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Six methods for classifying lower-limb dominance are not associated with asymmetries during a change of direction task.

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Abstract

Quantifying asymmetries between dominant and non-dominant limbs is a common research objective aimed at identifying systematic differences between limbs and establishing normative ranges of asymmetry. Multiple methods for classifying limb dominance exist and it is unclear how different methods relate to directional asymmetries during change of direction (CoD). This study aimed to determine if different methods of classifying limb dominance, including a novel CoD task-specific method, identified significant inter-limb asymmetries during a 90° CoD task. Fifty participants completed a testing battery consisting of jumping, hopping, CoD and isokinetic dynamometry. Limb dominance was classified for each participant according to preferred kicking limb, vertical jump height, horizontal hop distance, initial force plate contact during landing, max isokinetic knee extensor strength, and turning velocity. Asymmetries in whole-body and joint-level mechanics were defined using each method. No method for classifying limb dominance was associated with consistent inter-limb biomechanical asymmetries during CoD and no method was related to any other method. The magnitude of asymmetry relative to the magnitude of absolute asymmetry present within the cohort suggests that using these tasks to classify the dominant limb in this CoD is akin to assigning dominance to a randomly-selected limb. Previous observations of group symmetry during CoD may be statistical artefacts as opposed to a true indication of normative movement. Until an appropriate means of classifying limbs during CoD is established, quantifying normative asymmetry based on limb dominance should be done with caution.

Keywords: *Lower-limb dominance, inter-limb asymmetry, change of direction.*

Introduction

Inter-limb asymmetry refers to differences in movement and performance between limbs during voluntary motor tasks (Bishop et al., 2018). In the absence of pathology, asymmetry is believed to be driven by differences between dominant and non-dominant limbs, though ambiguity remains with respect to the appropriate method for classifying limbs as dominant and non-dominant. Limb dominance is attributed to functional difference in the two hemispheres of the human brain and is associated with the preferential use of one limb in voluntary (Kapreli et al. 2006; Sadeghi et al. 2000) . Within many sports the ability to use both limbs effectively in tasks such as kicking, jumping and turning is desirable, meaning that large inter-limb asymmetries may negatively impact athletic performance (Bloomfield et al. 2007; Pollard et al. 2020; De Ruiter et al. 2010). Asymmetries in kinematic and kinetic measures are also associated with increased injury risk (Hewett et al. 2005; Paterno et al. 2010; Zifchock, Davis, and Hamill 2006). Quantifying inter-limb asymmetries between dominant and non-dominant limbs is therefore a common research objective aimed at identifying systematic differences between limbs and establishing normative ranges of asymmetry (Kobayashi et al., 2010; Marshall et al., 2015; Pollard et al., 2020; Promsri et al., 2018; van der Harst et al., 2007).

Methods used to classify limbs as dominant and non-dominant include the self-preferred kicking limb (Brown et al., 2014; Marshall et al., 2015), the limb that attains the greatest single-leg countermovement jump height (Kobayashi et al., 2013), the limb that attains the furthest single-leg hop distance (van der Harst, Gokeler, and Hof 2007), the limb that contacts the ground first when landing from a vertical drop jump (Paterno et al. 2011) and the strongest limb based on isokinetic peak knee extension torque (Coratella et al., 2018). Using different methods will manifest as different limbs being classified as the dominant and non-dominant. Multiple studies have shown that individuals vary their preferred limb across different lower-limb tasks (Huurnink et al., 2014; Mulrey et al., 2018; van Melick et al., 2017), while Mulrey et al. (2018) demonstrated that the limb classified as the dominant differed within the similar hopping tasks of vertical jump height and horizontal hop distance.

