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Comparison of frontal plane trunk kinematics and hip and knee moments during anticipated and unanticipated walking and side step cutting tasks

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Abstract

Background: Frontal plane trunk and lower extremity adjustments during unanticipated tasks are hypothesized to influence hip and knee neuromuscular control, and therefore, contribute to anterior cruciate ligament (ACL) injury risk. The aims of this study were to examine frontal plane trunk/hip kinematics and hip and knee moments (measures of neuromuscular control) during unanticipated straight and side step cut tasks.

Methods: Kinematic and kinetic variables were collected while subjects performed two anticipated tasks, including walking straight (ST) and side step cutting (SS), and two unanticipated tasks (STU and SSU). Foot placement, thorax–pelvis–hip kinematic variables and hip and knee moments were calculated over the first 30% of stance.

Findings: Hip abduction angles and knee moments were significantly affected by task and anticipation. Hip abduction angles decreased, by 4.0–7.6°, when comparing the SSU task to the ST, STU and SS tasks. The hip abduction angles were associated with foot placement and lateral trunk orientation.

Interpretation: Hip abduction angles and foot placement, not lateral trunk flexion influence trunk orientation. Anticipation influences hip and knee neuromuscular control and therefore may guide the development of ACL prevention strategies.

Keywords: Knee; Thorax; Moments; Kinematics; Side step cut; Motor control; Biomechanics

1. Introduction

The disability and cost associated with anterior cruciate ligament (ACL) injury has led to a focus on understanding non-contact ACL injury mechanisms with the goal of preventing this injury [1]. Videotape analysis of subjects injuring their ACL during sports play confirm that cutting and landing tasks pose a greater risk than straight ahead tasks [2–5]. Controlled in vitro studies, using loading patterns observed during cutting tasks, suggest knee rotation, extension, and abduction moments at the knee place the ACL at risk [6–8]. Prospective trials suggest frontal plane knee moments strongly contribute to ACL injury [9]. Because of the strong association of ACL injury and frontal plane moments, studies of neuromuscular control that identify strategies influencing frontal plane knee moments are useful. Although, trunk/hip neuromuscular control strategies are hypothesized to influence ACL loading during sports [1,10] no investigations focus on linkages between trunk kinematics, lower extremity posture and knee loading. For example, McLean et al. [11] found that hip flexion, hip internal rotation and knee abduction angles at initial contact were correlated to greater knee adduction moments during a running side step cut. This study did not assess the effects of trunk position or anticipation. Sports movements that require quick

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adjustments, such as unanticipated cutting tasks, may induce frontal plane adjustments in trunk position and lower extremity posture that influence knee loading [1,10,12–14].

Because few studies include objective measures of trunk/hip neuromuscular control, how anticipation influences trunk/hip neuromuscular control and frontal plane lower limb mechanics is not clear. Patla et al. [15–17] noted that anticipation influences frontal plane trunk orientation (thorax with respect to the global coordinate system) during walking cut tasks. Associated with unanticipated cut tasks were a lateral trunk orientation and decreased stride width when compared to anticipated cut tasks. The change in step width was attributed to a decreased lateral foot placement of the plant foot. Changes in step width if not compensated for by alterations in trunk position may alter knee moments, potentially influencing ACL injury risk.

The combination of changes in step width and trunk position during walking unanticipated cut tasks may induce translation of the trunk center of mass (CoM) lateral to the knee joint placing the ACL at risk. The lateral trunk orientation associated with unanticipated cut tasks is consistent with a double inverted pendulum model of balance [16,18]. This model suggests as the trunk rotates laterally at the hip joint, synchronously, the lower limb rotates medially around the subtalar joint (Fig. 1). Applying this model to unanticipated cut tasks, the lateral trunk and lower extremity rotation is expected to translate the hip joint medially, maintaining the hip abduction angle (Fig. 1) [16,18]. Assuming no contribution of lateral trunk flexion (thorax with respect to the pelvis) [19], increased hip abduction may maintain the relationship of the foot relative to the trunk CoM. The constrained kinematics (decreased step width) induced by unanticipated cut tasks may place subjects at risk of ACL injury if medial rotation of the lower limb around the subtalar joint does not contribute, leaving the trunk CoM more lateral. A lateral position of the trunk CoM relative to the knee joint center is predicted to shift knee moments toward adduction, which is associated with ACL injury risk.

Models of dynamic balance during walking [18] suggest controlling frontal plane knee loading may depend largely on hip joint mechanics. Winter [20] showed that the frontal plane hip moments balance the trunk while the knee contributes little to frontal plane balance. However, Winter [20] observed a covariance of the hip and knee moments during walking suggesting the hip influences knee loading. Further, it is unclear whether anticipated tasks shift the trunk CoM lateral or medial relative to the hip and knee joint centers. If hip and knee moments are shifted toward adduction by unanticipated tasks, anticipation may play a role in ACL injury mechanisms. Prevention programs seeking to control frontal plane knee loading as a means to reduce ACL injury risk [1,15,21,22] will benefit from studies documenting the influence of trunk/hip kinematics and lower limb posture on hip and knee loading.

