ORIGINAL ARTICLE

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Gait disturbances in football, rugby players and skiers following anterior cruciate ligament reconstruction

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SUMMARY

Background. Patients who have undergone anterior cruciate ligament (ACL) reconstruction surgery may exhibit post-operative lower limb gait disturbances. **Design.** Laboratory in vivo controlled study. **Methods.** Kinematics and kinetics parameters of knee motion were measured in post-ACL reconstruction participants (n = 5; m = 4 / f = 1, age 30.6 years, height 179.2 cm, weight 80.4 kg) and control participants (n = 10; m = 6 / f = 4, age 30.3 years, height 173.5 cm, weight 65.3 kg). Kinematics and kinetics were recorded for normal gait, 'cutting' gait and 'weaving' gait ($\bar{x}$ = 3 per gait type) using instrumented motion analysis and ground embedded force plates. Between groups, differences in knee joint alignment were determined in the frontal plane for normal gait, and in the coronal plane for cutting and weaving. Five of the subjects were recruited for this study had an ACL reconstruction in the past (at least two years before the test), and ten were part of a control group. Each subject performed three different tasks with both legs on a force plate: normal walking, a weaving movement, and a cutting movement. Kinematic and kinetic data were collected with four optoelectronic cameras and two force plates. Comparisons were made in the frontal plane for walking and in the coronal plane for cutting and weaving between the reconstructed knee and the contralateral, healthy knee in the late stance period. **Results.** There were no significant differences between the ACL reconstructed knees and the contralateral healthy knees in the walking task (p = 0.27 - 0.49). Knee coronal plane rotation showed between group similarity (cutting = 21.82° vs 11.29°, p = 0.175; weaving = 17.88 vs 21.34°, p = 0.406). **Conclusions.** There is an increased rotation of the knee during walking and cutting in ACL reconstructed knees when compared to the contralateral knee, although this difference was not statistically significant.

KEY WORDS

anterior cruciate ligament; biomechanics; football; kinetics; kinematic abnormalities; reconstruction; rugby

BACKGROUND

Even after intensive rehabilitation following anterior cruciate ligament reconstruction (ACLR), these patients are at a greater risk of reinjury and knee osteoarthritis (1,2). No investigation has provided clear scientific evidence that ACL reconstructed patients do return to a normal gait pattern (3). Movement asymmetries are pervasive following ACL injury and reconstruction, and have been reported for up to 2 years after surgery (4). Athletes with multiplanar biomechanical asymmetries at the hip and knee at the time of return to sport were at least three times more likely to incur a second ACL injury within the next year than those without these asymmetries (5). Individuals who have had ACLR exhibit altered knee kinematics and kinetics during dynamic tasks such as side-step cutting and landing, even though they have been released to full participation in sport or full activity (6,7). Altered movement patterns have been suggested to be an instigating factor in the initiation and development of osteoarthritis in the ACL-injured knee as well as a risk factor for future reinjury (5,8). There still exists

clinical uncertainty as to whether the ACL reconstructed knee can fully return to its preinjury functional capacity (9). This study analysed the biomechanics of the knee while walking, weaving and cutting in ACL reconstructed and fully rehabilitated participants, to detect kinematics and kinetics abnormalities in their knees. We hypothesised that there is a difference between the ACL reconstructed knee and the contralateral knee (non-operated knee) while walking, and that there is a difference in knee rotation while doing cutting and weaving movements between the injured knees and the non-operated ones.

METHODS

Subjects

A total of 15 participants (**table I**) were recruited. Five participants (m = 4 / f = 1, age 30.6, height 179.2, weight 80.4, BMI 24.8, Lysholm Score 91.2, time from surgery 6.2 years, years of sports experience 16.2) had undergone an ACL reconstruction; all of them were fully rehabilitated, and back to their chosen sports. All participants met our inclusion criteria: football players, rugby players and skiers had more than the minimum of 2 years of experience in their sport (range between 10 and 20 years), their age ranged between 20 and 45 years, they all had a confirmed ACL reconstruction surgery in the past (confirmed by an MRI and their scar), and were completely rehabilitated. Ten healthy recreational athletes (m = 6 / f = 4, age 30.3, height 173.5, weight 65.3, BMI 21.27) without any knee pathology were recruited as controls.

Participants were excluded from the study if they had less than 2 years of sports experience, had knee contracture, radiographic evidence of patellar osteoarthritis which, in the opinion of the treating physician, would have preclude enrolment, history of patellar instability, tight iliotibial band or iliotibial band syndrome, femoral or tibial bony deformity, bone metabolic disease, diseases affecting the connective tissue or muscle and any cardiovascular disease.

