The effects of core muscle activation on dynamic trunk position and knee abduction moments: Implications for ACL injury

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Abstract

Anterior cruciate ligament (ACL) injury is one of the most common serious lower-extremity injuries experienced by athletes participating in field and court sports and often occurs during a sudden change in direction or pivot. Both lateral trunk positioning during cutting and peak external knee abduction moments have been associated with ACL injury risk, though it is not known how core muscle activation influences these variables. In this study, the association between core muscle pre-activation and trunk position as well as the association between core muscle pre-activation and peak knee abduction moment during an unanticipated run-to-cut maneuver were investigated in 46 uninjured individuals. Average co-contraction indices and percent differences between muscle pairs were calculated prior to initial contact for internal obliques, external obliques, and L5 extensors using surface electromyography. Outside tilt of the trunk was defined as positive when the trunk was angled away from the cutting direction. No significant associations were found between pre-activations of core muscles and outside tilt of the trunk. Greater average co-contraction index of the L5 extensors was associated with greater peak knee abduction moment ($p = 0.0107$). Increased co-contraction of the L5 extensors before foot contact could influence peak knee abduction moment by stiffening the spine, limiting sagittal plane trunk flexion (a motion pattern previously linked to ACL injury risk) and upper body kinetic energy absorption by the core during weight acceptance.

1. Introduction

Anterior cruciate ligament (ACL) rupture is a major injury for an athlete to sustain. Athletes often lose the remainder of their season, experience pain in the knee even after surgical repair and rehabilitation which can limit future involvement in sport, and have an increased risk of developing osteoarthritis later in life (Dunn and Spindler, 2010; Lohmander et al., 2004; Ruiz et al., 2002). In addition, decreased academic performance has been reported in high school and collegiate athletes after experiencing an ACL tear (Freedman et al., 1998; Trentacosta et al., 2009). ACL rupture also poses a large financial burden with estimates of total, direct medical costs reaching into the billions (PearlDiver, 2010a, 2010b). It has been estimated that 70% of ACL injuries are non-contact in nature (Griffin et al., 2000), often resulting from pivoting or a sudden change in direction (Andersson et al., 1997; Bere et al., 2011; Boden et al., 2000, 2010; Hewett et al., 2009; Koga et al., 2010; Krosshaug et al., 2007; McNair et al., 1990; Sheehan et al., 2012). Because non-contact ACL rupture tends to be a function of an athlete’s own movements (Griffin et al., 2000), many different researchers have developed neuromuscular training programs that have been successful at reducing ACL injury rates (Emery et al., 2007; Gilchrist et al., 2008; Hewett et al., 1999; Mandelbaum et al., 2005; Myklebust et al., 2003), although it remains unclear what components of these programs contribute to risk reduction or how interventions to prevent ACL injury can be made more efficient (Shultz et al., 2012).

Core stability has become a popular topic in the literature and popular culture and is speculated to aid in injury prevention and improve athletic performance (Akuthota et al., 2008; Aminaka et al., 2011; Fredericson and Moore, 2005; Kibler et al., 2006). Hodges and Richardson (1997) have demonstrated that the abdominal muscles activate before the prime movers of the extremities which is a basis for the phrase “proximal stability for distal mobility” (Kibler et al., 2006). The premise underlying this phrase is that a more stable core, one that is better able to adapt to or anticipate changing conditions, will allow for enhanced movements of the extremities, which is speculated to both improve...
performance and reduce injury risk (Akuthota et al., 2008; Aminaka et al., 2011; Fredericson and Moore, 2005; Kibler et al., 2006). However, partially due to the lack of consistent definitions and the broad application of "core stability," confusion and contradictory findings are prevalent in the literature regarding the core and athletic performance and injury. For the purposes of this study, the core will be defined as the region of the body bounded by the pelvis and diaphragm, which includes the muscles of the abdomen and lower back. The trunk, a combination of the core and the thorax, will be defined as the region of the body bounded by the pelvis and the clavicles. Finally, core stability will be defined as "the body’s ability to maintain or resume an equilibrium position of the trunk after perturbation," a definition which was first used by Zazulak et al. (2007).