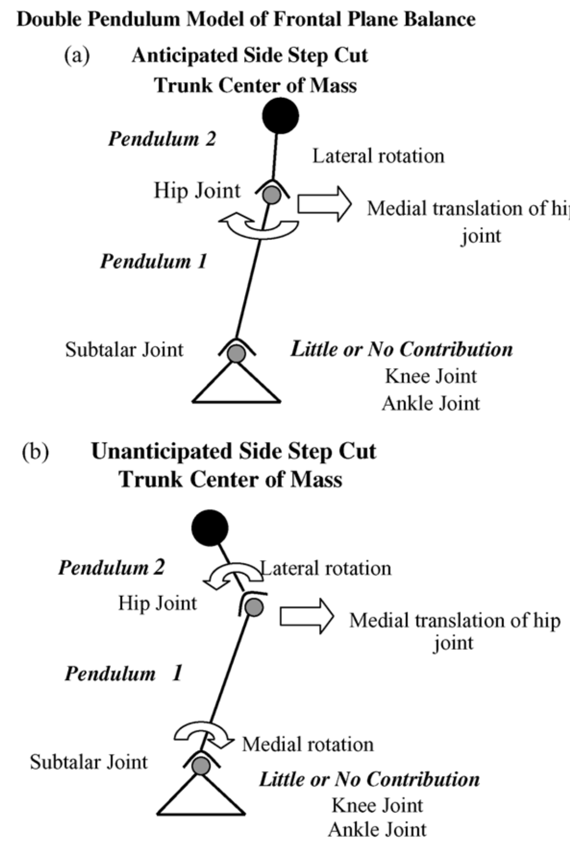

Fig. 1. Diagram of frontal plane model of balance control during walking anticipated (a) and unanticipated (b) side step cut task.

The first purpose of this study was to compare frontal plane trunk orientation, lateral foot placement, lateral trunk flexion and hip adduction/abduction angles among two anticipated (straight (ST) and side step cut (SS)) and two unanticipated (straight (STU) and side step cut (SSU)) tasks. We hypothesized that hip abduction angles during early stance would not change across tasks (ST, STU, SS, and SSU). This hypothesis assumed: (1) that there would be no contribution of lateral trunk flexion to trunk orientation and (2) that lateral trunk orientation and medial rotation at the subtalar joint would compensate for a decreased lateral foot placement, maintaining the hip flexion angle. A second purpose was to compare frontal plane knee and hip moments among two anticipated (straight (ST) and side step cut (SS)) and two unanticipated (straight (STU) and side step cut (SSU)) tasks. We hypothesized that both hip and knee moments would be similar during the ST and STU tasks; however, the moments would be shifted toward adduction when comparing SSU to the SS task. We also hypothesized a moderate to strong correlation would occur between the peak hip and knee moments during the SS and SSU tasks, suggesting manipulation of the hip moment during movement could alter the knee moment [18].

2. Methods

2.1. Sample

A sample of convenience of 14 healthy subjects (six females, eight males) 22.1 (2.6) years old, 1.7 (0.1) m, and 75.3 (17.3) kg, respectively, with no known lower extremity problems participated in the study after giving informed consent. A power analysis using standard deviations from a previous study [23] and effect sizes taken from pilot data confirmed this sample size was adequate for moderate effect sizes (power = 80%). All subjects were recreational athletes that had played on either high school or college sports teams. All subjects preferred to kick a ball with the right lower extremity suggesting they were right limb dominant. The internal review boards of the university and college affiliated with the primary author approved the study protocol.

2.2. Kinematics and force plate recordings

The infrared diodes of the Optotrak Motion Analysis System (Northern Digital Inc., Waterloo, Ont., Canada Model 3020) were tracked at a sampling rate of 60 Hz. Ground reaction forces were recorded at a sampling rate of 420 Hz using a force plate (Kistler Instrument Corp., Amherst, NY, USA Model 9865B) mounted in the floor. Prior to processing, the force (Fx, Fy and Fz) and position data (x, y, z) were smoothed using a fourth order, low pass, Butterworth, zero phase lag filter, with 25 and 6 Hz cut off frequencies, respectively. A threshold of 10 N of the vertical ground reaction force was used to determine heel strike and toe off.

