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Research article

Is There a Sex Difference in Trunk Neuromuscular Control among Recreational Athletes during Cutting Maneuvers?

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Abstract
Trunk motion is most likely to influence knee joint injury risk, but little is known about sex-related differences in trunk neuromuscular control during changes of direction. The purpose of the present study was to test whether differences in trunk control between males and females during changes of direction exist. Twelve female and 12 male recreational athletes (with at least 10 years of experience in team sport) performed unanticipated changes of direction with 30° and 60° cut angles, while 3D trunk and leg kinematics, ground reaction forces and trunk muscles electromyography were recorded. Trunk kinematics at the time of peak knee abduction moment and directed co-contraction ratios for trunk muscles during the pre-activation and weight acceptance phases were determined. None of the trunk kinematics and co-contraction ratio variables, nor peak knee abduction moment differed between sexes. Compared to the 30° cut, trunk lateral flexion remained unchanged and trunk external rotation was reduced ($p < 0.001$; η^2_p (partial eta squared for effect size) = 0.78), while peak knee abduction moment was increased ($p < 0.001$; $\eta^2_p = 0.84$) at 60°. The sharper cutting angle induced muscle co-contraction during the pre-activation directed less towards trunk flexors ($p < 0.01$; $\eta^2_p = 0.27$) but more towards trunk medial flexors and rotators opposite to the movement direction ($p < 0.001$; $\eta^2_p > 0.46$). However, muscle co-contraction during the weight acceptance phase remained comparable between 30° and 60°. The lack of sex-related differences in trunk control does not explain knee joint injury risk discrepancies between sexes during changes of direction. Trunk neuromuscular strategies during sharper cutting angles revealed the importance of external oblique muscles to maintain trunk lateral flexion at the expense of trunk rotation. This provides new information for trunk strength training purposes for athletes performing changes of direction.

Key words: Core stability, trunk lateral flexion, knee abduction moment, anterior cruciate ligament, co-contraction.

Introduction

Lateral movements with changes of direction are common in many team sports. During cutting maneuvers, for instance, an athlete performs a complex dynamic task to execute a change of movement direction while controlling their balance. At the same time, these types of movements challenge knee joint stability and are associated with increased loadings at the anterior cruciate ligament (ACL) (Alentorn-Geli et al., 2009; Olsen et al., 2004). Since female athletes have a higher risk of injuring their ACL than male athletes (Agel et al., 2005; Arendt et al., 1999), many studies have investigated the influence of sex on different biomechanical determinants of ACL injury during cutting maneuvers.

External knee abduction moment, as a predictive variable for ACL injury risk (Hewett et al., 2005), has frequently been investigated during a change of direction to understand differences in the knee injury rate between males and females (McLean et al., 2005; Pollard et al., 2004; Sigward and Powers, 2006; Sigward et al., 2012; Thomas et al., 2020; Weir et al., 2019). While not consistent across all studies, female athletes have been found to exhibit greater external knee abduction moments (McLean et al., 2005; Sigward and Powers, 2006; Sigward et al., 2012; Thomas et al., 2020). Moreover, other differences in lower extremity kinematics, kinetics and neuromuscular control have been reported between male and female athletes (Benjaminse et al., 2011). However, few and inconsistent knowledge exists about sex-related differences in trunk control during cutting maneuvers, although trunk motion is very likely to influence knee joint loading (Hewett et al., 2009; Hughes, 2014; Jamison et al., 2012; Wyatt et al., 2019).

Greater lateral trunk motion has been reported during anterior cruciate ligament injury situations, i.e. changes of direction, in female athletes than in their male counterparts, whereas trunk forward flexion was not significantly different between the sexes (Hewett et al., 2009). Different results were found during an anticipated 180° change of direction, where males demonstrated greater trunk forward flexion and lateral flexion than females (Nagano et al., 2011). When the change of direction was executed in the frontal plane (lateral reactive jump), trunk forward flexion and lateral flexion were not influenced by sex (Weltin et al., 2015; Weltin et al., 2016), but females rotated their trunk more towards the rebound direction than males (Weltin et al., 2016). Thus, sex-related discrepancies in trunk motion during cutting maneuvers are not well understood and need further research to tease out whether these differences could at least in part explain the higher knee injury risk in female than in male athletes.

