Descriptive trunk kinematics in healthy collegiate women's soccer players indicate trunk center of mass is laterally positioned prior to decelerating and cutting

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ARTICLE INFO

Keywords:
Anterior cruciate ligament
Knee injury
Sports medicine research

ABSTRACT

Objectives: Trunk kinematics can contribute to lower extremity biomechanical risk factors for anterior cruciate ligament (ACL) injury. However, normative trunk kinematics during unilateral athletic tasks in a large population of “healthy” (no history of ACL injury and no known future ACL injury) women's soccer players have not been well-described. This study's purposes were to describe trunk kinematics in a population of 37 healthy collegiate women's soccer players completing a step-down, a deceleration, and a 90° cut, and to provide a reference for normative values.

Methods: A cross-sectional cohort of 37 female soccer players were analysed for this study. Trunk forward flexion and lateral flexion were measured relative to the pelvis, and trunk centre of mass position was measured relative to the proximal tibia. Trunk kinematics were characterized by individual values at key events during the tasks and time-series curves normalized to 100% of the time.

Results: Participants demonstrated increasing trunk forward flexion with increasing knee flexion angle, small amounts of increasing ipsilateral trunk flexion with increasing peak knee abduction moment, and trunk centre of mass position that moved medially during the deceleration and cut tasks. Additionally, participants demonstrated peak trunk lateral flexion angles milliseconds before peak knee flexion angle.

Conclusion: This study provides a reference for identifying aberrant trunk mechanics that may increase the risk for non-contact ACL injury.

Level of evidence: Level II.
What are the new findings

- Soccer players' trunk flexion increases with knee flexion during unilateral tasks
- Peak trunk lateral flexion occurs closer to peak knee flexion than peak knee abduction moment during a cut
- Trunk centre of mass moves medially during a pre-planned 90° cut, which may reduce knee abduction moments

Introduction

Anterior cruciate ligament (ACL) injuries are a significant problem among women's soccer players with both short- and long-term consequences such as lost playing time and a significantly higher risk of developing knee osteoarthritis [1,2]. The majority of ACL injuries among women soccer players occur without contact from another player, with poor neuromuscular control and biomechanical patterns having been identified as risk factors associated with non-contact ACL injuries [3-5]. Motion analysis has been used to identify lower extremity biomechanical risk factors for ACL injury [5,6]. Trunk kinematics may influence lower extremity biomechanical risk factors for ACL injury. However, typical trunk kinematics in female soccer players during athletic tasks have not been well described before.

Retrospective video analysis of ACL injuries has demonstrated that female athletes who incur an ACL injury are in less trunk forward flexion at the time of injury than female athletes who are performing similar tasks and do not incur an ACL injury, with 0° indicating a neutral trunk position [4]. Biomechanical analysis of ACL injuries among men's soccer players suggests that players who sustain an injury were typically at 0° of trunk flexion at the time of ACL injury [7]. Increasing trunk forward flexion during a drop jump landing may lead players to utilize more knee flexion when performing dynamic manoeuvres, which may be protective for the ACL [8]. Blackburn et al. demonstrated that study participants landed with greater hip and knee flexion when cued to actively flex their trunk. Furthermore, simulations have demonstrated that performing a step-down task with greater trunk flexion can decrease the load on the ACL [9].

Lateral trunk flexion angle during cutting tasks has been linked to peak knee abduction moment, a risk factor for non-contact ACL injury [10-13]. Lateral trunk flexion angle toward the stance foot increases peak knee abduction moment secondary to the increased moment arm between the vertical ground reaction force and the knee joint [4,12]. Since cutting is one of the most common mechanisms of non-contact ACL injury among soccer players, trunk position during this task may be an important variable to examine when evaluating ACL injury risk [14]. Trunk lateral flexion angle during a cut may affect athletic performance too [15]. Lateral flexing the trunk in the direction the athlete intends to travel toward can improve cutting speed [15]. However, what constitutes a typical amount of lateral trunk flexion while cutting and decelerating has not yet been explored in a prospective cohort of soccer players who do not go on to ACL injury.