Cohort, cross-sectional, and intervention studies have produced evidence linking the core to aspects of ACL injury risk (Chaudhari et al., 2012). A three-year prospective study demonstrated that athletes with worse core stability, quantified as exhibiting more torso displacement after experiencing a releasing perturbation to the trunk, were more likely to sustain an ACL tear (Zazulak et al., 2007). Several cross-sectional studies have suggested that outside tilt (lateral trunk lean away from the direction of the cut) is associated with greater peak external knee abduction moment (pEKAbM) (Dempsey et al., 2012, 2007; Jamison et al., 2012b), which causes higher ACL strain (Fleming et al., 2001; Kanamori et al., 2002; Markolf et al., 1995; Shin et al., 2008, 2011) and was found in one prospective study to be predictive of increased ACL injury risk (Hewett et al., 2005). Further, two intervention studies suggest an association between improved control of the trunk and reduced knee loading (Dempsey et al., 2009; Jamison et al., 2012a).

While these studies suggest that trunk motion is influential in knee loading, it is unclear what role the core musculature plays in positioning the trunk during the cutting task and what effect this muscle activation has on knee loading. A better understanding of the core musculature’s influence on both trunk positioning and knee loading during cutting might lead to enhancements in current training strategies for change-of-direction tasks, improving their effectiveness at reducing ACL injury risk. Given that ACL rupture is thought to occur within the first 40 ms after the foot comes into contact with the ground (Koga et al., 2010; Shin et al., 2007), which is faster than reported core muscle voluntary activation times (Skotte et al., 2004), the preparatory, or anticipatory, activation (pre-activation) of the core muscles may be of most importance when examining the relationship between the core muscles and knee loading.

The purpose of this study was to evaluate whether pre-activation of the core musculature was associated with lateral trunk positioning and peak external knee abduction moments (pEKAbM) during an unanticipated cutting task. We hypothesized that increased asymmetry in right and left core muscle pre-activation (increased percent difference) would be associated with an increase in trunk outside tilt as well as an increase in pEKAbM, since the two have previously been associated with each other (Dempsey et al., 2012, 2009, 2007; Jamison et al., 2012b). Further, we hypothesized that a simultaneous decrease in right and left core muscle pre-activation (decreased co-contraction) would also be associated with increases in trunk outside tilt and pEKAbM.

2. Methods

2.1. Subjects

Forty-six subjects (23M, 23F; height $=1.75 \pm 0.98$ m; mass $=70.9 \pm 12.5$ kg; age $=22.9 \pm 4.2$ yrs), a convenience sample from the university and surrounding community, participated in this study after providing IRB approved consent. Subjects had no previous history of serious lower extremity injury (ligament, meniscus, tendon, or muscle tear), abdominal hernia, lower extremity surgery, or abdominal surgery. Persons with a BMI greater than 30 were excluded due to excessive soft tissue artifacts in both kinematic and electromyography data. Subjects were physically active, with a self-reported average of 3 exercise sessions per week for the 3 months immediately preceding testing. Subjects also self-reported a Tegner activity score (Tegner and Lysholm, 1985) greater than 3, indicating, at minimum, they participated in cycling, jogging on uneven ground, or other similar activities.

2.2. Unanticipated run-to-cut maneuver

Subjects performed an unanticipated run-to-cut maneuver by starting on a pressure sensitive mat, taking three steps at a self-selected running pace, and planting their dominant foot within a target area (80 cm wide x 60 cm long) defined by two force plates placed side-by-side. During the approach, one of two arrows, chosen at random, would illuminate in front of the subject to indicate if the subject should perform the side-step cut or continue to run forward (subjects were not asked to perform a cross-over cut during this study). A successful cut was one in which the subject planted his/her dominant foot within the area of the force plates and his/her new direction lay over a line drawn on the ground at a 45° angle to the approach path. The time delay between the subject leaving the starting mat and arrow illumination, as well as the distance between the starting mat and the target area, could be adjusted for each subject to account for individual stride lengths, reaction times, and approach speed. Fig. 1 shows the laboratory set-up. Four successful cutting trials were recorded and used for analysis. Unanticipated cutting was chosen to more closely mimic on-field conditions for athletes and because unanticipated cutting has been shown to produce higher knee loading than a planned cut (Beiser et al., 2001).

