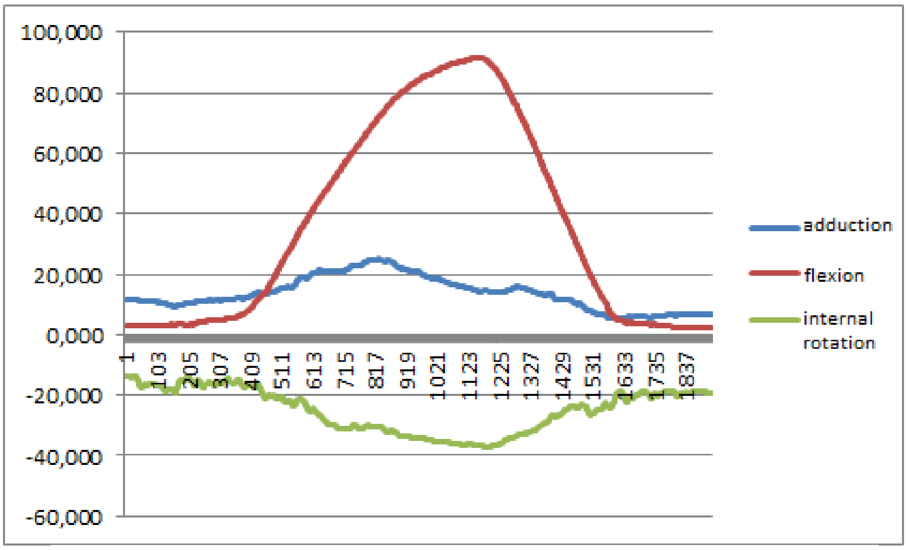

Figure 5: Example of outcome measures hip. Red line: sagittal plane, blue line: frontal plane, green line: horizontal plane.

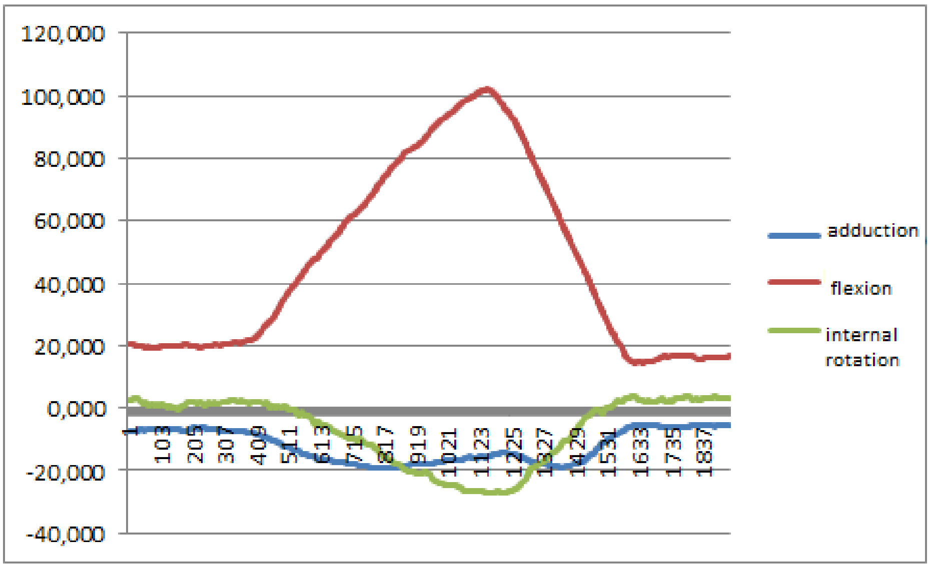

Figure 6: Example of outcome measures knee. Red line: sagittal plane, blue line: frontal plane, green line: horizontal plane.

Ethical issues

There was a small risk of injury/loss of balance or falling while testing the dominant leg or during the performance of the one leg squat. The participants were informed beforehand about risk factors and that they were allowed to stop at any time during the experiment without giving any reason why. All subjects read and signed a consent form before participating. For a copy of the informed consent form, see appendix II. The experimental design of this study was approved by Fontys University of Applies Sciences (see project approval, appendix III).

No names were used in the report or in the processing of data, only subject numbers. A confidentiality form, stating that information will remain secret, can be found in appendix IV along with a conveyance of rights agreement (appendix V).

Privacy was respected to the extent it was possible. Apart from the questionnaire about lower extremity complaints and general info, no personal questions were asked. The subjects had to be properly undressed for the measuring which could cause some discomfort. Participants were informed about this before the day of the experiment. None of the subjects expressed any discomfort about the matter.

Results

Neither the anthropometric nor the range data displayed normal distribution. Anthropometric data displayed in median and including p-values are shown in table 3. Weight and height were significantly different across gender (p: 0,000), also when BMI was used to compare the two groups (p: 0,009).
Measures of joint angle ranges of the hip and the knee from the one leg squat in degrees are reported in table 4-5. Females (f) versus (vs.) males (m) showed a greater amount of hip adduction (f:14,33° vs. m:13,70°), knee abduction (f:11,06° vs. m:4,41°) and knee external rotation (f:14,33° vs. m:11,45°). Females showed a lower amount of hip internal rotation (f:3,57° vs. m:4,77°), hip flexion (f:62,52° vs.m:70,17°) and knee flexion (f:61,50° vs. m:64,78°) than males.
Of these results, only knee abduction was significantly different across gender (p: 0,035).

