Reliability assessment of a Qualisys 3D gait analysis system

Michael Eigster

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Michael Eigster

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Advisors:
Logi Jónsson supervisor
Þórarinn Sveinsson advisor

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Life and environmental sciences
Engineering and natural sciences
University of Iceland
Askja, Sturlugötu 7
107 Reykjavík

Telephone number: +354 525 4600

Abstract

To evaluate the reliability of the Qualisys 3D motion analysis system, one test subject's gait was recorded (N_{total}=24) by eight high-speed cameras. Markers were used for tracking the movements (TrackManager by Qualisys) and together with force plate data was analyzed with 3D-analysis software (Visual 3D basic by C-Motion). Examined parameters were joint angles for both legs, and moments and powers for the right leg. These parameters were examined in the sagittal (X), frontal (Y) and the transverse (Z) plane. Another criterion was the targets direction of approach (coming from negative and positive y-direction). Although most of the resulting data appears to be consistent, a higher level of noise was noticed for the moment and power signals on the second force plate, when the target approached from the positive y-direction. Another source for imprecise data is the array of the cameras. At least one camera's field of view was inhibited by an obstacle and all of them were placed on the same transverse plane. Fields for further research could be experimentation with camera arrays and increasing the sample size significantly, to justify the expedient use of statistics for further analysis.

Útdráttur

Til að meta áreiðanleika Qualisys þrívíddar hreyfigreiningar kerfisins, var ganga hjá einum einstaklingi skráð (N=24) af átta háhraða myndavélum. Mælipunktar voru notaðar til að spora hreyfingarnar (TrackManager í Qualisys) og ásamt gögnum frá kraftplötum var síðan unnið frekar úr gögnunum með hugbúnaði til þrívíddargreiningar (Visual 3D basic frá C-Motion). Mæliþættir sem voru skoðaðir voru liðhorn beggja fótleggja, og kraftvægi og afl fyrir hægri fótlegg. Þessir þættir voru skoðaðir í þykktar- (X), breið- (Y), og þver- (Z) skurðarfleti. Þá voru gögnin einnig borin saman eftir því í hvaða átt (jákvæð eða neikvæð y-stefna) einstaklingurinn gekk. Þó flestir mæliþættirnir reyndust áreiðanlegir, sást meira suð í fyrir kraftvægi og afl af kraftplötu tvö þegar einstaklingurinn kom frá jákvæðri y-stefnu. Aðrar ástæður fyrir ónákvæmi í mælingunum eru að myndavélarnar eru allar staðsettar í sama þverskurðarfleti og sjónarhorn einnar myndavélarinnar var að hluta til byrgt af burðarsúlu. Frekari rannsóknir gætu kannað aðrar staðsetningar á myndavélum og aukið fjölda endurtekninga í mælingum til að efla tölfræðina í frekari greiningum.

Table of Content

Figures

I would like to dedicate this thesis to my mother, who was always supporting me in what I did.

I would like to thank Þórarinn Sveinsson for his time, support and his open door attitude.

1 Introduction

Motion capturing and 3D-analysis is used in therapy and rehabilitation, sport analysis and scientific motion research in general. Since former studies showed that gait assessment by inexperienced and experienced observers (Ong, 2008) is far less reliable than 3D-analysis (Kawamura, 2007), its application becomes more important. Thus the main goal of this research is to determine the reliability of the used equipment that is needed for 3D-analysis. Technical parts, like the eight 3D-cameras by Qualisys or force plates are just as much a part of this examination, as the used software (Qualisys Track Manager and Visual3D basic). To work in a proper and scientific way it has to be clarified that the materials and methods used for the research are reliable and thus results are reproducible.

2 Material & Methods

2.1 Equipment

For tracing the test subject's movements an array of eight high speed cameras (type: 'Oqus') by the company 'Qualisys' was used (http://www.qualisys.com/). The analyze-space for the cameras was calibrated by moving and rotating a rod with reflecting markers in the space that the subject had walked. Furthermore, two AMTI (American Management Technology, Inc.; http://amti.biz/) force plates were used independently to determine the resulting moments and power in the subject's hip, knee and ankle joints for the right leg.

2.2 Test Subject

The test subject was a male, 52 years old, 183 cm in height and 86 kg in weight. The subject's lower body, beginning with the pelvis, was equipped with markers. The defining markers, which enabled Visual 3D to reconstruct the digital skeleton of the subject, included the following: Pelvis defining proximal markers were placed on the right and left lateral aspect of the iliac crest. Distal endpoints were placed at the left and right greater trochanter. Defining proximal markers for the thigh were the same as the distal pelvis endpoints. The thigh's distal points were placed on the lateral and medial epicondyle on both legs. Proximal endpoints markers for the shank were the same as the thigh's distal end points. The distal endpoints for the shank were placed on the lateral and medial malleolus on both legs. Defining markers were removed during the movement trial, as they were not needed after the static trial. Markers tracked by the cameras consisted of anterior (right and left superior iliac spine) and one central posterior superior iliac spine pelvic marker. Four thigh markers per leg were placed in a posterior-lateral position. Four shank markers per leg were also placed in a posterior-lateral position. One heel marker per leg was placed on the posterior side of the calcaneus. Two markers per leg were placed on the first and fifth metatarsal bone. A notable anatomical attribute of the test subject, was his limping right knee. The subject had an anterior-cruciate-ligament (ACL) replacement surgery on his right knee one year ago and has osteoarthritis changes in the joint.

2.3 Data-Processing

To record the movement and force plate data the software 'Track Manager', by the company of 'Qualisys' (s. TrackManager), was used. The definition of the tracking markers was also done in 'Track Manger'. To reconstruct the subject's lower body's anatomy digitally, 'Visual 3D Basic' by the company of 'C-Motion' (http://www.c-motion.com/) was used. This program was also used for the calculation of angle-change for the test subject's left and right hip, knee and ankle joints. Force plate data was also processed with 'Visual 3D' used to calculate the resulting moments and power in the subject's hip, knee and ankle joints for the right leg.

2.4 Analysis

To ensure that the cameras and force plates recorded properly from both sides of the y-axis (defined as the direction of walking), the test subject entered the analyze-space from positive y-direction half of the trials, while the other half he was entering from the negative y-direction. To test the comparability of the force plates, half the trails were done stepping with the subject's right foot on force plate 1. The second half of the trails the subject stepped with his right foot on force plate 2. The resulting total amount of trials was 24 ($N_{total}=24$). Two events in time were defined to ensure that a comparison between trials of the processed data is standardized. These events are labeled as 'right on' (RON) and 'right off' (ROFF). RON represents the point in time (frame), where the subject's right foot hits the examined force plate and ROFF is the frame, where the subject's foot does not apply any force on the force plate anymore, because it has left it. The z-axis is defined as the vertical axis and the x-axis as the axis perpendicular to both y- and z-axis. The X-plane is defined as the two-dimension plane that is perpendicular to the x-axis, i.e. the sagittal plane. Similarly, the Y-plane is perpendicular to the y-axis (frontal plane) and Z-plane is perpendicular to the z-axis (transverse plane).

3 Results

Resulting data consists of graphs for angular changes, moments and power in the joints of the hip, the knee and the ankle. In the upper half of the figures the subject is coming from a positive y-direction (marked by a ‘+’), while in the lower half of the figures the subject is approaching the force plates from a y-negative direction (marked by a ‘-’). The red curve in every graph indicates the mean values of all trials. The x-axis in every graph represents the timeframe, when the test subject’s right foot hits the recording force plate and leaves it. Angle-changes were measured for the right and left leg’s joints in sagittal plane (see Figure 1 and 2). The frontal plane angle-changes for the right and left leg’s joints are shown in Figure 3 and 4. Transverse plane angle changes for both leg’s joints were also measured (see Figure 5 and 6). Since only the right leg’s joints were analyzed for the moment data, the distinction in the figures is made between force plate 1 and force plate 2. Moment data for both force plates was recorded for the sagittal plane (see Figure 7 and 8), the frontal (see Figure 9 and 10) and the transverse plane (see Figure 11 and 12). Right leg’s joints power data for both force plates is represented by Figure 13 and 14 for the sagittal, Figure 15 and 16 for the frontal and Figure 17 and 18 for the transverse plane.