Ethics

This study meets the ethical standards of the journal (10). This research study was approved by the Queen Mary University of London (QMUL) Ethics Committee. Each subject received a detailed information sheet and a signed consent form before participating.

Procedures

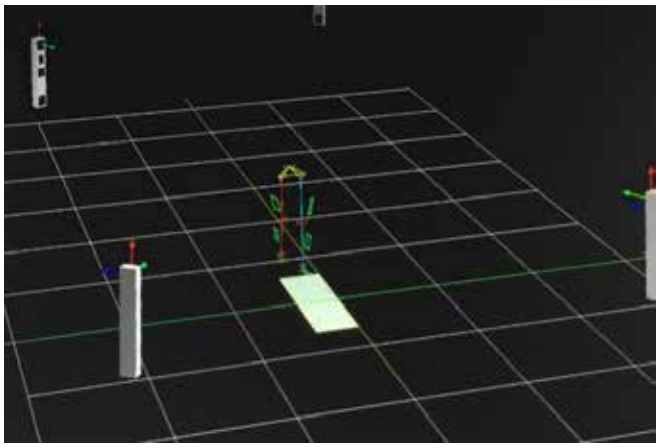
All participants performed three tests. All procedures were performed in the Human Performance Laboratory of QMUL. All participants answered a questionnaire and completed a Lysholm Scoring questionnaire before performing the tests.

The first-test was a standardized walking protocol (**figure 1**) to establish a baseline for each participant's normal gait. During this task, the participant was required to walk normally in a straight line over the force plates and stop one meter after crossing them.

The second test was a cross over movement called weaving (**figure 2**). The participant walked towards the force plate. Once arriving at the force plate, the stance leg was supporting the body as the person rotated internally over the knee. When walking to the left side, the participant used the left leg as the stance leg on the force plate and cross over with the right leg. When walking to the right side, the participant used the right leg as a stance leg and crossed over with the left leg.

Table I - Demographics.

	ACL reconstructed participants (mean)	Control group (mean)	t-test (p value)
age	30.6 (28 - 33)	30.3 (26 - 38)	0.433
sex	m = 4, f = 1	m = 6, f = 4	0.23
height (cm)	179.2 (173 - 186)	173.5 (158 - 195)	0.157
weight (kg)	80.4 (58 - 93)	65.3 (47 - 95)	0.040
BMI	24.82	21.27	0.021
sport experience during the years	16.2	NA	
MRI	Yes	NA	
rehab	15.6	NA	
time from surgery	6.2 (3 - 9)	NA	
Lysholm score	91.2 (83 - 100)	100	**0.001**
sport	football (2), rugby (2), skiing (1)	different types of sport	



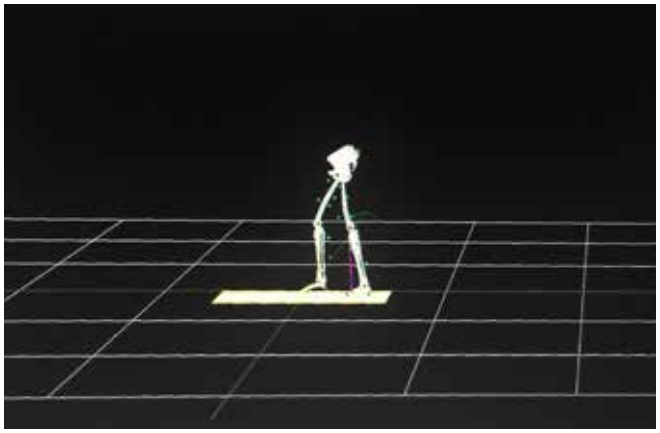
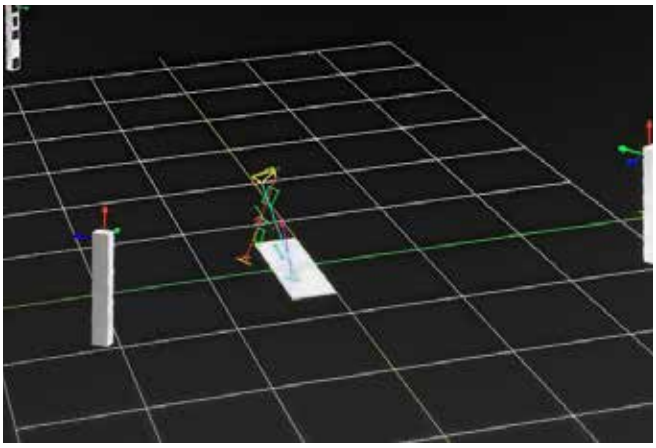


Figure 1a and **b** - Walking task.



