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Original Research

Increased Visual Attentional Demands Alter Lower Extremity Sidestep Cutting Kinematics in Male Basketball Players

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Background

In basketball, changing direction is one of the primary mechanisms of anterior cruciate ligament (ACL) injury, often occurring within complex game situations with high cognitive demands. It is unknown how visual attention affects sidestep cutting kinematics during the entire energy absorption phase of the cut in an ecologically valid environment.

Purpose

The purpose of this research was to study the effect of added cognitive load, in the form of increased visual attentional demands, on sidestep cutting kinematics during the energy absorption phase of the cut in an ecologically valid environment.

Study Design

Crossover Study

Methods

Fifteen male basketball players (aged 22.1 ± 2.3) performed ten sidestep cutting movements without (BASE) and with (VIS) a visual attention dual task. 3D kinematics of the hip, knee and ankle were recorded utilizing Xsens IMU motion capture. Temporal kinematics were analyzed using Statistical Parametric Mapping. Discrete time point kinematics were additionally analyzed at initial contact (IC) and at peak knee flexion utilizing paired t-tests. Effect sizes were calculated.

Results

Hip flexion was significantly reduced in the VIS condition compared to the BASE condition ($p<0.01$), including at IC (VIS 35.0° ± 7.2°, BASE 40.7° ± 4.9°, $p=0.02$, $d=0.92$) and peak (VIS 37.8° ± 9.7°, BASE 45.5° ± 6.9°, $p=0.001$, $d=0.90$). Knee flexion was significantly reduced in the VIS condition, in comparison to the BASE condition ($p<0.01$), at peak (VIS 59.9° ± 7.5°, BASE 64.1° ± 7.4°, $p=0.001$, $d=0.55$).

Conclusion

The addition of visual attention during sidestep cutting altered lower limb kinematics, which may increase ACL injury risk. It is suggested that ACL injury risk screening and

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prevention should include sidestep cutting with visual attentional demands, in order to mimic the cognitive demands of the sports environment.

Level of Evidence

3

INTRODUCTION

Injuries of the anterior cruciate ligament (ACL) have increased in incidence over the last decennia, with an increase of 14% in basketball specifically.[1,2] Sustaining an ACL injury is associated with numerous adverse health effects[3-7] and impaired athletic performance.[8-10] These facts indicate the need for better primary prevention of ACL injuries and justify the current study.

Of all ACL injuries in basketball 58-67% are non-contact in nature,[11,12] of which sidestep cutting is one of the primary injury mechanisms.[13] One of the primary playing situations in basketball in which ACL injuries happen is the first step after picking up the ball when attacking.[14] During the energy absorption phase (i.e. initial contact (IC) to peak knee flexion) of sidestep cutting several factors may contribute to high knee joint loading, such as low knee flexion angles,[15] high initial knee abduction angle,[13,16] low hip flexion angle,[17] high hip abduction angle,[15] and low initial hip internal rotation.[18] These unfavorable kinematics are especially prevalent during unplanned sidestep cutting maneuvers.[19,20]

The aforementioned sidestep cuts are made during games in a dynamically changing environment in which athletes are exposed to numerous stimuli.[14,21] Visual attention, defined as the goal-directed allocation of cognitive resources to external stimuli,[22] aids the uptake of relevant information in this dynamically changing environment.[23] While visual attention is a lower order cognitive function, it facilitates higher order cognitive functions such as working memory, inhibitory control and cognitive flexibility.[24] Increased cognitive task demands, which challenge the aforementioned cognitive functions, are consistently linked to an increase in at-risk biomechanics for lower extremity injury.[25]

A deficit or delay in attentional processing can contribute to a decreased ability to coordinate movement, which could result in the aforementioned unfavorable knee joint loading.[26] This has been demonstrated in studies where primarily female basketball players performed sidestep cuts with a passing or dribbling task which divided their attention, which elicited reduced knee flexion,[27] increased knee abduction angles,[27] increased knee abduction moments,[28,29] and increased hip abduction angles compared to when they did not perform the task.[29]

