The reliability of lower limb 3D gait analysis variables during a change of direction to 90- and 135-degree manoeuvres in recreational soccer player

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Abstract

Background: Several biomechanical outcomes are being used to monitor the risk of injuries; therefore, their reliability and measurement errors need to be known.

Objective: Measure the reliability and measurement error in lower limb 3D gait analysis outcomes during a 90° and 135° change of direction (COD) manoeuvre.

Methods: A test re-test reliability study for ten healthy recreational players was conducted at seven-day intervals. Kinematics (Hip flexion, adduction, internal rotation angles and knee flexion abduction angles) and kinetics (Knee abduction moment and vertical ground reaction force) data during cutting 90° and 135° were collected using 3D gait analysis and force platform. Five trials for each task and leg were collected. Standard error of measurement (SEM) and the intraclass correlation coefficient (ICC) were calculated form the randomised leg.

Result: The ICC values of the kinematics, kinetics, and vertical ground reaction force (VGRF) outcomes (90° and 135°) ranged from 0.85 to 0.95, showing good to excellent reliability. The SEM for joint angles was less than 1.69°. The VGRV showed a higher ICC value than the other outcomes.

Conclusion: The current study results support the use of kinematics, kinetics, and VGRF outcomes for the assessment of knee ACL risk in clinic or research. However, the hip internal rotation angle should be treated with caution since the standard measurement error exceeded 10% compared to the mean value. The measurement errors provided in the current study are valuable for future studies.

Keywords: Biomechanics, Measurement Reliability, Change of direction (COD), Kinematics, Kinetics, Cutting manoeuvers, Risk, 3-dimansional video analysis.

1. Introduction:

An anterior cruciate ligament (ACL) injury is considered one of the most devastating injuries in sports (1). The annual prevalence of ACL injury among recreational athletes has been found to range between 0.03% and 1.62% (2). A more recent systematic review and meta-analysis showed an incidence proportion of 3.5% for females and 2% for males and an incidence rate of 1.5/10000 and 0.9/10000 for ACL injury over a period of one session to 25 years (3). ACL injury has been linked to the development of knee osteoarthritis (OA). A previous systematic review showed a seven to eight times increase in the likelihood of developing OA after ACL in around 10 years (4). This fact highlights the importance of identifying risk factors and designing a preventive program to reduce this injury.

Previous studies have shown that increasing the knee external abduction moment and knee valgus angle (abduction angle) will lead to a higher risk of noncontact ACL injury (5–7). Moreover, it has been found that ACL is under great stress when the knee extension is combined with a high increase in the valgus moment, angle, and internal tibial rotation (8,9). In addition, previous studies have shown that increasing the knee valgus angle and external abduction moment is associated with the hip positioned in more flexion, abduction, and internal rotation (10–12). A recent study showed that a reduction in the knee flexion angle and a higher vertical ground reaction force are associated with increased ACL injury risk (13). The previously mentioned variables were identified from activities associated with a higher risk of ACL injury, such as a change of direction (COD).

COD manoeuvres are essential and crucial in many sports, such as soccer. Unfortunately, it can lead to a noncontact ACL injury (14,15). In addition, COD is related to both ACL risk and sports performance (16) and has been used to assess the risk of injury and to identify talented individuals (17). The high prevalence of ACL injury has led to the development of a preventive program that targets biomechanical risk factors to reduce the risk of injury (18,19). Such a program's effect on biomechanical variables can be measured using a three-dimensional (3D) gait analysis system commonly used in lower limb biomechanics and is considered a gold standard (20–22). However, before using any outcome to assess the risk of ACL injury, its reliability (23) and measurement errors should be known. This knowledge will let the researcher know if the change passes the measurement error and is considered a real change.

Although researchers investigated the reliability of lower limb biomechanical outcomes during COD manoeuvres at 45° (24,25), sharper angles are more important due to higher risk (26). Only one study investigated the reliability of 90° COD (20) and drawing a conclusion based on one study without replication is scientifically not accurate. The previous study showed fair to good ICC and had lower boundary speed during the cutting task (3 m/s and above) and did not control it which may not allow comparison to the previous literature. In addition, adopting a new technique in the application of the markers such as measuring the distance between markers and markers to the floor may help to improve the reliability. Moreover, there is an urgent need for studies that investigate sharp angles (135°) reliability. Conducting such a study will help future researchers properly evaluate the treatment effect and ensure that the observed change is real and not induced by marker position, static alignment, marker reapplication, and task difficulty (27,28). Therefore, the current study aimed to assess the reliability of lower 3D gait analysis outcomes during 90° and 130° COD manoeuvres between days. We hypothesised that there would be an agreement between the external knee abduction moment, knee flexion and abduction angles, hip flexion, adduction, internal rotation angles, and VGRF in the 90° and 130° COD manoeuvres between days.