The related sample test of the test-retest samples showed no difference of significance from day to day (p: 0,500-1,000;see table 6), which indicates sufficient reliability. Knee abduction, hip adduction and hip internal rotation showed the least difference (1,000).

Table 3: Anthropometric measurements. n=10 male subjects, n=10 female subjects.

	Age (years)		**Weight (kg)**		**Height (cm)**		**BMI**		**H_activity***		**I_activity***	
	M	f	m	f	m	f	m	f	m	f	m	f
Median (IQR*	25,00 (22,75-26,75)	23,00 (22,75-25,00)	73,00 (71,00-80,00)	57,50 (54,00-64,50)	179,50 (176,00-183,50)	169,50 (162,75-171,25)	22,92 (22,10-24,76)	20,79 (19,48-22,15)	5,75 (4,38-7,75)	4,50 (3,38-5,63)	14,00 (10,00-16,00)	12,50 (11,50-13,88)
ES*.	0,393		**0,000**		**0,000**		**0,009**		0,165		0,529	

*H_activity: reported hours of activity every week. I_activity: reported intensity of activity on a scale from 0-20.
IQR=Interquartile Range (25-75 %). ES=Exact significance (distribution across gender): p < 0,05.

Table 4: Hip ranges. n=10 male subjects, n=10 female subjects.

	Hip x*,°		Hip y*,°		**Hip z*,°**	
	M	f	m	F	m	f
Median (IQR*)	**13,70 (8,92-17,29)**	**14,33 (11,92-16,35)**	70,17 (60,44-81,30)	62,52 (52,56-66,39)	**4,77 (1,96-9,62)**	**3,57 (2,37-6,13)**
ES*	0,796		0,089		0,684	

*x=Adduction, y=Flexion, z=Internal rotation. m=male, f=female.
IQR=Interquartile Range (25-75%). ES=Exact significance (distribution across gender): p < 0,05.

Table 5: Knee ranges. n=10 male subjects, n=10 female subjects.

	Knee x*,°		Knee y*,°		**Knee z*,°**	
	m*	f*	m	f	m	f
Median	**4,41**	**11,06**	64,78	61,50	**11,45**	**14,33**
(IQR*)	**(3,05-11,58)**	**(7,67-16,47)**	(52,62-73,97)	(59,86-65,87)	**(8,11-23,01)**	**(9,14-17,78)**
ES	**0,035**		0,912		0,912	

*x=Abduction, y=Flexion, z=External rotation. m=male, f=female.

IQR=Interquartile Range (25-75%). ES= Exact significance (distribution across gender): $p < 0,05$.

Table 6: Test-retest values. n=2 male subjects.

	Hip x*,°		**Hip y*,°**		**Hip z*,°**		**Knee x,°**		**Knee y,°**		**Knee z,°**	
	d_1*	d_2*	d_1	d_2	d_1	d_2	d_1	d_2	d_1	d_2	d_1	d_2
median	15,60	15,32	63,00	58,64	4,29	3,69	6,73	5,97	62,76	59,94	20,40	9,46
ES*	**1,000**		**0,500**		**1,000**		**1,000**		**0,500**		**0,500**	

*x=frontal plane movement, y: sagittal plane movement, z=horizontal plane movement

d_1=first testing, d_2=retest. ES= Exact Significance (2-tailed). $p < 0,05$.

Discussion

The purpose of this study was to explore possible gender differences in the performance of a one leg squat in healthy subjects. The research question was: “What is the influence of gender on 3D kinematics of the knee during a one leg squat in healthy subjects?”. It was hypothesized that women would show more components of valgus collapse. Hence a difference in degrees of movement between gender was expected in the frontal and the horizontal planes where women were thought to show more hip adduction and hip internal rotation as well as more knee abduction and knee external rotation.

The results showed that women had more knee abduction, hip adduction and knee external rotation and less hip internal rotation, hip flexion and knee flexion. Of these, only knee abduction was significantly different across gender. Although not significant, the results showed a trend in direction of the hypothesis except for rotation of the hip, which was less for females than for males. It is important to look at these results in comparison to previous literature to see if a trend of outcomes across research can be found. This can have implications for clinical practice.

Frontal plane

Most gender differences were found in frontal plane, especially in the knee. Knee abduction was higher in women: 11.06°(7,67°-16,47°) than in men: 4,41°(3,05°-11,58°). No significant difference could be found for the hip.

The findings in frontal plane correspond with previous research done on the topic(24,25,31). Graci et al.(24),Zeller et al.(31) and Baldon et al.(25) all found significant differences in the frontal plane where women showed more hip adduction and knee ‘valgus’ (knee abduction). Willson et al.(32) studied the frontal plane projection angle (FPPA), which is the angle between the midline of the femur and the tibia measured in the frontal plane, and found that women moved into more extreme FPPA while men moved more towards neutral joint position. An increased FPPA indicates more hip adduction and more knee abduction.