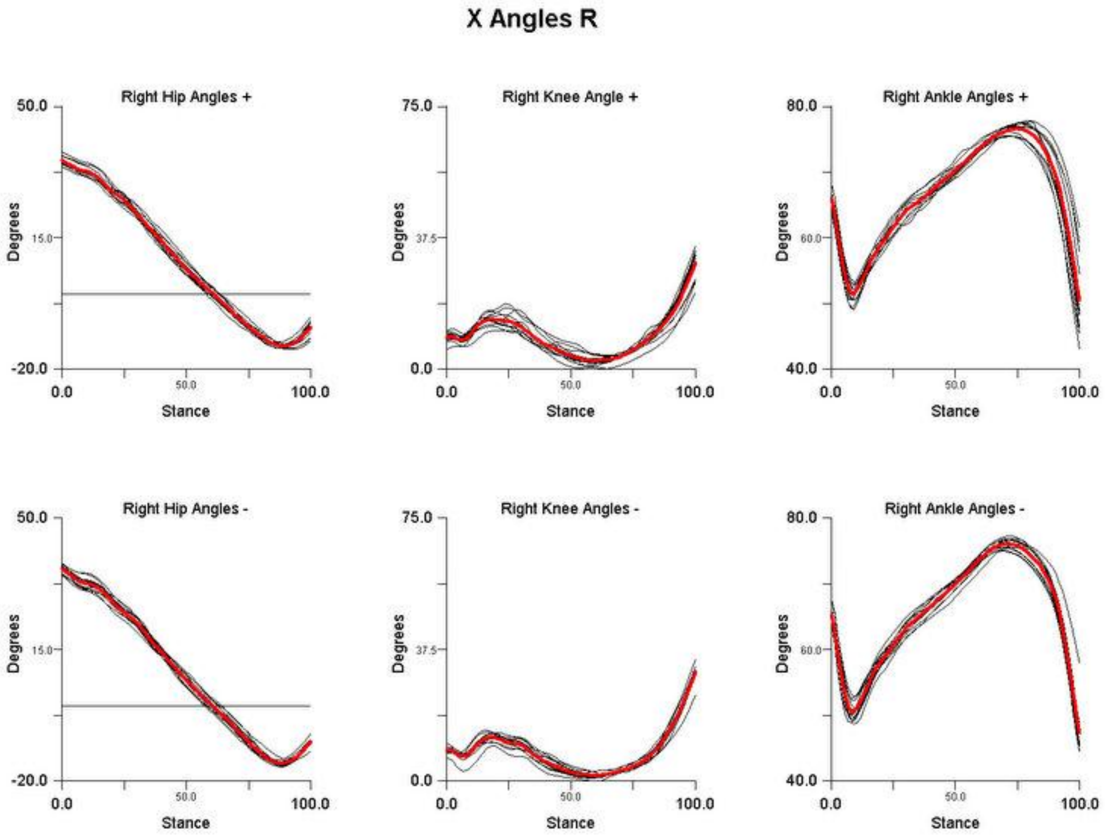

Figure 1: Joint angles in the sagittal plane (X-plane) for the right leg joints during y-positive and negative (+/-) walking directions.

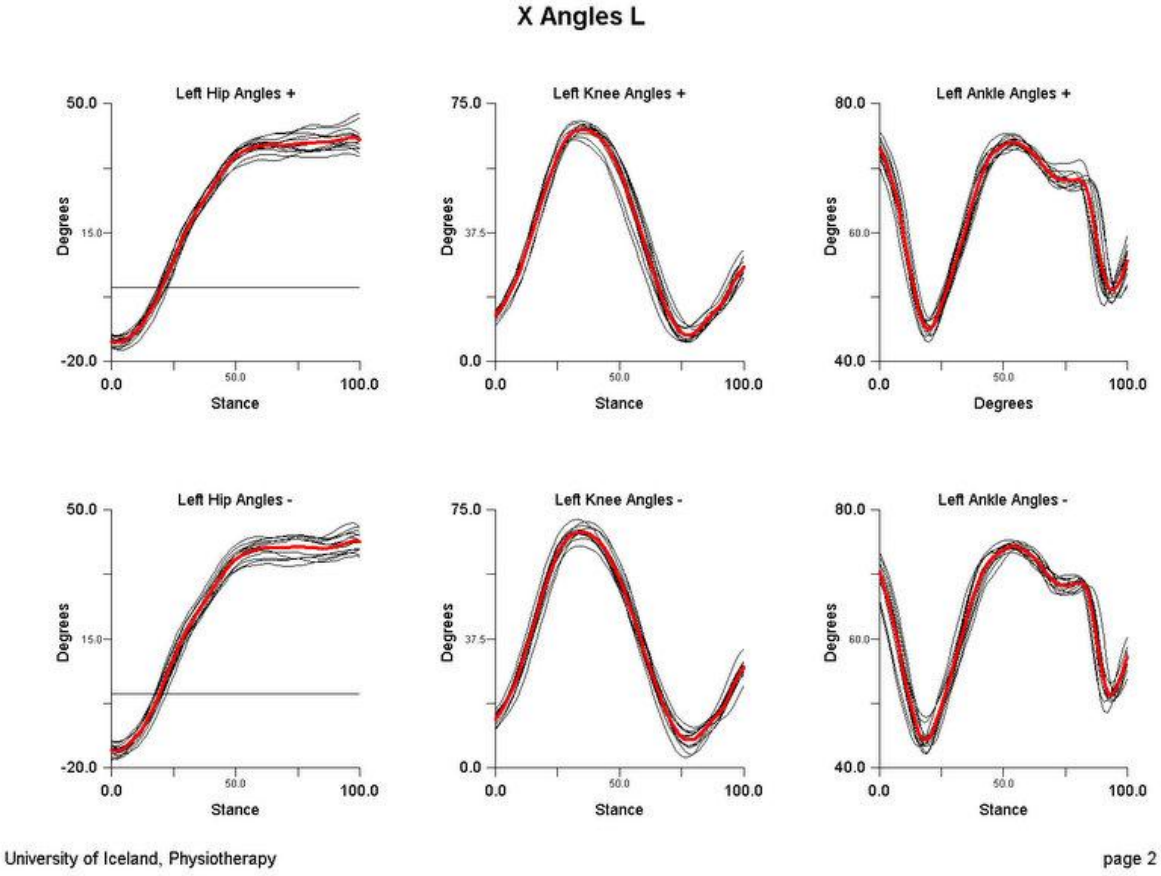

Figure 2: Joint angles in the sagittal plane (X-plane) for the left leg joints during y-positive and negative (+/-) walking directions.

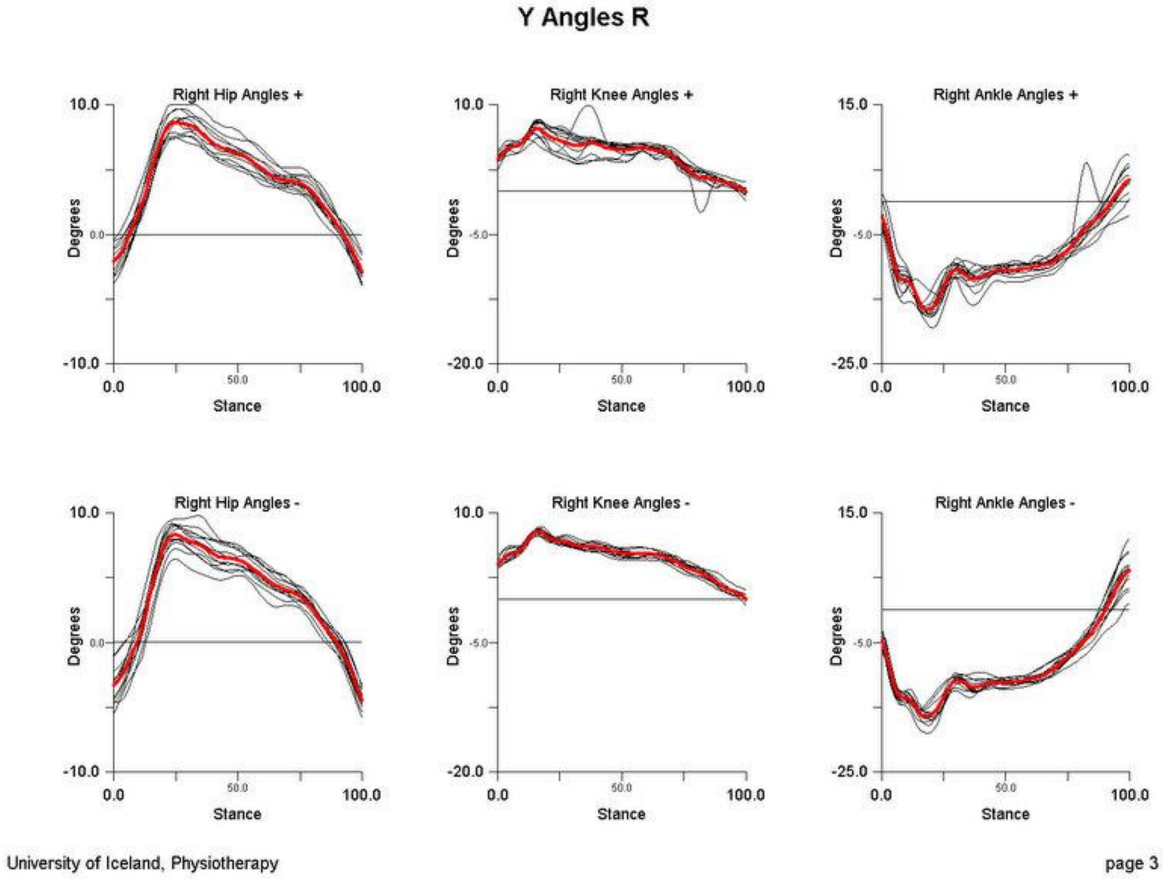

Figure 3: Joint angles in the frontal plane (Y-plane) for the right leg joints during y-positive and negative (+/-) walking directions.