The inability to consistently assign a limb classification across different tasks has led to the suggestion that limb dominance should be classified according to the demands of the task being studied (Gabbard and Hart 1996). Dörge et al. (2002) and Ball et al. (2011) noted significant differences in lower-extremity kinematics between dominant and non-dominant limbs during kicking tasks when classifying limbs according to the self-preferred kicking limb, while Sinclair et al (2014) made similar observations when examining differences in kinematics during jumping between dominant and non-dominant limbs as classified by vertical jump height (Dörge et al., 2002; Sinclair et al., 2014). These methods therefore classify limbs as dominant and non-dominant in a manner that identifies group directional asymmetries during the task being studied, i.e. the dominant limb value is systematically larger or smaller than the non-dominant limb value. The extent to which the method used to classify dominance achieves this can be considered along a continuum ranging from a perfect relationship, where asymmetry direction is consistent across all participants and mean directional asymmetry magnitude is equal to absolute asymmetry magnitude, to no relationship, where asymmetry direction varies randomly across participants and mean directional asymmetries approach zero with positive and negative values cancelling out. Thus, unless the method used to classify dominance in a study relates in some manner to the directional asymmetries during the task studied, movement symmetry may be falsely inferred from low directional asymmetry group means. Large discrepancies between absolute and directional asymmetries would indicate that the chosen dominance definition has not captured the observed asymmetry in the execution of the task.

Large discrepancies between absolute and directional asymmetry magnitudes are apparent in studies examining inter-limb asymmetries during change of direction (CoD) (Bencke et al., 2013; Brown et al., 2009; King et al., 2009; Marshall et al., 2015; Mok et al., 2018; Pollard et al., 2020). Analyses of inter-limb asymmetries during CoD have gained popularity due to CoDs relevance to sporting performance and its association with anterior cruciate ligament (ACL) injury (Bencke et al., 2013; Brown et al., 2009; Marshall et al., 2015; Mok et al., 2018; Pollard et al., 2018). Studying inter-limb asymmetry during CoD is important to quantify performance deficits, identify underlying risk factors for injury and establish normative ranges of asymmetry that can be used to guide rehabilitation programmes. King et al. (2019) compared absolute asymmetries during a CoD task between an injured (post ACL-reconstruction) and healthy control groups and noted relatively large absolute asymmetries within the control group. For example, mean asymmetries of 5.6° in knee flexion angle were observed during CoD stance phase, which is larger than the magnitude of asymmetry observed between operated and non-operated limbs post ACL-reconstruction (King et al., 2018). In contrast, in non-injured groups, mean directional asymmetries between dominant and non-dominant limbs for knee flexion angle during CoD have been reported as ranging between 0.7° and 2.5° (Brown et al., 2014; Greska et al., 2017; Marshall et al., 2015; Pollard et al., 2020).

The preferred kicking limb is the most common method used for classifying limb dominance when studying CoD asymmetries (Brown et al., 2009; Marshall et al., 2015; Mok et al., 2018; Pollard et al., 2018). The rationale for classifying limbs in this manner when studying CoD is unclear as the demands associated with CoD, particularly in the early deceleration phase where ACL injury occurs, more closely mirror those experienced by the stance limb during a kicking motion than the kicking limb itself (Koga et al. 2010). Alternative methods based on jumping and hopping may be more appropriate when studying CoD due to an overlap in qualities such as strength, power and rapid force generation. There may also be scope for the development and implementation of a task-specific method for classifying lower-limb dominance during CoD. Mechanically, CoD involves the deceleration, reorientation and acceleration of the body's centre of mass (CoM) in the intended direction of travel. From a performance perspective, the ability to complete this process over the shortest time-period is critical. Dominance as classified by these features may provide a useful means of distinguishing between stance limbs during CoD.

Thus, this study had two aims. Firstly, we aimed to determine if five previously-used methods of classifying lower limb dominance and a new task-specific CoD method identified significant inter-limb asymmetries in whole body and joint level mechanics during a 90° CoD task, indicative of systematic directional asymmetries across participants. We hypothesized that dominance as classified by jumping/hopping ability and a task specific CoD definition would identify significant inter-limb asymmetries during CoD due to a relationship between the task studied and the method used. Secondly, we aimed to assess the consistency between the limb dominance classification specified by each definition.

