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Reliability of lower limb biomechanics in two sport-specific sidestep cutting tasks

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Abstract

The purpose of this study was to assess the within- and between-session reliability of lower limb biomechanics in two sport-specific sidestep cutting tasks performed by elite female handball and football (soccer) athletes. Moreover, we aimed at determining the minimum number of trials necessary to obtain a reliable measure. Nineteen elite female handball and 22 elite female football (soccer) athletes (mean ± SD: 22 ± 4 yrs old, 168 ± 5 cm, 66 ± 8 kg) were tested. The reliability was quantified by intra-class correlations (ICC), typical error and Spearman’s rank correlation. Only minor improvements in ICC values were seen when increasing the number of trials from 3 to 5. Based on trials 1-3, all variables showed good to excellent within-session reliability (mean ICC: 0.91, 95% CI: 0.89-0.93), fair to good between-session reliability (mean ICC: 0.73, 95% CI: 0.70-0.76), moderately positive between-session rank correlation coefficients (mean: 0.72, 95% CI: 0.69-0.76). A few frontal plane biomechanical variables displayed lower between-session reliability in the football task compared with the handball task. The moderately positive between-session ranking and practically small typical error implies that the measurements could reliably reproduce the ranking of individuals in multiple-session studies. Adequate reliability could be attained from 3 trials, with only minor improvements when adding more trials.

Keywords:

3D motion analysis, kinematics and kinetics, elite female athletes, test-retest, screening task.

Introduction

Sidestep cutting tasks have been studied extensively in ACL injury related research (McLean, Lipfert, & van den Bogert, 2004; Ford, Myer, Toms, & Hewett, 2005; Sigward & Powers, 2006; Dempsey, Lloyd, Elliott, Steele, & Munro, 2009; Kristianslund, Krosshaug, & van den Bogert, 2012). Marker-based 3D motion analysis have been used to investigate, for instance, the influence of gender on knee biomechanics (Sigward & Powers, 2006) or the effect of cutting technique on knee abduction loading (Kristianslund, Faul, Bahr, Myklebust, & Krosshaug, 2014). In some protocols, the task has been made more sport-specific by involving a static defender (McLean et al., 2004; Kristianslund & Krosshaug, 2013), passing/receiving a ball (Fedie, Carlstedt, Willson, & Kernozek, 2010) or performing unanticipated cuts (Ford et al., 2005).

Surprisingly, the reliability of lower limb biomechanical measurements during sidestep cutting has not been adequately evaluated. Recently, Sankey et al. (2015) investigated the reliability of knee loading variables during sidestep cutting. However, the generalisability of results is limited because the sample size was restricted to four males and four females. Sigward and Power (2006) reported the between-session waveform reliability to be acceptable, but only five female football (soccer) athletes were included Ford et al. (2005) reported the within-session intra-class correlation (ICC) coefficients for knee and ankle frontal plane kinematics to be excellent in 126 adolescent basketball athletes. However, the between-session reliability was not reported. Lastly, Kaila (2007) reported the reliability of lower limb biomechanics in 15 male football athletes using Pearson’s correlation coefficients. However, Pearson’s correlation is insensitive to systematic differences, and is therefore inappropriate for reliability measurements (Weir, 2005).

A sport-specific sidestep cutting task is more complex and varied than a simple change-of-direction cut, because the sport-specific setting such as ball-passing and static defender could induce movement variations. Therefore, it may result in a lower reliability. It is necessary to determine the minimum number of trials necessary to obtain a reliable measure for such as a task.

Thus, the purpose of this study was to assess the within-session and between-session reliability of lower limb biomechanics in two sport-specific sidestep cutting tasks among elite female handball and football athletes. The hypothesis was that biomechanical variables quantified during sport-specific sidestep cutting task would be reliable for both elite female handball and football athletes. Moreover, we aimed at determining the minimum number of sidestep cutting trials necessary to obtain a reliable measure.

Methods

Participants. Nineteen elite female handball and 22 elite female football athletes (mean ± SD: 22 ± 4 yrs old, 168 ± 5 cm, 66 ± 8 kg) performed a sport-specific sidestep cutting task in our biomechanics laboratory. All athletes were from the top division of the Norwegian Handball or Football leagues. They attained full match-fitness during the data collection. The study was approved by the Regional Ethics Committee and all participants provided signed informed consent forms.

