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Between-limb differences during 180° turns in female soccer players: Application of Statistical Parametric Mapping

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Abstract

This study was exploratory in nature, and investigated the ability of statistical parametric mapping (SPM) to assess between-limb differences in lower-extremity movement change of direction. Fourteen female soccer players (mean ± SD; age = 20.6 ± 0.6 years; height = 1.65 ± 0.07 m; body mass = 56.04 ± 6.20 kg). For comparisons between preferred and non-preferred limbs, vertical (Fz) and horizontal (Fx) GRFs were determined along with hip, knee, and ankle angles and moments in the sagittal plane during weight acceptance during the final contact. Additionally, frontal plane knee abduction angles and moments were calculated during the final contact. SPM software was then used to assess for differences between the entire weight acceptance phase of preferred and non-preferred limbs. There were no differences between limbs in all variables using SPM. These results demonstrate that female soccer players exhibit little side-to-side differences in certain lower-limb biomechanics when performing a turn manoeuvre. These findings can be utilised by practitioners and clinicians when developing injury prevention and rehabilitation programmes.

Keywords: deceleration; knee abduction moment, change of direction ability,
side-to-side differences

INTRODUCTION

A between-limb difference is a change in performance or function of one limb with respect to the other (35) pertaining to muscle strength, movement coordination, and movement timing (i.e. kinetics and kinematics); such examples may include isokinetic peak torque difference between left and right limbs (7), or difference in change of direction time between left and right limbs) (13). Due to laterality, humans will preferentially use one side of the body when performing a motor task, typically resulting in more skillful and therefore become the preferred side (26), thus it is unsurprising that athletes tend to display limb dominance. Indeed, between-limb differences may be developmental, or functional in specific sporting contexts (35), potentially due to the chronic exposure to repeated asymmetrical sport-specific actions (29). Specifically, any sport which has a preferred limb for a particular skill is preferentially recruited for the activity, and this is why between-limb differences arise in kicking actions in soccer (1) and Australian rules football (17). Thus, understanding the between-limb biomechanics underlying a turn task is essential for mitigating injury risk and facilitating performance.

Limb preference has been suggested to play a sex-based role in non-contact anterior cruciate ligament injury, specifically in soccer players (5). Indeed, 74% (20/27 cases) of males sustained a greater number of non-contact anterior cruciate ligament (ACL) injuries to the dominant limb, compared to 32% (10/31 cases) in females. Thus, female soccer players were more likely to injure their ACL in the non-dominant limb (support/stance) limb, whereas males demonstrated the opposite. These injuries most likely occur due to the high joint loads when adopting postures such as lateral trunk flexion (10), knee valgus (9), limited knee flexion (24), wide lateral foot plant (21), and high ground reaction forces (24). Several attempts have been made to explore differences in lower-limb biomechanics during change of direction manoeuvres (12); these studies typically compare preferred push-off and non-preferred push-off limbs, dominant (stronger) and nondominant (weaker) limbs, and kicking and non-kicking limbs. The general aim of these studies has been to better understand the potential role of between-limb differences in injury prevention and rehabilitation programs. To date there has been little agreement on the role of between-limb differences, with studies demonstrating findings in favor of greater injury risk (8,15,27,28) and against risk of injury (3,6,32). However, with the exception of Marshall et al. (27), these investigations have compared limb differences at discrete points (i.e. average and peak values) and may play a limited role to aid in the understanding of the overall performance and movement patterns of interest. Very little is currently known about between-limb differences when analyzing the entire waveform for variables during change of direction. Therefore, given that anterior cruciate ligament injuries occur early and often with the knee extended and hip flexed early in ground contact, possibly in slight valgus (knee abduction) alignment (25); it might be worth exploring whether side-to side differences are present that relate to these critical positions early in ground contact rather than global peak magnitudes which could occur at different points during ground contact.