2. Method:

The current study is a reliability study that gained ethical approval from the Salford University ethical committee under ethical number HSCR16–88 (approval date: 13/9/2016). The research complied with all relevant national regulations and the Declaration of Helsinki.

2.1 Participants

To be enrolled in the study, a participant must be of the general population, healthy, and physically active. The participant must be a recreational, non-elite soccer player who practices soccer for at least 30 minutes three times a week over the last six months in regular basis. Moreover, each participant had to practice 90° and 135° COD manoeuvres in their routine sports activity. Participation was limited to those between 18 and 35 years old, since they practice soccer the most and are the most prone to injury (29). Those with previous injuries in the last six months were excluded. An injury was defined as any musculoskeletal complaint that led them to stop their regular exercise activity. Participants were excluded if they were overweight (above 24.9 BMI), had any deformities or disease known to affect their ability to walk and run, or were not able to give informed consent. Any individual who was not able to follow the procedure was not allowed to participate in the study.

2.3 Procedure:

A Qualisys motion analysis system (Gothenburg, Sweden) with ten cameras (Qualisys Oqus 700+) synchronized with three force platforms (AMTI BP400600, USA) operating via Qualisys Track Manager software (version 2.16) was used. The sampling rate was 250 Hz for kinematics and 1000 Hz for kinetics. Participants were tested twice at the same time of the day, one week apart. The selection of a time interval in reliability depends on whether the time should be enough to reduce recall bias and not too long to cause real change. Based on previous similar studies, seven-day intervals were selected (20,30).

Before the participants arrived in the lab, the lab was calibrated. A supervisor familiar with specialised techniques manages the lab and calibrates the force platform to ensure that it runs perfectly regularly. The calibration process starts by placing the L-shaped metal frame in a previously specified place along the corner of one of the force platforms. Then, the wand is waved randomly in the required volume. For the calibration to be accepted, it must get residual volume below 1 mm for each camera based on the manufacturer’s recommendation.

Upon the participants’ arrival, the experiment was described, and consent forms were distributed and obtained after providing enough time for participants to think, ask questions, and decide. Demographic characteristics (age, mass, height) and previous medical histories were taken. Then, each participant was asked to change into shorts and a T-shirt. Standardized shoes (New balance, UK) were used to reduce the possibility of interaction between shoes and the surface. The Calibrated Anatomical System Technique (CAST) method was used to place the markers (31), as shown to reduce error compared to an earlier model (32). The CAST model allows for two sets of 14.4 mm markers (technical marker, anatomical marker). The anatomical marker is used to define the local coordinate system in relation to the anatomical frame, while the technical marker is used to track movement. The segment was defined by the proximal and distal endpoints (Table 1) (33). Four clusters were attached securely with a Velcro strap in each participant's shank and thigh in an anterior lateral direction (Figure 1). Each participant was given enough time to practice until they felt comfortable and natural. The static trial was captured, and after that, static markers were taken off (34).

To perform the required task, participants were asked to run in a straight direction for five meters, and when they hit the force platform by the required limb, they changed the direction (90° or 130°) toward the opposite limb and ran for three meters. To guide the participants and ensure that all of them performed the same required angle, cones were placed along the track (Figure 2). Contacting the force platform with the selected leg was achieved by monitoring the participants' starting point in relation to different coulure taps on the floor. Five successful trials were conducted for each task and limb after performing five minutes of low-intensity warm-up (cycle ergometer) to help avoid any injury and reduce the risk of discomfort (35,36). A successful trial was defined as one in which the foot fully contacts the force platform with the required speed and good marker view. Rest times of five minutes between tasks and a half minute between trials were provided to reduce the effect of fatigue. A Brower Timing Gate system (TC-Timing System, USA) was used to control the speed and was placed along the eight-meter path at the hip level. The speed was controlled for 4.2 m/s ± 0.5 to allow comparison between limbs, tasks and previous literature (26). For the current study, the selected limb in the analysis was assigned via Randomization.com. The same procedure was applied in the second test after seven days by the same examiner. To improve the reliability of the data, the distance between the markers and the floor and the distance between the markers were measured. These were used in the second session to improve accuracy.