Design and protocol. The athletes were tested in two separate sessions, on average separated by two weeks. The athletes wore indoor shoes, shorts and a sports bra. Thirty-seven reflective markers were attached over anatomical landmarks on the legs, arms and torso (Kristianslund et al., 2012). All marker positions were defined uniquely, also those not defined by anatomical landmarks. One experienced physiotherapist, with several years practice for marker placement, was employed for skin marker placement in both sessions.

The handball athletes performed a handball-specific faking manoeuvre involving a static human defender (Kristianslund, Krosshaug, & van den Bogert, 2013; Kristianslund & Krosshaug, 2013; Kristianslund et al., 2014), whereas the football athletes performed a sidestep cutting with a football through pass.

For the handball-specific protocol, the athlete used an approach run of close to 6 m, allowing match-like approach speed. The athlete received a lateral pass from a teammate before executing a match-like faking manoeuvre to pass a 170 cm tall static defender (Figure 1a). The defender adjusted her position during practice trials to ensure that the athlete stepped onto a force platform with her stance foot.

For the football-specific protocol, the athlete also used an approach run of close to 6 m. A teammate passed a football in a direction that forced the athlete to perform a sharp sidestep cutting manoeuvre in order to catch up (Figure 1b).

For both tasks, athletes were allowed to have at least three practice cuts to familiarize themselves with the situation, and at least five successful trials from each side (left-right and right-left) were completed. Two test operators ensured that these trials were performed with match-like intensity with the stance foot on the force platform and all markers firmly attached to the athlete’s skin.

We used a 480 Hz 16-camera system (Oqus 4, Qualisys, Gothenburg, Sweden) to capture the motion, while we recorded ground reaction forces using a force platform (AMTI LG6-4-1, Watertown, Massachusetts, USA) collecting data at 960 Hz. We calibrated the motion analysis system according to guidelines from the manufacturer, and tracked marker trajectories using the Qualisys Track Manager (Version 2.8, Qualisys, Gothenburg, Sweden). We defined the contact phase as the period where the unfiltered vertical ground reaction force exceeded 20 N. Marker trajectories and force data were filtered and interpolated using Woltring's smoothing spline in the cubic mode with 15 Hz low-pass cut-off (Kristianslund et al., 2012). We calculated the hip joint centre using the method proposed by Bell, Pedersen, and Brand (1990) with the anterior-posterior position of the hip joint decided by the anterior-posterior position of the marker over the greater trochanter. Furthermore, we defined the knee joint centre according to Davis, Ounpuu, Tyburski, and Gage (1991), and the ankle joint centre according to Eng and Winter (1995). Anatomical coordinate systems of the thigh and shank were determined from the static calibration trials. We defined the vertical axis in the direction from the distal to the proximal joint centre, while the anteroposterior axis was defined perpendicular to the vertical axis with no mediolateral component. The third axis was the cross product of the vertical and anteroposterior axes. Consequently, all segments had neutral internal/external rotation in the static calibration trial. We obtained technical, dynamic thigh and shank segment coordinate systems using an optimisation procedure involving singular value decomposition (Soderkvist & Wedin, 1993). We used the Grood and Suntay (1983) convention for calculating joint kinematics from the marker-based motion analysis.

We estimated inertia parameters based on 46 measures of segment heights, perimeters and widths using a regression method (Yeadon, 1990), with hand and foot parameters calculated with the method of Zatsiorsky and Seluyanov (1983). We calculated joint kinetics with inverse dynamics using recursive Newton-Euler equations of motion as described by Davis et al. (1991) and projected onto the three rotational axes of the joint according to the joint coordinate system standard (Bresler & Frankel, 1950; Grood & Suntay, 1983; Wu et al., 2002; Kristianslund, Krosshaug, Mok, McLean, & van den Bogert, 2014). The horizontal ground reaction force was projected on the shank coordinate system, resulted as the anterior shear force and medial shear force components. We ran all calculations using custom Matlab scripts (MathWorks Inc., Natick, Massachusetts, USA).