2.3. Trunk and lower extremity modeling

A five-segment model including two trunk segments (thorax and pelvis) and three segments of the right lower extremity including the foot, leg and thigh were used to estimate joint angles and moments in three dimensions [24]. Rigid body representation of each segment were achieved by placing three infrared emitting diode's (IREDs) on each segment similar to previous studies (Fig. 2). The IREDs used to represent the thorax were placed on a plastic base and secured to the skin over the sternum using adhesive. The IREDs used to represent the pelvis were placed on the skin over the right and left anterior superior iliac spine (ASIS) and a hollow aluminum rod extending from the sacrum. The left ASIS IRED extended on a hollow aluminum rod approximately 5 cm anterior. The IREDs used to represent the femur include two IREDs mounted on a femoral tracking device and a marker placed 10 cm distal to the greater trochanter [24]. The IREDs used to represent the tibia were placed over the anterior border of the tibia. The IREDs used to track the foot were placed on the lateral side of the shoe with one proximal to the fifth metatarsal head. All subjects were required to wear low top running style shoes.

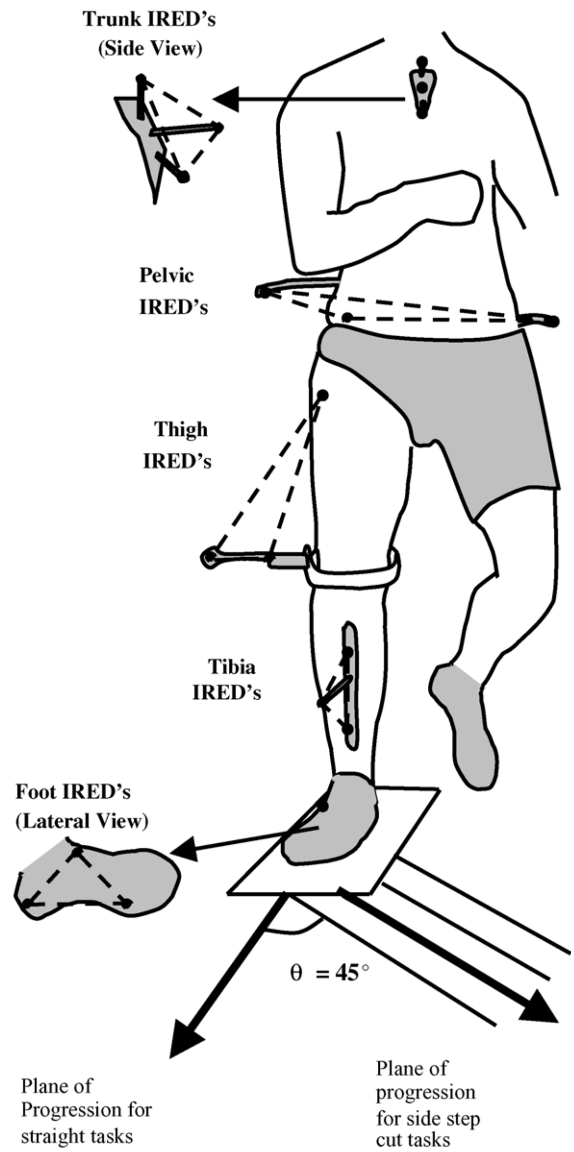

Fig. 2. Infrared diode (IRED) placements used to generate a five segment model including the foot, leg, thigh, pelvis and trunk.

Joint angles and moments were calculated from the position and force data using the Kingait3 software package [25]. Subjects stood with their feet placed in a T-shaped frame that was aligned with the global coordinate system for a 1 s trial that was used to establish anatomic coordinate systems. The thorax, pelvic and foot segments were aligned with the global axes. The approach used to establish the anatomic coordinate systems of the leg and thigh from digitized landmarks is consistent with a previous publication [26]. The Kingait3 software package determines joint angles using International Society of Biomechanics recommendations [27] and angle conventions proposed by Grood and Suntay [28]. The frontal plane thorax angle with respect to the pelvis was defined as lateral trunk flexion. Estimates of segment inertial properties were consistent with published protocols [29] and segment CoM with published tables [30].

Filtered ground reaction force data, position data and estimated inertial properties were combined to calculate net joint moments [30]. Net joint moments were resolved into the local coordinates of the distal segment. The net joint moments reported are the internal moments, or bodies reaction to the external load, reflecting demands on muscle and passive joint restraints to maintain equilibrium. Lateral foot placement was the lateral distance of the center of pressure, determined from the force plate, to the thorax CoM in the medial/lateral direction.