Methods

A cohort of 50 male participants (24.8 ± 4.3 years, 182.3 ± 6.38 cm, 83 ± 7.4 kg) with no history of ACL injury or knee injury that required surgery and no lower-limb injuries in the preceding 12 weeks. All participants participated in multi-directional field-based sports (gaelic football, hurling and soccer) at an amateur level. Ethical approval was granted by the University of Roehampton (LSC 15/122) and the Sports Surgery Clinic Hospital Ethics Committee (25AFM010). Participants gave informed, written consent prior to participation in the study. Data collection took place in a biomechanics laboratory using a ten-camera motion analysis system (200 Hz; Bonita-B10, Vicon, UK) recording the positions of 28 reflective markers (14 mm diameter), synchronized (Vicon Nexus 2.3) with two force platforms (1000 Hz BP400600, AMTI, USA). Markers were secured using tape at bony landmarks on the lower limbs, pelvis and trunk according to a modified Plug-in-Gait marker set (Marshall et al., 2014).

Data Collection

Prior to testing participants undertook a standardised warm up consisting of a 2-minute jog, 5 bodyweight squats, 2 submaximal countermovement jumps and 3 maximal countermovement jumps. Following this each participant completed a testing battery consisting of single-leg countermovement jumps (SLCMJ), double-leg drop jumps (DLDJ), single-leg hops (SLHop) and a pre-planned 90° CoD task. Three valid, maximal effort trials were recorded for each task and for single leg exercises (SLCMJ, SLHop and CoD), participants completed three trials on each leg.

For all jumping exercises, the participants were instructed to complete the task with their hands placed on their hips. The SLCMJ consisted of a maximal vertical jump where the participants were instructed to "stand on one foot, perform a quick dip prior to jumping straight into the air as high as you can". The SLHop was a maximal horizontal jump where the participants were instructed to "stand on one leg and jump horizontally as far as possible while maintaining a balanced landing position". For the DLDJ, participants were positioned upon a 30 cm box and instructed to "drop off the box with both feet simultaneously and upon landing jumper vertically for maximal height and spend as little time as possible on the ground". The box was positioned in a manner that meant that the participant's two feet landed on separate force platforms. Lastly, the CoD task involved the participants running maximally towards the laboratory force platforms before planting their outside foot on the force platform to cut 90° to the left or right, i.e. planting their right foot to cut to the left. The start line was 5 m from the force plates, while the finish line was 2 m from the force plates. Three trials were collected from each leg. A full description of the testing protocol is given in King et al. (2018).

Finally, seated concentric knee extensor and flexor peak torques were assessed at an angular velocity of 60°/s using an isokinetic dynamometer (model Cybex Norm, Computer Sports Medicine Inc, Stoughton, MA) through an angular range of 0-100° knee flexion. Participants completed an initial warm up set consisting of 4 submaximal and 1 maximal repetition followed by two maximal-effort sets each consisting of 5 repetitions. A 60 second rest period was allowed between sets. Participants were instructed to push and pull as hard and fast as possible against the resistance through the full range of motion.

Lower-limb dominance classification

Lower-limb dominance was classified for each participant using six methods. These were (1) the self-preferred kicking limb defined by participants response to the question "which limb would you preferentially use to kick a ball with?" (KICK), (2) the limb that attained the greatest vertical jump height calculated using flight time (JUMP), (3) the limb that attained the greatest horizontal hop distance (HOP), (4) the limb that made contact with the force plate first during the initial landing of the DLDJ based on a threshold of 10 N (LAND), (5) the limb that recorded the highest peak knee extension torque during isokinetic dynamometry testing (ISO), and (6) a newly formed task specific method for classifying dominance during CoD (TURN). For JUMP and HOP, the mean of three trials for vertical jump height and horizontal hop distance were used to classify dominance, while for ISO, peak torque was extracted from both working sets and mean peak torque was calculated. Gravity corrections were applied to all torque values. For LAND, the limb that most frequently made initial contact in the three recorded trials was used.