One method for comparing lower-limb kinetics and kinematics over an entire movement sequence is statistical parametric mapping (SPM) (31,34). SPM is based on random field theory and calculates a critical threshold for each test, considering both the magnitude and shape of the entire data set for each curve. SPM has been used to evaluate GRF data and joint kinetics and kinematics in athletic populations (33,36). Furthermore, SPM has been used to examine biomechanical differences between limbs in patients with anterior cruciate ligament injury 9 months after reconstruction during change of direction (22,23) and during running and landing in multiple populations (19). In each of these prior cases, SPM enabled a more in-depth evaluation of movement throughout various tasks and identified additional limb differences that were found with traditional discrete analyses alone. Furthermore, SPM removes the need for potentially biasing discretization, whilst allowing for non-directed hypotheses. To date, the few studies investigating the differences in between-limb biomechanics during change of direction have only included discrete analyses and potential differences between full waveforms (i.e. one-dimensional or 1D analysis) are yet to be fully explored. The aim of this study therefore, was exploratory in nature and designed to examine the differences in preferred and non-preferred limb GRFs, and lower-limb sagittal and frontal plane joint angles and moments over the entire waveform, using SPM during change of direction. The intention of this study is also to provide a valid hypothesis to be tested as a part of future 1D testing in future research.

METHODS

Experimental Approach to the Problem

Fourteen female soccer players (mean ± SD; age = 20.6 ± 0.6 years; height = 1.65 ± 0.07 m; body mass = 56.04 ± 6.20 kg) participated in the study. All subjects were registered with soccer clubs playing in the second tier of English Women's Soccer. At the time of testing, subjects were performing 4–5 sport-specific sessions, plus 3 resistance training sessions per week. All subjects had >8 years' competitive experience and >3 years' resistance training experience. All subjects met the inclusion criteria: (1) fully active (i.e., 3 sessions per week) in female soccer competition, (2) did not suffer from an ACL injury and (3) did not suffer from any other lower limb injury within the last 6 months before data collection. Written informed consent was attained from all subjects and approval for the study was provided by the Institutional Review Board. The study was conducted in accordance with the Declaration of Helsinki.

Procedures

All subjects were fitted with appropriate size compression tops (Champion Vapor, Champion, Winston-Salem, NC, USA) and indoor shoes (Balance W490, New Balance, Boston, MA, USA). The leg which a player preferred to turn with was noted as the preferred limb. Testing took place on an indoor synthetic running surface (Mondo, SportsFlex, 10 mm; Mondo America Inc., Mondo, Summit, NJ, USA). All subjects performed a 180° turn task, turning off the preferred and non-preferred limbs, considered to be representative of the nature of competitive soccer match-play (14). All subjects performed a standardised progressive warm-up directed by the investigator including various bodyweight lunges and squats, interspersed with footwork and sprint mechanics drills, replicating the athlete's standardised warm-ups before training. This was followed by practice trials of the 180° turn (3 on each limb). The 180° turn involved running towards a single force platform, used to measure GRFs from the final foot contact. Subjects were instructed to sprint to a line marked on the central portion of the force platform, 5 m from the start, planting their preferred or non-preferred foot on the line, turn 180° and sprint back 5 m through the finish. During the test session, all subjects performed a minimum of 6 acceptable trials turning off each limb (preferred and non-preferred) in a randomized order and counterbalanced between subjects. Subjects were instructed to perform trials with maximum effort whilst contacting the central portion of the force platform during final contact to ensure a homogeneous distance of travel between trials and without prior stuttering or prematurely turning prior to final contact. Verbal feedback was provided to rectify any of the abovementioned aspects on subsequent trials. Each subject was allowed time prior to data collection to identify their exact starting point to ensure an appropriate force platform contact. Brower timing lights (Brower Timing Systems, Draper, UT, USA) were set at approximate hip height for all participants. The mean of the 3 fastest trials were retained for further analysis.

The procedures have been reported previously (20), thus only a brief overview is provided here. Reflective markers (14 mm spheres) were placed on the following body landmarks; mid-clavicle, 7th cervical vertebrae, right and left; shoulder, iliac crest, anterior superior iliac spine, posterior superior iliac spine, greater trochanter, medial epicondyle, lateral epicondyle, lateral malleouli, medial malleouli, heel, 5th, 2nd and 1st metatarsal heads using double-sided adhesive tape. Subjects wore 'cluster sets' (4 reflective markers attached to a lightweight rigid plastic shell) attached using Velcro elasticated wraps on the right and left thigh and shin to approximate the motion of these segments during dynamic trials. The pelvis and trunk cluster sets were attached using an elasticated belt and compression top, respectively. Three dimensional motions of these markers were collected whilst performing the turning using 10 Qualisys 'Oqus 7' (Model no. MCU 240) infrared cameras (240 Hz) operating through Qualisys Track Manager software (version 2.14). Ground reaction forces were collected from a single AMTI (Model no. 600900) force platform (1200 Hz) embedded into the indoor surface.