Moreover, this closer look at trunk control would require an analysis of neuromuscular parameters to better define muscle activation strategies behind trunk motion. Recent studies have provided information about trunk muscle neuromuscular control during cutting maneuvers (Jamison et al., 2013; Oliveira et al., 2013a; Oliveira et al., 2013b) or during an isolated trunk perturbation paradigm (Vera-Garcia et al., 2007) and during a squat task (Linde et al., 2018). Interestingly, some authors used trunk muscle contraction ratios beside the mean activation amplitude to provide a functional explanation for trunk motion (Jamison et al., 2013; Vera-Garcia et al., 2007). Accordingly,

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analyzing sex-related trunk neuromuscular strategies using co-contraction ratios could help in better understanding possible differences in trunk control between males and females.

Among the different parameters influencing the execution of a change of direction, the cutting angle has been demonstrated to influence lower limb biomechanics (Dos'Santos et al., 2018). Specifically, a sharper change of direction increased knee joint abduction moments during unanticipated (Cortes et al., 2011; Sigward et al., 2015) and anticipated cuttings (Schreurs et al., 2017). It is worth noting here that the latter authors also underlined that sex-related differences in knee joint moments were influenced by the cutting angle. Accordingly, sex-related trunk neuromuscular strategies during cutting maneuvers might be better understood if the analysis took cutting angle into account.

The purpose of the present study was to evaluate differences in trunk control between males and females during unanticipated cutting maneuvers performed at different cutting angles. We tested the hypotheses that i) female athletes would perform cutting maneuvers with a trunk showing higher flexion, lateral flexion and rotation opposite to the new movement direction than males, and ii) female athletes would accordingly demonstrate a different trunk muscle activation strategy than males, in favor of trunk flexors, lateral flexors and trunk rotators towards the opposite to the new movement direction.

Methods

Participants

Using data from the literature evaluating sex differences in knee joint loading during cutting maneuvers (McLean et al., 2005; Sigward and Powers, 2006), the sample size was estimated to achieve 80% statistical power with an alpha level of 0.05. Accordingly, 12 recreational male athletes (age: 24.2 ± 2.5 years; height: 1.80 ± 0.06 m; mass: 74.1 ± 8 kg) and 12 recreational female athletes (age: 21.6 ± 1.4 years; height: 1.67 ± 0.05 m; mass: 59.3 ± 7.3 kg) participated in the study. All participants had at least 10 years of experience in their respective team sport (e.g. handball, football, basketball), trained over three times a week and played at least at the regional level. Moreover, they did not have a previous history of serious knee injury (fractures around the knee, ligament or meniscus tears) or any current knee pain. Prior to testing, all participants were informed about possible risks and gave written informed consent. Moreover, the study was approved by the local ethics committee (approval 46/12) and conformed to the requirements stipulated in the Declaration of Helsinki.

Procedures

Measurements were conduct in December, i.e. during the first half of the season. Participants were asked to perform three different cutting tasks on a force plate in a randomized order, including a cutting maneuver to 30°, another to 60° and a crossover to -20° with an approach running speed of 4 ± 0.2 $m.s^{-1}$ (Vanrenterghem et al., 2012). Movement direction was indicated by a light signal occurring 460 ms before the right foot contacted the force plate.