For TURN, marker and force data from each CoD trial were filtered using a fourth order zero-lag Butterworth filter (cut-off frequency 15 Hz) (Kristianslund et al., 2012). Initial contact and toe-off were identified from when the vertical ground reaction force (GRF) crossed a 20 N threshold. The speed and angle at which an individual changes direction are the two fundamental components of every CoD manoeuvre (Dos Santos et al., 2018; Havens & Sigward et al., 2015; Vanrenterghem et al., 2012) thus our TURN method aimed to combine these measures. The change in angle during CoD (Δ CoD Angle) was calculated as the difference between the orientation of the velocity vector of the CoM in the horizontal (x-y) plane at initial contact and toe-off. Ground contact time (GCT) was also extracted from each trial and the rate of change in CoM angle was calculated as:

$$\frac{\Delta\ CoD\ Angle}{GCT}$$

The mean of the three trials to each side were calculated and the limb side which attained the largest value was classed as the dominant.

Asymmetry calculations

Asymmetries were calculated for both whole body and joint level mechanical variables. In order to calculate whole body mechanical variables, ground reaction force (GRF) data were rotated to align with the body's local co-ordinate system using a rotation matrix (Havens and Sigward 2015). The CoM was used as the origin of the body's local co-ordinate system. Medio-lateral and anterior-posterior impulses were calculated as the integration of the newly rotated medio-lateral and anterior-posterior GRF data. Braking impulse was determined as negative anterior-posterior impulse and propulsion as positive anterior-posterior impulse. Peak vertical ground reaction force during stance phase was also extracted. Lower extremity kinematics at the hip, knee and ankle, as well as knee joint moments were extracted during stance phase for each trial and time normalised to 101 data points.

Inter-limb asymmetries in whole body mechanical variables and lower-extremity kinematics and kinetics were calculated six times, on each occasion using dominance as classified by one of the six methods (KICK, JUMP, HOP, LAND, ISO and TURN). Directional asymmetries were calculated as:

$$Non\text{-}dominant - Dominant$$

Absolute asymmetries were also calculated as:

$$\sqrt{(Right - Left)^2}$$

For joint level kinematic and kinetics, inter-limb asymmetries were calculated at 20% of stance as this phase is commonly reported in ACL and CoD literature (Dempsey et al. 2007; Stearns and Pollard 2013) (Fig 1). One-sampled t-tests were performed on directional inter-limb asymmetries calculated using each method against a value of 0. The relationship between dominance as classified by each method was assessed using Chi-square tests for independence.

**** Figure 1 here ****

Results

The percentage of participants who were classified as right and left leg dominant under each method is presented in Table 1. No statistically significant inter-limb asymmetries were identified in whole body mechanics using the KICK, HOP, ISO and TURN methods. The LAND method identified significant differences in peak vertical GRF ($p = 0.03$, $d = 0.3$) (Fig 2), which corresponded to 39.3% of the magnitude of the corresponding mean absolute asymmetries. The JUMP method identified significant inter-limb asymmetries in medio-lateral impulse ($p = 0.03$, $d = 0.31$) (Fig 2), hip flexion angle ($p = 0.04$, $d = 0.3$) and knee abduction moment ($p = 0.01$, $d = 0.29$) (Fig 3). These asymmetries corresponded to 38.7%, 33.5 % and 42.6 % of the respective mean absolute symmetries. Lastly, using the HOP method, significant inter-limb asymmetries were identified in knee flexor moment ($p = 0.04$, $d = 0.25$), which corresponded to 35.4 % the corresponding mean absolute asymmetry.

**** Table 1 here ****

**** Figure 2 here ****

**** Figure 3 here ****

Chi-square tests for independence did not identify relationships between any of the methods used to classify limb dominance (Table 2).