Statistical analysis. Thirty-three discrete variables were extracted from the joint kinematics, joint kinetics and unfiltered ground reaction forces waveform for the reliability analysis. We defined the dominant leg as the preferred leg when kicking a ball. We used paired t-tests and Pearson's correlations to evaluate the symmetry between dominant and non-dominant leg (Sadeghi, Allard, Prince, & Labelle, 2000). We report the mean, standard deviation, and typical error of the within- and between-session measurements. The typical error was calculated from the standard deviation of inter-trial differences divided by the square root of two (Hopkins, 2000). We computed ICC values for within sessions (ICC(3,k)) and between sessions (ICC(3,1)) reliability measures. The ICC classification of Milner et al. (2011) (less than 0.4, poor; between 0.4 and 0.75, fair; between 0.75 and 0.9, good; greater than 0.9, excellent) was used to interpret the ICC values. The ICC values were computed based on trials 1-3, 1-4 and 1-5, separately. We used a Z-test to test the significance of difference between the ICC values of handball and football athletes. The critical value for the Z-score was set at 1.96.

To assess the consistency of athlete ranking between-sessions, Spearman's rank correlation coefficients and between-session ICC were calculated based on the mean measurements from sessions 1 and 2. The classifications of Zou, Tuncali, and Silverman (2003) (greater than 0.5, moderately positive; greater than 0.8, strongly positive) were used to interpret the rank correlation coefficients. Paired t-tests were employed to assess the mean difference between sessions. Cohen's *d* was computed to assess the effect size of the mean differences (less than 0.2, none; between 0.2 and 0.5, small to medium; 0.5 and 0.8, medium to large; and greater than 0.8, very large) (Cohen, 1992). Statistical significance was set at $p \leq 0.05$. Statistical analyses were performed using SPSS 18 (SPSS Inc., Chicago, IL, USA) and the statistics toolbox of Matlab (MathWorks Inc., Natick, Massachusetts, USA). Moreover, the mean curves were time-normalised from 0% to 100% of the stance phase to represent the motion.

Results

The time courses of mean joint kinematics (Figure 2a), joint kinetics (Figure 2b) and ground reaction forces (Figure 2c) were consistent between sessions. However, we could observe a noticeable difference in the waveforms between the handball- and football-specific sidestep cutting tasks.

The mean ICC values for dominant and non-dominant sides were calculated with respect to trials 1-3, 1-4 and 1-5 (Table 1). Only small changes were seen increasing the number of trials from three to five. For the dominant side, the mean between-session ICC value improved from 0.73 (fair) to 0.75 (good), and the mean within-session ICC values improved from 0.91 (excellent) to 0.95 (excellent). For the non-dominant side, the mean between-session ICC value improved from 0.75 (good) to 0.78 (good), and the mean within-session ICC values improved from 0.91 (excellent) to 0.94 (excellent). Since there were only slight improvements in reliability from increasing the number of trials, we have reported reliability measures based on trials 1-3 in the following.

All 33 variables showed a statistically significant correlation between sides (mean: 0.59, 95% CI: 0.53-0.65). Significant differences between limbs were only observed for four of the variables (paired t-test; peak hip abduction angle, peak knee internal rotation angle, peak knee valgus moment and peak knee flexion moment). This implies that the majority of the variables were dependent and symmetrical between dominant and non-dominant side in the sport-specific sidestep cutting task. For simplicity, we will therefore report reliability measures based on the dominant leg only.

There were no significant differences in the within-session ICC values of handball and football athletes. For the between-session ICC values, two variables on the dominant side and five variables on the non-dominant side showed a significant difference (Table 2). Since the vast majority of the ICC values showed no significant difference between handball and football, we have pooled the results of handball and football athletes (Table 3). Six variables showed a significant difference between sessions. All the Cohen's d values were less than 0.21, which implies a small effect size. All the variables showed excellent within-session reliability (mean ICC: 0.91, 95% CI: 0.89-0.93), and fair to good between-session reliability (mean ICC: 0.73, 95% CI: 0.70-0.76). In addition, all the between-session rank correlation coefficients demonstrated moderate to strong positive correlation (mean: 0.72, 95% CI: 0.69-0.76).