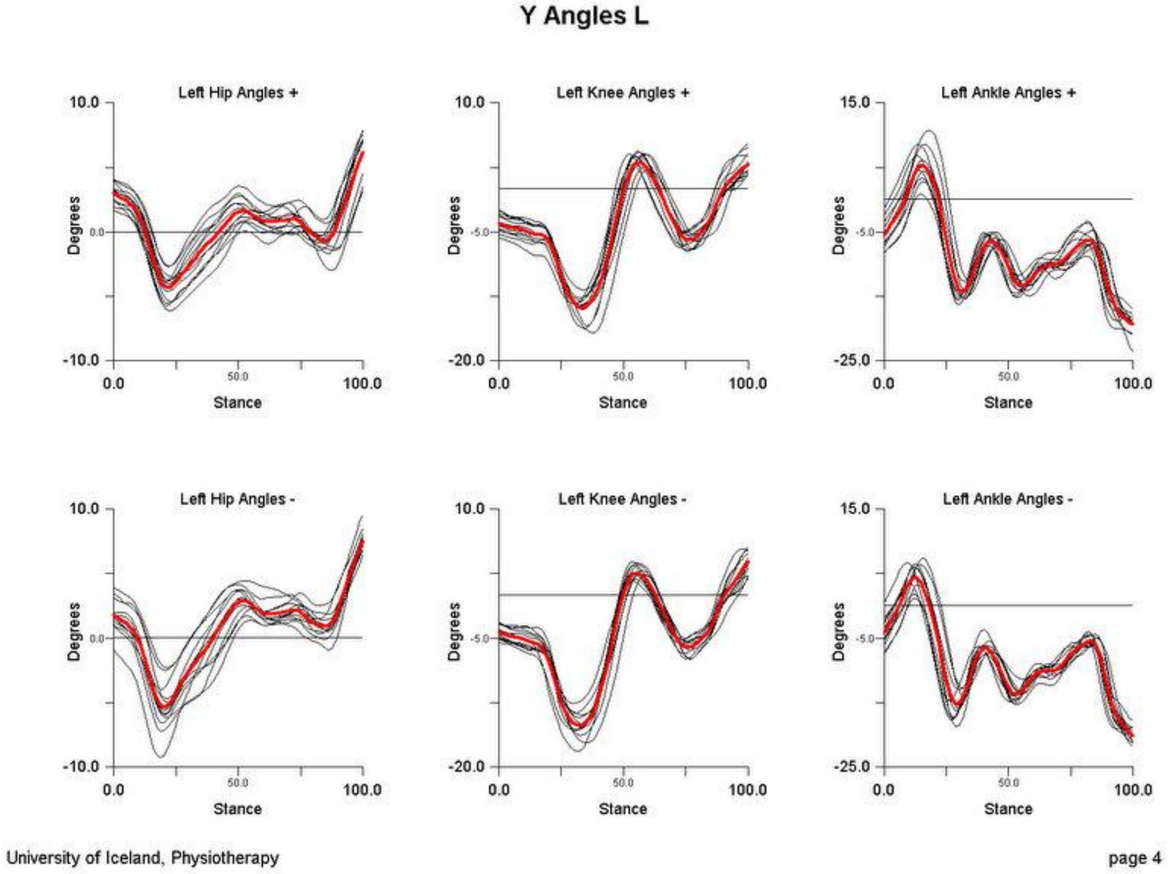

Figure 4: Joint angles in the frontal plane (Y-plane) for the left leg joints during y-positive and negative (+/-) walking directions.

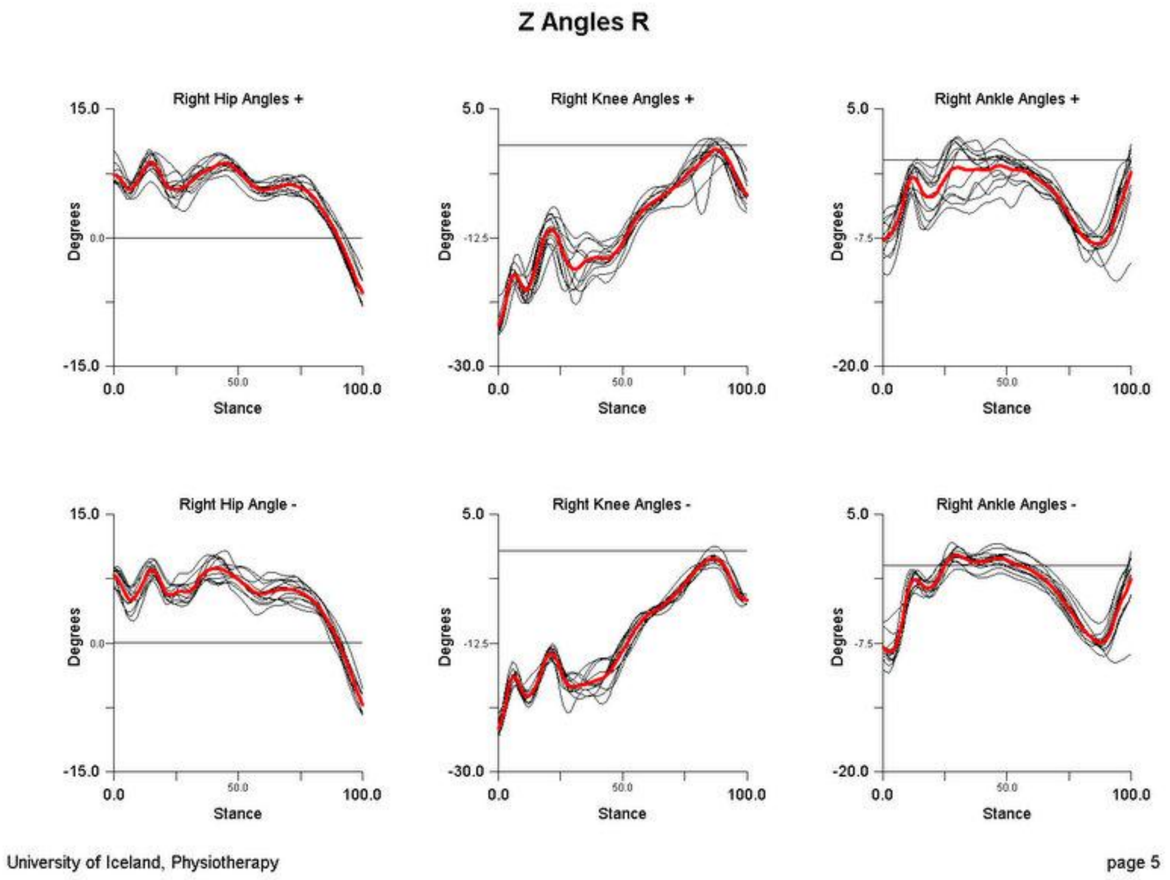

Figure 5: Joint angles in the transverse plane (Z-plane) for the right leg joints during y-positive and negative (+/-) walking directions.

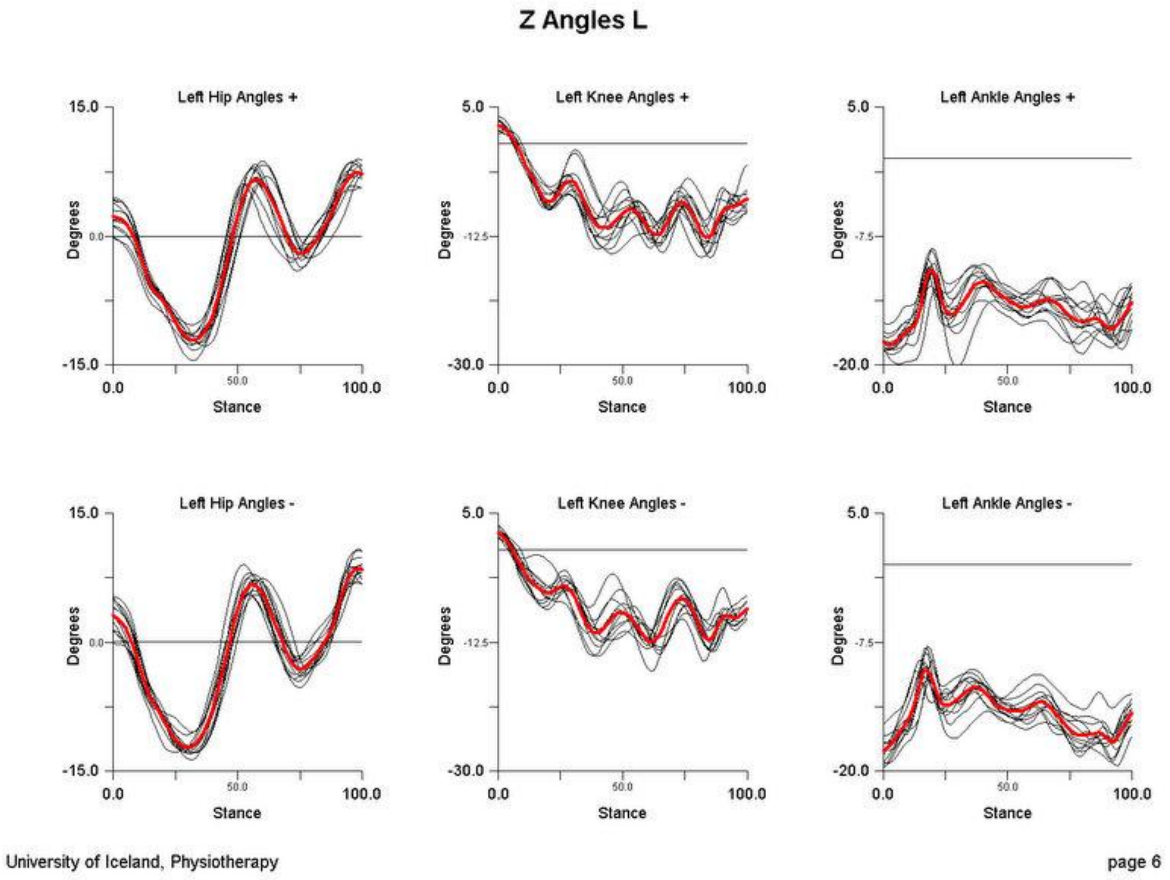

Figure 6: Joint angles in the transverse plane (Z-plane) for the left leg joints during y-positive and negative (+/-) walking directions.