**** Table 2 here ****

Discussion

None of the six methods used to classify limb dominance in this study provided a useful means of distinguishing between limbs and quantifying directional asymmetries during CoD. No variable indicated a significant inter-limb asymmetry using the KICK, ISO or TURN methods. While some significant inter-limb asymmetries were identified in variables using the JUMP, HOP and LAND methods, these asymmetries were small relative to the respective absolute asymmetries, consisting of magnitudes between 35.4 – 42.6% of the corresponding absolute values. These findings indicate that "dominance" as classified using each method was not a major factor in the presence of asymmetry within this cohort. The results therefore failed to support our initial hypothesis that methods based on jumping/hopping and the CoD task-specific definition would be related to systematic inter-limb asymmetries.

We did not identify consistent dominant limb classification between any methods (Table 2). Despite some methods sharing common physical qualities e.g. jumping and hopping, the limb classified as the dominant varied across participants and methods. This is in agreement with findings by Huurnink et al., (2014) and Mulrey et al., (2018) who noted that limb preference and the limb that performed best did not correspond across different tasks. We expand on these findings to demonstrate that a task-specific method of classifying dominance during CoD does so in a manner that is independent of other, more commonly used methods. However, unlike previous research implementing task specific methods, we failed to identify any significant inter-limb asymmetries in kinematics and kinetics. Where previous studies have classified dominance according to the outcome of the task being studied, ball kicking and preferred kicking limb (Dörge et al. 2002), vertical jumping and single-leg countermovement jump height (Kobayashi et al., 2013), hopping and horizontal hop distance (van der Harst, Gokeler, and Hof 2007), it is not possible to form such a direct classification method for CoD. Classifying limbs solely on task outcomes such as completion time and/or ground contact time, fails to account for any side-to-side differences in the angle over which the CoM passes. Both approach velocity and angle influence CoD biomechanics and it has been shown that at higher approach speeds, individuals deviate more from the intended CoD angle (Dos Santos et al. 2018; Vanrenterghem et al. 2012). While we attempted to account for both these features in our task specific method, it is possible that they interact differently across participants and that the effect on biomechanics is non-linear, with a larger effect occurring at higher velocities and more acute CoD angles.

Our findings suggest that observations of apparent symmetry between dominant and non-dominant limbs during CoD are likely statistical artefacts as opposed to a true reflection of normative movement. In six previous studies examining inter-limb asymmetry during CoD, three failed to identify any significant inter-limb asymmetries between dominant and non-dominant limbs in kinematics or kinetics (Bencke et al., 2013; Brown et al., 2014; Greska et al., 2017)**,** while three failed to identity significant differences in the vast majority of variables studied (87.9 – 95% of variables) (Marshall et al., 2015; Mok et al., 2018; Pollard et al., 2018). The self-preferred kicking limb was used to classify limb dominance in five of these studies (Bencke et al., 2013; Brown et al., 2014; Marshall et al., 2015; Mok et al., 2018; Pollard et al., 2020). We have shown that the preferred kicking limb is not related to directional asymmetries during CoD and that its use as a means of distinguishing between limbs in this setting is akin to assigning a randomly-selected limb as the dominant. For example, we identified mean absolute asymmetries of 5.3° ± 4.8° in knee flexion angle. This is comparable in magnitude to normative absolute asymmetries reported by King et al. (2019) during a similar CoD task and larger than the magnitude of asymmetry considered clinically relevant between the operated and non-operated limb following ACL-reconstruction, indicating that there are relatively large inter-limb asymmetries present in knee flexion angle in non-injured individuals during CoD. However, using the KICK method to classify limbs, we identified mean inter-limb asymmetries of 0.08° in knee flexion angle, corresponding to just 1.5% of the absolute asymmetry magnitude and suggesting that there was near perfect symmetry between limbs in the cohort. The inconsistency between absolute and directional asymmetries demonstrates that, although individuals completed the CoD with relatively large absolute asymmetries in, for instance, knee flexion angle, the direction of these asymmetries was not captured by the KICK, or indeed any, dominance definition. This was true for the vast majority of variables analysed in this study (Fig 2 and 3).