From a standing trial, a 6-degree-of-freedom model of the lower extremity and trunk was created for each participant, including trunk, pelvis, thigh, shank and foot using Visual3D software (C-Motion, version 3.90.21). This kinematic model was used to quantify the motion at the hip, knee and ankle joints using Cardan angle sequence (16). The local coordinate system was defined at the proximal joint centre for each segment. The static trial position was designated as the subject's neutral (anatomical zero) alignment, and subsequent kinematic measures were related back to this position. Lower limb joint moments were calculated using an inverse dynamics approach (37) through Visual3D software and are defined as external moments. Segmental inertial characteristics were estimated for each participant (11). The model utilised a CODA pelvis orientation (2) to define the location of the hip joint centre. The knee and ankle joint centres were defined as the mid-point of the line between lateral and medial markers. The trials were time normalised to 100 data points, each representing 1% of the weight acceptance phase for each subject of the turn task. Initial contact was defined as the instant after ground contact that the vertical GRF was higher than 20 N and end of contact was defined as the point where the vertical GRF subsided past 20 N for the final contact. The weight acceptance phase of ground contact was defined as from the instant of initial contact to the point of maximum knee flexion during ground contact, as used previously (18,20). Joint coordinate and force data were smoothed in Visual3D with a Butterworth low pass digital filter with cut-off frequencies of 12 and 25 Hz, respectively. Cut off frequencies were selected based on a residual analysis (37) and visual inspection of the data.

For comparisons between preferred and non-preferred limbs, vertical (Fz) and horizontal (Fx) GRFs were determined along with hip, knee, and ankle angles and moments in the sagittal plane during weight acceptance during the final contact. Additionally, frontal plane knee abduction angles and moments were calculated during the final contact. Joint moment data were normalised to body mass (Nm/kg).

Statistical Analyses

For the waveform analyses, force and lower-limb angles and moments were registered to 101 nodes. Open-source SPM software (30) was then used to assess for differences (paired t-test) between the entire weight acceptance phase of preferred and non-preferred limbs. Differences in performance time between limbs were examined using standardized differences (effect size, ES [± 95% confidence interval]), based on Cohen's effect size principle.

RESULTS

There were unclear differences in performance times between limbs (ES = 0.30 [-0.13 to 0.73]). There were no significant differences between limbs in vertical and horizontal GRF during weight acceptance (Figure 1). Sagittal plane hip, knee, and ankle angles and moments revealed no differences between limbs (Figure 2). Similarly, no between-limb differences were found in frontal plane knee abduction angles and moments (Figure 3).

DISCUSSION

Although several reports have investigated between-limb differences in lower-limb biomechanics during change of direction tasks (12), few have explored differences using 1D approaches. Understanding lower-limb biomechanics during turning is key to injury prevention and rehabilitation programming due to the braking demands and body alignment, which is associated with increased loading, and therefore, surrogates of injury risk. While few studies have explored lower-limb biomechanical differences between limbs in cutting using full waveform analyses (12), this exploratory study is the first to examine the differences during a turn manoeuvre. After analysing GRFs and lower-limb sagittal and frontal plane joint angles and moments, no between-limb differences were detected for change of direction biomechanics during turning in female soccer players. Thus for the current study, it appears that there are no differences in lower-limb joint angles and moments at critical instances during weight acceptance between preferred and non-preferred limbs.