Two phases of the cutting maneuver were analyzed: flight (pre-contact) and weight acceptance. The flight phase was defined as the interval from the preceding foot leaving the ground to initial contact (vertical ground reaction force $>10$ N), when the athlete is in the air preparing his/her body for initial contact. This interval averaged 88.1 ± 57.1 ms in duration. All core muscle pre-activations were examined during flight phase. Weight acceptance was defined as the interval between initial contact and peak knee flexion. During weight acceptance the athlete is decelerating his/her body while also initiating a change of direction. Kinematics and kinetics were examined during weight acceptance because non-contact ACL ruptures are thought to occur during this time (Boden et al., 2000).

![Line at 45° from approach](https://via.placeholder.com/150)

![Force Plate Target](https://via.placeholder.com/150)

![Start Mat](https://via.placeholder.com/150)

**Fig. 1.** Laboratory set-up for unanticipated run-to-cut maneuver. Subjects performed the maneuver by starting on a pressure sensitive mat, taking three steps at a self-selected running pace, and planting their dominant foot within a target area (80 cm wide x 60 cm long) defined by two force plates placed side-by-side. During the approach, one of two arrows, chosen at random, would illuminate in front of the subject to indicate if the subject should perform the side-step cut or continue to run forward (subjects were not asked to perform a cross-over cut during this testing). A successful cut was one in which the subject planted his/her dominant foot within the area of the force plates and his/her new direction lay over a line drawn on the ground at a 45° angle to the approach path. The time delay between the subject leaving the starting mat and arrow illumination, as well as the distance between the starting mat and the target area, could be adjusted for each subject to account for individual stride lengths, reaction times, and approach speed. Both right and left foot plants were possible with this set-up.
2.3. Kinematic and kinetic data collection

Marker data was collected at 300 Hz using 8 Vicon MX-F40 cameras (Vicon; Oxford, UK) and filtered using a Woltring filter with generalized cross-validation (GCV) (Woltring, 1986). Ground reaction forces were sampled at 300 Hz (to match the marker data) from two Bertec 4060-10 force plates (Bertec Corp; Columbus, OH). Subjects wore standard spandex shorts during data collection, requiring some of the markers to be placed on the shorts instead of the skin. To ensure that the markers placed on the shorts were not causing a proximal translation of the thigh segment during testing, subjects performed squats, lunges, and other dynamic activity to allow the shorts to “settle” before marker placement. Marks were placed on the thighs just below the hem of the shorts to enable confirmation during testing that the shorts were not sliding upwards over time.

2.4. Peak external knee abduction moments

The point-cluster technique (Andriacchi et al., 1998) (Fig. 2) and a functional hip joint center (Camomilla et al., 2006) were implemented using custom Vicon Bodybuilder and MATLAB (MathWorks, Inc., Natick, MA) scripts to calculate kinematics and kinetics of the lower extremities during the cut. Peak external knee abduction moments (pEKAbM) were estimated during the weight acceptance phase of the cut (initial contact to peak knee flexion). Knee moments were normalized by body weight and height.

2.5. Outside tilt

The upper body Plug-In Gait marker set (Gutierrez et al., 2003) (Fig. 2) was used to calculate the peak frontal plane torso angle. Outside tilt was defined as the angle between the trunk and vertical, with positive being a trunk lean away from the cutting direction (or toward the plant foot side). Frontal plane motion was examined because lateral trunk control has been associated with ACL injury risk (Zazulak et al., 2007) and peak outside tilt has been associated with pEKAbM (Jamison et al., 2012a, 2012b). Peak outside tilt was examined during the weight acceptance phase of the cut.

2.6. Core muscle pre-activation

Trunk muscle pre-activation was quantified using a wireless surface electromyography (EMG) system (Telemyo DTS, Noraxon USA, Inc; Scottsdale, AZ) during the unanticipated cutting task. Surface electrodes (Vermied, Inc; Bellows Falls, VT) were placed bilaterally over the internal obliques (IO), external obliques (EO), and L5 extensors (L5) according to McGill et al. (1996) (Fig. 3). All electrodes were pre-gelled Ag/AgCl and were oriented parallel to muscle fibers. Electrode locations were shaved then lightly abraded and cleaned with alcohol pads. At IO and L5 muscles, two single electrode discs (A10005; 38.1 mm diameter) were used with the end opposite the pull-tab trimmed to allow a closer inter-electrode distance (30.5 mm). Dual electrodes were used for the EO muscles (A10011; 41.275 × 82.55 mm) with an inter-electrode distance of 42 mm.