Directional symmetries in normative cohorts are regularly compared to those in injured cohorts across various movement tasks (Gardinier et al., 2014; Gokeler et al., 2010; Kuenze et al., 2015; Paterno et al., 2007; Xergia et al., 2013). These comparisons have been used to contextualise the magnitude of asymmetry in injured cohorts and set rehabilitation targets with respect to their restoration. We have shown that if the method used to define limb dominance does not relate to directional asymmetries in the task studied, conducting such comparisons runs the risk of falsely assuming symmetry within normative cohorts, overinterpreting the magnitude of asymmetry in injured cohorts and setting unattainable targets for injured individuals with respect to restoring asymmetry to normative levels during rehabilitation. King et al. (2019) and O'Malley et al., (2018) raised this issue previously, choosing instead to compare absolute asymmetries due to the inability to make standardised comparisons between groups. The findings of this study further highlight the challenges in making such comparisons and demonstrate the importance giving proper consideration to the method used to classify limb dominance when quantifying directional asymmetries in normative cohorts.

In conclusion, quantification of directional asymmetries in normative cohorts during CoD and, in particular, comparison to injured cohorts should be done with caution until an appropriate method for classifying limb dominance in non-injured individuals is established. These findings relate to CoD and further research is required to determine if it is also true for other movement tasks such as jumping and landing. Until a suitable classification for limb dominance can be determined, we recommend reporting absolute asymmetries as an alternative to directional asymmetries. If directional asymmetries are reported, they should be done in conjunction with the corresponding absolute asymmetries, allowing readers to interpret directional asymmetries with an understanding of the level of asymmetry within the group and assess the probability that they accurately reflect normative movement.

Perspectives

Until this point, the relationship between the method used to classify limb dominance and directional asymmetries during specific tasks has not been investigated. Our findings demonstrate that classifying limb dominance using a method that does not relate to directional asymmetries during the task studied can result in incorrect conclusions with respect to the magnitude of asymmetry present within a group. Previous research has not given proper consideration to how limb dominance is classified, instead defaulting between commonly used methods without clear justification for their use. Such research has formed the basis for recommendations in clinical/performance settings whereby individuals are expected to restore between limb asymmetries to normative levels, typically defined as less than a 10% difference between limbs, in order to minimise injury risk and maximise performance. These may be unattainable or unrealistic targets to set depending on the variable and population being studied. These findings are of interest to both clinical practitioners who monitor patient asymmetry during rehabilitation and performance coaches who quantify asymmetry when profiling athletes, as they highlight the importance of considering limb dominance in such settings and present a means of determining the appropriateness of a specific method to classify dominance, i.e. the comparison between directional and absolute asymmetry magnitudes.

Data Availability Statement

Research data are not shared.

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Table 1.

	KICK	JUMP	HOP	LAND	ISO	TURN
Right	68%	38%	58%	52%	62%	62%
Left	32%	62%	42%	48%	38%	38%

Table 2.