Each of the three lights was placed at head height, in the new movement direction. Cutting maneuvers of 30° and 60° were further analyzed due to the relevance of this task when investigating knee joint loading during lateral movements. These two modalities should place participants at a different level of constraint, as a 60° cutting maneuver would require higher braking prior to push-off than the 30° cut, but without involving significantly the penultimate foot contact in the braking strategy (Dos'Santos et al., 2018). Thirty-six randomized trials were carried out (12 in each direction) with a one-minute rest between trials. A trial was defined as successful if the approach speed was reached, the right foot hit the force plate and the change of direction was conducted towards the light stimulus already one step after the force plate while keeping the approach speed. Additionally, participants performed a running trial at 4 $m.s^{-1}$ used as a reference task to normalize electromyography recordings. The different movements were performed while wearing a neutral sport shoe without any specific technology or damping material (Adidas Samba).

The approach running speed was measured over the last 3 m before the force plate (Timer S3, Alge-Timing, Palling, Germany). The visual light stimulus was triggered automatically via a light switch (M18 series, Panasonic Electric Works Europe AG, Holzkirchen, Germany) during the approach run. The three lights were placed at eye level in the directions of the three tasks, 7 m away from the force plate (BP600900, AMTI, Watertown, USA).

Three-dimensional trunk and leg kinematics were recorded using reflective skin markers (∅ 14 mm) attached with self-adhesive tape on anatomical landmarks of the participants' trunk, pelvis and both right and left legs. Specifically, markers were placed on the sternum and the xiphoid process, the T6 vertebra, the anterior superior iliac spine, the posterior superior iliac spine, the lateral side of the thigh, the medial and lateral epicondyle of the knee, the tibia (two markers), the medial and lateral malleolus, and on the foot (6 markers). Markers were captured with a 12-camera motion analysis system (Vicon V-MX, VICON Motion Systems Ltd., Oxford, UK) with a sampling frequency of 200 Hz. Joint kinematics in three rotational degrees of freedom were determined using a YXZ Euler rotation sequence of the respective segment coordinate system. This marker placement and kinematic modelling were used, for instance, in a previously published article (Weltin et al., 2015).

Surface electromyography recordings (EMG) of trunk muscles were obtained from the rectus abdominis (RAB), the external oblique (EOB) and the erector spinae (ESP) of the right and left sides. After skin preparation to obtain impedance below 5 kΩ (shaving of hair, skin abrasion and alcohol application to cleanse skin), a pair of self-adhesive wet gel Ag/AgCl 30 x 22 mm electrodes (Ambu BlueSensor N, Ambu, Bad Nauheim, Germany) were attached to the skin with an inter-electrode distance of 20 mm. The electrodes were placed longitudinally above each muscle belly with respect to tendon and fiber direction, following the SENIAM guidelines for sensor locations (Hermens et al., 2000). EMG data were recorded with a wireless EMG system (myon RFTD-E08, myon AG, Baar, Switzerland) at 1000 Hz via the Vicon recording system

(12-bit resolution, 5–500 Hz bandwidth).

Data analysis

Marker trajectory and ground reaction force signals were both filtered with a low-pass Butterworth filter (4^{th} order, 15 Hz cut-off frequency) prior to calculating external joint moments with an inverse dynamics approach. Kinematic data of the trunk segment were defined relative to the global coordinate system. Kinematics and kinetics of the knee joint were further analyzed to determine the effects on knee joint loading. For further analysis, these variables were extracted at the time of peak knee abduction moment (PKAM), as this parameter is associated with knee injury (Hewett et al., 2005).

All EMG data were band-pass filtered (10 Hz–500 Hz) using a fourth-order Butterworth filter. Root mean square (RMS) values were determined during the pre-activation (PRE) phase (100 ms prior to the initial contact with the force plate) and during the weight acceptance (WA) phase (30 ms after initial contact). The activation of the different muscles was then normalized to their peak filtered value recorded during the running trial at 4 $m.s^{-1}$ (Donnelly et al., 2015). To assess information on the simultaneous activation of agonist and antagonist muscles, directed co-contraction ratios (DCCR) were computed (Donnelly et al., 2015; Weir et al., 2019). For that purpose, trunk muscle functional anatomies with respect to trunk motion were determined as shown in Table 1. Using this assessment, DCCR values above 0 would indicate co-contraction directed toward muscles yielding trunk flexion, medial flexion and axial rotation to the left, while a zero DCCR value would indicate equal activation of agonist and antagonist trunk muscle groups.