Discussion and Implications

All the discrete biomechanical variables achieved good to excellent reliability in both within- and between-session analyses. The between-session rank correlations were moderate to strong, implying that the measurements could reliably reproduce the ranking of individuals in multiple-session studies. We furthermore found adequate reliability to be attained from three trials. Handball- and football-specific sidestep cutting tasks showed good to excellent reliability level in most of the variables, except the between-session reliability of a few frontal plane biomechanical variables in the football-specific sidestep cutting task.

Importantly, we found that increasing the number of trials from three to five trials only slightly improved the reliability of the measurements, even if these tasks can be considered technically demanding. Thus, adequate reliability can be attained using only three trials. However, it should be noted that we required the athlete to have at least three practice trials before the official trials. In some cases, the athlete needed up to five practice trials to become familiarized with the task.

The between-session ICCs were, as expected, lower than the within-session reliability. Similar findings have been reported in 3D motion analysis studies of gait (Kadaba et al., 1989), running (Ferber, Davis, Williams, & Laughton, 2002), and vertical drop jumps (Ford, Myer, & Hewett, 2007). Although several explanations exist, such as the differences in movement execution, this phenomenon can likely be explained predominantly by differences in marker placement between sessions (Kadaba et al., 1989; Steinwender et al., 2000). Nevertheless, the between-session ICC values attain good reliability level for all discrete variables (Table 3). Moreover, the moderate to strong between-session rank correlations implies that all the discrete variables can provide a consistent ranking of athletes, which is essential for reliable screening of athletes. Coupled with the considerably small between-session typical error and effect size, the two sport-specific sidestep cutting tasks can generally provide reliable within- and between-session biomechanical measurements.

Handball- and football-specific sidestep cutting tasks were found to have comparable reliability in most of the variables. A few variables showed lower between-session reliability for the football athletes, especially on the non-dominant side (Table 2). These were mainly frontal plane biomechanical variables of the hip and knee. A possible reason for this difference is that the handball faking manoeuvre is a fundamental motion and performed repeatedly in every training session, which in turn may enhance movement consistency (Zebis, Andersen, Bencke, Kjaer, & Aagaard, 2009). In addition, handball athletes tend to have a favourite side enabling them to shoot with their favourite arm. For instance, a right-handed athlete would usually fake and go to the right, thus using the non-dominant leg. It could be explainable for the difference of reliability between the dominant and non-dominant side. McLean et al. (2004) reported that a static defender could provoke the athlete to change direction more rapidly during cutting, and thereby affect frontal plane biomechanics of the lower limb. In line with the findings of McLean et al. (2004), we found that the protocol including a static defender induced larger medial ground reaction force, larger hip abduction angle and knee valgus angle (Figure 2a and 2c). The static defender could thus potentially limit the possibility for movement variability, and thereby enhance the reliability.

The sport-specific sidestep cutting tasks investigated in the current study showed similar reliability characteristics to the other motion tasks, except the between-session peak knee flexion angle and peak knee internal rotation angle. When comparing our results with gait (McGinley, Baker, Wolfe, & Morris, 2009), running (Ferber et al., 2002) and vertical drop jumps (Ford et al., 2007), the between-session peak flexion angle is more reliable in gait (ICC: 0.96) and running (ICC: 0.93), than vertical drop jumping (ICC: 0.62) and sidestep cutting (ICC: 0.63). In contrast to sidestep cutting and vertical drop jumps, gait and running are daily life motions which have been executed and developed from early childhood (Sutherland, 1997; Cahppell & Limpisvasti, 2008; Desloovere et al., 2010). However, sidestep cutting manoeuvre (ICC: 0.82) has substantially higher between-session knee internal rotation reliability compared to gait (ICC: 0.54), and similar reliability compared to running (ICC: 0.83) and vertical drop jumping (ICC: 0.87).