Raw EMG data (recorded at 1500 Hz) from the flight phase were high-pass filtered at 10 Hz with a zero-lag 4th order Butterworth filter to remove motion artifact. Filtered EMG data were then full wave rectified and smoothed using an RMS filter with a 20 ms window. The RMS data were then normalized by the maximum voluntary isometric contraction (MVIC) for each muscle to obtain continuous EMG curves in %MVIC. MVIC trials were performed for trunk flexion, extension, and lateral bending to each side while the subject pulled isometrically, with the spine vertical, against a fixed cable attached to an upper body harness at approximately the 10th thoracic vertebra. The highest 500 ms running average after rectification and smoothing for each muscle, in any direction, was used for normalization. The average normalized pre-activation of each muscle was calculated over the flight phase for further analysis.

Quality control of EMG was accomplished by manual inspection of each muscle’s raw pre-activation EMG signals. EMG of questionable quality (inappropriate magnitude suggesting signal was affected by movement of electrodes, missing data due to loss of connection between wireless transmitters and receiver during testing, etc.) was marked as invalid and withheld from subsequent analysis. Two hundred and thirty-four of the possible 1104 (46 subjects × 6 muscles × 4 trials) core muscle pre-activations were removed.

Fig. 2. Anterior (left) and posterior (right) views of the lower body Point-Cluster marker set with the upper body Plug-In Gait marker set. EMG electrodes for external obliques and L5 extensors are shown (internal oblique electrodes hidden by shorts). Transmitters, taped down to keep them secured, are also pictured. Electrodes, wires, and transmitters for lower extremity muscles can be seen, though data from these muscles is not presented here.

Fig. 3. Electrodes, wires, and transmitters for external obliques, internal obliques and L5 extensors (internal oblique electrodes hidden by shorts). Transmitters attached to the electrodes were taped to keep them secured. Both the internal and external obliques act to laterally bend, rotate, and flex the trunk. The L5 extensors act to extend and laterally bend the trunk as well as stiffen the spine.

Eq. 2
2.7. Average percent differences and co-contraction indices

Average percent differences (avg%DIFF)

\[ \text{avg}_i^\%\text{DIFF} = \frac{1}{n_i - 1} \sum \left( \frac{\text{higher EMG}_i - \text{lower EMG}_i}{\text{lower EMG}_i} \times 100\% \right) \]

as well as average co-contraction indices (avgCCI) (Lewek et al., 2005)

\[ \text{avgCCI}_i = \frac{1}{n_i - 1} \sum \left( \frac{\text{lower EMG}_i - \text{higher EMG}_i}{\text{lower EMG}_i} \times (\text{lower EMG}_i + \text{higher EMG}_i) \right) \]

were calculated for each of the three muscle pairs (external obliques, internal obliques, and L5 extensors). In both equations, “i” indicates a single normalized pretaction EMG value, while “n” indicates the number of single normalized pretaction EMG values in the flight phase of the trial. Both the co-contraction index and percent difference evaluate the relative, simultaneous activation of antagonist muscles. For the core, muscles of the same name on opposite sides of the body will act to laterally pull the trunk in opposite directions, making them antagonists for lateral trunk flexion. Changes in avg%DIFF are an indication of when both muscles increase or decrease activation while its pair is decreasing activation, which would suggest that the subject is attempting to accelerate or decelerate lateral trunk motion. Changes in avgCCI are an indication of when both muscles increase or decrease activation together, which would suggest that the subject is attempting to modulate the overall stiffness of the spine in all directions.

2.8. Statistics

Originally, the study sample size was based on muscle activation onset timing. The standard deviation of muscle activation onset during a dynamic landing task similar to our run-to-cut maneuver is about 35 ms, as reported by Cowling et al. (2003). A priori, we estimated that a change in the muscle activation timing of 15 ms would be clinically significant. A sample size of 45 was proposed to provide at least 80% power to detect an effect size of 15/35 = 0.43 using a one-sided paired t-test at a significance level of 0.025. After data collection and examination, we determined that onset timing of the core muscles would not be feasible for our cutting task and switched to an analysis based on the level of preactivation for the core muscles.