Dywer et al.(17) and Claiborne et al.(26) however did not find a significantly greater knee valgus (abduction) position in women. In fact, Dwyer et al.(17) found that the men displayed more valgus than the women during the single leg squat (14,1°± 8,80 vs 12,4°± 9,10, respectively). They explained the lack of sex differences in frontal plane movement in their and Claiborne’s study by females not squatting deep enough to provoke compensations in the frontal plane. In Claiborne et al.’s study the participants were instructed to squat to approximately 60° of knee flexion. Dwyer et al. did not control depth of the squat but females still showed similar degrees of knee flexion (60°±13,3 vs.66,8°±9,70 in males). They proposed that the low amount of knee flexion was due to a non-athletic population and suggested that women may lack control of the hip to maintain neutral knee angles as knee flexion increases. Nevertheless, in this current study, where squat depth was also not controlled, the females did not squat to more than 61,50°(IQR: 59,86°-65,87°) of knee flexion and a significant gender difference in knee abduction could still be found. Taking into account the mechanisms of an ACL injury, Ireland(33) stated that a typical ACL tear happens early in the movement with relatively little knee flexion. This would suggest that squatting to a knee flexion of 60° should be sufficient amount of knee flexion to simulate the problematic activity. The same accounts for patellofemoral complaints as Lee et al.(15) found that the patella position was better and there was less influence of tibial rotations in greater angles of knee flexion.

Another reason why frontal plane compensations are not significantly different across gender in the studies of Claiborne et al.(26) and Dwyer et al.(17) could be that the female participants may have compensated by side flexion of the trunk instead. Side flexion of the trunk to the side of the loaded leg may decrease hip adduction,(24) and as these studies did not look at trunk movements, this is an unknown variable that might have an influence on the results. The same accounts for the non significant difference observed in hip adduction in this current study as compensational trunk movements were not controlled.

A reasonable explanation why females in this study did not show significantly more hip adduction than males during the one leg squat could have been the difference in degrees of hip adduction in the starting position. Women started in more hip adduction: 3,13°(1,60°-5,87°) than men: -3,40°(-9,74°-9,48°), which could be explained by a different lower extremity bone alignment across gender,(34). This could have reduced the range of movement still being possible into adduction direction. The difference in degrees of hip adduction was, however, non significant (p: 0,393). Therefore the aforementioned reasoning cannot be supported.

Frontal plane movement abnormalities could be attributed to decreased hip muscle control; especially the gluteus medius is said to be important to control moments in the frontal plane.(35) This means that the greater knee abduction in women might be due to decreased function of the gluteus medius in the female subjects. Altered gluteus medius function in the form of delayed onset and shorter activity duration have been reported in subjects with anterior knee pain,(36) and therefore has a link with patellofemoral complaints. Shirey et al(29) found better hip and knee kinematics in frontal plane during performance of a single leg squat from a step when abdominal muscles were intentionally engaged. This suggests that proximal stabilizing musculature have a role in lower limb kinematics in the frontal plane.

Horizontal plane

No significant gender differences were observed in horizontal plane movements. This might be due to the low sample size (n=20) of this experimental study. In addition, as several other authors also have suggested,(17,31) the one leg squat might be too slow and controlled to simulate the compensation mechanisms provoked by cutting and landing mechanisms where ACL tears typically occur. This may be a reason why significant kinematic differences in rotations could not be found.

Although not significant, the results from the horizontal plane showed that hip internal rotation was less in women: 62,52°(52,56°-66,39°) than in men: 70,17° (60,44°-81,30°), which is not in accordance with the hypothesis. Nevertheless, Graci et al.(24), Zeller et al.(31) and Baldon et al.(25) all did not find more internal rotation in women. In fact, most of the research done on the topic shows women displaying external rotation instead of internal rotation.(17,24,25,27,31)

Zeller et al.(31), who found significantly more hip external rotation in women, noted that the women tended to rotate their pelvis away from the standing leg and speculated that this pelvic rotation could have been interpreted as external rotation of the hip on the loaded side. This is however not the case in all studies, as other studies report pelvis rotation occurring in direction of the standing leg in women.(24,25)

Baldon et al.(25), who focused on patellofemoral pain in females, explained that the lateral rotation during the one leg squat in women might be an attempt to decrease the quadriceps angles caused by hip adduction and knee abduction. They argued the possibility that women cannot maintain this ‘compensation’ mechanism in a more functional situation. Several authors have stated that women are quadriceps dominant vs. men that are hamstrings dominant.(17,31,37) This makes the theory of Balson et al. more plausible in the sense that women are trying to keep a rather neutral position of the hip in order to maintain working conditions for quadriceps femoris functioning. Quadriceps dominance is an imbalance in hamstring/quadriceps function. If the hamstrings are counteracting the quadriceps properly, there is less chance of ACL injury(38). Hence, a balance between the functioning of the upper leg muscles is therefore important.

The explanation of reducing quadriceps angle cannot be applied to the results of this study, as women in this study did internal rotation when doing the one leg squat. Range of motion into internal rotation was quite large for both genders in this study. This could imply weakness of the lateral rotators in both groups. The results might have shown different with a greater population size, however. Especially considering that most other studies found external rotation of the hip.

Most of the studies reporting hip external rotation were the same studies finding more hip adduction in females(17,24,25,31). This is interesting because, as explained before, adduction is coupled with internal rotation in the valgus collapse mechanism. It could be however, as mentioned by Dwyer et al.(17), that since most of the studies used peaks of range of motion (ROM), the adduction peak and the external rotation peak may have occurred at different moments throughout the one leg squat.

Sagittal plane

Although it is not included in the hypothesis, sagittal plane movements are important to look at in order to get an overview of all the movement dimensions and their influence on each other. Looking at sagittal plane we see that men had more hip flexion: 70,17° (60,44°-81,30°) than women: 62,52° (52,56°-66,39°) as well as more knee flexion: 64,78° (52,62°-73,97°) than women: 61,50° (59,86°-65,87°). Although not significant, it coincides with existing literature(17,24). Zeller et al.(31), on the other hand, observed more hip and knee flexion in women than in men. This finding could be influenced by the fact that they used college athletes, hence the women may have been stronger and more trained than the average population of females.