2.4. Procedures

Colored tape placed at 45° angles from the force plate was used to provide visual feedback to subjects enabling reproducible cut angles near 45°. An infrared photo-relay (Safehouse Infrared Photorelay, RadioShack, USA Model # 490-0551A) placed across the walkway triggered a visual display indicating if subjects were to side step cut or proceed straight for the unanticipated tasks (Fig. 3). During a practice session, the infrared light beam was placed one stride length from the center of the force plate. Subjects were allowed three to five practice trials and asked if they felt the activity was safe and within their abilities. If they answered, ''yes'', the distance was decreased by 15% of their stride length and the process was repeated until the subjects answered negatively. The last distance the subjects felt was safe and within their abilities was identified as the minimum cue distance. All the subjects minimum safe cue distance, expressed as a % of stride, ranged between 50 and 65% of a stride length from infrared beam to the center of the force plate. The practice session lasted approximately 30 min.

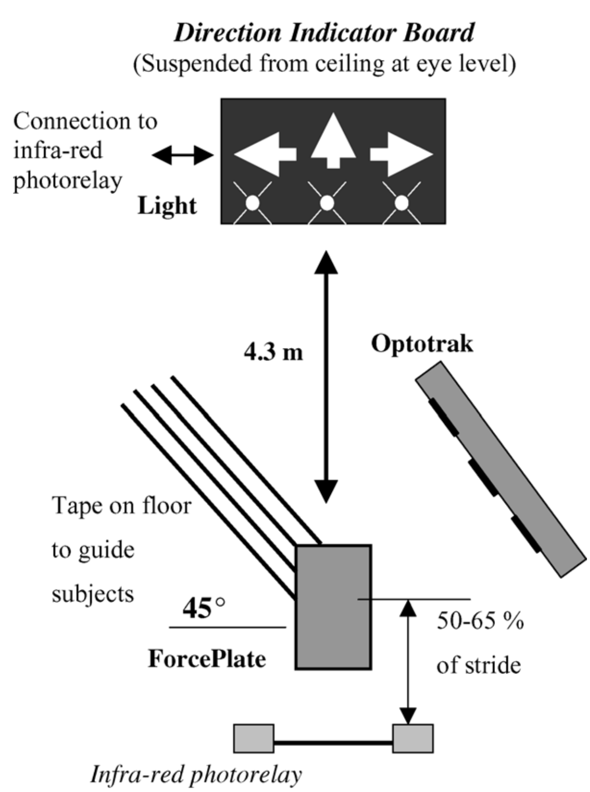

Fig. 3. Schematic of panel used (direction indicator board) to cue subjects to turn or proceed straight after infrared photo-relay is tripped. For all subjects, the infra-red photo relay was 50–65% of a stride away from the center of the force plate.

After the practice session, subjects attended a second session were they performed two anticipated tasks including walking straight (ST) and side step cutting (SS) and two unanticipated tasks walking straight (STU) and side step cutting (SSU). At least five trials of each task were recorded and used in the analysis for each subject. The ST and SS task were performed first. Subsequently, the STU and SSU tasks were performed in a random sequence to minimize the ability of subjects to ''game'' their response. Only trials in which subjects completed the task with in the tape marks and at the monitored approach speed were kept for analysis.

Further, to ensure that the differences between the SS and SSU tasks were not due to alterations in cut angle the cut angle for each task was measured using force plate data. Similar to a previous study [26], the cut angle for each task was defined by the medial/lateral and anterior/posterior ground reaction force peaks during late stance. The push off force in the medial/lateral and anterior/posterior ground reaction force (GRF) are associated with change in direction [17] and therefore were used to determine the overall change of direction achieved by each task. The equation used is shown below where the peak medial/lateral and peak anterior/posterior are the peak medial/lateral and anterior/ posterior GRF during late stance (Eq. (1)):

$$\text{cut angle} = \text{arc tangent}\left(\frac{\text{peak medical/lateral}}{\text{peak anterior/posterior}}\right) \tag{1}$$

velocity during all tasks were monitored during the test sessions and measured after testing to determine whether the tasks resulted in similar overall demands. Subjects were given feedback of their target approach walking speed (2.0 m/s) using a timing system (Bower Timing Systems, Draper, UT, USA). Subsequent analysis of the distance traversed by the center of mass of the pelvis from heel strike to toe off in the transverse plane (x, z plane) was divided by stance time to determine actual velocity of forward progression during each condition. The calculated velocity and cut angle for each condition were not significantly different across conditions (velocity, $P = 0.22$; cut angle, $P = 0.21$) suggesting the methods achieved a consistent cut angle and velocity across tasks (Table 1).

Table 1
Average (S.D.) of performance variables during each task

Variables	ST	STU	SS	SSU
Velocity (m/s)	2.1(0.3)	2.2 (0.1)	1.9 (0.2)	1.9 (0.2)
Cut angle (°)	7.9 (2.9)	12.8 (3.5)	52.6 (4.2)	50.1 (6.4)

Table 2
Average intraclass correlation coefficients (ICC, model 1, 1) across stance

Variables	ST	SS
Global kinematic		
Trunk orientation (thorax w.r.t. global) (°)	0.83	0.79
Pelvis w.r.t. global (°)	0.96	0.88
Thorax/pelvis kinematic		
Lateral trunk flexion (thorax w.r.t. pelvis) (°)	0.97	0.91
Hip angle (°)	0.97	0.94
Moments		
Hip moment (Nm/kg)	0.95	0.95
Knee moment (Nm/kg)	0.92	0.95

w.r.t., with respect to.