The relationship between trunk centre of mass (COM) position relative to the knee joint may also provide insight into future ACL injury risk. Lateral foot position relative to the pelvis COM during a 90° cut has demonstrated positive correlations with peak knee abduction moment [13]. And, imposing a technique of planting the foot wide relative to the body also leads to increases in peak knee abduction moment [10]. Consequently, it can be expected that completing unilateral, athletic tasks with the knee joint lateral to the trunk COM will be correlated with knee abduction moment. However, this relationship has not been examined before.

A variety of tasks have been used to study athlete biomechanics that may increase the risk for ACL injury. Prospectively collected trunk kinematics during a step-down have not been analysed before. Trunk kinematics during a step-down task could be a clinically useful assessment of neuromuscular control and injury risk. However, this task may not provide an adequate representation of trunk control during sport-specific, dynamic tasks [16]. Cutting often occurs in conjunction with a sudden deceleration [17]. Trunk kinematics during an isolated deceleration have not been described before. Additionally, although the trunk kinematics of healthy individuals completing a variety of cutting tasks have been described before, these have been in small cohorts and have not had follow-up regarding injury status throughout the season [12,13,18]. Therefore, the purpose of this study was to describe the trunk kinematics of three progressively dynamic, unilateral tasks: a step-down task, a deceleration, and the deceleration phase of a 90° cut, in a cohort of healthy collegiate women's soccer players.

Methods

Sixty-nine NCAA Division 1 and Division 2 women's collegiate soccer players, whose teams participated in this study based on geographic location, willingness to participate, and ability to implement an intervention for another aim of this study, were enrolled. This study's procedures were approved by the University of Delaware's Institutional Review Board (approval #: 637078), and all participants signed informed consent documents prior to participation in the study. Participant demographics and injury histories were collected at the time of study enrollment. Additionally, the respective athletic trainer for each soccer team recorded injuries throughout the following soccer season and four non-contact ACL injuries were reported at the conclusion of the study. Participants completed preseason motion analysis of three progressively dynamic, unilateral tasks: a step-down, a deceleration, and a planned 90° cut.

Twenty-two retroreflective markers were placed bilaterally by a single investigator on bony prominences of the acromion, iliac crest, greater trochanter, medial and lateral femoral condyle, medial and lateral malleoli, the base of the fifth metatarsal, the base of the first metatarsal, and the posterior calcaneus. Additionally, rigid marker clusters were placed on the trunk, pelvis, lateral thighs, and lateral shanks. A static, standing calibration trial was taken before the motion trials were completed. Kinematic and kinetic data were recorded simultaneously. Kinematic data were recorded using an eight-camera motion system (VICON, Oxford Metrics Ltd, London, England) sampling at 240 Hz. Kinetic data were recorded using three embedded force plates sampling at 1080 Hz (Bertec, Worthington, OH, USA).

The step-down task was completed on a custom-built 20.5 cm box. For the step-down task, participants were given a demonstration of the task and instructed to: Step on top of the box, extend their right leg in front of them, and squat on their left leg three times in a row, return their right foot back to the top of the box, and then step off. The task was then repeated on the right leg. Three step-downs were completed on the right and the left limb. For the deceleration task, each participant was given a demonstration of the task and instructed to: Accelerate over a 10-m distance to full speed and decelerate as the lower extremity strikes the centre of the force plate. Participants were encouraged to ensure that their foot landed in the centre of the plate and that their heels did not touch the perimeter of the plate. Three trials were collected on the right and the left limb. For the 90° cut, participants were also given a demonstration of the task and instructed to: Quickly run forward, plant their entire foot straight forward on the force plate, turn 90°, and continue their run. Participants were encouraged to ensure that their entire foot landed in the centre of the plate. Three acceptable trials of the deceleration and cutting tasks were collected on the right and on the left limb. Only trials where the entire foot contacted the force plate were collected, and trials were rejected if the foot was in more than 45° of internal rotation.