Reliability of Codamotion

Maynard et al. (39) that studied Codamotion found a poor correlation for intra-rater reliability for kinematic parameters. Monaghan et al. (40) found that variability of kinematic parameters decreased with number of measurements and suggest a number of 10 measurements to be done. As the participants in this study were practicing the movement five times before the testing and at least four one leg squats were necessary for the recordings, the author believes increasing the number of measurements would be too much as it could give fatigue. Hence, according to the previous mentioned literature, the between-day variability could still be an issue.
To account for this, a retest was done with two randomly chosen participants from the male group. There

was no significant differences from day to day. Especially for frontal plane, the results were good. Median knee abduction was 6,73° for day one and 5,97° for day two. This is important as knee abduction was the only significant outcome measure. These results indicate that the Codamotion system was reliable enough for these specific outcome measures.

Limitations

This study has several limitations. The most important limitation is concerning sample size. Even though other researchers have found significant differences between gender with a similar sample size(24,31), it is believed that the differences observed across gender in this study could have shown significant with a greater population size.

Another limitation of this study is that only physiotherapy students were included, due to insurance reasons. Hence, the participants were all active young people involved in recreational sport on a weekly basis. This would be the target group that are vulnerable for ACL injuries, but makes it difficult to generalize the results to more sedentary population. As this study not only focuses on ACL injuries, but also discusses patellofemoral complaints, a more general population would have been preferred. Perhaps if a more general population had been studied, significant gender differences in hip adduction, and hip and knee rotations could have been found.

The activity level is seen as an important anthropometric measurement in this case and the participants were therefore asked about amount and intensity of activity to be able to detect any difference between the groups. Although no significant differences were found, the questions were answered very subjectively. The participants were asked to grade the intensity of activity on a scale from 0-20 but no further explanation of the scale was given. Some of the subjects also participated in several sports and thus graded the average intensity of all sports they were doing. For the future it is recommended to use the maximal intensity of all sports combined and to use a more objective scale.

This study only addressed kinematics and did not include electromyography (EMG) or muscle strength measures. The testing of muscle strength on forehand and recording EMG values during the performance of the one leg squat would have given more information and as well a more causative directed investigation to gender differences in movement.

As mentioned in the method, depth of the one leg squat was not controlled, and no time limit for the one leg squatting was set. This was however done on purpose in order to better simulate the individual differences that can be found in a clinical setting. Still, a minimum time for the one leg squat was set to three seconds in order to exclude the possibility that someone would perform the one leg squat too fast for compensations to occur. This gives a relatively slow movement that, although it gives an impression of the movement pattern of an individual, does not necessarily simulate the more explosive situations where injuries like ACL tears occur.

Some limitations occurred due to limited time. For time efficiency, two people were putting on markers instead of one. Although the marker placement was checked by the principal investigator, it would have been better if all markers were placed by the same person. Also, due to a limited time period in the gait laboratory, the retest was done with only males in order to be able to test them on the same day as the females. A better option would naturally be to randomize the retest from both groups and include more subjects in the retesting.

Body weight and height were significantly different across the gender groups; men were taller and heavier than women. During the statistical processing of the data, BMI appeared to be a factor that to unknown extent could have been an influence to the results. Unfortunately, since normalizing with degrees is difficult, this factor could not be excluded. Graci et al.(24) compared two males and females from their one leg squat testing that were of similar height and weight and concluded that it was unlikely that the significant gender differences in kinematics was due to anthropometric variables. However, there was no significant gender difference between BMI in their study population, which there was in this study. Although it can be argued that the association between BMI and degrees of ROM during a one leg squat is rather weak, it cannot be excluded that these anthropometric factors are of influence.

Strengths

This study looked at gender difference in 3D-kinematics of a one leg squat, thus observing all planes of motion. Although the definition of valgus collapse only includes the horizontal and frontal plane, all planes are important to look at, as movement in one plane can be linked to movement in other planes. Literature on the topic focuses mostly on frontal plane(25,26,32) and thus fails to take into account the true definition of a valgus collapse.

Another strength to the current study is the retesting. With the exception of Graci et al.(24), not many authors have tested the Codamotion system for reliability with regards to the one leg squat. Hence, a retest helps to give an idea of the day to day variability of the instruments and the variability of measurements within each subject, specific to the exercise. In the authors opinion it would however be advisable for future research with Codamotion to do a whole group retest in order to be able to do more extensive reliability testing.

Most studies used the dominant leg for testing, and determined the dominant leg by asking their participants which leg they would use to kick a ball with. In this study, the choice of testing leg was intentionally done in a different way. As ACL injuries often happen in a position where the leg is loaded such as in landing from a jump(27,30,41), using the leg that the subjects found it natural to land on seemed like a more functional option. It is thus seen as a strength that this study uses ‘dominant stance leg’ as the testing leg.

Clinical implications

Since significant differences could not be found in all planes, it is difficult to give advice to physiotherapists based on these results only. Based on other literature and the increased amount of knee abduction found in this study, the author suggests paying attention to proximal stabilizers in the hip and trunk during rehabilitation of women in order to control frontal plane movement in particular. It is also advisable to work towards a balanced hamstrings/quadriceps relation and decrease side to side differences.

Even though a trend towards gender based differences can be seen, a proper evaluation must still be performed for every individual patient. Information about general gender differences in kinematics can however facilitate the diagnostic process.