2.5. Analysis

Frontal plane angle and moment patterns for each variable for five trials were ensemble averaged over stance at 2% intervals to gain a representative pattern for each subject across stance for each condition. This analysis focused on the first 30% of stance, when the risk of ligament injury is hypothesized to be the highest [4]. At discrete points of the first 30% of stance (initial contact, 0–10% of stance and loading response, 10–30% of stance) peak frontal plane joint angles and moments were compared using a repeated measures two-way ANOVA model. When a peak could not be defined values at comparable points of stance were used for the comparison. One factor was task, with two levels including straight ahead (ST) and side step cutting (SS). The second factor was planning, with two levels, including anticipated (ST and SS tasks) and unanticipated (STU and SSU tasks). Applying a Bonferroni correction to maintain an α-level of 0.05, probability values <0.006 ($0.0063 = 0.05/8$) for each test were considered significant [31]. A priori relationships between variables were tested using a Pearson Product Moment Correlations Coefficient. Intrasession reliability for each subject was determined for the ST and SS tasks of all five trials using the intraclass correlation coefficient model (1, 1) (Table 2) [31].

3. Results

The kinematic variables suggest subjects altered their hip angles and not lateral trunk flexion in response to the STU and SSU tasks (Table 4 and Fig. 4). The SS task was characterized by significantly greater lateral foot placement (task × planning, $P = 0.001$) relative to the ST and STU tasks. In contrast, the SSU task resulted in greater right lateral thorax orientation (relative to the global vertical axis) than all other tasks (task × planning, $P = 0.001$). Lateral trunk flexion remained near 8–10° during all tasks (task × planning, $P = 0.58$). A post hoc analysis revealed that this trunk position was achieved by a decrease in the left lateral tilt orientation of the pelvis (taken at the same instant in stance as lateral trunk orientation) during the SSU task by 2–3° compared to the ST, STU and SS tasks (Table 3). The hip abduction angle was significantly lower by 4.0–7.6° during the SSU task compared to all other tasks. In contrast, the STU task was characterized by an increased hip abduction angle of 2.4° compared to the ST task. This resulted in a significant interaction between task and planning ($P = 0.001$) for hip angles.

The knee frontal plane moments showed significant differences in response to the unanticipated tasks (Table 4 and Fig. 5). Near initial contact (0–10% of stance) the peak knee moments during the SSU tasks were in abduction (−0.15 Nm/kg) compared to an adduction moment of (0.075–0.10 Nm/kg) for the other three tasks. This resulted in a significant interaction between task and planning for the peak knee frontal plane moments ($P = 0.002$). The knee abduction moments during the loading response (10–30% of stance) were significantly lower during the SSU task, resulting in a similar moment as that observed during the ST task. In contrast, the abduction moments were larger during the STU task, resulting in similar values as the SS task. This resulted in a significant interaction for knee moments during loading response (Knee, $P < 0.001$). A similar trend existed for the hip moments, however, were not significant using the adjusted alpha level (Hip, $P = 0.014$). The correlation between the peak knee and hip moments during the SS and SSU tasks were not significant. This negative finding prompted a post hoc analysis of the hip and knee moments during the unanticipated tasks expressed as a percentage of the SS task (SS–SSU). This post hoc analysis of the correlations between the differences in the hip and knee moments (SS–SSU) was strong at initial contact ($r = 0.90$, $P < 0.01$) and moderate during loading response ($r = 0.71$, $P = 0.01$).

Table 3
Average (S.D.) peak global kinematic variables of the trunk and foot placement.

Variables (<30% stance)	ST	STU	ST–STU	SS	SSU	SS–SSU	Task/planning/task × planning[a]
Lateral foot placement (cm) (+lateral/−medial)	8.3 (5.0)	7.2 (3.9)	1.1	13.8 (5.6)	5.5 (3.5)	8.3	**0.001/0.001/0.001**
Trunk orientation[b] (°) (+right lateral)[c]	2.8 (3.0)	2.2 (3.3)	0.6	1.4 (3.5)	5.1 (3.3)	−3.7	0.214/0.008/**0.001**
Pelvis w.r.t. global (°) (+right lateral)[c]	−9.2 (2.1)	−10.3 (3.0)	1.1	−12.7 (2.9)	−9.8 (2.6)	−2.9	0.007/0.171/**0.001**

[a] Results of the two-way repeated measures analysis of variance. Bolded values are <0.006.
[b] Thorax with respect to the global.
[c] Corresponds to a counter clockwise rotation around the anterior/posterior axis of the segment.