Statistical analysis

The selected parameters were averaged across ten trials for the 30° and 60° cutting maneuvers. These parameters served as the basis for the statistical analysis (Statistica 12, StatSoft, Inc., Tulsa, OK, US). All results are presented as group mean (standard deviation, SD). After having confirmed that data followed a normal distribution (Shapiro-Wilk W), homogeneity was verified by means of Levene's test. The influence of sex (male vs. female) and cutting angle (30° vs. 60°) conditions on the dependent variables was tested using a two-way analysis of variance with repeated measures. The magnitude of the changes was assessed with effect size by means of partial eta squared (η^2_p) values and were considered small (0.01 - 0.06), medium (0.06 - 0.14) and large (> 0.14) according to Cohen (1988). The level of significance was set at $p < 0.05$.

Results

At the time of PKAM, there was only a main effect of sex on the knee abduction angle. Indeed, none of the trunk kinematics variables differed between males and females (Table 2). Although knee abduction was greater for females than males ($p = 0.03$), knee flexion and rotation, as well as knee joint moments, were not influenced by the sex condition (Table 2).

Figure 1 presents the trunk muscle activation profiles during the cutting maneuver. No main effect of sex was found on trunk neuromuscular control. Indeed, none of the muscle RMS values during PRE and WA were influenced by the sex condition. DCCR values were also comparable between males and females.

Table 1. Trunk muscles functional anatomy and directed co-contraction ratios with respect to trunk kinematics.

Flexion	Extension	Medial flexion	Lateral flexion	Rotation left	Rotation right
rectus abdominis L+R external oblique L+R	erector spinae L+R	external oblique L erector spinae L	external oblique R erector spinae R	external oblique R	external oblique L
Agonists	**Antagonists**	**Agonists**	**Antagonists**	**Agonists**	**Antagonists**
DCCR trunk flexors		DCCR trunk medial flexors		DCCR trunk rotators	
If agonist mean EMG > antagonist mean EMG : DCCR = 1 – antagonist mean EMG / agonist mean EMG					
If agonist mean EMG < antagonist mean EMG : DCCR = agonist mean EMG / antagonist mean EMG – 1					

Trunk kinematics is flexion/extension, medial/lateral flexion (i.e. respectively a lean to the left or right during the cutting maneuver to the left), and rotation to the left/right (i.e. respectively towards or opposite to the new movement direction during the cutting maneuver to the left). Left (L) and right (R) rectus abdominis, external oblique and erector spinae muscles during a bilateral contraction (L+R) or a unilateral contraction (L or R) yielded different trunk motion in 3D. Accordingly, directed co-contraction ratios (DCCR) served as information for trunk control.

Table 2 Mean (SD) for trunk and knee kinematics (degrees) as well as knee joint moments ($Nm \cdot kg^{-1}$) at peak knee abduction moment for males vs. females and 30° vs. 60° cutting angles.