Recommendations

Since lower extremity movements can be influenced by trunk movement, more studies of gender differences and compensation should include analysis of trunk and pelvis movement together with the lower extremity analysis.

Studies done on this topic with 3D analysis generally include a relatively low sample size(17,24,31). Other studies like this one have a uniform subject group. More studies are needed with a greater sample size that can better represent the general population. This will improve the quantification of information about the topic in order to create a definite consensus of sex related differences in relation to movement.

It is also recommended that the relationship between weight and degrees of ROM is looked into as to whether normalization to body weight is necessary or not when measuring differences in ROM between gender.

Conclusion

A significant gender difference could be found in the frontal plane where women displayed more knee abduction then men. This was in line with the hypothesis. There was no significant differences found in horizontal plane or sagittal plane, thus those parts of the hypothesis were rejected.
More research needs to be done, especially for horizontal plane movements as gender differences in this plane are not clear. Future studies should include a greater sample size.

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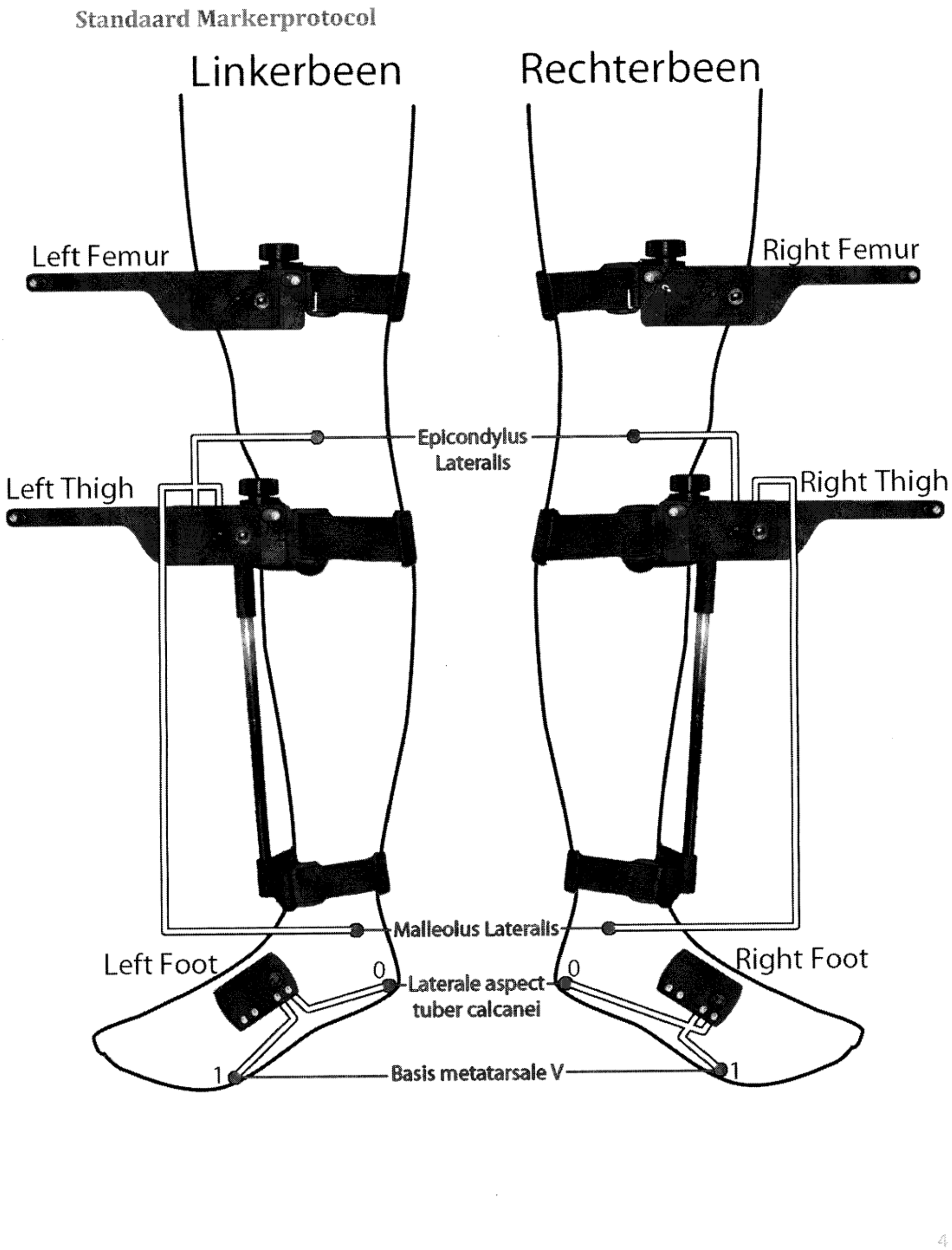
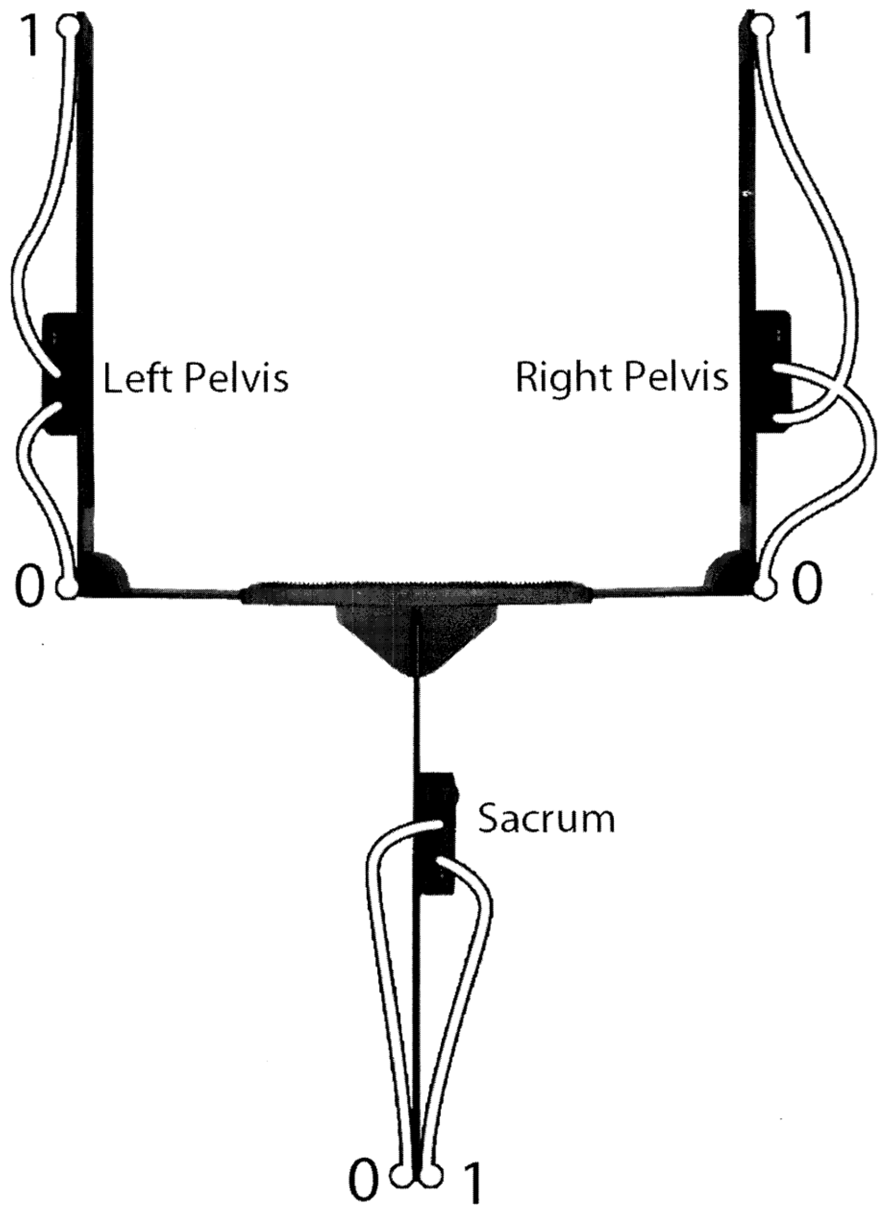
Appendix I; Codamotion protocol, marker placement