2.4 Outcomes:

Peak vertical ground reaction force (VGRF), peak knee flexion angle and peak abduction angle, peak external knee abduction moment (KAM), peak hip joint flexion, adduction, and internal rotation angle outcomes were selected. The rationale for choosing these outcomes is that higher VGRF will lead to higher KAM, and a previous study showed an increased risk in ACL with higher VGRF (13). An increase in the knee abduction angle has been linked to an increased risk of ACL injury and KAM increase (16,37). In the sagittal plane, reducing the knee flexion angle has been linked to increasing ACL loads (13). A higher KAM leads to an increase in the tension on the ACL and an increase in the risk of injury (16). A previous review highlighted that the sagittal plane hip had been linked to the occurrence of ACL injury (16). In contrast, transverse plan hip motion has been linked to increased abduction through dynamic valgus (16). Moreover, the increase in the hip adduction angle was found to be a significant predictor for the knee abduction angle (11).

2.5 Data processing:

The raw data were captured and labelled through Qualisys Track Manager Software (version 2.16). After labelling, each trial was exported as a visual 3D file to be processed in Visual 3D (Version 6.00.16, C-Motion Inc., Rockville, MD, USA). In Visual 3D, the kinematics and kinetics data were filtered by a 25 Hz and 12 Hz Butterworth fourth-order bi-directional low pass filter, respectively, and interpolated for ten frames. This filter cut-off was selected based on previous studies (38,39).

The lower extremity model was then created and modelled as a conical frustra using the inertial parameters estimated via the anthropometrics data. X-Y-Z Euler rotation sequences were used to process the joint kinematic angles, where X represents flexion-extension, Y means abduction-adduction, and Z represents internal-external rotation (40). The joint kinematic data were calculated based on inverse dynamics theory. Joint moments were normalised on body mass and presented as an external moment, while kinetics and kinematics data were normalised on 100% of the stance phase. Initial contact was defined as the point when VGRF exceeds 20 newtons, while toes off when VGRF falls below 20 newtons (20).

2.6 Statistical analysis:

The required sample was calculated based on a previous method published in 2018 (41). The minimum accepted reliability value for ICC was 0.40 in the equation. The expected reliability value for the ICC was between 85 to 95 with 90% power, which shows that the required sample size ranged from 7 to 17 participants.

The statistical analysis was conducted using Statistical Package for Social Sciences (SPSS) software version 21. The mean of the five trials from both visits was used to calculate reliability. An ICC two-way mixed model with absolute agreement was used since only one investigator conducted all the measurements (42). The ICC model was interpreted according to the following criteria: 0.40 to 0.70 fair, 0.70 to 0.90 good and 0.90 and above excellent (43). The confidence interval (CI) and standard deviation (SD) were also calculated and presented. Moreover, the standard error of measurement (SEM) was calculated since the ICC cannot alone provide any indication of the level of disagreement (23). SEM was calculated based on the following formula: SD* SQR(1-ICC) (44). SQR can be defined as a square root. SEM provides a number with the same unit for the outcome measure, with a lower value indicating low measurement error. The mean of both visits and absolute difference between visits were calculated.

Results:

Ten healthy male recreational soccer players were recruited for the current study. The sample's age, height, mass, and body mass index (BMI) were 22 ± 4 years, 1.73 ± 0.05 m, 66 ± 10 kg, and 22.05 ± 3.21 kg/m^2 respectively.

3.1 The reliability of 90° COD manoeuvres

Table 2 represents the between-day reliability for 90° COD manoeuvres. In general, the ICC values ranged from 0.98 to 0.88, which was interpreted as good to excellent. The absolute difference between day one and day two for hip flexion, hip adduction, hip internal rotation, knee flexion, and knee abduction angles ranged from 1.6° to 4.2°. For the KAM, the difference between the first and second visits was low (0.10 Nm/Kg). The VGRF value changed slightly between visits with 0.09 body weight (BW). The SEM for all variables in 90° COD manoeuvres was low, with only up to 1.2° for angle, 0.03 Nm/Kg for KAM, and 0.01 BW for VGRF. In the 90° COD manoeuvres, hip flexion angle, hip adduction angle, hip internal rotation angle, knee flexion angle, knee abduction angle, KAM, and VGRF average between-day values were 48.4°, -12.1°, 7.7°, 63.0°, -6.4°, 0.825 Nm/Kg, and 2.285 *BW, respectively.