	Males		Females			Sex effect		Angle effect		Sex × Angle	
	30°	60°	30°	60°		p	η^2p	p	η^2p	p	η^2p
Trunk flexion (+)	7.9 (8.0)	9.8 (6.9)	8.7 (5.2)	10.4 (5.1)	†	0.78	<0.01	0.02	0.22	0.91	<0.01
Trunk lateral flexion (-)	-9.1 (4.4)	-10.7 (4.9)	-7.0 (2.5)	-7.6 (3.4)		0.09	0.12	0.09	0.12	0.42	0.03
Trunk left axial rotation (+)	-6.7 (8.4)	0.6 (8.1)	-13.5 (9.9)	-4.7 (12.1)	†	0.14	0.10	<0.001	0.78	0.43	0.03
Knee flexion (+)	28.7 (4.1)	24.8 (3.8)	29.3 (7.4)	24.7 (5.0)	†	0.89	<0.01	<0.001	0.53	0.65	0.01
Knee abduction (-)	3.4 (4.0)	2.4 (4.4)	-0.2 (3.6)	-2.0 (4.9)	*,†	0.03	0.20	0.001	0.38	0.26	0.06
Knee ext. rotation (+)	2.8 (6.1)	6.4 (7.9)	2.4 (5.3)	1.5 (7.0)	‡	0.32	0.05	0.06	0.16	0.004	0.33
Knee flexion moment (+)	-0.09 (0.83)	0.24 (0.74)	0.32 (0.57)	0.62 (0.66)	†	0.17	0.09	<0.001	0.46	0.87	<0.01
Knee abduction moment (-)	-0.41 (0.28)	-1.06 (0.37)	-0.40 (0.25)	-1.03 (0.45)	†	0.87	<0.01	<0.001	0.84	0.82	0.02
Knee ext. rotation moment (+)	0.00 (0.09)	-0.09 (0.10)	0.00 (0.07)	-0.12 (0.08)	†	0.58	0.01	<0.001	0.78	0.26	0.06

Main and interaction effects are reported using p values (p) and effect size (η^2p). * expresses a significant difference between males and females (main effect of sex) † expresses a significant difference between 30° and 60° (main effect of cutting angle) ‡ expresses a significant sex × cutting angle interaction.

Table 3. Mean (SD) for trunk muscles directed co-contraction ratios for males vs. females and 30° vs. 60° cutting angles.

	Males		Females			Sex effect		Angle effect		Sex × Angle	
	30°	60°	30°	60°		p	η²p	p	η²p	p	η²p
Trunk flexors PRE	0.40 (0.38)	0.32 (0.25)	0.56 (0.21)	0.41 (0.27)	†	0.26	0.06	<0.01	0.27	0.39	0.04
Trunk flexors WA	0.25 (0.33)	0.28 (0.25)	0.19 (0.27)	0.20 (0.31)		0.51	0.02	0.65	0.01	0.78	<0.01
Trunk medial flexors PRE	0.00 (0.43)	0.36 (0.39)	0.05 (0.40)	0.29 (0.34)	†	0.92	<0.01	<0.001	0.49	0.42	0.03
Trunk medial flexors WA	0.56 (0.21)	0.49 (0.26)	0.33 (0.34)	0.44 (0.29)	‡	0.21	0.07	0.64	0.01	0.04	0.18
Trunk left rotators PRE	-0.03 (0.46)	-0.38 (0.41)	-0.05 (0.44)	-0.32 (0.42)	†	0.88	<0.01	<0.001	0.46	0.54	0.02
Trunk left rotators WA	-0.47 (0.25)	-0.46 (0.31)	-0.25 (0.51)	-0.45 (0.34)		0.43	0.03	0.07	0.15	0.06	0.16

PRE and WA represent the pre-activation and weight acceptance phases, respectively. Main and interaction effects are reported using p values (p) and effect size (η²p). † expresses a significant difference between 30° and 60° (main effect of cutting angle). ‡ expresses a significant sex × cutting angle interaction. No main effect of sex was reported