Inverse dynamics and rigid body analysis were completed in Visual 3D (C-motion) using custom-written scripts. Kinematic and kinetic data
were low pass filtered at 6 Hz and 40 Hz respectively with a fourth-order Butterworth filter. For the trunk model, iliac crest and acromion markers were used to define the proximal and distal segments, respectively. The trunk segment was represented as a cylinder and a uniform segment depth of 0.12 m was applied [19]. The first, second, and third repetitions of the step-down were analysed due to the continuous nature of the task, but only the second and third repetitions of the deceleration and 90° cut were analysed due to higher reliability [20,21].

The COM of the trunk segment (COMt) was calculated relative to the position of the proximal end of the shank. COMt position was resolved in the lab coordinate system. COMt position was normalized to the length of the femur segment. This resulted in the COMt being a unitless measurement. Medial-lateral signs for the left limb were negated so that (+) signals indicated COMt was lateral to the proximal end of the shank for both the right and the left limb, and (−) signals indicated that COMt was medial to the proximal end of the shank.

The smallest detectable change (SDC) values were calculated for forward trunk flexion and lateral trunk flexion [21,22]. Interclass correlation coefficients were used to calculate the standard error of the mean (SEM). The SEM was used to calculate the SDC with the following formula SDC = SEM × 1.96 × √2 [22]. Comprehensive interclass correlation coefficients and SDCs can be found in Appendix A. All three repetitions of the step-down task were included in the analysis, but only the second and third repetitions of the deceleration and 90° cut were analysed secondary to higher reliability [20,21,26]. SDC values were calculated based on data for 45 participants with complete marker data, regardless of injury history or incurrence of future ACL injury.

Descriptive statistics including means, standard deviations, and ranges were calculated for the 37 participants with no history of ACL injury, who did not go on to incur ACL injury during the soccer season, and marker data with no drop-out for the three tasks. Again, all three repetitions of the step-down task were included in the analysis, but only the second and third repetitions of the deceleration and 90° cut were analysed secondary to higher reliability [20,21]. Descriptive statistics were calculated at the following time points: trunk forward flexion at initial contact and peak knee flexion, trunk lateral flexion at initial contact and peak knee abduction moment, and lateral COMt position at initial contact and peak knee abduction moment. Additionally, Pearson’s correlations between trunk excursion angle and time were calculated for initial contact to peak knee flexion for trunk forward flexion angle and initial contact to peak knee abduction moment for trunk lateral flexion angle. Alpha was set a priori at p < 0.05.

Results

Participant demographics are presented in Table 1. For the step-down task (Fig. 1), participants demonstrated increasing trunk forward flexion with increasing knee flexion. The mean trunk forward flexion excursion throughout the task was −9.2° for the right step-down and −11.1° for the left step-down (Table 2). Participants also demonstrated increasing ipsilateral trunk lateral flexion with increasing knee abduction moment (PKAM). The mean trunk lateral flexion excursion from the start of the task to the peak knee abduction moment was 0.8° for the right step-down and −0.6° for the left step down (Table 3). COMt moved laterally from the start of the step-down to the time of PKAM. The mean COMt excursion was 0.02 for the right step-down and 0.01 for the left step-down (Table 4) (see Fig. 2 and Fig. 3).

For the deceleration task (Fig. 2), participants demonstrated increasing trunk forward flexion with increasing knee flexion (Table 2). The mean trunk forward flexion excursion from initial contact to peak knee flexion angle was −8.3° for the right deceleration and −12.1° for the left deceleration. Participants demonstrated increasing ipsilateral trunk lateral flexion with increasing knee abduction moment for the right deceleration, and an increasing contralateral trunk lateral flexion for the left deceleration (Table 3). The mean trunk lateral flexion excursion from initial contact to peak knee abduction moment was 0.8° for the right deceleration and 0.3° for the left deceleration. COMt moved medially from initial contact to the time of PKAM for the deceleration (Table 4). The mean COMt was −0.01 for the right deceleration and −0.004 for the left deceleration.