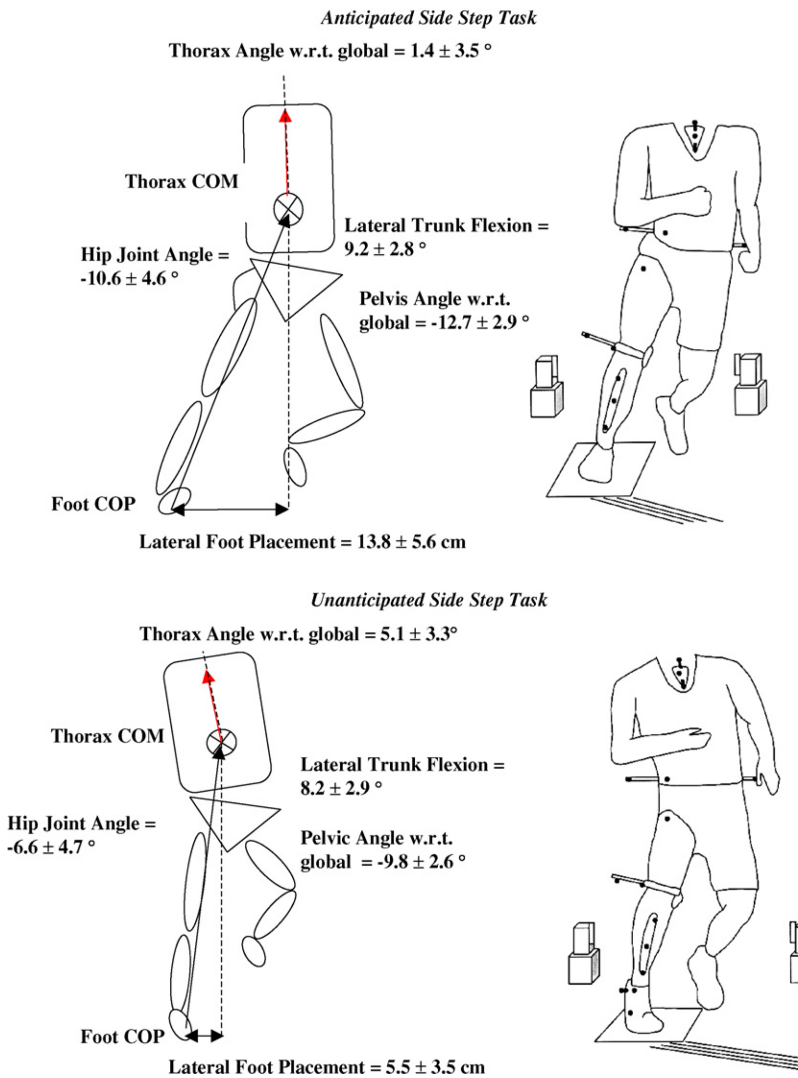

Fig. 4. The average values (±S.D.) used during the anticipated side step cut task (top left) and mean values (±S.D.) used during an unanticipated side step cut task are illustrated to the left (bottom left). An outline of a single subject performing a representative unanticipated side step cut task (top right) and unanticipated side step cut task (bottom right). The w.r.t. global notation indicates that the angle reported is ‘‘with respect to’’ the global reference frame. Negative values for the pelvis indicate counterclockwise rotation.

Table 4
Average (S.D.) peak joint kinematic and kinetic variables

Variables (<30% stance)	ST	STU	ST–STU	SS	SSU	SS–SSU	Task/planning/ task × planning[a]
Lateral trunk flexion (°) (−left/+right)	11.1 (3.1)	10.7 (3.6)	0.4	9.2 (2.8)	8.2 (2.9)	1.0	0.01/0.258/0.579
Hip angle (°) (−abduction/+adduction)	−11.8 (2.7)	−14.2 (3.6)	2.4	−10.6 (4.6)	−6.6 (4.7)	-4.0	**0.001**/0.222/**0.001**
0–10% of stance							
Hip moment (Nm/kg) (−abduction/+adduction)	−0.05 (0.23)	−0.13 (0.32)	0.08	0.02 (0.21)	0.06 (0.30)	−0.04	0.09/0.112/0.455
Knee moment (Nm/kg) (−abduction/+adduction)	0.10 (0.08)	.075 (0.08)	0.02	0.08 (0.10)	−0.15 (0.22)	0.23	**0.006/0.001/0.002**
10–30% of stance							
Hip moment (Nm/kg) (−abduction/+adduction)	−1.34 (0.49)	−1.59 (0.33)	0.35	−1.62 (0.31)	−1.39 (0.30)	−0.23	0.299/0.813/0.014
Knee moment (Nm/kg) (−abduction/+adduction)	−0.67 (0.33)	−0.83 (0.32)	0.16	−0.91 (0.33)	−0.65 (0.41)	−0.26	0.410/0.079/**0.001**

[a] Results of the two-way repeated measures analysis of variance. Bolded values are equal to or less than 0.006.