Bovenaanzicht
Pelvisbeugel



Appendix II: Informed consent form

Informed Consent

RESEARCH SUBJECT INFORMED CONSENT FORM

Prospective Research Subject: Read this consent form carefully and ask as many questions as you like before you decide whether you want to participate in this research study. You are free to ask questions at any time before, during, or after your participation in this research.

Project Information	
Project Title: One leg squat and gender	Location: Dominee Theodor Fliednerstraat 2, 5631 BN Eindhoven
Principal Investigator: Kine M. Berg	E-mail: k.berg@student.fontys.nl

1. PURPOSE OF THIS RESEARCH STUDY

You are being asked to participate in a research study designed to explore if the movement pattern of females varies from that of males. If there is a gender difference in performance of the one leg squat this can be important for explaining a reported gender difference in prevalence of knee complaints, especially ACL damage.

2. PROCEDURES

You will be asked to do a one leg squat x4. Before this, dominant leg will be checked, markers will be placed on your lower legs and you will get instructions on how to perform the one leg squat. You will be allowed to practice this 5 times before the measurements take place.

A 3D codamotion marker system will be used to detect the angles of your lower extremity joints from these 4 trials. No video will be used. T will not be possible to recognize your person from the recordings.

The whole experiment is expected to take around half an hour of your time. For every one leg squat, 8 seconds will be recorded with the marker system.

3. POSSIBLE RISKS OR DISCOMFORT

There are minimal risks connected to this experiment. There is a risk that you will lose your balance during the one leg squat measuring or the testing of the dominant leg. There is as well a small risk that you will fall.

4. FINANCIAL CONSIDERATIONS

There is no financial compensation for your participation in this research.
There is no obligatory costs to the subject that might result from participation in this study.

5. CONFIDENTIALITY

Your identity in this study will be treated as confidential. Information about subjects will be kept private on the researchers computer and no data will be shared in combination with names. The results of the study, including laboratory or any other data, will be official but will not give your name or include any identifiable references to you. Only subject numbers will be used in reporting and discussing the data.

6. TERMINATION OF RESEARCH STUDY

You are free to choose whether or not to participate in this study. There will be no penalty or loss of benefits to which you are otherwise entitled if you choose not to participate.
In case of cancelling, please notify the researcher (Kine M. Berg) as soon as possible of your decision so that you can be replaced.
You are at any time of the experiment allowed to stop and withdraw yourself from the study without having to give a reason why. In the event you decide to discontinue your participation in the study, there are no potential consequences for you resulting from this decision.