For the 90° cut (Fig. 3), participants demonstrated increasing trunk forward flexion with increasing knee flexion. The mean trunk forward flexion excursion from initial contact to peak knee flexion angle was −10.3° for the right 90° cut and −16.7° for the left 90° cut (Table 2). Participants also demonstrated increasing ipsilateral trunk lateral flexion with increasing knee abduction moment. The mean trunk lateral flexion excursion from initial contact to peak knee abduction moment was 3.0° for the right 90° cut and −2.9° for the left 90° cut (Table 2). COMt moved medially from initial contact to the time of PKAM for the 90° cut (Table 4). The mean COMt was −0.55 for the right 90° cut and −0.62 for the left 90° cut.

Discussion

The purpose of this study was to describe trunk kinematics in healthy collegiate women’s soccer players during three progressively dynamic unilateral tasks: a step-down, a deceleration, and a 90° cut. For all three tasks, players demonstrated increasing trunk forward flexion with increasing knee flexion. Players also demonstrated increasing ipsilateral trunk lateral flexion with increasing knee abduction throughout almost all of the tasks. Additionally, players demonstrated lateral excursion of the trunk COM during the step-down tasks, and a medial excursion of the trunk COM during the deceleration and 90° cutting tasks.

Throughout each of the tasks, participants demonstrated increasing trunk forward flexion with increasing knee flexion. Trunk flexion during dynamic tasks, like the deceleration phase of the 90° cut, may help facilitate hip and knee flexion, which may be protective for ACL injury [8, 23]. Since excessive trunk displacement has been previously implicated as an ACL injury risk [23], this data set of collegiate women’s soccer players who did not go on to ACL injury may provide clinicians and sports performance professionals with an estimate of normative trunk forward flexion excursions during athletic tasks. A previous analysis of trunk kinematics during a 180° change of direction demonstrated a positive correlation between trunk forward flexion excursion and stance time [18]. Our data set did not indicate a significant relationship between trunk forward flexion excursion and time from initial contact to peak knee flexion for the deceleration or deceleration phase of the 90° cut. Stance time can be used as a measure of performance, with shorter times indicating better performance [15]. So, the absence of correlation between time and trunk forward flexion excursion on these tasks may indicate that moderate amounts of trunk flexion during dynamic tasks are natural and do not decrease performance.

Examining the timing of biomechanical events within the tasks, particularly the deceleration and 90° cut, may provide more insight into trunk lateral flexion patterns rather than focusing exclusively on trunk lateral flexion angles at specific events. For the deceleration and 90° cut, peak trunk lateral flexion angle occurred on average 0.01–0.05s before peak knee flexion angle (Table 2). Since the majority of ACL injuries occur within milliseconds of the foot contacting the ground, trunk mechanics during the landing phase of the deceleration or cut may contribute to knee loading and ACL injury risk [24]. Previous research has indicated that ipsilateral trunk flexion is a factor that contributes to peak knee abduction moment [4,13]. Although our sample also

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**Table 1**

Participant demographics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Participants (N = 37)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)</td>
<td>1.68 ± 0.05</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>63.7 ± 6.8</td>
</tr>
<tr>
<td>Age (years)</td>
<td>19.8 ± 1.1</td>
</tr>
<tr>
<td>Limb dominance (L = left, R = right)</td>
<td>L = 3, R = 34</td>
</tr>
</tbody>
</table>
demonstrated a small increase in ipsilateral trunk flexion with increasing knee abduction moment, the sequence of biomechanical events observed in our sample may indicate that studying trunk and lower extremity biomechanical risk factors for ACL injury at other time points is also pertinent. Additionally, a previous analysis of 26 sub-elite and elite female soccer players reported that they were in 11° of ipsilateral lateral flexion at initial contact when completing a 90° cut [13]. Our sample of 37 collegiate players who did not go on to ACL injury in the subsequent seasons demonstrated much smaller lateral flexion angles, with a mean initial contact angle of 6.5° for the right 90° cut and 1.2° for the left 90° cut. Although greater ipsilateral trunk lateral flexion at initial contact has previously been linked to greater knee abduction moments, our results indicate that some amount of lateral flexion may be normal when completing a cut. A larger sample of prospective data on participants who go on to ACL injury would be needed to calculate a cut-off for what constitutes a “safe” amount of lateral flexion.