3.1 135° COD manoeuvres reliability

Table 3 represents the between-day reliability for 135° COD manoeuvres. In general, the ICC values ranged from 0.95 to 0.85, which was interpreted as good to excellent. The SEM of the joint angles was below 1.69°, representing a low measurement error, while the maximum absolute difference was up to 4.3° (for hip joint internal rotation angle). For KAM, the absolute difference between days was 0.14 Nm/kg with SEM of 0.10 Nm/kg. The VGRF showed low SEM with 0.05 and 0.19 BW absolute difference between days. In the 135° COD manoeuvres, hip flexion angle, hip adduction angle, hip internal rotation angle, knee flexion angle, knee abduction angle, KAM, and VGRF average between-day values were 51.4°,-15.2°, 8.5°, 67.5°,-7.0°, 0.83 Nm/Kg, and 2.16 *BW, respectively.

3. Discussion:

The current study aimed to investigate the between days' reliability of lower limb 3D gait analysis outcomes during 90° and 135° COD manoeuvres by a recreational healthy soccer player. The current study results generally showed good to excellent reliability, with most variables being excellent.

The ICC values ranged from 0.85 to 0.98 for COD manoeuvres (90° and 135°). The current study ICC results are consistent with previous studies showing good reliability for COD manoeuvres (20,24). A direct comparison can only be made to one study due to similarity in COD angle (90°) (20) while other study investigated the reliability of a 45° COD manoeuvre (24). Interestingly, the hip kinematics ICC value was higher in 90° COD manoeuvres in the current study (ICC 0.90–0.92) compared to a previous study (ICC 0.51–0.75) (20). This finding may be because the current study adopted a new method of placing markers by measuring the distance between them and their height from the floor. Supporting evidence shows that using a marker placement device that has a similar concept to measuring the distance to improve marker placement yields good results (45). Another possible explanation for the high ICC value is that current study participants frequently perform COD manoeuvres in their sport, reducing variabilities. When comparing the present study to another study used two-dimensional analysis, the results showed that the ICC for knee abduction angle was 0.92 in 90° COD manoeuvres, which was slightly better than the current study (ICC=0.89) (46).

In addition, VGRF showed a high reliability value with low measurement error in both tasks (90°, 135°) compared to other kinematics and kinetics outcomes. This finding may be because the VGRF is the sum of the mass, gravitational vector, and segmental acceleration. Therefore, no markers are needed to calculate the value of VGRF, and the assumption can be made that VGRF is more reliable than other kinematic and kinetic variables. Several factors have been identified that affect the between-day or within-day reliability, such as reference statistic alignment, marker movement, and task difficulty (47,48). Moreover, markers' placement has been highlighted as a cause of reduction of between-day reliability (49). Markers' placement in the current study was conducted with one researcher, which may explain the high-reliability results.

One of the essential measurements in reliability is the measurement error since it help to estimate the range in which the true value lie (44). Gaining such value is essential, especially in follow-up sessions, such as post-treatment. Knowing SEM allows the researcher to know that if observed improvement exceeds the measurement error, it is considered a real improvement (50). The current study showed that in the joint angle, the value for standard error of measurement was between 0.44° and 1.68°, representing low measurement error. Previous studies have shown that the standard error of measurement is less than 5 degrees, which is generally consistent with the current research (20,51). Although the ICC value for the hip internal rotation was 0.90 (excellent) for 90° COD manoeuvres and 0.85 (good) for 135° COD manoeuvres, the SEM is considered high, since it represents more than 10% of the mean value. This may be explained by the high standard deviation indicating variation in performance. The knee abduction moment is considered a critical outcome that can be used as a risk factor for ACL injury. It has shown high reliability and low measurement error, which supports research use.

The result of the current study is subjective to limitations. First, the generalizability of the results is limited to settings like the laboratory, researcher ability, and the model used. Second, the shoe used in the current study (Mondo) was standard, which may be uncommon, and the interaction between the shoe and floor may not be similar to that between shoe and grass. An effort was applied by providing time for familiarization until participants felt natural with the shoe. However, there is a need for a study that will investigate the effects of real sports shoes on grasses. Interestingly, only intrarater reliability was investigated in the current study; therefore, future studies should investigate interrater reliability and calculate minimal detectable change. Finally, the present study sample was a recreational healthy soccer player; therefore, the result may not apply to those elite players, and more studies need to investigate such a population.