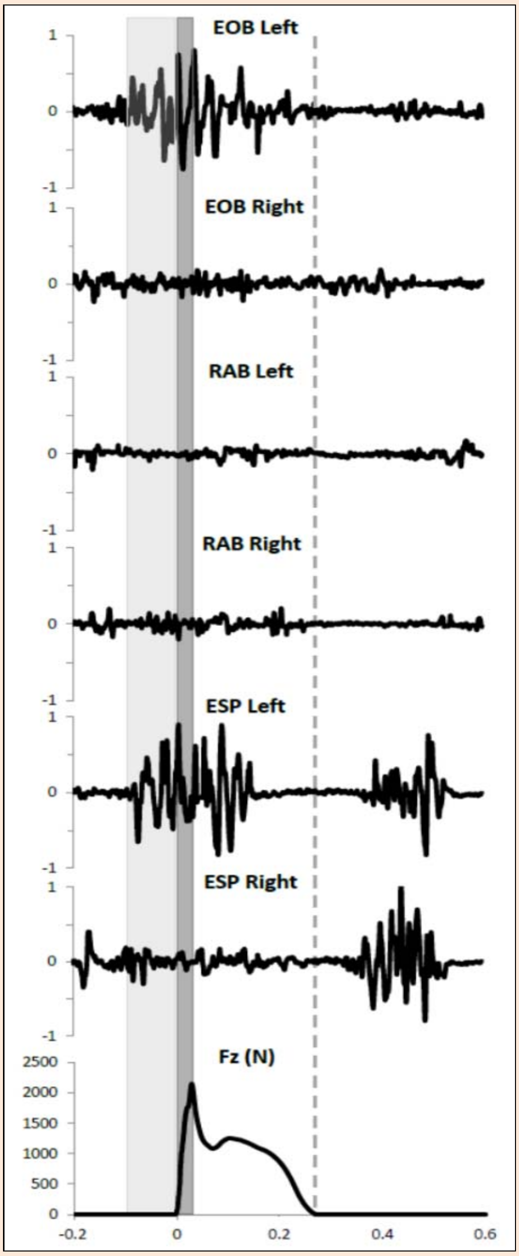

Figure 1. Typical trunk muscles activation profiles during a cutting maneuver for a representative participant at 60°. Raw EMG signals (mV) for *external oblique* (EOB), *rectus abdominis* (RAB) and *erector spinae* (ESP) left and right muscles are depicted from 0.2s prior to contact until 0.6s after initial contact. The first shaded area represents the pre-activity prior to the initial contact, the second shaded area depicts the weight acceptance phase and the vertical dashed line marks the end of the contact phase during the cutting maneuver.

A main effect of cutting angle on most of the trunk and knee kinematics and knee joint moment variables was found. Compared to the 30° cutting maneuver, the 60° cut increased trunk flexion ($p = 0.03$) and reduced trunk rotation to the opposite direction ($p < 0.001$), while trunk lateral flexion was not significantly different ($p = 0.1$) at the time of PKAM (Table 2). Knee kinematics and kinetics were influenced by the cutting angle (Table 2). Knee joint flexion was reduced ($p < 0.001$) and knee joint was more abducted ($p = 0.001$) during the 60° cutting maneuver. Moreover, knee joint flexion, abduction and internal rotation moments were significantly greater for 60° than 30° ($p < 0.001$).

A main effect of cutting angle was also reported for most of the neuromuscular parameters. Indeed, compared to 30°, left and right erector spinae demonstrated higher RMS values during PRE (+79% and +27%, respectively; $p < 0.02$) and WA (+19% and +39%, respectively; $p < 0.02$) for 60°. The left rectus abdominis enhanced its neuromuscular activity during PRE and WA for the sharper cutting angle (+26% and +32%, respectively; $p < 0.02$), while the right rectus abdominis was only more activated during the weight acceptance phase at 60° compared to 30° (+15%; $p = 0.02$). Left external oblique RMS values were significantly higher for 60° than 30° during PRE and WA (+62% and +36%, respectively; $p < 0.001$), but no difference was found for the right external oblique. Table 3 summarizes the different DDCR variables during the cutting maneuver.

Less muscle co-contraction directed towards trunk flexors was observed at 60° than at 30° during pre-activation ($p = 0.01$), while the cutting condition did not influence DCCR for trunk flexors during WA. The 60° cut yielded significantly greater DCCR values for trunk medial flexors than the 30° cut during the pre-activation ($p < 0.001$). It is worth noting that DCCR for trunk medial flexors during WA at 30° were close to 0, indicating almost equal activation of trunk medial flexors (left EOB and ESP) and their antagonists (right EOB and ESP). Finally, DCCR for trunk rotators showed an increased co-contraction towards the antagonist muscle at 60° with respect to 30° ($p < 0.001$) during pre-activation, i.e. towards the right side (EOB left). As for trunk flexor and medial flexor DCCR values, the cutting condition did not influence muscle co-contraction involved in trunk rotation during WA.