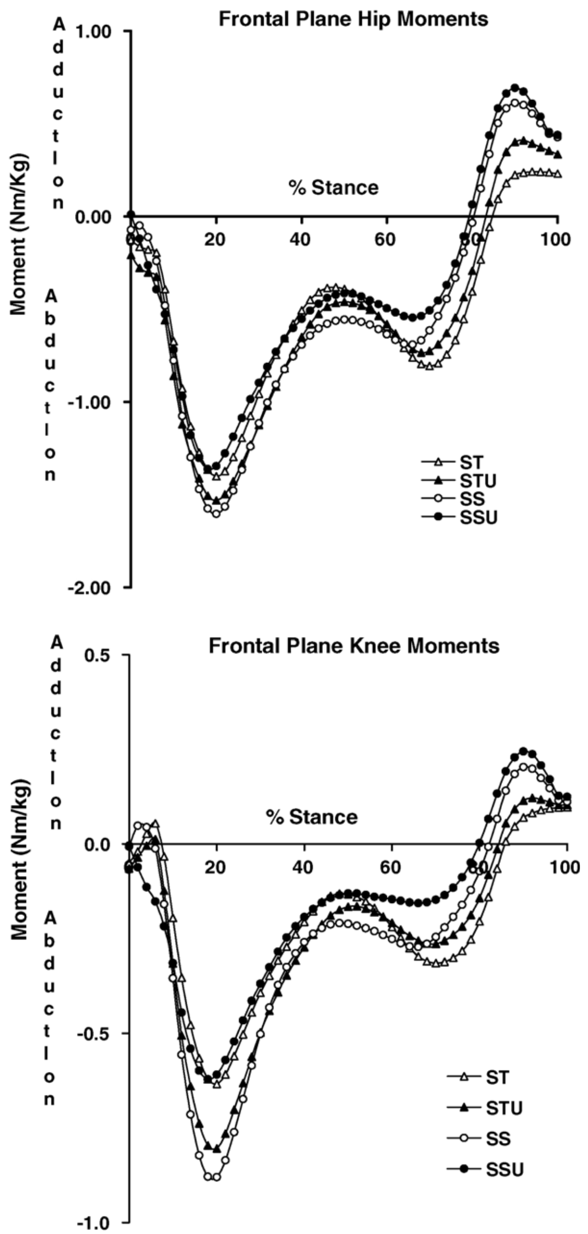

Fig. 5. Ensemble average patterns (n = 14) of the hip and knee frontal plane moments across stance for the two anticipated tasks (walk straight (ST, unfilled diamonds) and side step cut (SS, unfilled circles)) and two unanticipated tasks (walk straight (STU, filled diamonds) and side step cut (SSU, filled circles)).

4. Discussion

The findings of this study suggest that anticipation effects frontal plane kinematics and kinetics during both straight and cutting tasks. Our original hypothesis was based on previous studies that suggested the lateral trunk orientation observed during the SSU task might also be associated with medial rotation of the lower extremity at the subtalar joint, inducing medial translation of the hip joint [16,17]. However, the decreased hip joint angles suggest the original hypothesis was incorrect. Because lateral trunk orientation increased, the decreased hip joint angle is likely a failure of the lower extremity to medially rotate around the subtalar joint during the SSU task. The alterations in trunk kinematics and lower extremity posture due to anticipation resulted in changes in frontal plane joint moments during straight and cut tasks, which show the potential for anticipation to enhance ACL injury risk [15].

The data from this study suggest the interaction of trunk orientation and foot placement play an important role in cutting tasks (Fig. 4). During the SS task lateral foot placement increased, resulting in maintenance of a similar hip abduction angle as observed during the ST task (Table 4). The lateral trunk orientation of $\approx 5^{\circ}$ that occurred during the SSU task is similar to previous studies [16,17]. New to this study is the observation that lateral trunk orientation was not a result of lateral trunk flexion, suggesting even during unanticipated tasks the pelvis and thorax rotated as a single segment. If not for the decreased lateral tilt of the pelvis coincident with the thorax (Table 3), the hip abduction angle would have decreased further due to the medial foot placement. The decreased hip abduction angle during the SSU task suggests the proposed medial rotation of the lower extremity at the subtalar joint was not effective in this study.