4. Conclusion:

Change of direction manoeuvre is associated with a higher risk of ACL injury caused by an increase in knee abduction moment and change in kinematic and kinetic variables. However, for such an outcome to be used in the clinic and field, it must be reliable. The current study showed that all the biomechanical outcomes measured in 90° and 135° COD manoeuvres achieved good to excellent reliability and can be used as outcome measurements in clinics and research. However, the hip internal rotation angle should be used with caution, since the measurement error reaches above 10% of the mean. The current study's finding is relevant to a study investigating the change in biomechanical outcomes with treatment compared between groups or within group. Moreover, the standard error of measurement was provided, allowing the researcher to know that the observed value of the outcome exceeded the measurement error and considered real change. The results of this study were only found in recreational players and therefore may not apply to other population.

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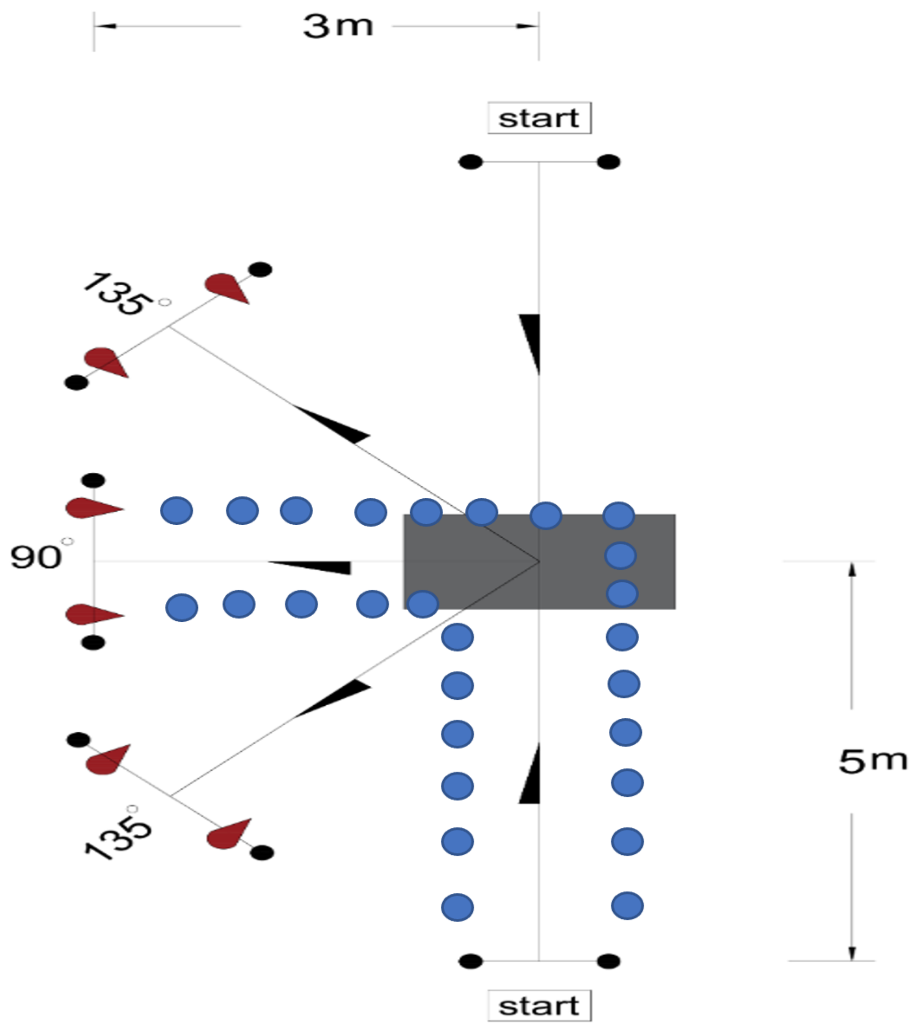
Figure 1: Markers placement for one participant as an example



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452 Figure 2: Experimental setting with cones placed at 90° as an example

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Table 1: Anatomical and tracking markers and joint location