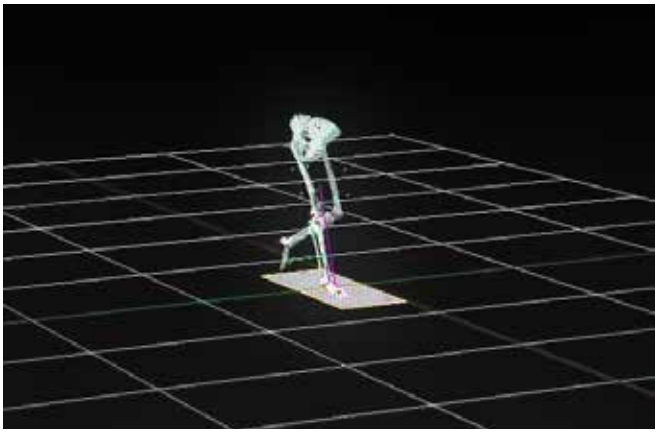


Figure 2 a and **b** - Weaving task.

The third task was a cutting movement (**figure 3**). While undertaking the task, the participant had to walk straight towards the force plate. The participant put the contralateral leg as a stance leg on the force plate to support the body while the ipsilateral knee was in swing and changed direction. For the movement to the left, the right leg was used and the subject then put the right leg on the force plate as a stance leg while performing a cutting movement to the left. For movements to the right side, the left leg was used as a stance leg on the force plate while changing direction to the right.

Data collection

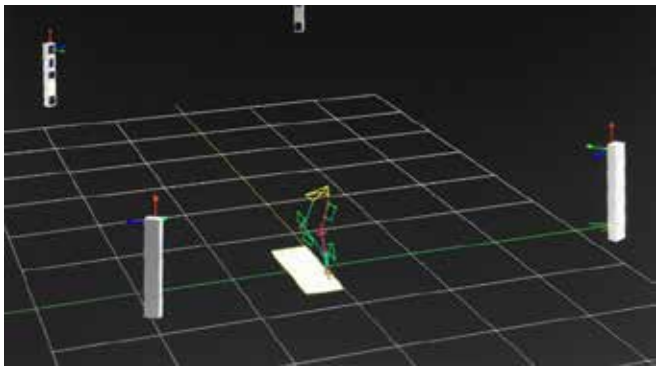
Kinematics data were collected using the Codamotion ODIN system (Charnwood Dynamics Ltd., Leicestershire, UK) at the Human Performance Laboratory, Centre of Sports and Exercise Medicine, Queen Mary University of London.

A cluster protocol based on the Modified Helen Hayes Protocol (**figure 4**) was used to place the markers on the subjects. The markers were placed on the lateral aspect of the 5th metatarsal and the lateral aspect of the calcaneus. Markers were placed on the anterior sacroiliac spine and on the posterior sacroiliac spine. ASIS-ASIS (pelvic width) was measured; ASIS- spine (pelvic depth); knee width and ankle width (medial to lateral epicondyle and malleolus) (**figure 5**, **figure 6**, **figure 7**).

Movement data from the Codamotion markers were collected at a rate of 200 Hz. Kinetic data were collected from 2 ground embedded force plates (Kistler Type 9281B, Kistler Corporation, Winterthur, Switzerland). Ground reaction force data were collected at a sampling rate of 500 Hz and graphed in the anterior-posterior axis; medial-lateral axis and superior-inferior axis.

Data analysis

Data extraction and analysis were made using the Matlab® Software (Matworks®, Natrick, Massachusetts, USA)



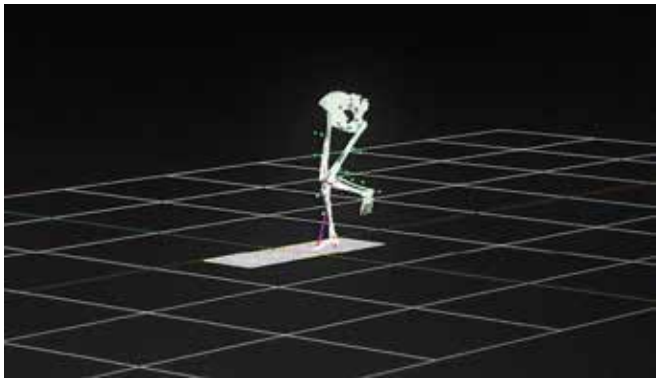


Figure 3 a and **b** - Cutting task.