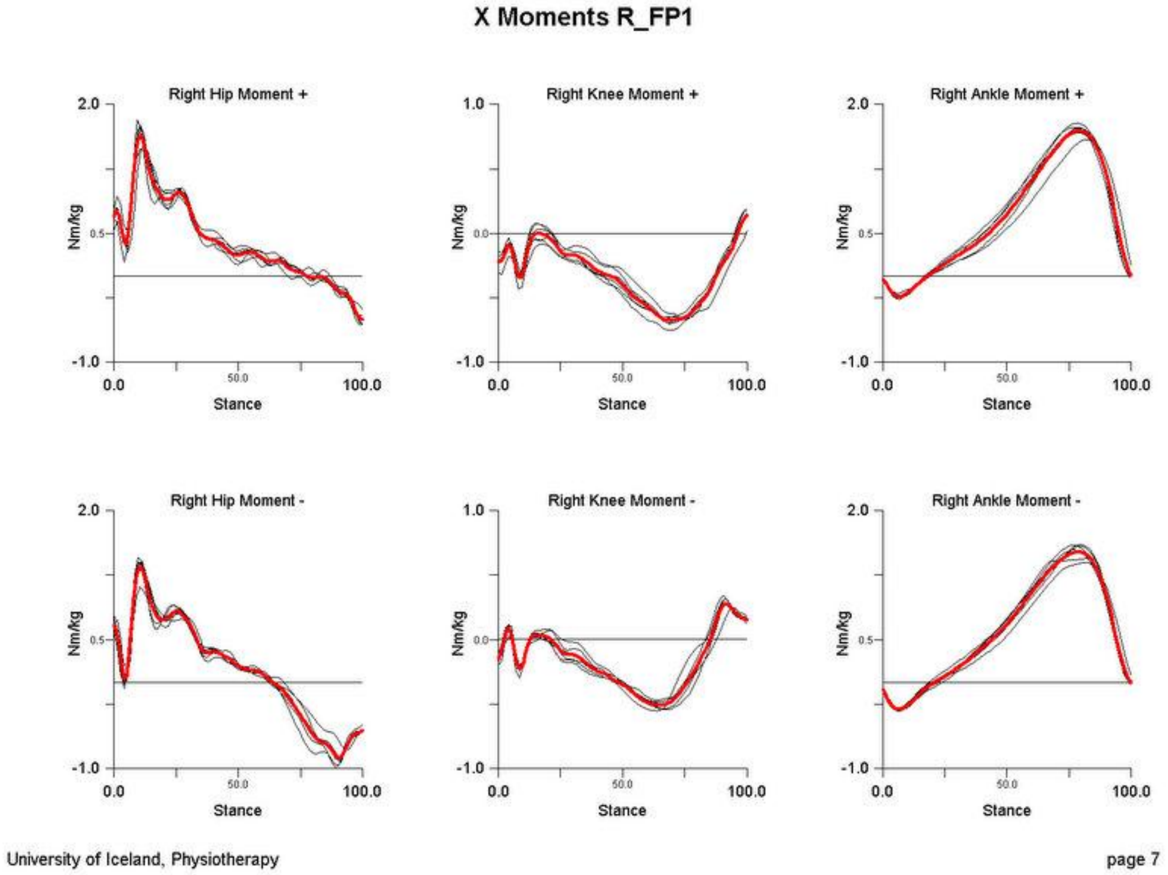

Figure 7: Moments in the saggital plane (X-plane) for the right leg joints (force plate 1) during y-positive and negative (+/-) walking directions.

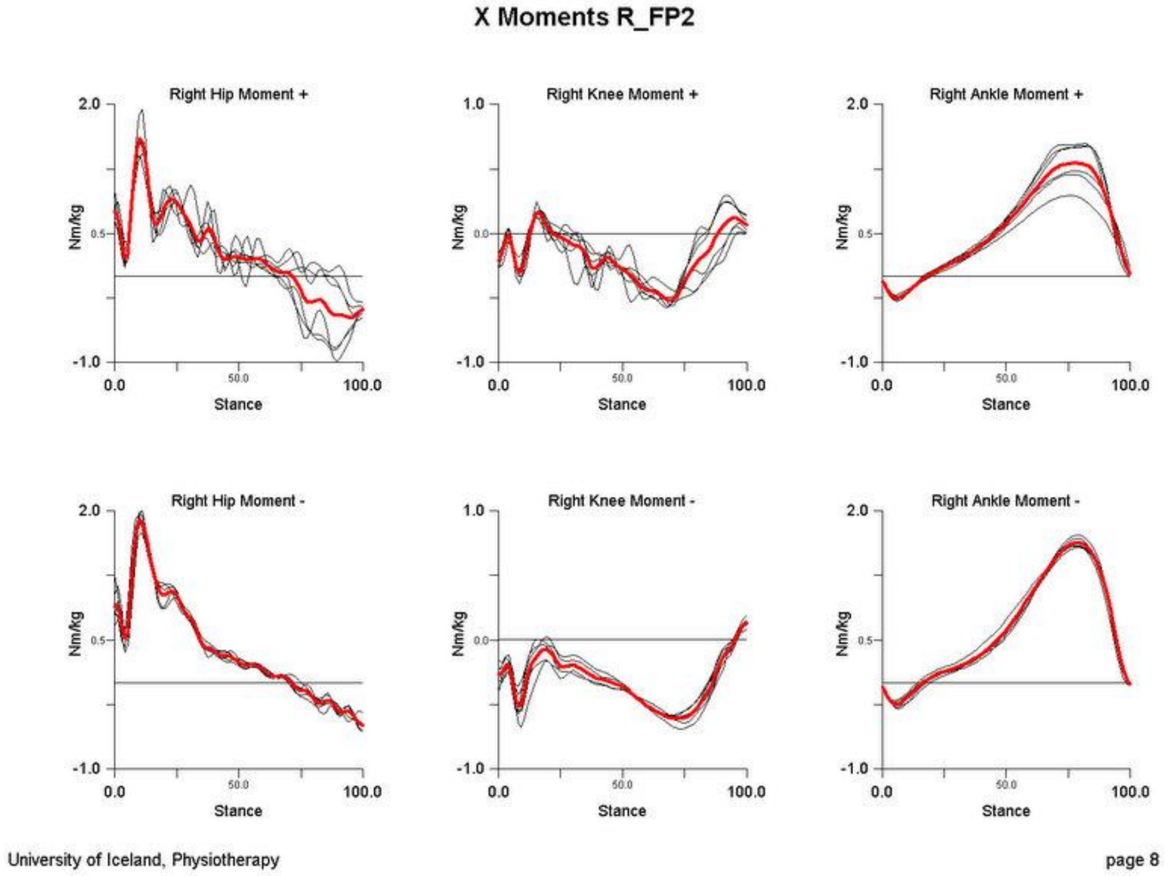

Figure 8: Moments in the saggital plane (X-plane) for the right leg joints (force plate 2) during y-positive and negative (+/-) walking directions.

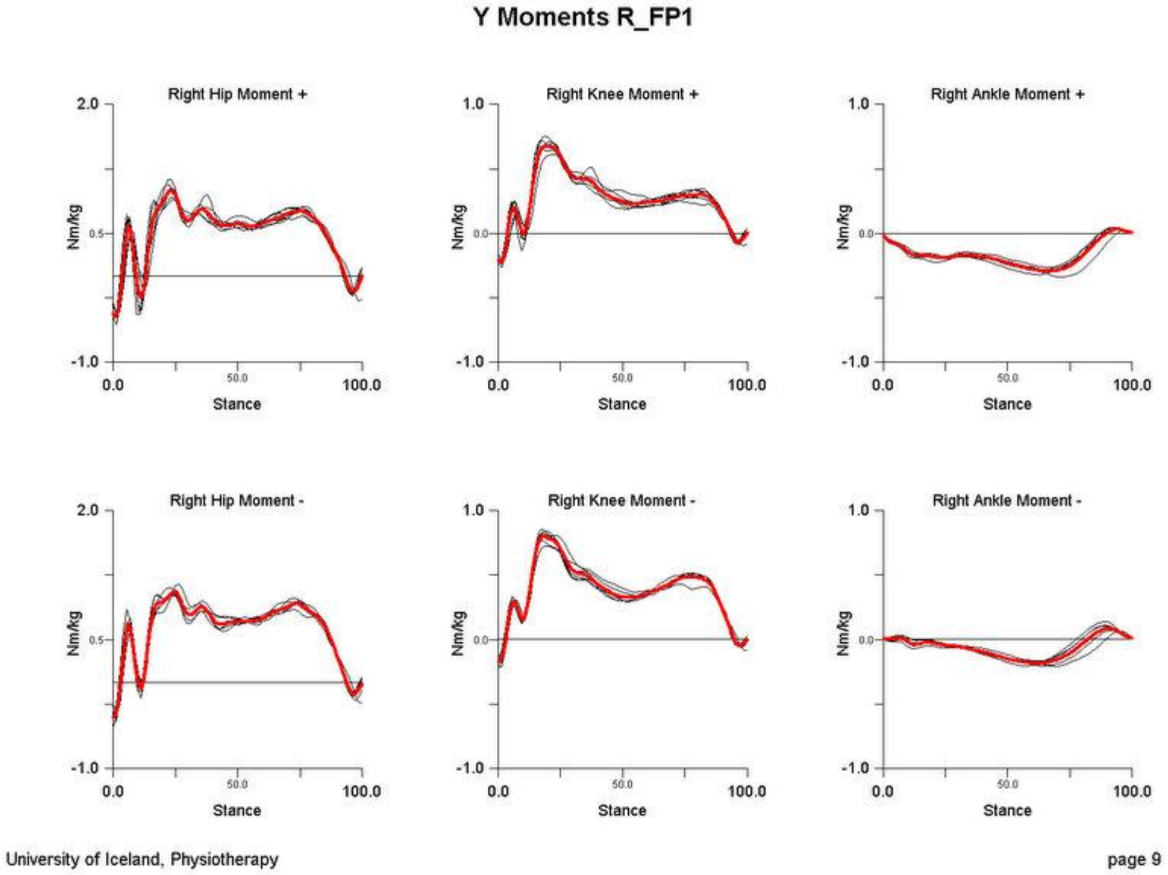

Figure 9: Moments in the frontal plane (Y-plane) for the right leg joints (force plate 1) during y-positive and negative (+/-) walking directions.