The pattern of trunk COM movement during the tasks was an interesting finding of this study. For the step-down tasks, the trunk COM moved laterally to the knee joint with increasing knee abduction moment. This is consistent with previous research that has indicated that shifting the trunk COM lateral to the knee joint should also be associated with directing the ground reaction force laterally, which ultimately increases knee abduction moment [4]. During the deceleration, there was a negligible excursion in the trunk COM. For the 90° cut, the trunk COM moved medially from the time of initial contact to peak knee abduction moment. Like the peak trunk lateral flexion angle, this pattern can be explained by the timing of lower extremity events during the 90° cut. On average, peak knee abduction moment...
50 ms of initial contact, it is interesting that our participants’ abduction moments of the trunk COM is not a contributing factor to increased COM from initial contact to peak knee abduction moment is likely from time and excursion. Therefore, the medial shift of the trunk was more lateral at initial contact [24]. Landing with the trunk COM displaced laterally may increase the risk of ACL injury [4], and the current data provide normative values for comparison.

A strength of this study was the calculation of SDC values for trunk kinematics that fall outside of the tremity events during the step-down, deceleration and 90° cut. These SDC values allow clinicians to estimate trunk kinematics that fall outside of the current data provide normative values for comparison.

Table 2
Trunk forward flexion angle descriptive statistics for 37 healthy collegiate women’s soccer players.

<table>
<thead>
<tr>
<th>Task</th>
<th>Mean angle at IC° Range</th>
<th>Mean angle at PKF° Range</th>
<th>Mean excursion IC to PKF° Range</th>
<th>Time IC-PKF</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Step-down</td>
<td>-7.1° ± 9.3°</td>
<td>-16.2° ± 12.2°</td>
<td>-9.2° ± 7.9°</td>
<td>0.59s ± 0.18s</td>
<td>R = -0.42 (p = 0.01)</td>
</tr>
<tr>
<td></td>
<td>10.6° – 25.3°</td>
<td>11.7° – 39.2°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Step-down</td>
<td>-6.9° ± 9.4°</td>
<td>-18.0° ± 12.9°</td>
<td>-11.1° ± 7.7°</td>
<td>0.56s ± 0.21s</td>
<td>R = -0.37 (p = 0.02)</td>
</tr>
<tr>
<td></td>
<td>10.1° – 26.2°</td>
<td>7.3° – 45.4°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Deceleration</td>
<td>-17.2° ± 13.3°</td>
<td>-25.4° ± 13.6°</td>
<td>-8.3° ± 5.0°</td>
<td>0.31s ± 0.9s</td>
<td>R = 0.07 (p = 0.70)</td>
</tr>
<tr>
<td></td>
<td>1.4° – 57.8°</td>
<td>4.6° – 68.7°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Deceleration</td>
<td>-13.5° ± 13.3°</td>
<td>-25.6° ± 14.6°</td>
<td>-12.1° ± 5.3°</td>
<td>0.30s ± 0.9s</td>
<td>R = -0.25 (p = 0.13)</td>
</tr>
<tr>
<td></td>
<td>4.9° – 62.5°</td>
<td>-0.6° – 76.2°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right 90° Cut</td>
<td>-14.8° ± 12.6°</td>
<td>-25.1° ± 13.8°</td>
<td>-10.3° ± 6.4°</td>
<td>0.20s ± 0.05s</td>
<td>R = -0.01 (p = 0.97)</td>
</tr>
<tr>
<td></td>
<td>5.3° – 45.4°</td>
<td>1.3° – 60.6°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left 90° Cut</td>
<td>-9.3° ± 10.9°</td>
<td>-26.0° ± 13.1°</td>
<td>-16.7° ± 6.7°</td>
<td>0.22s ± 0.07s</td>
<td>R = -0.24 (p = 0.16)</td>
</tr>
<tr>
<td></td>
<td>13.1° – 28.9°</td>
<td>6.2° – 52.5°</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a IC: Initial contact.  
b PKF: Peak knee flexion angle. Correlations are between time and excursion.