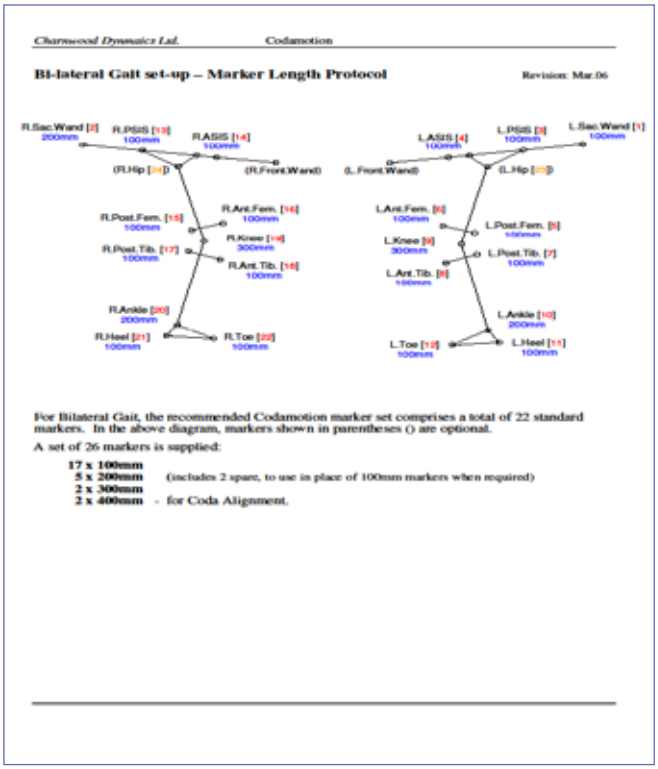


Figure 4 - Helen Hayes Protocol.

Figure 5 - Data collection: two of the four cameras, two force plates, a participant wearing markers (the left thigh marker placement was corrected for the tests and pelvic markers were also included)

Figure 6 - Data collection: two of the four cameras, two force plates, a participant wearing markers (pelvic markers were also included for the tests).

Figure 7 - Data collection: two of the four cameras, two force plates, a participant wearing markers (pelvic markers were also included for the tests).

version 2013 b. A pre-existing custom written programme was used to measure kinematic data by calculating the joint angles without gait. New custom written programmes were used to calculate joint rotation during cutting and weaving. Kinematics and kinetics abnormalities of the knees were calculated by inverse dynamics from the kinematic data and the ground reaction data measured by the force plates. The ground reaction force vector was divided into its component planes. The distance from the joint centre to the vector throughout the movement was graphed as the change in angle of the knee in the coronal and transverse planes.
Kinematic and kinetic data calculated the transverse plane while walking and the coronal plane during knee rotation when executing cutting and weaving movements in the late stance period (heel off - toe off). A specific gait moment, the late stance phase, was selected for each participant in the Matlab programme for the walking, weaving and cutting task. Given the small sample size, data were unlikely to be normally distributed. Therefore, all data were log transformed to allow parametric analysis. Statistical significance was set at $p < 0.05$.

Statistics

Statistics were performed using the IBM SPSS software, version 22. Paired t-tests were used to ascertain whether there was a difference in knee rotation during the late stance phase in either cutting or weaving movement between the good limb and the ACL reconstructed limb. Demographic characteristics between groups were compared with the Independent Samples t-test for numerical variables.
For walking, data were analysed using Windows Excel 2013. T-tests were used to obtain the relevant p values during the late stance phase in this task, and ascertain whether there is a significant difference between the limb which had undergone surgery and the healthy limb. The standard error of the mean (SEM) was used to compare the non-operated limb with the ACL reconstructed knee.
For normality, dependent variables were tested to compare the shape of the sample distribution to the shape of a normal curve. The Kolmogorov and Shapiro-Wilk tests were used. Reliability was tested using Intraclass Correlation Coefficients (ICC), which were used to assess the consistency or reproducibility of quantitative measurements, taken twice when measuring the same quantity (control groups were measured twice for reliability). For reliability, one single investigator performed the test on two separate occasions to reduce the chances of external confounding variables. Each subject was tested on the same day of the week and at the same hour of the day.