		JUMP	
		Left	Right
KICK	Left	8	8
	Right	23	11

$X^2 = 0.79$, $p = 0.38$

		HOP	
		Left	Right
KICK	Left	5	11
	Right	16	18

$X^2 = 0.56$, $p = 0.45$

		LAND	
		Left	Right
KICK	Left	4	12
	Right	20	14

$X^2 = 3.72$, $p = 0.05$

		ISO	
		Left	Right
KICK	Left	8	8
	Right	11	23

$X^2 = 0.79$, $p = 0.38$

		ISO	
		Left	Right
KICK	Left	7	9
	Right	12	22

$X^2 = 0.07$, $p = 0.79$

		HOP	
		Left	Right
JUMP	Left	15	16
	Right	6	13

$X^2 = 0.76$, $p = 0.38$

		ISO	
		Left	Right
JUMP	Left	13	18
	Right	6	13

$X^2 = 0.19$, $p = 0.67$

		ISO	
		Left	Right
JUMP	Left	13	18
	Right	6	13

$X^2 = 0.19$, $p = 0.67$

		TURN	
		Left	Right
JUMP	Left	14	17
	Right	5	14

$X^2 = 1.07$, $p = 0.3$

		LAND	
		Left	Right
HOP	Left	12	9
	Right	12	17

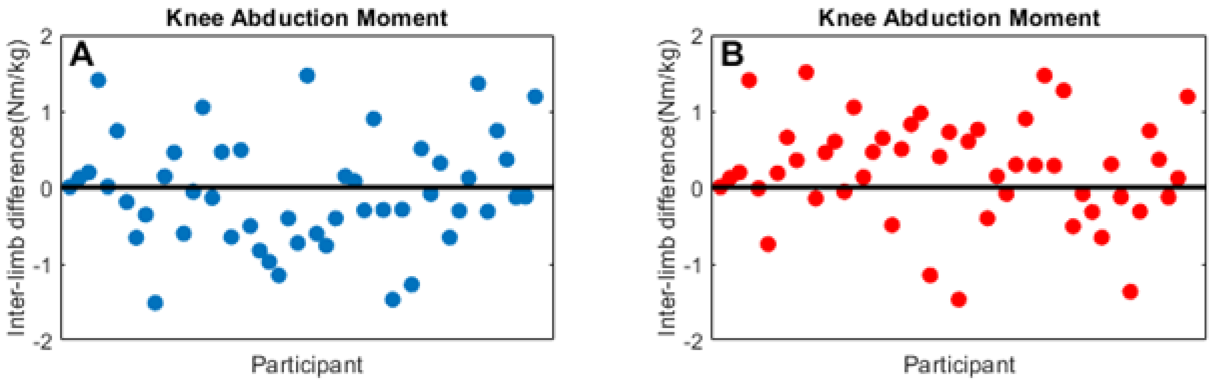
$X^2 = 0.66$, $p = 0.42$

		ISO	
		Left	Right
HOP	Left	6	15
	Right	13	16

$X^2 = 0.76$, $p = 0.38$

		TURN	
		Left	Right
HOP	Left	8	13
	Right	11	18

$X^2 = 0.08$, $p = 0.78$



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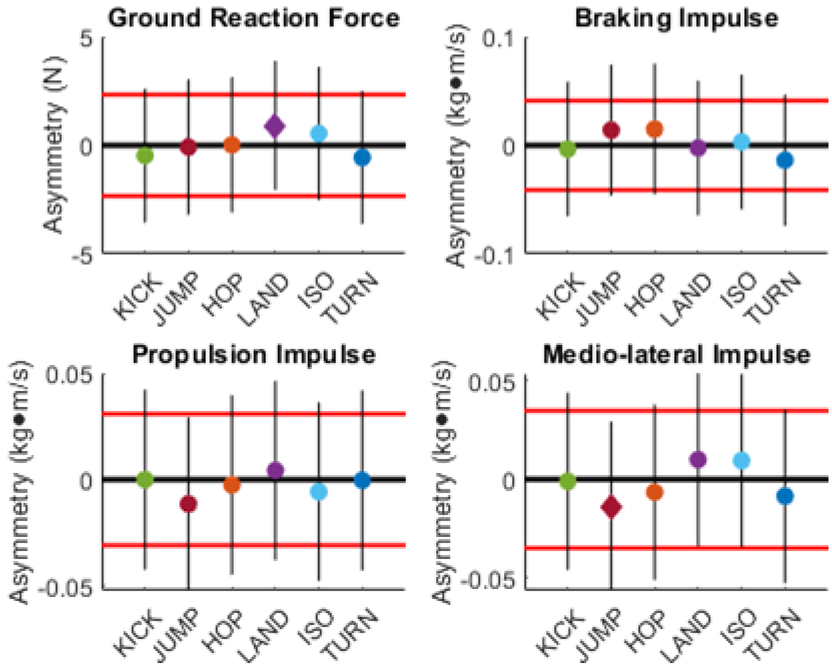