Table 3
Trunk lateral flexion angle descriptive statistics for 37 healthy collegiate women’s soccer players.

<table>
<thead>
<tr>
<th>Task</th>
<th>Mean angle at IC° Range</th>
<th>Mean angle at PKAM**° Range</th>
<th>Mean excursion IC to PKAM° Range</th>
<th>Time IC-PKAM</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Step-down</td>
<td>1.3° ± 2.9°</td>
<td>2.1° ± 3.0°</td>
<td>0.8° ± 1.8°</td>
<td>0.23s ± 0.22s</td>
<td>R = 0.27 (p = 0.10)</td>
</tr>
<tr>
<td></td>
<td>-3.4° – 9.9°</td>
<td>-5.6° – 8.5°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Step-down</td>
<td>1.6° ± 2.9°</td>
<td>1.0° ± 3.1°</td>
<td>-0.6° ± 1.2°</td>
<td>0.08s ± 0.18s</td>
<td>R = -0.26 (p = 0.12)</td>
</tr>
<tr>
<td></td>
<td>-3.48° – 7.3°</td>
<td>-5.8° – 6.8°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Deceleration</td>
<td>2.2° ± 4.3°</td>
<td>3.0° ± 4.0°</td>
<td>0.8° ± 3.3°</td>
<td>0.58s ± 0.13s</td>
<td>R = 0.12 (p = 0.49)</td>
</tr>
<tr>
<td></td>
<td>-9.2° – 13.8°</td>
<td>-4.7° – 11.4°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Deceleration</td>
<td>4.3° ± 4.1°</td>
<td>4.6° ± 4.9°</td>
<td>0.3 ± 4.0°</td>
<td>0.61s ± 0.15s</td>
<td>R = -0.01 (p = 0.96)</td>
</tr>
<tr>
<td></td>
<td>-11.5° – 10.9°</td>
<td>-8.6° – 14.4°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right 90° Cut</td>
<td>6.5° ± 4.9°</td>
<td>9.5° ± 5.0°</td>
<td>3.0° ± 5.3°</td>
<td>0.37s ± 0.09s</td>
<td>R = -0.16 (p = 0.35)</td>
</tr>
<tr>
<td></td>
<td>-4.2° – 21.0°</td>
<td>-0.1° – 19.1°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left 90° Cut</td>
<td>1.2° ± 4.5°</td>
<td>-1.7° ± 5.8°</td>
<td>-2.9° ± 5.3°</td>
<td>0.42s ± 0.10s</td>
<td>R = 0.27 (p = 0.10)</td>
</tr>
<tr>
<td></td>
<td>-11.4° – 9.7°</td>
<td>-15.4° – 14.3°</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(+) angles indicate right lateral flexion, (−) angles indicate left lateral flexion; a IC: Initial contact. b PKAM: Peak knee abduction moment. Correlations are between time and excursion.

occurred after peak knee flexion. Therefore, the medial shift of the trunk COM from initial contact to peak knee abduction moment is likely from the player initiating trunk movement for the 90° cut while their foot is still in contact with the force plate [25]. This may indicate that position of the trunk COM is not a contributing factor to increased peak knee abduction moments. Since the majority of ACL injuries occur within 50 ms of initial contact, it is interesting that our participants’ trunk COM...
normative values reported in this study. Studies of neuromuscular training programs typically look for statistically significant changes in biomechanics [27]. While statistical significance can be an important marker of whether a biomechanical change occurred with an intervention, the application of SDCs can strengthen analyses and provide more clinical context of what equates to a true change. However, a limitation of the SDCs calculated for this study is that they were calculated for specific events within the tasks and cannot be applied to other events within the tasks.