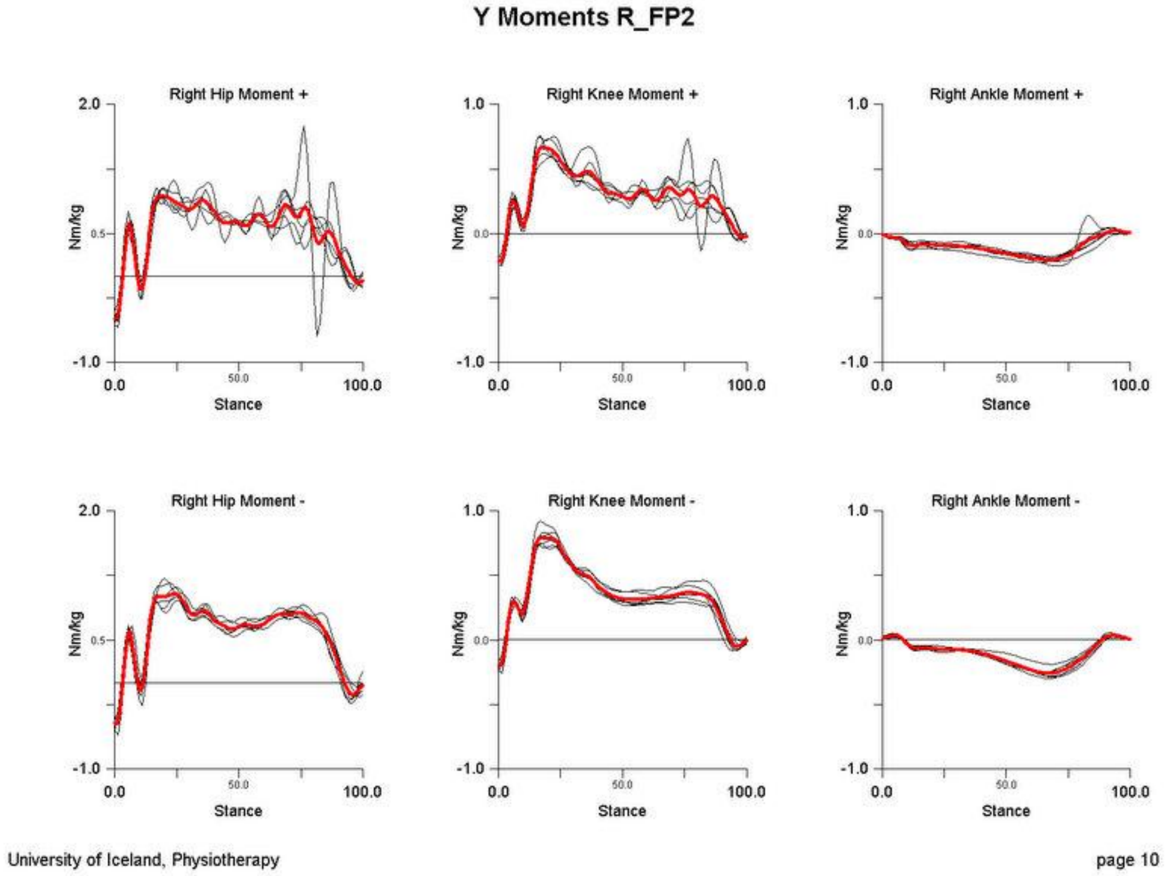

Figure 10: Moments in the frontal plane (Y-plane) for the right leg joints (force plate 2) during y-positive and negative (+/-) walking directions.

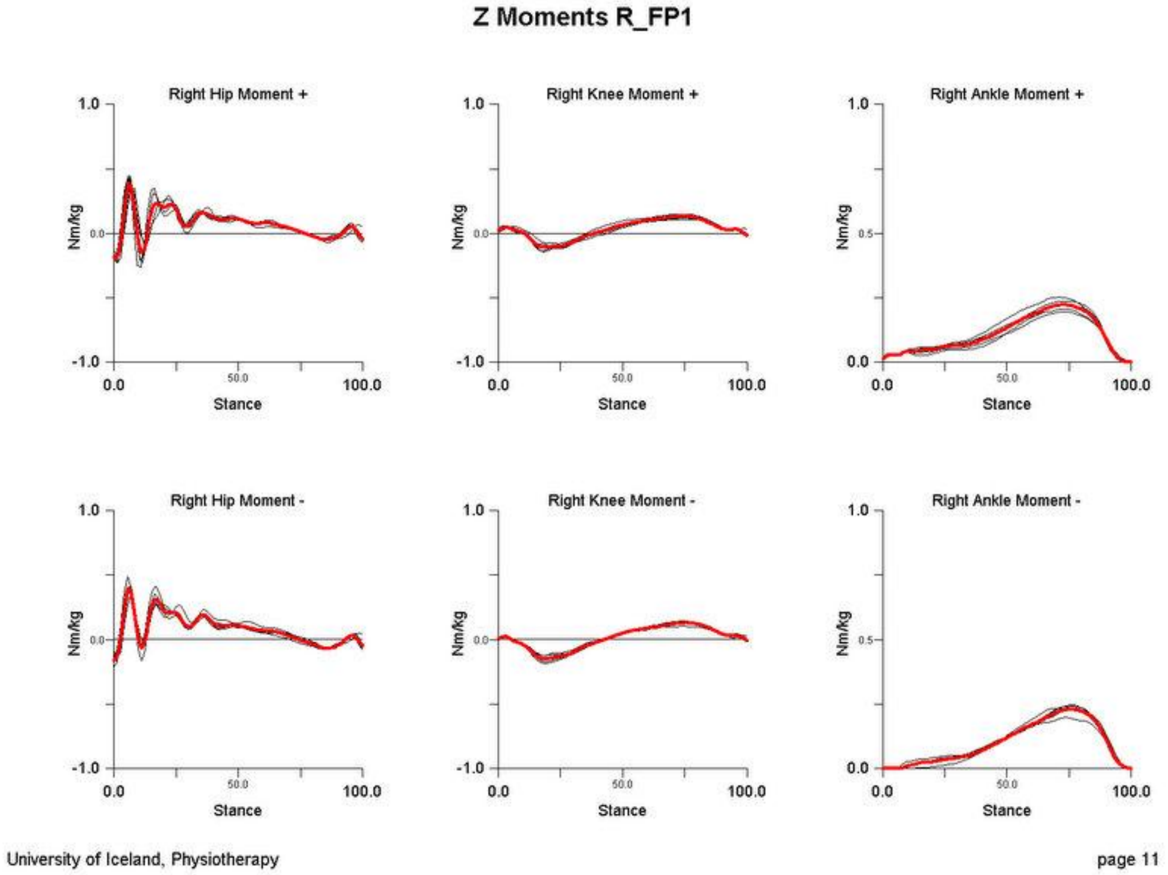

Figure 11: Moments in the transversal plane (Z-plane) for the right leg joints (force plate 1) during y-positive and negative (+/-) walking directions.