In addition, your participation in the study may be terminated by the investigator without your consent under the circumstances that you do not match the inclusion criteria:
-being a current student of Fontys.
-no history of ACL injury/surgery.
-no recent injury or surgery of the dominant landing leg.
-no current lower extremity complaints or other complaints that can affect standing one leg.
-able to stand on one leg without losing balance.
(all ages are accepted).

7. AVAILABLE SOURCES OF INFORMATION

Any further questions you have about this study, including questions about your rights as a research subject, will be answered by:

Name: Kine M. Berg
Phone Number: 0031647892771
E-mail address: k.berg@student.fontys.nl

8. AUTHORIZATION

I have read and understand this consent form, and I volunteer to participate in this research study. I voluntarily choose to participate, but I understand that my consent does not take away any legal rights in the case of negligence or other legal fault of anyone who is involved in this study. I further understand that nothing in this consent form is intended to replace any applicable Federal, state, or local laws. I have read the inclusion criteria and I agree to comply to these.

Subject nr:

Participant Signature:
Date:

Principal Investigator Signature:
Date:

Signature of Person Obtaining Consent:
Date:

Appendix III; Project Approval

Fontys Paramedische Hogeschool

B4 Assessment form project plan

Name: Kine Marie Berg   Student no: 2141612

Date: 2013-05-13

Title: What is the influence of gender on 3D kinematics of the knee during a one-leg squat in healthy subjects?

General

- The project plan is according to format — (yes) / no
- Spelling and language are correct — (yes) / no

Problem description and problem definition (introduction)

- The problem description is sufficiently clearly formulated — (yes) / no
- The problem description reflects social and paramedical relevance — (yes) / no
- A concrete and relevant research question (or questions) can be formulated based on the problem definition, including possible sub questions — (yes) / no

Objective

The objective is:

- Sufficiently clearly and concretely formulated — (yes) / no
- Relevant for a selected target group within the (paramedical) professional practice — (yes) / no
- Practically feasible — (yes) / no
- Achievable within the set time — (yes) / no

Project product (report)

The project product:

- Is in line with the problem definition, research question and objective — (yes) / no
- Is usable for the selected target group — (yes) / no
- Is in line with the client's wishes — (yes) / no
- The product requirements are accurately described — (yes) / (no)

Activities/method

Sufficient insight is given into the type of activities and types of sources for the performance of the research and the realization of the product — (yes) / no

Time schedule

- The time schedule gives a global phasing and time investment for the project as a whole and for the coming weeks an increasingly detailed schedule — (yes) / no
- Important moments are recorded in the table (typographically noticeable) (e.g. contact moments, handing-in moments) — (yes) / no
- The time schedule gives a global task division of the planned activities — (yes) / no

Study Guide PPP version 2012 - 2013   1

Estimated costs

Clear insight is given in:

- The costs to be expected concerning money and hours — yes / no
- The division of these costs (project leader, student, programme) — yes / no

Literature

- Used and planned literature is specific and mentioned to a sufficient extent — yes / no
- Relevant and recent literature is referred to — yes / no
- Literature references, in the text and in the literature list, are made according to the Writer's Guide (Wouters 2012) — yes / no

Comments:

All points under B3.1 up to and including B3.8 must be answered with a 'yes' in order to receive a GO for the project. The supervisor discusses with the student which points need adjustment.

GENERAL:	GO / NO GO

Name assessor:	Date + Signature
Ton de Lange	2013-05-13
Anke Voesenek	2013-05-14

Appendix IV: Confidentiality statement

Confidentiality statement

Name: Student No°:

Title:

___

Content (description)**:**

1. By signing this Statement, the Fontys Paramedic University of Applied Sciences in Eindhoven commits itself to keep any information concerning provided data and results obtained on the basis of research of which is taken cognizance as part of the above practical research project and of which it is known or can be reasonably understood that said information is to be considered secret or confidential, in the strictest confidence.
2. This confidentiality requirement also applies to the employees of the Fontys Paramedic University of Applied Sciences, as well as to others who by virtue of their function have access to or have taken cognizance of the aforesaid information in any way.
3. The above notwithstanding, the student will be able to perform the practical research project in accordance with the statutory rules and regulations.

Student: **Supervisor:**

Name: Kine Marie Berg Name: ______________________________

______________________________________ ______________________________________
(signature) Date:__/__/_____ (signature) Date:__/__/_____

Coordinator: for receipt Name: ______________________________

____
(signature) Date:__/__/_____

Appendix V: Conveyance of rights

Conveyance of Rights Agreement

AGREEMENT
Pertaining to the conveyance of rights and the obligation to
convey/return data, software and other means

The undersigned:

1. Mr/Ms

   ____

   [*full name as stated in passport*], residing at

   ____

   [*postal code, place of residence*] at the _______________________________________

   [*street and house number*], hereinafter to be called "**Student**"

and

2. Fontys Institute trading under the name Fontys University of Applied Sciences, Rachelsmolen 1, 5612 MA Eindhoven, hereinafter to be called "**Fontys**"

CONSIDERATION

A. Student is studying at the Fontys Paramedic University of Applied Sciences in Eindhoven and is performing or will perform (various) activities as part of his/her studies, whether or not together with third parties and/or commissioned by third parties, as part of research supervised by the lectureship of Fontys Paramedic University of Applied Sciences. The aforesaid activities will hereinafter be called "**Lectureship Study Activities**". At the time of the signing of this Statement, the Lectureship of Fontys Paramedic University of Applied Sciences supervises in any case the studies listed in Appendix 1, but this list is not an exhaustive one and may change in the future.