One limitation of this study was the marker set. A single cluster of markers represented the trunk segment, which does not allow for a more nuanced analysis of trunk mechanics. Given the volume of participants completing motion analysis testing within the narrow timeframe of collegiate pre-season, this approach was the most practical option. Future studies should consider a more comprehensive marker set. Another limitation of this study was that only four non-contact ACL injuries were in fact recorded, and this number was still too small to compare to our uninjured cohort. Finally, analysis of pre-planned tasks is a limitation. The kinematics and kinetics of an anticipated cut are different from an unanticipated cut [25,26]. Thus, the biomechanical patterns observed in this study may not fully reflect on-field events, where cutting and decelerating are more likely to be unanticipated and in response to others’ movements. Future studies may consider an on-field analysis of trunk mechanics during cutting and decelerations.

Conclusion

This study explored trunk mechanics during three unilateral tasks in collegiate women’s soccer players with no association with an ACL injury. Participants demonstrated increasing trunk forward flexion with increasing knee flexion during the tasks and demonstrated small increases in ipsilateral lateral trunk flexion with increasing knee abduction moment during the tasks. Additionally, participants demonstrated greater lateral trunk COM displacement at initial contact than peak knee abduction moment which may be perilous for ACL injury. However, this pattern for lateral trunk COM displacement may indicate trunk position is not a substantial factor in peak knee abduction moments in our population of uninjured collegiate female soccer players. These results, in conjunction with the smallest detectable values, provide a reference for identifying aberrant trunk mechanics that may increase the risk for non-contact ACL injury. Further research in a prospective cohort is needed to identify whether trunk mechanics can differentiate between players who go on to ACL injury and those who do not.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Thank you to the women’s soccer teams, coaches, and athletic training staff for their participation in this study. Thank you to the research assistants, especially Rotem Itzhaki, for their assistance in data processing.

The work of Celeste Dix was supported by National Institutes of Health under T32 HD007490. The work of Amelia Arundale was supported by the National Institutes of Health under RO1 AR048212 and R44 HD068054 and a Foundation for Physical Therapy Promotion of Doctoral Studies I Scholarship. The work of Holly Silvers-Granelli was supported by the National Institutes of Health under R44 HD068054. The work of Ryan Zarzycki was supported by the National Institutes of Health under R37 HD037985.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsis.2022.03.002.

References


Table 4

<table>
<thead>
<tr>
<th>Task</th>
<th>Mean COM position at IC* Range</th>
<th>Mean COM position at PKAM** Range</th>
<th>Mean excursion IC to PKAM</th>
<th>Time IC-PKAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Step-down</td>
<td>−0.05 ± 0.06</td>
<td>−0.00 ± 0.05</td>
<td>0.02 ± 0.05</td>
<td>0.23 ± 0.22s</td>
</tr>
<tr>
<td>Left Step-down</td>
<td>−0.35 ± 0.05</td>
<td>−0.09 ± 0.14</td>
<td>0.01 ± 0.05</td>
<td>0.08 ± 0.18s</td>
</tr>
<tr>
<td>Right Deceleration</td>
<td>−0.08 ± 0.06</td>
<td>−0.08 ± 0.08</td>
<td>−0.01 ± 0.07</td>
<td>0.58 ± 0.13s</td>
</tr>
<tr>
<td>Left Deceleration</td>
<td>−0.17 ± 0.17</td>
<td>−0.24 ± 0.14</td>
<td>−0.14 ± 0.06</td>
<td>0.61 ± 0.15s</td>
</tr>
<tr>
<td>Right 90° Cut</td>
<td>−0.22 ± 0.07</td>
<td>−0.26 ± 0.08</td>
<td>−0.55 ± 0.17</td>
<td>0.37 ± 0.09s</td>
</tr>
<tr>
<td>Left 90° Cut</td>
<td>−0.39 ± 0.13</td>
<td>−1.12 ± 0.10</td>
<td>−0.62 ± 0.16</td>
<td>0.42 ± 0.10s</td>
</tr>
</tbody>
</table>

(+) values indicate COM medial to the knee, (−) values indicate COM lateral to the knee; *IC Initial contact. **PKAM: Peak knee abduction moment. COM was normalized to length of the femur segment resulting in a unitless measurement.