These findings show the influence of cognitive function, in the form of decision making and divided visual attention, on lower limb biomechanics and the need to include these factors in ACL injury screening and prevention practices.[30,31] The effect of decision-making and visual attention has been studied more directly in various sports, eliciting unfavorable biomechanics.[32-34] However, the effects of increased visual attentional demands during the entire energy absorption phase of the sidestep cut in male basketball players remain unknown. Previous research has been limited to studying biomechanics at initial contact and peak values in a lab setting, as opposed to in the natural sporting environment.[35] Furthermore, previous research has shown that discrete time point analysis failed to identify statistically significant biomechanical differences which were uncovered with full waveform analysis.[36] Gaining insight into the kinematics of the entire energy absorption phase of the sidestep cut could thus provide valuable information on how the movement execution is affected by including a temporal element in the analysis, as opposed to an analysis limited to two discrete timepoints.[37]

This study will investigate kinematic changes during a sport-specific task and will be conducted on an indoor basketball court, increasing its ecological validity.[35] The purpose of this research was to study the effect of added cognitive load, in the form of increased visual attentional demands, on sidestep cutting kinematics during the energy absorption phase of the cut in an ecologically valid environment in male basketball players. The hypothesis was that increased visual attentional demands alter sidestep cutting kinematics unfavorably in the context of ACL injury risk.

Table 1. Subject characteristics (mean ± standard deviation).

Age (years)	22.1 ± 2.3
Height (cm)	188.5 ± 11.1
Mass (kg)	84.5 ± 11.9
Leg dominance left/right	14/1
Hours of basketball played per week	6.4 ± 2.9
Playing level	National (N=5) Regional (N=2) Local (N=8)

METHODS

SUBJECTS

Fifteen male subjects were recruited from different basketball clubs from the north of the Netherlands (Table 1). Inclusion criteria were male, player in an official basketball team, 18-30 years, >3 hours of team training and game time per week. Exclusion criteria were recent lower-limb injury (<6 months), ACL injury in history, alcohol or caffeine 24h before measurements and color blindness. All subjects had normal or corrected-to-normal vision. Leg dominance was defined as the leg with which a participant pushes off during a lay-up.[38,39]

PROCEDURES

The Central Ethical Review Board of the University of Groningen approved this study under ID number #11257. All subjects provided informed consent prior to participating. First, anthropometric measures were taken in order to scale the Xsens Motion Tracking System (XSens Techonolgies, Enschede, Netherlands) proprietary biomechanical model and calibrate the motion capture in Xsens MVN Analyze (v.2021.2.0).[40] Joint angles were defined using the Euler sequence ZXY. Xsens MVN has fair to excellent agreement on sagittal plane movements in relation to gold-standard optoelectronic motion capture and allows for sport specific on-field movements to be captured.[40,41] Subjects were required to wear their own basketball shoes.

SIDESTEP CUTTING KINEMATICS

The kinematics of each basketball player were recorded on an indoor basketball court. Before starting the actual trials, subjects were granted familiarization trials until they indicated that they were ready to start. The sidestep cutting kinematics were recorded during a 90° near full speed sidestep cut. The subjects were asked to perform the route at near full speed (80-90% of maximum effort) since this mimics the demands of a basketball game more realistically and because kinematics of near full speed cutting elicit biomechanical risk factors for ACL injury more clearly than cutting at 60% speed.[42] Furthermore, 90° sidestep cutting results in the highest knee internal rotation and knee abduction moments and angles compared to 45° or 180° cuts; indicating this might be the cutting angle with the greatest inherent risk.[43]

Each trial started with a participant initiated 8.35m forward sprint followed by a sidestep cut with the non-dominant leg in the direction of the dominant leg. This was followed by a 3.5m forward sprint resulting in a 90° sidestep cut with the dominant leg, which was recorded for analysis. Each trial ended with a 3.5m forward sprint immediately after this last sidestep cut to finish the route. (Figure 1)

First, each subject performed ten trials of baseline sidestep cutting, without cognitive load (BASE). The Fitlights (FITLIGHT Corp, Canada, 2022, v2.17) placed upon the boxes on this predefined route would light up before and during the whole duration of the trial.