RESULTS

Lysholm

The mean of the Lysholm scale for the ACL reconstructed participants was 91.2 (83 - 100) with the results ranging from fair to excellent. For the heathy participants, the mean was 100.

Reliability

Reliability was tested using ICC tests. Reliability for the left knee rotation in the cutting movement was poor ($p = 0.576$, ICC = 0.178, df = 6). Reliability for the right was better than for the left knee ($p = 0.176$, ICC = 0.551, df = 6,). Regarding the weaving movement, the reliability was poor for the left leg ($p = 0.363$, ICC = 0.258, df = 6), but good for the right leg ($p = 0.071$, ICC = 0.724, df = 6).

Walking

T-tests were used to analyse the data gained from the walking task. **Figure 8** shows the results obtained from the frontal plane during the late stance phase and compared the non-operated limbs means to the ACL reconstructed means. There was no significant difference between the two limbs ($p = 0.27$ - 0.49).
P values (green line) found during the walking task (**figure 8**) compared to standard, significant p values (red line) sampled during the late stance phase of the gait cycle. Vertical line = p values; horizontal line = gait cycle.
Standard error of the mean deviations (**figure 9**) were used to compare the non-operated knee with the ACL reconstruc-

Figure 8 - Walking test p values.

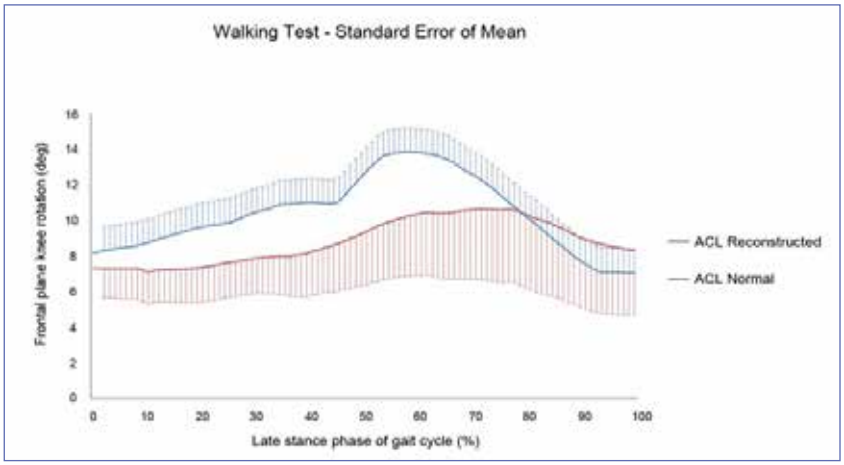


Figure 9 - Walking test, Standard error of Mean (SEM).

ted knee. In the uninjured knee, the rotation of the knee was constant when compared to the injured knee, where there was more variation in the movement.

Cutting

Paired t-tests were used to analyse the data for ACL participants while cutting. The result was not significant ($t = 1.644$, $df = 4$, $p = 0.175$). Although the result is not significant, **table II** shows that ACL reconstructed knees have more rotation (21.82°), normalised to time when compared to the non-operated side (11.29°) (**figure 10**).

Weaving

When comparing the ACL reconstructed knees with the contralateral knees while undertaking the weaving task (**table III**), the knee rotation was greater in the non-operated knees (17.88° and 21.34°). The result was not significant ($t = 0.929$, $df = 4$, $p = 0.406$).

The ACL reconstructed knees and the non-operated knees were normally distributed in both cutting and weaving tasks.

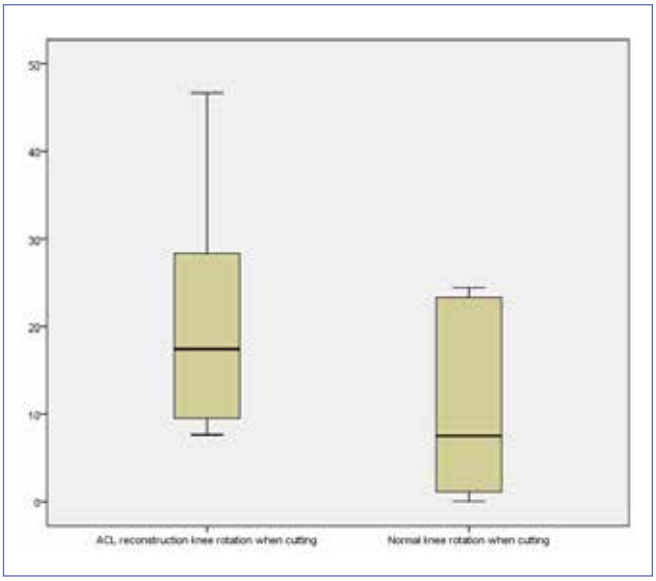


Figure 10 - Knee rotation while performing the cutting test. The vertical line represents the knee rotation in degrees.