The results of this study did not show any significant differences between limbs in lower-limb biomechanics during a turn manoeuvre. Specifically, vertical and horizontal GRFs, sagittal plane hip, knee, and ankle moments, and frontal plane knee abduction angles and moments failed to demonstrate any between-limb differences when turning off the preferred and non-preferred limbs. In these cases, SPM was able to provide information the full waveform of the weight acceptance phase regarding differences (or lack of) in movement patterns and overall performance. SPM enables a more comprehensive understanding of differences in movement patterns and overall performance between limbs that could better inform clinical and training interventions, decision making, and rehabilitation targeted at these specific regions of difference (22). However, in this experiment, SPM did not identify any between-limb differences, despite differences between limbs being identified in previous studies for vertical GRF (15,27), peak knee flexion angle (15), peak knee flexion moment (28), and peak knee abduction moment (8,28). It is difficult to explain this result, but it might be related to the fact with the exception of Marshall et al (27), the aforementioned studies compared between-limb differences based on discrete point analyses; potentially leading to regional focus bias and does not provide information regarding temporal differences. This form of analysis could also lead to a large proportion of potentially valuable and meaningful information of the full waveform being left unexamined. Another possible explanation for this is that as SPM does have a multiple comparison correction built in, the threshold for statistical significance is higher with SPM than with discrete analysis (null hypothesis significance testing). There is abundant room for further progress in determining between-limb differences in change of direction biomechanics using SPM. Future studies on the current topic are therefore recommended.

SPM has been used to compare differences between limbs in lower-extremity movement during running (19). Previous work has also used full waveform analyses to evaluate between-limb biomechanics during a 75°cut in male international rugby players (27).

Using these approaches, prior studies have provided additional information regarding between-limb differences that are not available using discrete point analyses. For example, when using discrete analyses, Marshall et al. (27) found only 1 variable of 28 (ankle internal rotation moment) to demonstrate statistical significance between limbs for male rugby players. Moreover, full waveform analysis between limbs revealed additional limb differences that were not observed during discrete analyses on measures such as ankle dorsi-flexion angle, knee abduction angle, knee internal rotation moment, knee flexion angle, and vertical GRF. Similarly, Hughes-Oliver et al. (19) found SPM to provide clinically meaningful movement differences between limbs during running in healthy and anterior cruciate ligament reconstruction patients. Subsequently, the current study adds to our understanding about lower-limb biomechanics in female soccer players during a turn manoeuvre, using SPM. This study includes SPM findings in healthy female soccer players during turning to broaden the base of information regarding the use of SPM to evaluate between-limb kinetic and kinematic differences.

Although this study does provide novel information regarding between-limb differences in change of direction biomechanics, there are several limitations to this study. First, the pre-planned execution of the turn manoeuvre, whereas unanticipated change of direction has shown to elevate knee joint loads during cutting (4). Another limitation is that some differences (with respect to knee abduction angles and moments) may be concealed by the preferred limb displaying greater values than the non-preferred limb, and vice versa (i.e. some athletes will be higher risk for the preferred limb and some high-risk for the non-preferred). It is unknown whether individual analyses might actually reveal some athletes display a temporal pattern which indicate a particular limb may be a heightened risk of injury. Future research on this topic is therefore warranted. Notwithstanding these limitations, the results of this study demonstrate SPM can be used to assess between-limb differences in lower-limb kinetics and kinematics of female soccer players during turning. Although this method provides additional information about between-limb differences than the evaluation of discrete measures alone, SPM may require larger sample sizes to be sufficiently powered to detect all between-limb differences. In addition, SPM may provide a method for determining clinically meaningful movement differences between limbs that could be used in the development of change of direction intervention programs. The use of SPM for determining between limb differences should be further investigated in additional sporting populations and change of direction tasks (i.e. sidestep cutting). Finally, given that no differences in lower-limb kinetics and kinematics were noted as a part of this exploratory analysis, no unique 1D hypotheses were framed as a part of future research. Despite this, future explorations asymmetries in female populations should incorporate larger samples and evaluation of temporal differences across movement cycles.

PRACTICAL APPLICATIONS

The results of this exploratory study show that no differences exist in lower-limb kinetics and kinematics between the preferred and non-preferred limbs during turning in female soccer players. As such, coaches and practitioners should consider these findings when assessing and monitoring between-limb differences in lower-limb kinetics and kinematics during turning maneuvers. Specifically, whether a particular limb is of heightened risk of injury when female soccer players perform a turn maneuver, practitioners should aim to reduce high risk postures and knee joint loads in both the preferred and non-preferred limbs, and potentially adopt an individual approach.

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Declaration of Interest

The authors report no conflict of interest

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