Second, each subject performed around fifteen trials of sidestep cutting in the cognitively loaded condition (VIS). The difference with the BASE and the VIS condition is that the subject did not know the route before the trial. The subject had to pay attention to, and then respond to, the Fitlights which dictated the direction. In the VIS condition the subject was tasked to perform distractor trials and actual capturing trials, intertwined with each other. The ratio between actual capturing and distractor trials was 2:1 respectively. In the distractor trials any of the directions was possible. In the actual capturing routes of the VIS condition the directions were exactly the same as the BASE condition, with the only difference being the added cognitive load through the increased visual attentional demands. Ultimately ten valid trials were performed in which the subject

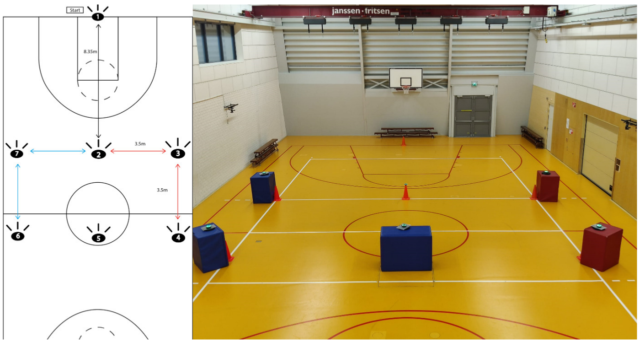

Figure 1. Left, in red: schematic route of sidestep cut for participants with left sided leg dominance. Right: experimental set-up on the basketball court with FitLights.

thus had to visually scan the environment on approach to (at Fitlight #2) and during (at Fitlight #3) the sidestep cut which was recorded.

DATA PROCESSING AND STATISTICAL ANALYSIS

An initial *a priori* sample size estimate was performed using Gpower 3.1,[44] with a paired t-test where α was set at 0.05, β at 0.20. With an effect size of 0.7 this analysis indicated that 15 subjects were sufficient to achieve adequate power. While sample size calculation using this method is valid for traditional 0D outcome data, the estimated sample size is in line with recommendations for 1D power analysis in biomechanical variables using a paired t-test with medium to large effect sizes.[45,46] The region of interest in this study is 0% to 50% of the sidestep cut, since the ACL is most at risk during this energy absorption phase.[15,17] The energy absorption phase in this study is defined as from the instance of IC to peak knee flexion angle, in line with previous research.[18,47,48] While the analysis focuses on the energy absorption phase, the kinematics of the entire sidestep cut are shown for clarity.

Trials were cropped from initial contact (IC) to toe off (TO). IC was defined as the instant where the vertical acceleration of the foot Inertial Measurement Unit (IMU) reached its minimum value.[49] TO was defined as the instant where peak knee extension was achieved.[50] All trials were time normalized at IC on a scale of 1-100% of the stance phase to allow for statistical analysis.

A customized Python script (Python 3.9, Python Software Foundation, Delaware, USA) was used in order to perform Statistical Parametric Mapping (SPM) (Spm1D 0.435, http://www.spm1d.org). A two tailed paired t-test was performed to compare hip, knee and ankle kinematics between the BASE and VIS conditions.

The kinematic outcome measures were flexion/extension angles of the hip and knee, dorsi- and plantarflexion of the ankle, abduction/adduction angles of hip and knee, and internal/external rotation angles of the hip, during the entire stance phase of the sidestep cut.

Alpha was set at 0.05 for all analyses. Effect sizes for statistically significant differences between conditions at IC and at peak values were indicated with Cohen's *d*, small (*d*=0.2), medium (*d*=0,5), large (*d*=0,8).[51] As the timing of peak values can differ inter-individually this may not be visible in the SPM figures, which average every participant on a set window of 0-100%. The differences between conditions at peak values (i.e. discrete time point) are thus additionally analyzed and reported separately, to allow comparison with other research.

RESULTS

KINEMATICS BASE VS VIS

Hip flexion was significantly reduced over the entire sidestep cut during the VIS condition in comparison to the BASE condition (p<0.01). At IC the hip flexion angle in the VIS condition (35.0° ± 7.2°) was significantly reduced compared to the BASE condition (40.7° ± 4.9°) (*t(14)*=3.717, p=0.02, *d*=0.92). The peak hip flexion angle in the VIS condition (37.8° ± 9.7°) was also significantly reduced compared to the BASE condition (45.5° ± 6.9°) (*t*(14)=4.344, p=0.001, *d*=0.90). Hip external rotation was significantly increased during the entire sidestep cut during the VIS condition in comparison to the BASE condition (p<0.01). Peak hip external rotation was significantly increased in the VIS condition (13.2° ± 8.8°) compared to the BASE condition (8.2° ± 9.3°) (*t*(14)=2.798, p=0.014, *d*=0.56). Results for the hip joint can be found in Figure 2 and Table 2.