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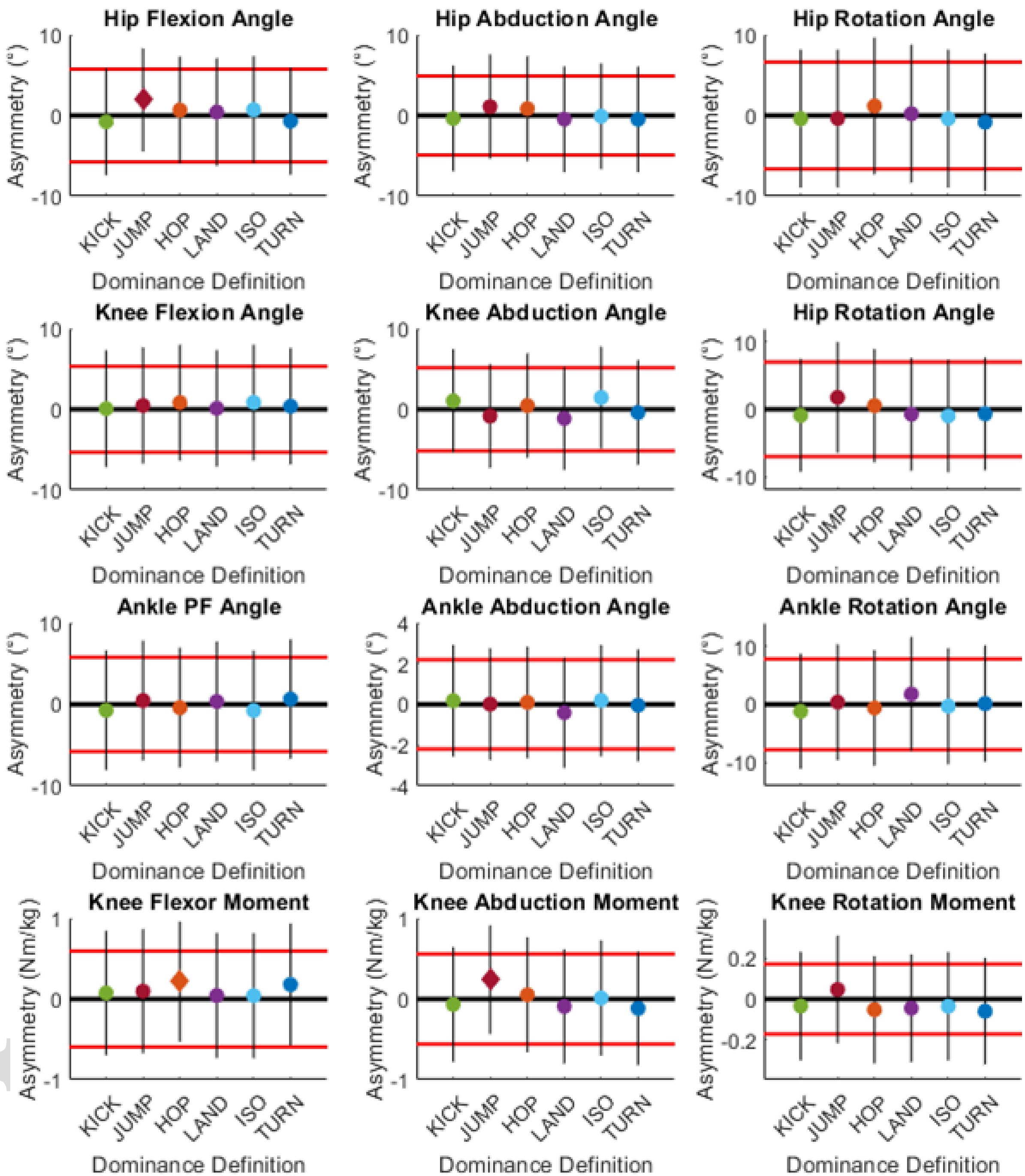

sms_14054_f3.png