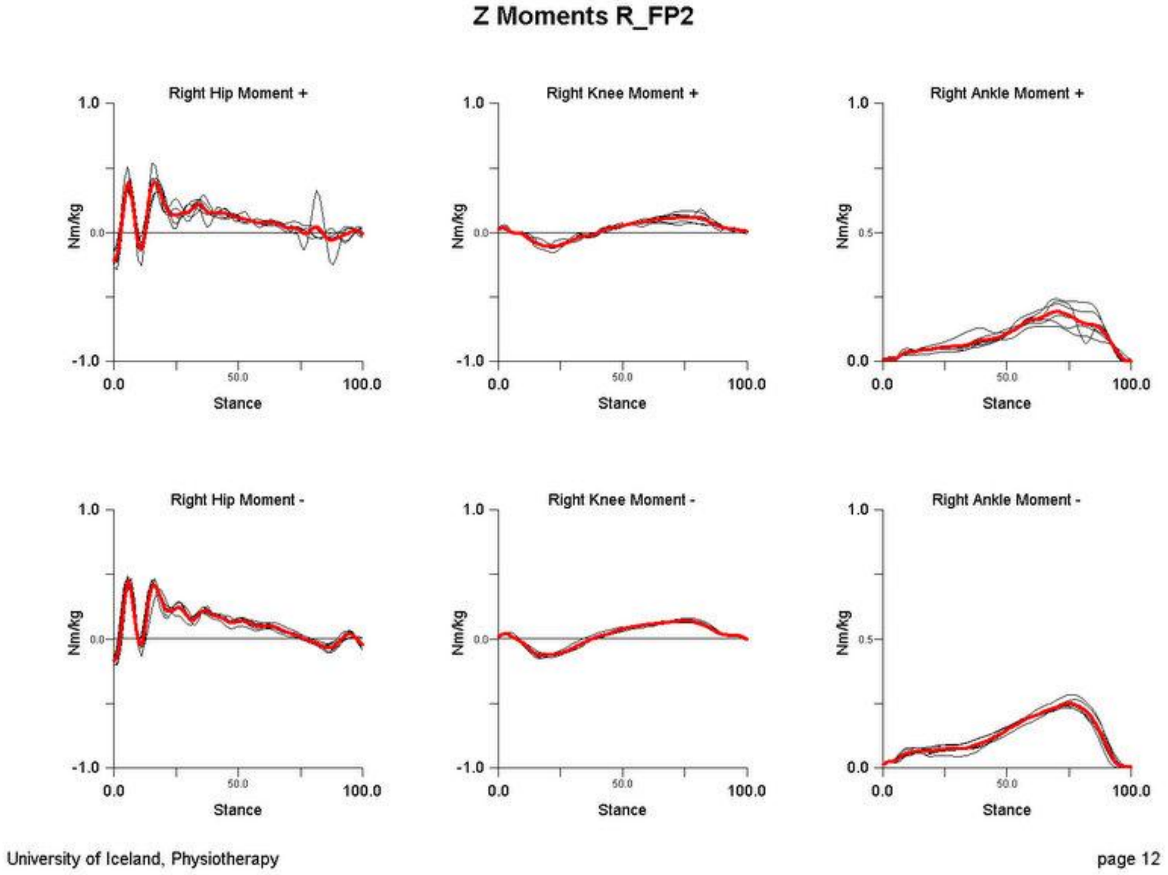

Figure 12: Moments in the transversal plane (Z-plane) for the right leg joints (force plate 2) during y-positive and negative (+/-) walking directions.

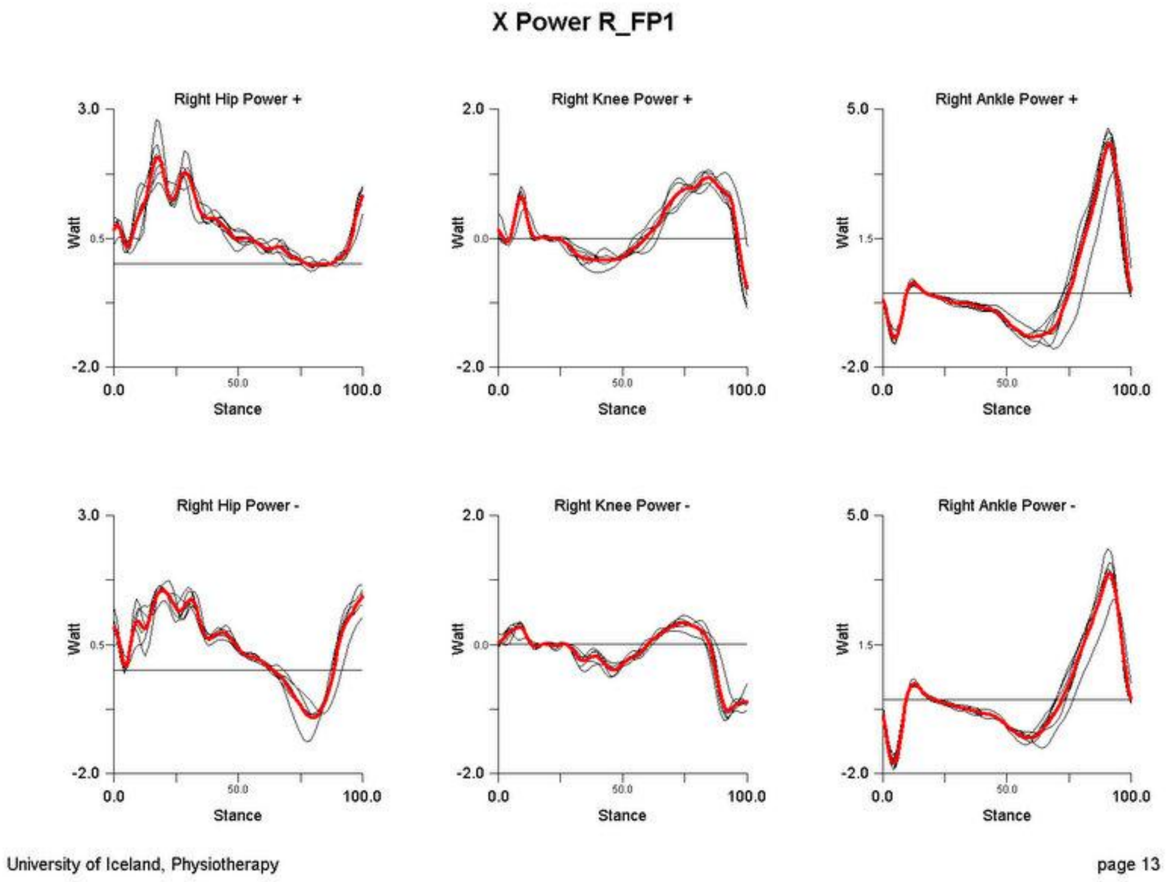

Figure 13: Power in the saggital plane (X-plane) for the right leg joints (force plate 1) during y-positive and negative (+/-) walking directions.

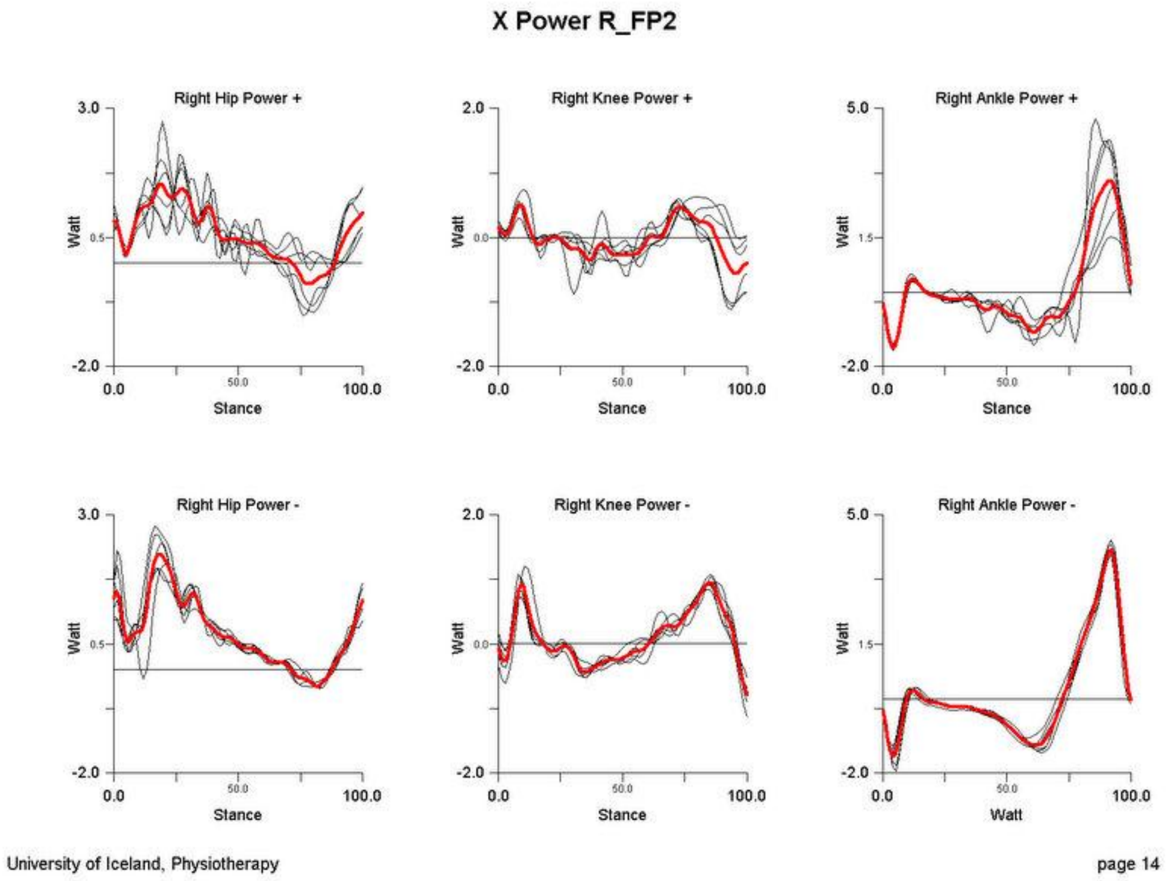

Figure 14: Power in the saggital plane (X-plane) for the right leg joints (force plate 2) during y-positive and negative (+/-) walking directions.