Normalization of four linear mixed effects models were used to determine the association between dependent and independent variables. The two dependent variables, pEKAbM and trunk outside tilt angle, were evaluated separately. Two sets of independent variables were used, avg%DIFF and avgCCI, each with values for the three muscle groups used. Approach speed, cut angle, and gender were included as fixed effects covariates in all models. Subject was included in all models as a random effect so that associations within an individual could be analyzed, rather than only relationships across the entire population. All muscle pre-activation variables and pEKAbM were log transformed to meet normality assumptions of the model, except for the avg%DIFF of the L5 pair, which was observed to be normally distributed. A significance level of \( \alpha = 0.05 \) was set a priori. No correction for multiple comparisons was applied.

A fifth statistical model was developed post hoc to further examine the results of the main models. For this secondary analysis, a mixed effects model was used with the change in trunk flexion throughout the weight acceptance phase as the dependent variable and log transformed L5-avgCCI during the flight phase as the independent variable; speed, cut angle, and gender as covariates; and subject as a random effect.

3. Results

After removal of bad EMG data during quality control, 74 of the 184 collected trials from 27 of the 46 enrolled subjects (14M, 13F; height = 1.77 ± 0.10 m; mass = 70.2 ± 11.2 kg; age = 22.5 ± 2.9 yrs) had valid data for all muscles to calculate avg%DIFF and avgCCI. Average statistics and ranges for parameters used in the models are presented in Table 1. The results of the mixed effects models can be found in Table 2.

3.1. External knee abduction moment

No significant associations were found between pEKAbM and any of the three avg%DIFF (Table 2, Model #1). A significant positive association was found between pEKAbM and L5-avgCCI \( (p = 0.0107) \) (Table 2, Model #2). For both models, approach speed and cut angle were found to be significant covariates for pEKAbM, but gender was not a significant covariate for pEKAbM.

### Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Independent variable</th>
<th>Slope</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ln(Peak external knee abduction moment)</td>
<td>Ln(IO-avg%DIFF)</td>
<td>-0.074</td>
<td>0.741</td>
</tr>
<tr>
<td></td>
<td>Ln(IO-avgCCI)</td>
<td>0.060</td>
<td>0.782</td>
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<tr>
<td></td>
<td>Ln(IO-avg%DIFF)</td>
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<td>0.233</td>
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<tr>
<td></td>
<td>Ln(IO-avgCCI)</td>
<td>0.009</td>
<td>0.964</td>
</tr>
<tr>
<td></td>
<td>Ln(L5-avgCCI)</td>
<td>0.485( ^{+})</td>
<td>0.0107</td>
</tr>
<tr>
<td>Peak outside tilt</td>
<td>Ln(IO-avg%DIFF)</td>
<td>0.963</td>
<td>0.419</td>
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<tr>
<td></td>
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<td>0.947</td>
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<tr>
<td></td>
<td>Ln(IO-avg%DIFF)</td>
<td>-0.014</td>
<td>0.439</td>
</tr>
<tr>
<td>Change in forward trunk flexion</td>
<td>Ln(L5-avgCCI)</td>
<td>1.304( ^{+})</td>
<td>0.015</td>
</tr>
</tbody>
</table>

Significant associations indicated in bold and with\( ^{+}\). \( \text{Ln}(\text{variable}) \) indicates the natural log of the variable. Significant variables were log transformed to meet model assumptions for normality. A positive change in forward trunk flexion indicates an increase in trunk flexion from initial contact to peak forward trunk flexion. pEKAbM, peak external knee abduction moment; EO, external obliques; IO, internal obliques; L5, L5 extensors; avg%DIFF, average percent difference; avgCCI, average co-contraction index.

3.2. Peak outside tilt

There was no evidence for a significant association between peak outside tilt and avg%DIFF (Table 2, Model #3) or avgCCI (Table 2, Model #4) for any muscle group \( (p = 0.2918 \text{ to } 0.9471) \). Neither approach speed, cut angle, nor gender were significant covariates for peak outside tilt.

3.3. Post hoc analysis

A significant, negative association \( (\text{slope} = -1.3041, p = 0.0145) \) was found between L5-avgCCI during the flight phase and the change in trunk flexion during the weight acceptance phase of the cut (Table 2, Model #5).
4. Discussion

The results of this study did not support our hypothesis that increases in percent differences and decreases in co-contraction indices would be associated with increases in peak external knee abduction moments (pEKAbM) and outside tilt of the trunk during an unanticipated cutting task. The only significant relationship between variables of interest contradicted our hypothesis and suggests that an increase in the co-contraction index of the L5 extensors just before initial contact of an unanticipated cut is associated with an increase in pEKAbM during the weight acceptance phase, potentially increasing ACL strain (Fleming et al., 2001; Kanamori et al., 2002; Markolf et al., 1995; Shin et al., 2009, 2011) and injury risk.