From an injury-risk screening perspective, the question is if the same individuals are identified as having outer-range scores (i.e. being at risk) with repeated tests. If using peak knee valgus angle (Spearman's rank correlation: 0.73) as the variable of interest, 10 out of 12 athletes that were classified as being at risk (identified among the top 30%) in session one were also classified among the top 30% in session two. However, if using peak knee abduction moment (Spearman's rank correlation: 0.59), only half of the high-risk athletes (six out of 12 athletes) in session one were also included in the top 30% in session two. Nevertheless, the accuracy of lower limb biomechanics for identifying the risk of ACL injury needs to be established from a prospective cohort study using injuries as the outcome.

A number of the topics in the discussion lead to the suggestion that sidestep cutting task is a reliable task but sport-specific. This notion is limited by the level of play and gender since only female elite athletes were tested. Moreover, the reliability measures can be slightly deviated because of the choice on model and approach (Weir, 2005).

Conclusion

All the discrete biomechanical variables examined achieved fair to excellent within- and between-session reliability in both within- and between-session analyses. In addition, the between-session ranking of athletes was moderately to strongly correlated, implying that the measurements can reliably reproduce the ranking of individuals if tested repeatedly. Adequate reliability could be attained from three trials only, with only minor increase in reliability when adding more trials. Handball- and football-specific sidestep cutting tasks were found to have comparable reliability in most of the variables. A few variables showed lower between-session reliability for the football athletes, especially on the non-dominant side.

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Table 1. The average ICC values (interpretation from Milner et al., 2011) of all 33 variables on dominant and non-dominant side from different sum of trials

	Side	Trial 1-3	Trial 1-4	Trial 1-5
Within-session	Dominant	0.91 (Excellent)	0.94 (Excellent)	0.95 (Excellent)
	Non-dominant	0.91 (Excellent)	0.93 (Excellent)	0.94 (Excellent)
Between-session	Dominant	0.73 (Fair)	0.74 (Fair)	0.75 (Good)
	Non-dominant	0.75 (Good)	0.77 (Good)	0.78 (Good)

Table 2. The list of variables having significant difference on the between-session ICC values between handball and football athletes, significant level set at Z-score > 1.96

	Between-session ICC		
Variables	Football	Handball	Z-score
Dominant side			
Peak hip adduction moment	0.37	0.90	2.71
Peak knee valgus angle	0.22	0.72	2.12
Non-dominant side			
Peak medial shear force	0.59	0.93	2.30
Peak ankle eversion moment	0.31	0.85	2.55
Peak knee abduction moment	0.51	0.95	2.57
Peak ankle plantarflexion angle	0.88	0.52	2.07
Peak hip adduction angle	0.32	0.91	3.05

Table 3. Within- and between-session mean, typical error and reliability measurements for dominant side from trials 1-3. SD: standard deviation; IC: initial contact; GRF: ground reaction force