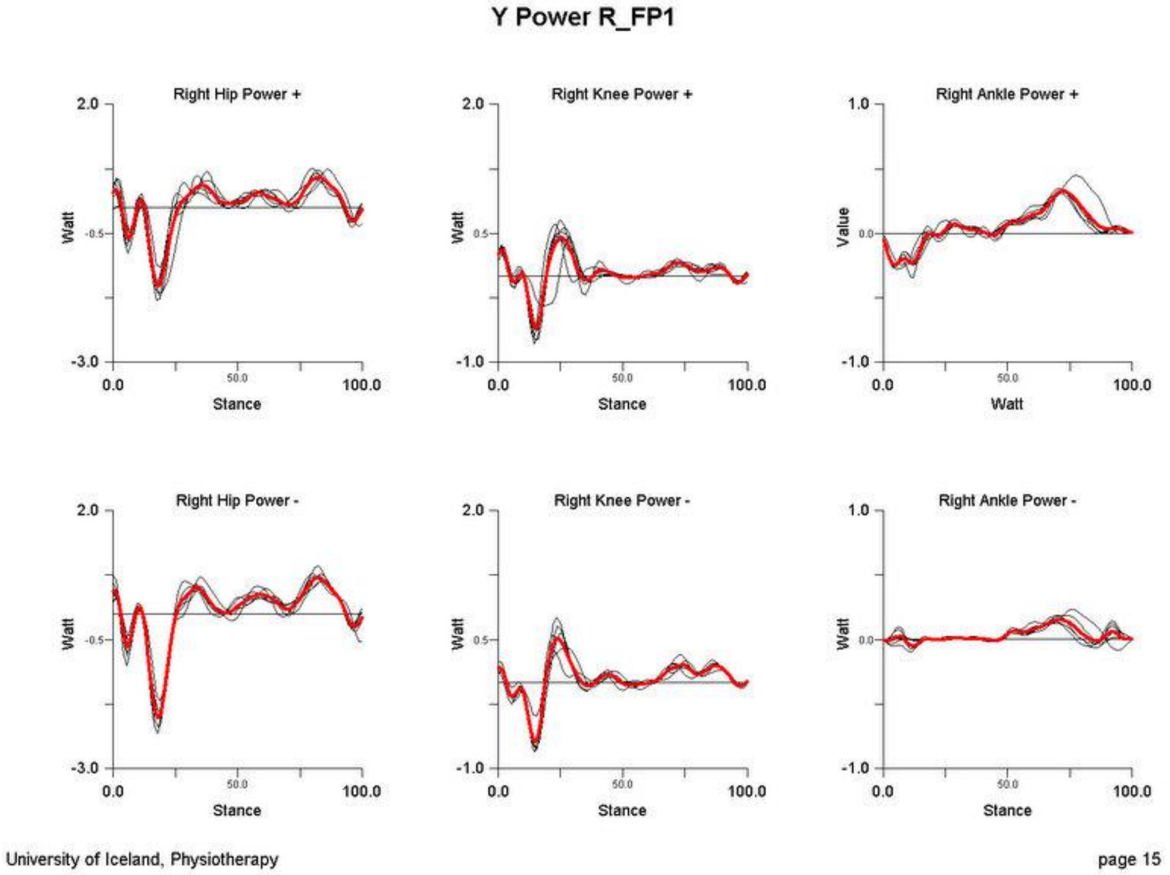

Figure 15: Power in the frontal plane (Y-plane) for the right leg joints (force plate 1) during y-positive and negative (+/-) walking directions.

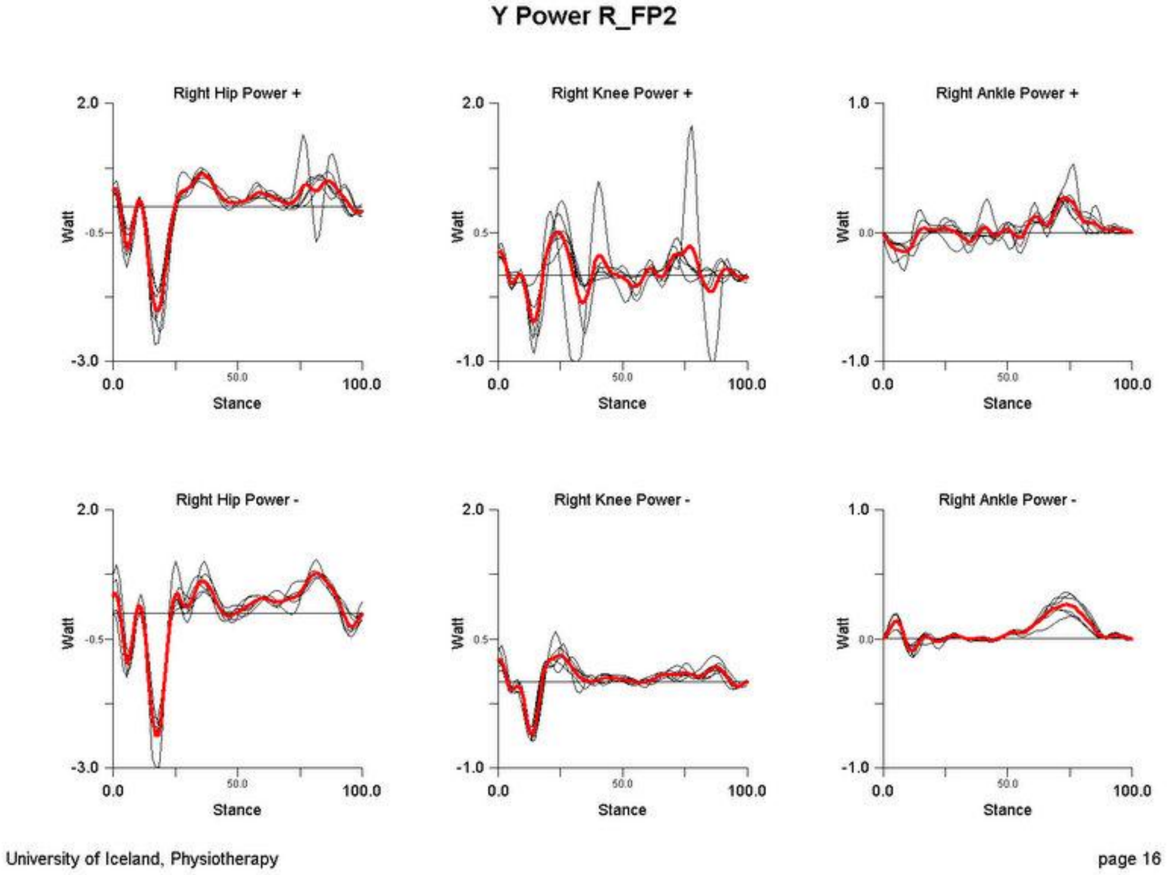

Figure 16: Power in the frontal plane (Y-plane) for the right leg joints (force plate 2) during y-positive and negative (+/-) walking directions.

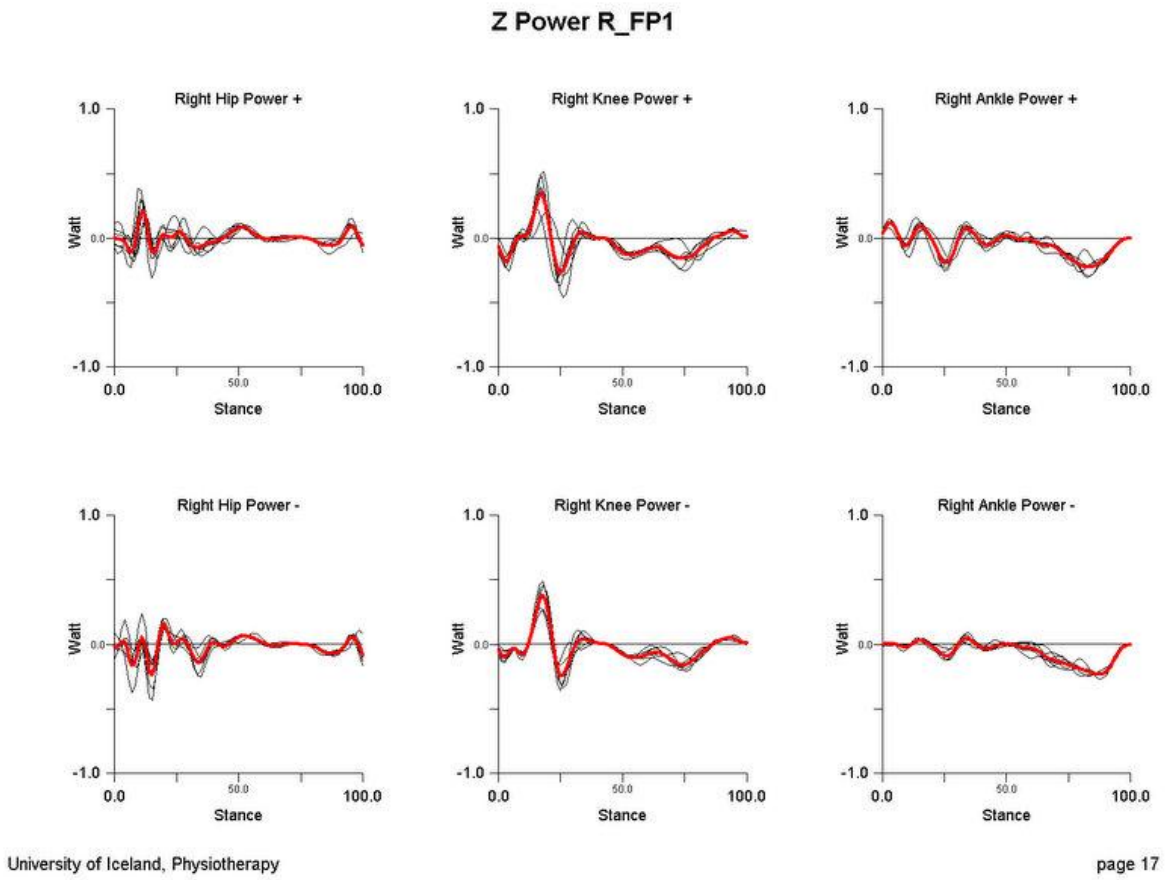

Figure 17: Power in the transversal plane (Z-plane) for the right leg joints (force plate 1) during y-positive and negative (+/-) walking directions.