Table II - Knee rotation while performing the cutting test.

	ACL reconstructed knee	Non-operated knee
mean Rotation (dθ / dTime)	21.92 ± 16.07	11.29 ± 11.86
t	1.644	
df	4	
p (2 tailed)	0.175	

Values for rotation are in degrees. No significant differences were found.

Table III - Knee rotation while performing the weaving test.

	ACL reconstructed knee	Non-operated knee
mean rotation (dθ / dTime)	17.88 ± 9.83	21.34 ± 11.14
t	0.929	
df	4	
p (2 tailed)	0.406	

Values for rotation are in degrees. No significant differences were found.

DISCUSSION

This study evaluated whether ACL reconstructed knees exhibit gait disturbances and whether these gait disturbances occurred in cutting and weaving movements. The participants answered the Lysholm scoring questionnaire at the beginning of the study to evaluate the outcome of the knee ligament surgery, the results being fair to good.

When comparing the knee which had undergone an ACL reconstruction surgery with the contralateral, there seemed to be greater variation in the movement of the ACL reconstructed knee, which showed a greater internal rotation while walking when compared to the non-operated knee, where the movement was more controlled. There could be more joint laxity in the ACL reconstructed knee compared to the non-operated knee loss of sensory information, which could result in errors in the joint coordinative patterns during gait (11). Other studies observed that healthy controls and ACL reconstructed individuals exhibited different knee joint coordination while walking (9). They also noticed that there were some additional differences between the shank-thigh phase dynamics while walking which were most pronounced in the late portion of the stance period, where ACL reconstructed subjects had a more out of phase relationship (9). Primary ACL injury occurs during early deceleration in cutting and landing movements (6). The cutting task showed that the rotation in the knee of the ACL reconstructed participants is larger than in the non-operated knees. The sample size was smaller than the minimum of ten subjects per group to have a statistical power of 80%. Stearns et al. found that female soccer players have abnormal frontal plane knee mechanics during sidestep cutting (6). Their female soccer players increased abduction angles and knee adductor moments post ACL reconstruction surgery (6). A study regarding postural adjustments following ACL rupture and reconstruction showed that compensatory postural responses of the lower limb to unpredictable perturbations of the knee joint were altered/delayed in ACL reconstructed participants when compared to healthy participants, while anticipatory responses to predictable perturbations were not different between ACL reconstructed and healthy participants. The study suggested that the earliest goals after ACL reconstruction should be to target compensatory adjustments in order to improve functional stabilisation of the knee joint by the time of return to sport (12).

During the weaving task, we found no difference in the late stance knee rotation between the ACL reconstructed knees and the non-operated knees. However, we caution that the sample size might have been too small.

There was better reliability on the right knees than on the left knees. This might have resulted from a visibility issue of the markers on the left knees. Reliability will need to be more robust to be able to obtain more "clean" data. The control group will need to be retested. A retest of the control group might present a better intra-class correlation coefficient. If the correlation coefficients will not appear to be improved, a method to handle improved (normalized) indicators which would better define the classes should be tested.

Another major limitation was the small sample size. Further studies would need to increase the number of participants. Also, the laboratory environment cannot recreate the aggressive movements employed during sports activity this study tested subjects while walking. Further research should include movements which are closer to those performed on sports fields and should also investigate the delay between compensatory postural responses and the neuromechanical deficits observed during demanding functional and sports specific movements such as running and landing tasks.

CONCLUSION

There were no evident gait disturbances between reconstructed knees and healthy contralateral knees in sportsmen who have undergone ACL reconstruction surgery. Furthermore, although there is an increased rotation of the knee during walking and cutting activity in ACL reconstructed knees, statistical analyses revealed no significance. We however point out that these results should be regarded as preliminary, given, for example, the mall sample size which was recruited.

For further studies, a larger sample size would provide more conclusive and significant results to clarify whether there are differences between the ACL reconstructed and the non-operated knees. Reliability will need to be more robust to be able to obtain more definitive data. The control group will need to be retested.

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