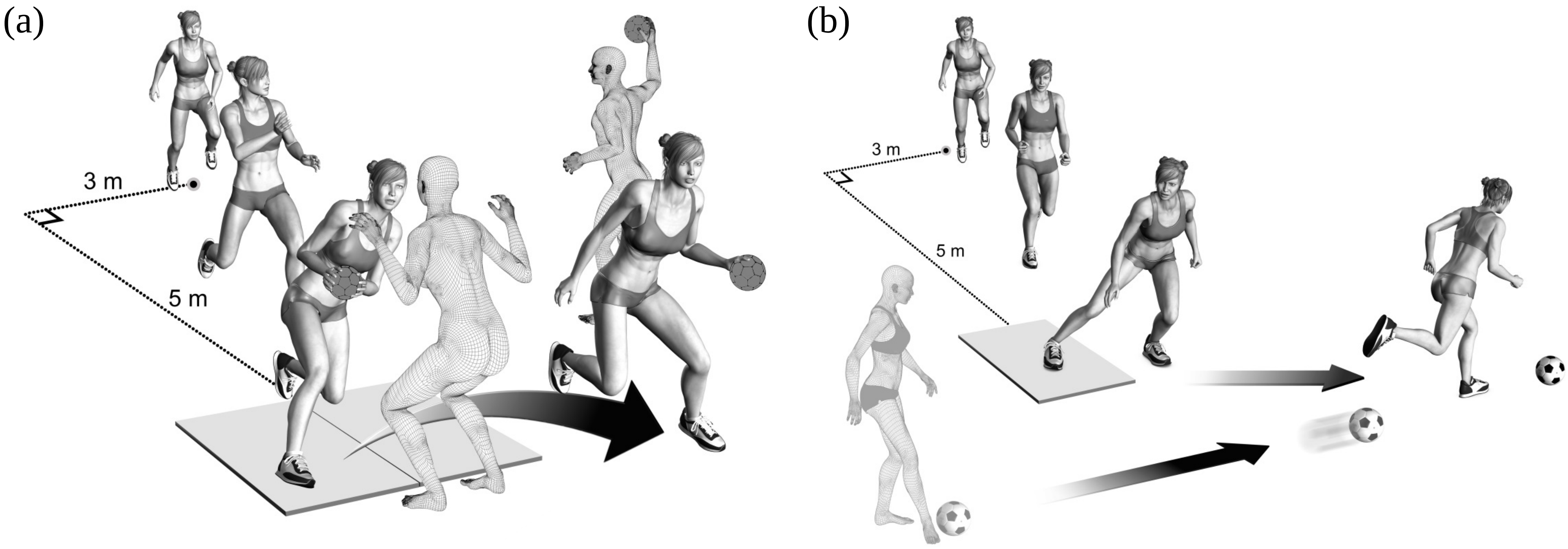
	Within-session					Between-session					
	Mean	SD	Typical Error	ICC(3,k)	95% CI	Typical Error	ICC(3,1)	95% CI	Spearman's rho	95% CI	Cohen's d
Kinematics											
Hip internal rotation angle at IC (°)	-1.7	8.4	2.1	0.94	0.90-0.97	3.3	0.64	0.42-0.79	0.64	0.37-0.82	0.11
Peak hip internal rotation angle (°)	10.9	7.7	1.8	0.95	0.92-0.97	2.6	0.73	0.55-0.85	0.74	0.52-0.87	0.07
Hip abduction angle at IC (°)	18.6	7.5	1.7	0.96	0.93-0.97	2.5	0.76	0.59-0.86	0.84	0.68-0.92	0.14
Peak hip adduction angle (°)	-11.2	7.1	2.4	0.92	0.87-0.96	2.7	0.64	0.42-0.79	0.72	0.49-0.86	0.13
Peak hip abduction angle (°)	27.9	6.9	1.8	0.94	0.89-0.96	2.5	0.66	0.44-0.80	0.69	0.44-0.84	0.18*
Hip flexion angle at IC (°)	43.1	11.9	1.5	0.99	0.98-0.99	4.5	0.72	0.53-0.84	0.83	0.68-0.92	0.01
Peak hip flexion angle (°)	51.3	13.6	2.9	0.96	0.94-0.98	4.4	0.74	0.56-0.85	0.78	0.58-0.89	0.06
Knee internal rotation angle at IC (°)	4.0	8.5	2.9	0.93	0.88-0.96	3.1	0.70	0.50-0.83	0.70	0.45-0.85	0.02
Peak knee internal rotation angle (°)	12.2	5.8	1.1	0.97	0.95-0.98	1.6	0.82	0.69-0.90	0.85	0.70-0.93	0.05
Knee valgus angle at IC (°)	5.5	3.5	1.2	0.92	0.87-0.96	1.7	0.55	0.29-0.73	0.55	0.24-0.76	0.06
Peak knee valgus angle (°)	11.8	5.3	1.4	0.95	0.92-0.97	2.5	0.64	0.42-0.79	0.73	0.50-0.86	0.06
Knee flexion angle at IC (°)	21.8	7.5	2.7	0.90	0.83-0.94	2.2	0.68	0.48-0.82	0.60	0.31-0.79	0.06
Peak knee flexion angle (°)	60.5	6.9	4.1	0.75	0.56-0.85	2.6	0.63	0.41-0.79	0.65	0.38-0.82	0.09
Ankle internal rotation angle at IC (°)	-5.2	5.4	1.7	0.93	0.88-0.96	1.3	0.83	0.70-0.90	0.83	0.68-0.92	0.04
Peak ankle internal rotation angle (°)	-2.4	5.9	2.5	0.88	0.79-0.93	1.6	0.83	0.70-0.90	0.84	0.69-0.92	0.05