B. It is of essential importance to Fontys Paramedic University of Applied Sciences that (the results of) the Lectureship Study Activities can be further developed and applied without any restriction by Fontys Paramedic University of Applied Sciences and/or used for the education of other students. Fontys wishes in any event – but not exclusively – (i) to be able to share with and/or convey to third parties (the results of) the Lectureship Study Activities, (ii) to publish these under its own name, where the Student may be named as co-author providing that this is reasonable under the circumstances, (iii) to be able to use these as a basis for new research projects.

C. In case intellectual ownership rights and/or related claims on the part of Student will be/are attached to (the results of) the Lectureship Study Activities, parties wish – taking into account that which was mentioned under (B) – Fontys Paramedic University of Applied Sciences to be the only claimant with regard to said rights and claims. The Student therefore wishes to convey all his/her current and future intellectual property rights as well as related claims concerning (results of) the Lectureship Study Activities to Fontys, subject to conditions to be specified hereafter;

D. Student furthermore wishes to enter into the obligation – again taking into account that which was mentioned under (B) – to convey all data collected by him/her as part of the (results of) the Lectureship Study Activities to Fontys and not to retain any copies thereof, and also to return all data, software and/or other means previously provided by Fontys as part of (the results of) the Lectureship Study Activities, such as measuring and testing equipment, to Fontys without retaining copies thereof, all the above being subject to conditions to be specified hereafter.

AGREE THE FOLLOWING

Conveyance of intellectual property rights

1.1 Student herewith conveys to the Fontys Paramedic University of Applied Sciences all his/her current and future intellectual property rights and related claims concerning (the results of) the Lectureship Study Activities, for the full term of these rights.

1.2 Intellectual property rights and/or related claims are understood to refer to, in any case – but not limited to – copyright, data bank law, patent law, trademark law, trade name law, designs and model rights, plant breeder's rights, the protection of know-how and protection against unfair competition.

1.3 The conveyance described under 1.1 shall be without restriction. As such, the aforesaid conveyance shall include all competences related to the conveyed rights and claims, and said conveyance shall apply to all countries worldwide.

1.4 Insofar as any national law requires any further cooperation on the part of Student for the conveyance mentioned under 1.1, Student will immediately and without reservation lend such cooperation at first request by Fontys Paramedic University of Applied Sciences

1.5 Fontys accepts the conveyance described under 1.1.

Waiver of personal rights

2.1 Insofar as permitted under article 25 'Copyright' and any other national laws that may apply, Student waives his/her personal rights, including – but not limited to – the right to mention Student's name and the right to oppose any changes to (the results of) the Lectureship Study Activities. If and insofar as Student can claim personality rights pursuant to any national laws notwithstanding the above, Student will not appeal to said personality rights on unreasonable grounds.

2.2 In deviation from that which was stipulated under 2.1, the Fontys Paramedic University of Applied Sciences may decide to mention the name of Student if this is reasonable in view of the extent of his/her contribution and activities.

Compensation

Student agrees that he/she will receive no compensation for the conveyance and waiver of rights as described in this Statement.

Guarantee concerning intellectual property rights

Student declares that he/she is entitled to the aforesaid conveyance and waiver, and declares that he/she has not granted or will grant in future, license(s) for the use of (the results of) the Lectureship Study Activities in any way to any third party/parties. Student indemnifies Fontys from any claims by third parties within this context.

Obligation to convey/return data, software and other means

5.1 At such a time as Student is no longer performing any Lectureship Study Activities and/or is no longer a student at Fontys, Student is obliged to convey to Fontys all data, in the widest sense of the word, collected by him/her as part of (results of) the Lectureship Study Activities, including – but not limited to – studies and research results, interim notes, documents, images, drawings, models, prototypes, specifications, production methods, process descriptions and technique descriptions.

5.2 Student guarantees not to have kept any copies in any way or form of the data meant under 5.1.

5.3 Student is obliged to return to Fontys all data, software and other means provided to him/her by Fontys as part of the Lectureship Study Activities, and guarantees not to have kept copies in any way or in any form, of the provided software and/or other means.

5.4 Student agrees that if he acts and/or proves to have acted contrary to the obligations mentioned under 5.1 up to and including 5.3, (a) he/she shall be liable for all and any damages incurred or to be incurred by Fontys, and (b) that this will qualify as fraud and that Fontys can apply the appropriate sanctions hereto. The sanctions to be applied by Fontys may consist of, among other things, the denying of study credits, the temporary exclusion of the Undersigned from participation in examinations, but also the definitive removal of the registration of the Undersigned as a student at Fontys.

Waiver

Student waives the right to terminate this Agreement.

Further stipulations

7.1 Insofar as this Agreement deviates from the Student Statute, this Agreement shall prevail.

7.2 This Agreement is subject to Dutch law. All disputes resulting from this statement will be brought before the competent judge in Amsterdam.

Student:	**Fontys Institute** **trading under the name Fontys Hogescholen** **Supervisor:**
Name: Kine Marie Berg	Name: ____________________________
___________________________________ (signature)	___________________________________ (signature)
Date:__/__/_____	Date:__/__/_____
Place: ___________________	Place: ___________________

I, Ms. M.H. de Waard, sworn translator for the English language registered at the Court in Groningen, the Netherlands, and registered in the Dutch Register of Sworn Translators and Interpreters (Rbtv) under nr. 2202, herewith certify the above to be a true and faithful translation of the attached Dutch document into the English language.

Groningen, 23 May 2012,

[M.H. de Waard]