The lack of evidence for significant associations between co-contraction indices or percent differences of core muscles before initial contact for cutting is likely due to the complex movement associated with cutting and the complex architecture of the trunk musculature. Core muscle activation was analyzed during the flight phase of the cut, before initial contact. During this time the subject has already received the visible signal to cut and is preparing. This preparation may involve all three planes of motion and the core muscles examined in this study influence motion in multiple planes. Both the internal and external obliques influence trunk motion in all three planes while the L5 extensors influence frontal and sagittal plane trunk motion. A more complex analysis may be necessary to fully characterize how the core muscles influence trunk positioning during the cutting task.

The significant, positive association between the co-contraction index of the L5 extensors and pEKAbM suggests that an increase in the co-contraction of the L5 extensors will lead to an increase in pEKAbM, which contradicted our hypothesis that focused on frontal plane trunk motion. This positive association between L5 co-contraction and pEKAbM may be explained by sagittal plane motion and kinetics. The significant, negative association found between L5 co-contraction during the flight phase and the change in trunk flexion during the weight acceptance phase of the cut suggests that as the co-contraction of the L5 extensors increases the spine is stiffened, reducing sagittal plane trunk motion. An increase in the stiffness of the spine during the flight phase (through increased L5 co-contraction) might persist during weight acceptance, requiring more of the upper body’s kinetic energy to be absorbed by the lower extremities. This increased energy absorption requirement for the lower extremities could result in higher knee abduction moments, increasing the risk of ACL rupture.

The results of this study should be considered in light of its limitations. Only three pairs of core muscles were considered for this study. Other core muscles may influence trunk motion during cutting and the sudden force release task, but technical challenges make quantifying their activations impractical at this time. The multifidus, quadratus lumborum, and transverse abdominis lie deep to more superficial structures and require fine-wire EMG or ultrasound to characterize their activations. The current fine-wire EMG and ultrasound techniques are not suitable for use with an activity as dynamic as cutting. While McGill et al. (1996) found that surface EMG of the superficial muscles predicted fine-wire EMG of the deeper quadratus lumborum and transverse abdominis during a variety of trunk flexion, extensor, lateral bending and twisting tasks, these muscles may diverge in their contributions during the more complex task of cutting. Additionally, the rectus abdominis was not considered because its main function is to flex the trunk forward, while lateral trunk motion was the primary focus of the current study. The significant association between co-contracted L5 extensors and pEKAbM from this study suggests that rectus abdominis activations may need to be considered when further investigating the role of trunk flexion in the mechanisms of ACL injury.

Another potential limitation was the simplicity of the analysis used to evaluate core muscle activation during an unanticipated cutting task. A simple model was chosen to facilitate both the physical interpretation of the results and relevance to clinical practice. However, both the anatomy and function of the core muscles, as well as the task, are complex in nature. The use of a simple model may have masked more complex relationships from being observed. Therefore more complex models and analyses, potentially utilizing all planes of motion and the continuous nature of the EMG data, may be necessary to fully characterize the role of the core muscles during cutting.

Lastly, subjects either performed a side-step cut or continued to run straight after approaching the force plate target area. It is possible that subjects may have attempted to anticipate which direction would light up, altering their movement from a true unanticipated maneuver. However, there were very few instances when subjects moved contrary to the arrows, giving us confidence that they were making their decision only after seeing the arrow illuminate.

5. Conclusions

This study observed a significant, positive association between the co-contraction of the L5 extensors and peak external knee abduction moments. Additionally, a significant, negative association was found between the co-contraction of the L5 extensors and frontal plane trunk motion. These results suggest that a stiffened spine and trunk may not be advantageous for protecting the knee during an unanticipated cut. The observed associations between core muscle activations and knee loading also support current clinical recommendations that focus on using the entire body to protect the knee, and ACL, during a change of direction maneuver. Future work is necessary to fully characterize how the muscles of the core influence trunk positioning and possibly loading of the knee during cutting.

Conflict of interest statement

The authors report no conflicts of interest.

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References