Ankle inversion angle at IC (°)	4.8	6.6	2.0	0.94	0.90-0.97	2.7	0.61	0.37-0.77	0.60	0.31-0.79	0.09
Peak ankle inversion angle (°)	28.4	5.9	1.4	0.95	0.92-0.97	2.1	0.71	0.49-0.84	0.74	0.51-0.87	0.21*
Ankle plantarflexion at IC (°)	8.0	12.1	5.6	0.90	0.83-0.94	4.0	0.77	0.60-0.87	0.77	0.57-0.89	0.15*
Peak ankle plantarflexion angle (°)	26.3	9.3	2.3	0.95	0.91-0.97	2.7	0.80	0.66-0.89	0.70	0.46-0.85	0.01
Peak ankle dorsiflexion angle (°)	23.2	6.8	1.8	0.94	0.89-0.96	2.5	0.69	0.48-0.82	0.54	0.22-0.75	0.09
Kinetics											
Peak hip internal rotation moment (Nm)	43.8	14.6	5.3	0.89	0.82-0.94	5.7	0.68	0.47-0.81	0.69	0.43-0.84	0.04
Peak hip adduction moment (Nm)	50.4	82.5	15.8	0.97	0.96-0.98	24.0	0.85	0.74-0.92	0.81	0.64-0.91	0.08
Peak hip flexion moment (Nm)	243.3	95.3	19.6	0.96	0.93-0.98	35.8	0.77	0.60-0.87	0.83	0.68-0.92	0.05
Peak knee external rotation moment (Nm)	27.4	13.5	3.3	0.95	0.91-0.97	4.6	0.74	0.56-0.85	0.63	0.36-0.81	0.06
Peak knee abduction moment (Nm)	120.3	39.5	13.0	0.90	0.82-0.94	13.6	0.72	0.52-0.84	0.59	0.29-0.78	0.17*
Peak knee flexion moment (Nm)	167.3	45.2	12.3	0.94	0.89-0.96	13.0	0.80	0.66-0.89	0.74	0.52-0.87	0.00
Peak ankle internal rotation moment (Nm)	63.9	18.2	6.1	0.91	0.85-0.95	6.7	0.71	0.51-0.84	0.72	0.49-0.86	0.19*
Peak ankle eversion moment (Nm)	36.5	15.4	4.6	0.93	0.88-0.96	4.4	0.76	0.59-0.86	0.70	0.45-0.84	0.05
Peak ankle dorsiflexion moment (Nm)	164.3	30.3	6.6	0.96	0.94-0.98	7.5	0.86	0.75-0.92	0.82	0.65-0.91	0.10
Ground Reaction Forces											
Peak vertical GRF (N)	1543.2	441.8	93.3	0.97	0.94-0.98	88.7	0.92	0.85-0.96	0.89	0.78-0.95	0.10
Peak posterior shear force (N)	439.1	159.2	47.2	0.94	0.90-0.97	53.1	0.77	0.60-0.87	0.76	0.54-0.88	0.15*
Peak medial shear force (N)	738.5	154.3	42.7	0.94	0.90-0.96	37.5	0.85	0.73-0.92	0.81	0.63-0.90	0.10