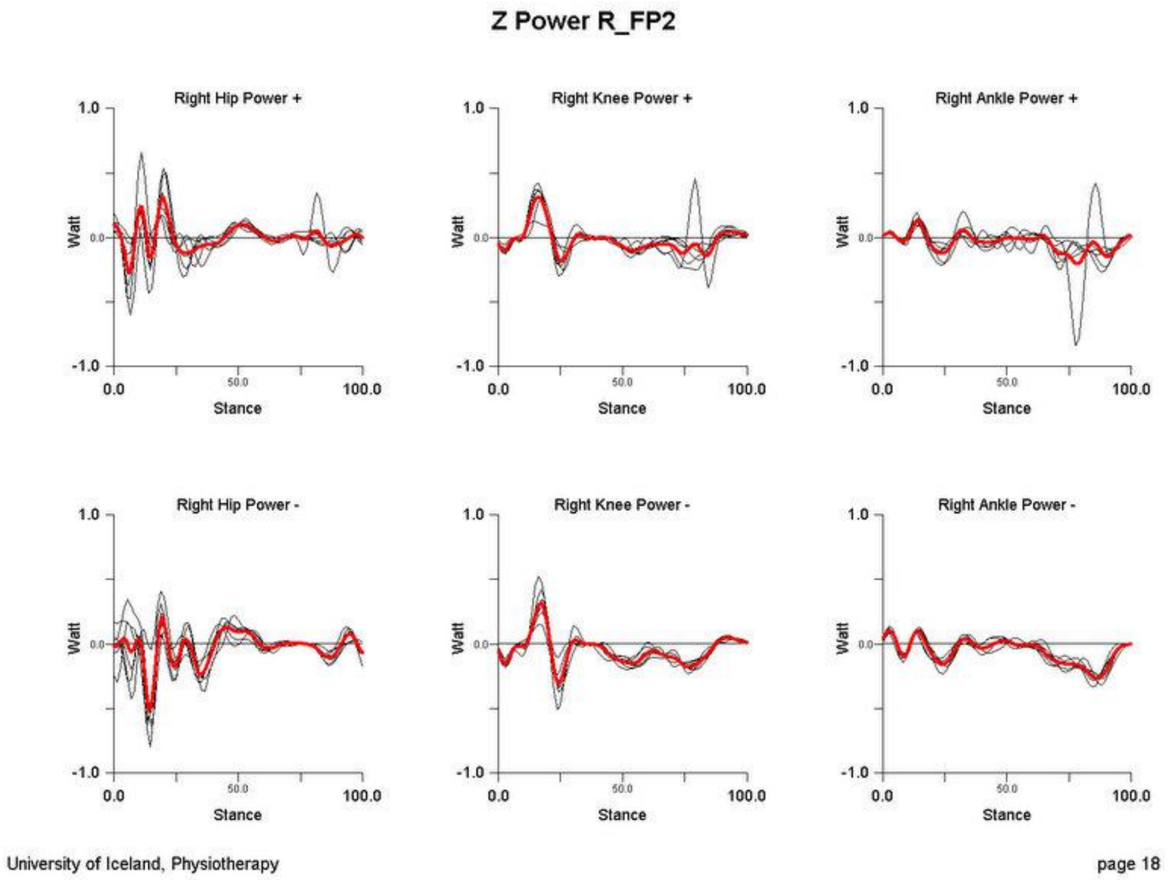

Figure 18: Power in the transversal plane (Z-plane) for the right leg joints (force plate 2) during y-positive and negative (+/-) walking directions.

4 Discussion

4.1 Angles

The x-axis angles for the right and left hip, knee and ankle joints show no considerable difference between positive (y+) and negative (y-) y-data (see Figure 1 and Figure 2). Right and left hip angles in the frontal plane for y+ and y- vary and are more dispersed in their values (see Figure 3 and 4). In Figure 3 angle changes for the right knee for y+ direction show runaway values that represent the data of one trial (trial23). This trial distorts a lot of data of y+ direction and was measured with force plate 2. Apparently the cameras had a problem with capturing the markers in this trial (essential for angle calculation). Also, the test subject did not land properly with his whole foot on the force plate (relevant for moment and force calculation). Angles for the transverse plane of the y+ knee and joint are dispersed (see Figure 5), which may indicate an issue with marker tracking and thus a problem with the camera angles. While only y+ direction of the right foot is affected by this dispersal, left foot's knee and ankle angles show dispersed values for y+ and y- direction (see Figure 6). Issues with marker tracking may be an explanation here as well. Since captured data for marker rotation on the transverse plane is easily influenced by the shift of loose markers on the subject, angle data for the transverse plane may not be a reliable data source for the camera installation that was used for this experiment.

4.2 Moments

Frontal plane moments for force plate one seem to be relatively even, whereas the second force plate's hip and knee data in y+ direction is inconstant (see Figure 7 and 8). Data for the frontal plane of force plate 1 and 2 shows no greater difference between the y-direction and the different force plates (see Figure 9 and 10). As mentioned above the values of trial 23 again distort the graph mean, which can be especially seen in the right hip moment in y+ direction on force plate 2 in Figure 10. Basically the same applies for the transverse plane, where most values are stable for both force plates (see Figure11 and 12). Trial 23 again distorts the mean for the y+ graphs of force plate 2, as shown in Figure 12.

4.3 Powers

While the power data for the sagittal plane is rather even for force plate 1 (Figure 13), signal-data for force plate two appears especially noisy for the y+ direction (Figure 14). Again there are few differences in power values for the frontal plane for force plate 1 (Figure 15), whereas the data for force plate two appears noisier (Figure 16), especially if the subject is coming from the y+ direction. Trial 23 is responsible for distorting the graph mean once again for data in the y+ direction and force plate 2. Transverse plane data shows that hip data for both plates and y-directions is rather noisy (see fig 17 and 18). This may be a result of difficulties in marker tracking for the cameras, and/or a too heavy impact on the force plates, when stepping on them. This explanation is not sufficient since knee and ankle powers seem to be rather undistorted. As well as in other data for force plate 2 in the y+ direction trial 23 distorts the data.

4.4 Equipment

A common methodical problem that is faced in this kind of experiments, are flaws in calibration and tracing the markers. Even though there are eight cameras to capture the movement markers from every angle, deficient camera positioning still leaves room for error. Especially camera one, which recording angle was partly covered by a supportive post in the lab during data collection may produce errors. The extent and significance of these possible errors can be a goal of future research. While processing the data it was discovered that the force plate that which was not stepped on, still produced a noise signal. This noise signal could be processed by ‘Visual 3D’, but has no relevance as long as this data is left out of the analyzed gaits.

4.5 Subject

The subject’s height and weight was estimated instead of being measured. This blurs the results for moment and power analysis, since the basic specifications are not accurate. Since the focus of this research is on reliability rather than qualitative analysis, this fact may be of minor importance. Another source for imprecise data is the inaccuracy in the placement of the markers on the subject’s anatomical landmarks. Although this error is lessened by the algorithms of the software, it will always influence data output. Since the subject has impairment in his right knee, this inevitably influenced his gait and the data that was collected.

4.6 Analysis

Only six trials in each direction for each force plate were collected and analyzed. Thus there is a higher probability that single irregular trials will influence the overall results (i.e. force-analysis of force plate 2, trial 23). This source for error is even more probable since each trial naturally differs slightly from the others. To decrease the impact of that problem events like RON and ROFF have been defined (see Material & Methods) to give the data a reference framework.

Conclusion

Most of the data is consistent and shows a certain degree of reproducibility. Still there are the noisy signals for the moments and power on force plate 2 in y+ direction (see Figures 10, 12, 14, 16 and 18). For most parts, this is due to one trial (trial 23). It distorts the graph mean for force plate 2 in y+ direction. However, this is not the only source of error. Since the sample size was relatively small (six gaits per y-direction, per force plate), noisy values have a great impact. To minimize that, future studies should base their data on a larger sample size. Another source for imprecise data is represented by the transverse plane angles in both y-directions (see Figure 5 and 6). With a few exceptions the graphs are quite far spread. Since this applies to both legs, a possible conclusion is inaccurate capturing of the markers by the cameras, or too much unintended marker movement on the subject itself. The reason for this imprecision may also lie in the array of the cameras. All eight cameras lie in the same transverse plane. To improve data collection for the transverse plane a more varied positioning along in their height seems appropriate. Camera placement in general represents one possible direction for further research. Furthermore, several methodical issues remain for further examination in upcoming researches. Improper calibration or the positioning of the cameras and the supportive post standing close to the force plates, blocking at least one camera’s field of view, are just a few that can be named. Summing up, a coarse idea of the strengths and weaknesses of the used materials and methods exists. The next step is to minimize the weaknesses to increase overall reliability.

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