There was a sex × cutting angle interaction effect for knee joint external rotation at PKAM ($p = 0.004$; Table 2) and medial flexor DDCR during WA ($p = 0.04$; Table 3). Indeed, compared to 30°, medial flexor DCCR towards left-side muscles decreased for males (from 0.56 to 0.49) but increased for females (from 0.33 to 0.44) at 60°.

Discussion

The present study aimed to compare trunk control during unanticipated cutting maneuvers performed at different cutting angles between males and females. Contrary to our hypothesis, female athletes performed cutting maneuvers with comparable trunk kinematics to male athletes. Accordingly, female athletes demonstrated a trunk muscle activation strategy quite similar to males. Finally, the sharper cutting angle led to greater knee joint loading and altered trunk neuromuscular control for both sexes.

No influence of sex on trunk kinematics during cutting maneuvers has been found. Although differences in trunk kinematics between males and females have been described in the literature during cutting (Nagano et al., 2011), lateral reactive jump (Weltin et al., 2016) or single-leg landing (Lessi et al., 2017) tasks, these results were obtained during measurement paradigms using anticipated movements (Nagano et al., 2011; Lessi et al., 2017), mainly executed in one plane, i.e. frontal (Weltin et al., 2016) or sagittal (Lessi et al., 2017). So even if some isolated sex-related discrepancies in trunk motion could appear in some situations, the present results suggest that trunk motion during a typical change of direction, i.e. a complex, dynamic and unanticipated whole-body task, is not influenced by sex per se. In addition, knee biomechanics was not influenced by sex, except for knee abduction angle, which was significantly higher for females than males and could be evidence of a higher risk of knee injury (McLean et al., 2005; Sigward et al., 2015). A comparable knee joint abduction moment between males and females is in line with Pollard et al. (2004) or Weir et al. (2019) but not with other studies (McLean et al., 2005; Sigward and Powers, 2006; Sigward et al., 2015; Thomas et al., 2020). But the different cutting angles or approach velocities and especially the anticipated versus unanticipated change of direction paradigms would explain the variability in these knee joint kinetic and kinematic results among all these studies (Benjaminse et al., 2011).

According to the lack of trunk kinematics differences above, no influence of sex on trunk neuromuscular control during cutting maneuvers has been found. The trunk muscle activation strategy during unanticipated cuttings yielded co-contractions directed toward trunk forward and medial flexors, as well as rotators to the right (trunk rotators DCCR < 0). Given the trunk kinematics observed, co-contraction strategies seem to support the trunk flexion and rotation to the right. The trunk lateral flexion would indicate that left external oblique and erector spinae muscles worked eccentrically to limit the trunk lateral lean during the cutting maneuver. The lack of sex-related difference in trunk kinematics and neuromuscular control reveals comparable coupling between the trunk and the lower limb for males and females during cutting maneuvers. Increasing the task demand by modulating the cutting angle did not help much to tease out possible differences between sexes, as only the knee joint rotation angle and co-contraction ratio for medial flexors during the weight acceptance presented interaction effects. However, sex-related differences in knee joint rotation angle variation between 30° and 60° might be difficult to be related to knee injury risk (Alentorn-Geli et al., 2009). But it is worth noting that female athletes presented a different trunk neuromuscular control in the frontal plane. Indeed, they kept increasing medial flexor co-contraction towards the new movement direction over the weight acceptance after the pre-activation, for 60° compared to 30° COD. On the contrary, male athletes rather reduced medial flexor co-contraction towards the new movement direction during the weight acceptance. Therefore, females seem more concerned about controlling trunk lateral flexion over a longer period of time when the cutting angle becomes sharper.