Segment	Markers' location	Definition	Tracking markers	Joint
Pelvic	Posterior and anterior superior iliac spine, Iliac crest,	Proximal: Left and right anterior superior iliac spine (ASIS) Distal: Left and right anterior posterior superior iliac spine (PSIS)	Left and right ASIS and PSIS markers	Hip joint centre: calculated by the regression model form ASIS and PSIS based on a previous study (31)
Thigh	Greater trochanter, knee medial and lateral condyle,	Proximal: Hip joint centre Distal: Lateral and medial knee condyles	The four markers in the cluster	
Shank	Medial and lateral malleolus	Proximal: Lateral and medial knee condyles Distal: Lateral and medial malleolus	The four markers in the cluster	Knee: Midpoint between medial and lateral knee condyles markers
Ankle	On each participant's shoe on the first, second, and fifth metatarsal head and calcaneus with the assumption of the foot being a rigid segment	Proximal: Lateral and medial malleolus Distal 1st and 5th metatarsal heads	1st, 2nd, and 5th metatarsal head markers and heel markers	Ankle: Midpoint between medial and lateral malleolus

Table 2: Between days reliability (ICC, SEM) for 90° COD manoeuvres

Outcomes	ICC (95%CI)	Visit 1 Mean (SD)	Visit 2 Mean (SD)	Mean difference between days	Average of day 1and day 2 (SD)	SEM
Hip Flexion Angle (°)	0.92 (0.68-0.98)	49.9 (6.3)	47.9 (6.8)	2.9	48.4 (6.3)	0.59
Hip Adduction Angle (°)	0.92 (0.66-0.98)	-12.3 (6.1)	-11.9 (5.2)	2.2	-12.1 (5.4)	0.61
Hip Internal Rotation Angle (°)	0.90 (0.56-0.97)	7.7 (6.8)	7.6 (6.6)	2.7	7.7 (6.4)	1.14
Knee Flexion Angle (°)	0.88 (0.50-0.97)	62.4 (7.2)	63.5 (9.1)	4.2	63.0 (7.7)	1.20
Knee Abduction Angle (°)	0.89 (0.57-0.97)	-6.2 (2.9)	-6.5 (4.1)	1.6	-6.4 (3.4)	0.48
KAM (Nm/Kg)	0.91 (0.65-0.97)	0.82 (0.28)	0.83 (0.22)	0.10	0.825 (0.24)	0.03
VGRF (*BW)	0.98 (0.92-0.99)	2.27 (0.45)	2.30 (0.44)	0.09	2.285 (0.44)	0.01

ICC = intra-class correlations, SEM = standard error of measurement, CI = Confidence Intervals, SD = standard deviation, Nm/Kg = newton meter per kilogram, ° = degree, BW = body weight.

Table 3: Between days reliability (ICC, SEM) for 135° COD manoeuvres

Outcomes	ICC (95%CI)	Day 1 Mean (SD)	Day 2 Mean (SD)	Mean difference between days	Average of day 1 and day 2 (SD)	SEM
Hip Flexion Angle (°)	0.90 (0.58-0.97)	51.8 (5.2)	51.0 (6.8)	3.1	51.4 (5.8)	0.63
Hip Adduction Angle (°)	0.92 (0.68-0.98)	-14.8 (5.6)	-15.7 (5.5)	2.0	-15.2 (5.3)	0.66
Hip Internal Rotation Angle (°)	0.85 (0.41-0.96)	9.6 (9.0)	7.3 (6.9)	4.3	8.5 (7.5)	1.68
Knee Flexion Angle (°)	0.92 (0.67-0.98)	67.1 (9.4)	67.9 (9.8)	4.1	67.5 (9.2)	0.89
Knee Abduction Angle (°)	0.90 (0.58-0.97)	-6.7 (3.5)	-7.3 (3.2)	1.6	-7.0 (3.2)	0.44
KAM (Nm/Kg)	0.90 (0.58-0.97)	0.85 (0.24)	0.81 (0.24)	0.14	0.83 (0.24)	0.10
VGRF (*BW)	0.95 (0.78-0.99)	2.18 (0.48)	2.14 (0.50)	0.19	2.16 (0.47)	0.05

ICC = intra-class correlations, SEM = standard error of measurement, CI = confidence intervals, SD = standard deviation, Nm/Kg = newton meter per kilogram, ° = degree, BW = body weight.