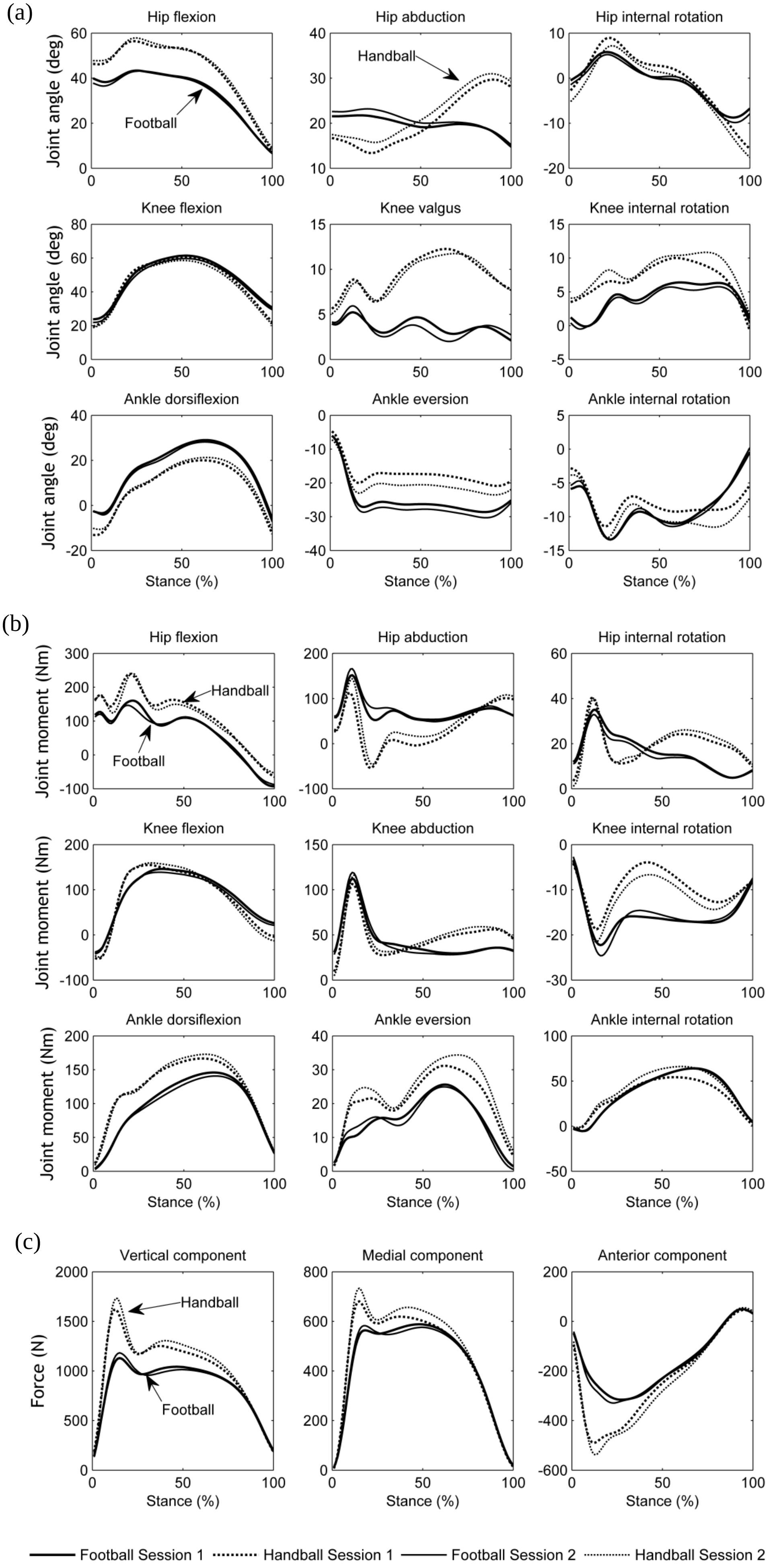
* p<0.05, significant difference between the mean measurements of session 1 and 2.

Figure captions

Figure 1. The testing situation of (a) the handball-specific sidestep cutting task and (b) the football-specific sidestep cutting task

Figure 2. The time courses of mean measurements of handball and football athletes from session 1 and 2, for (a) joint kinematics, (b) joint kinetics and (c) ground reaction forces


(a)
3 m
5 m
(b)
3 m
5 m



(a)
Hip flexion
Hip abduction
Hip internal rotation
Knee flexion
Knee valgus
Knee internal rotation
Ankle dorsiflexion
Ankle eversion
Ankle internal rotation
Joint angle (deg)
Handball
Football
Stance (%)
(b)
Hip flexion
Hip abduction
Hip internal rotation
Knee flexion
Knee abduction
Knee internal rotation
Ankle dorsiflexion
Ankle eversion
Ankle internal rotation
Joint moment (Nm)
Handball
Football
Stance (%)
(c)
Vertical component
Medial component
Anterior component
Force (N)
Handball
Football
Stance (%)
Football Session 1
Handball Session 1
Football Session 2
Handball Session 2