Nevertheless, increasing the task demand with sharper cutting to 60° compared to 30° provided further information about trunk neuromuscular control during cutting maneuvers with possible evidence for ACL injury prevention programs. Indeed, the sharper cutting angle induced lower knee flexion and adduction and larger knee joint moments, especially in the frontal plane, which is in line with previous results (Dos'Santos et al., 2018; Schreurs et al., 2017). Thus sharper cutting angles yielded knee joint biomechanics associated with higher joint injury risk (Alentorn-Geli et al., 2009). Trunk kinematics and neuromuscular control were influenced by the cutting angle. More specifically, directed co-contraction ratios were only altered during the pre-activation phase, which underlines the importance of the preparatory phase during cutting maneuvers (Dos'Santos et al., 2019; Mornieux et al., 2014; Staynor et al., 2020). Although trunk flexion increased at the sharper cutting angle, the reduced co-contraction prior to foot contact for trunk flexors during 60° compared to 30° COD might indicate that participants tried to avoid leaning forward too much. Limiting trunk flexion might be relevant in order to re-orient the trunk and the whole-body towards the new movement direction, and avoiding a more erect trunk position is certainly meaningful in preventing increased quadriceps muscle activity (Blackburn and Padua, 2009) and consequently the stress on the ACL (Kulas et al., 2012). During the pre-activation, the trunk medial flexor co-contraction ratio increased for 60° COD, while trunk lateral flexion remained at the same level whatever the cutting angle. This could be seen as a strategy i) to prevent further trunk lateral flexion, known to influence knee joint loading (Jamison et al., 2012; Mornieux et al., 2014), and ii) to move the center of mass towards the new direction (Patla et al., 1999). Finally, trunk rotators had already increased the co-contraction towards the opposite movement direction during the pre-activation for 60° COD. This is in line with trunk kinematics that described trunk rotation away from the new movement direction, as often reported in the literature (Frank et al., 2013; Mornieux et al., 2014). Given the neuromuscular strategy described above to maintain trunk lateral flexion, partly due to higher left external oblique muscle contraction, and the lack of increase in the right external oblique muscle activation, it is not surprising that the trunk would rotate to the right. Trunk rotation to the left would have been achieved if the right external oblique muscle had contributed more than its antagonist pair. However, this would have then compromised the trunk control in the frontal plane, as higher right external oblique activation would have supported higher trunk lateral flexion. Despite increased co-contraction towards the opposite movement direction when the cutting angle got sharper, the trunk still remained slightly rotated away toward the new direction. Thus, the trunk rotator strategy based on external oblique muscles might not fully match trunk kinematics around the vertical axis as modelled in the present study through the torso segment, as rotation coming from the head and shoulders might have influenced that from the torso.

This might underline the first limitation of the present study. Indeed, the trunk kinematic model used yielded a single torso segment. The lack of a specific lumbar segment might limit the direct association between abdominal and erector spinae muscles activity and the trunk motion. Moreover, the use of surface electromyography could only partially reflect the trunk neuromuscular control related to trunk motion, as several deep muscles activity could not be assessed with the present methodology.

Conclusion

The lack of sex-related differences in trunk control in the present study does not explain knee joint injury risk discrepancies between sexes during changes of direction reported in the literature. During unanticipated changes of direction, increasing the cutting angle allowed the description of trunk neuromuscular strategies to manage the higher overall loading during sharper cutting. Trunk muscle co-contractions revealed that participants tried to avoid leaning forward too much prior to contact. In addition, maintaining trunk lateral flexion seems to be the main strategy, probably at the expense of trunk rotation, which remains negative overall. Hence, trunk neuromuscular control based on superficial muscle EMG recordings enabled, at least partially, trunk kinematics to be explained during changes of direction.

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Key points

- Trunk neuromuscular control is not different between males and females during unanticipated changes of direction.
- Sharper cutting angles increase knee joint loads and trunk neuromuscular activity during unanticipated changes of direction.
- Trunk neuromuscular strategy during sharper cutting angles is to avoid leaning forward too much prior to contact, while maintaining trunk lateral flexion at the expense of trunk rotation.
- External oblique muscles play an important role during unanticipated changes of direction.

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