To control the trunk position and complete the turn, Patla et al. [16–18] suggested hip muscle force development was the limiting factor, not neural processing time in successfully completing an unanticipated turn. The trend toward lower hip abductor moments during the SSU task suggests less reliance on muscles such as the gluteus medius and tensor fascia lata. In contrast, the higher hip abduction angle and trend toward higher hip abduction moment when comparing the ST and STU tasks, suggest a possible overcompensation of hip abductor muscles. These alterations at the hip due to anticipation (STU and SSU) support the importance of neuromuscular control of the hip in maintaining control of the trunk in the frontal plane (Winter [20], McKinnon and Winter [18]).

In conflict with our initial hypothesis related to the joint moments, near initial contact (5% of stance) of the SSU task the knee moments were toward abduction, not adduction (Fig. 5). The brief knee adductor moment during the ST, STU and SS tasks during early stance is associated with initiating movement of the CoM toward the stance foot [16–18]. During the SSU task, the knee moment was toward knee abduction, suggesting an immediate response to redirect the CoM away from the stance foot, toward the new direction of travel. This result suggests during the SS task the subjects completed weight acceptance then executed the turn. In contrast, during the SSU task the subjects attempted to initiate the turn at initial contact. This finding suggests alterations in motor planning that subjects were able to implement quickly. However, the alterations in trunk kinematics and posture that occur by 20% of stance suggest the mechanical demands of the task constrained the subjects ability to implement a new motor plan. Studies of running unanticipated cut tasks suggest that at faster velocities knee adduction moments at initial contact are maintained [10,32]. This difference in knee loading at initial contact due to anticipation suggests that neuromuscular responses are speed and task dependent. Since not all subjects injure themselves at high speeds [2,4,33], a possible contributing factor may be difficulties implementing a motor control program rather than the intensity of the loading.

The data from this study corroborates the view that trunk orientation may influence the knee frontal plane moments [4,18]. The knee and hip moments during the STU and SS tasks are similar suggesting that during the STU task the subjects were anticipating an SSU task (Table 4). This anticipation, however, did not prevent the lateral trunk orientation or alteration in the knee moments toward adduction during the SSU task. Further, the changes in the hip and knee moments were coupled (r values 0.7–0.9), consistent with theories that suggest the knee frontal plane response is linked to hip loading. As the thorax CoM shifts laterally and the hip medially, the ground reaction force vector moves toward the knee joint center, resulting in a lower knee abduction moment. This supports the view that frontal plane trunk movements as observed during the SSU task may require modifications in hip muscle function that impact the knee.

Combining these observed kinematic and kinetic effects with studies of documented injury mechanisms lead to suggestions of how unanticipated movements may enhance the risk for ACL injury. Based on videotape analysis a position of high risk was associated with low knee flexion (0–30°), valgus and external tibial rotation [4]. The videotape analysis suggest subjects reach a critical point (i.e. ‘‘position of no return’’) after which the hip moves rapidly into adduction and internal rotation and the knee collapses into flexion and valgus. The movements in this study did not reproduce this observed injury mechanism, suggesting the tested tasks are not dangerous [4]. However, the SSU task moved the hip angle toward adduction and knee moment toward adduction during the loading response, demonstrating how a trunk perturbation may increase the likelihood for the knee to move into valgus. This was observed at a relatively slow speed in this study compared to sports play. This study enhances our understanding of frontal plane control and points at anticipation as a possible contributing factor to inducing knee valgus even during slower speed tasks.

4.1. Limitations

The findings of this study are limited by the characteristics of the sample and focus of the analysis. The sample characteristics are an even mix (six female and eight male) of young male and female recreational athletes. Gender differences in this study were not addressed because of the small sample of male and female participants. Studies of gender differences in knee stiffness [34,35], knee angles and EMG patterns during specified tasks [36,37] suggest that differences in motor control may exist during unanticipated side step cut tasks. However, during controlled laboratory movements some studies have confirmed differences due to gender [11,36–39], while others have not [32]. Further research using unanticipated tasks may assist in identifying gender differences that contribute to ACL injury risk. A further limitation of this study is the focus on the frontal plane kinematics and moments because videotape analyses [2–5] and previous papers of unanticipated cut tasks [16] suggested large differences in the frontal plane. In addition, frontal plane angle measurements are potentially effected by kinematic modeling and tracking methods [40,41]. It is anticipated that the patterns will be consistent across studies, however, the magnitudes of the kinematic and kinetic variables may be model specific.

In conclusion, this study suggests that anticipation influences hip angles and hip and knee moments during straight and cut tasks. Hip joint angles were a function of both lateral trunk orientation and foot placement. Lateral trunk flexion (thorax–pelvis relationship) did not contribute to trunk orientation suggesting the thorax and pelvis acted as a single segment. The hip angles and moments point to hip neuromuscular control as one key component of a successful change in direction during an unanticipated side step cut task. The association of the hip and knee frontal plane moments during the unanticipated tasks shows the potential of changes in hip muscle function (hip moments) to influence the knee.

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