In the VIS condition, knee flexion was significantly reduced from 10.7% of the sidestep cut and onwards compared to the BASE condition (p<0.01). Peak knee flexion was reduced in the VIS condition (59.9° ± 7.5°) compared to the BASE condition (64.1° ± 7.4°) (*t*(14)=4.028, p=0.001, *d*=0.55). Knee abduction was significantly reduced from 17.9% of the cut and onwards in the VIS condition, in comparison to the BASE condition (p<0.01). Results for the knee joint can be found in Figure 2 and Table 2.

At the ankle no significant differences were observed between the BASE and VIS conditions. Results for the ankle joint can be seen in Figure 2 and Table 2.

Time spent during the sidestep cut between IC and TO in the VIS condition (251.12ms ± 58.23ms) did not differ significantly from the BASE condition (259.20ms ± 40.95ms) (*t*(149)=1.596, p=0.113).

DISCUSSION

The addition of visual attentional demands to sidestep cutting resulted in reduced hip flexion and increased hip external rotation angles, and reduced knee flexion and knee abduction angles in the energy absorption phase of the cut. The difference in sidestep cutting kinematics between conditions primarily occurred in the sagittal plane for the hip and knee joint.

The current findings are in line with previous research, which indicates that divided visual attention can lead to reduced hip and knee flexion angles.[27] At baseline, participants in the current study performed the sidestep cut with 40.7° of hip flexion at IC whereas the participants in the study of Almonroeder et al.[27] performed the sidestep cut with 53.3° of hip flexion at IC. The magnitude of change differs however. In the study of Almonroeder et al.[27] hip flexion at IC only decreased by 2.5° under the influence of divided visual attention, compared to 5.7° in the current study. This indicates that the participants in the current study started with lower hip flexion angle, from which they reduced the hip flexion angle even further in the VIS condition. This finding, in combination with a reduced knee flexion angle in the VIS condition in the current study, could increase ACL injury risk since it could limit the ability to actively absorb energy during the sidestep cut through range of motion and ultimately transfer more load to the ACL.[16,18,52-54] A possible explanation for the differences between the studies is that in the current study subjects were required to perform the visual attention task during the sidestep cut, whereas in the study of Almonroeder et al.[27] the subjects had to perform the divided visual attention task directly after the sidestep cut. This could allow the participant to still focus on executing the sidestep cut,[27] something which was not the case in the current study. Additionally it should be noted that the study by Almonroeder et al.,[27] was performed with female basketball players, whereas the current study was performed with male basketball players.

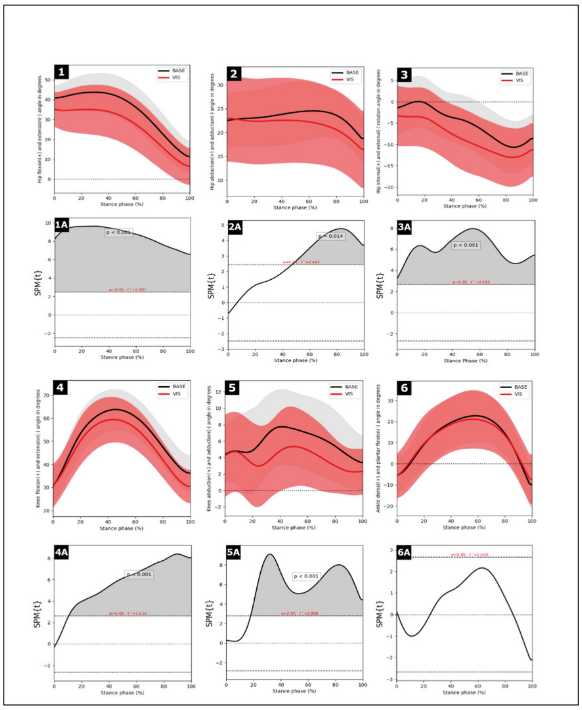

Figure 2. Means (solid line) and standard deviations (cloud) joint kinematics during the stance phase (IC=0%, TO=100%) of the sidestep cut (1,2,3,4,5,6). Significance graph of Statistical Parametric Mapping where grey indicates a statistically significant difference between conditions (1a, 2a, 3a, 4a, 5a, 6a).

Almonroeder et al.[27] reported no effect of visual attention on knee abduction angle at IC (6.4° at baseline vs 7.0° with divided visual attention). Other researchers have shown an increase in knee abduction angle from 7.4° to 8.5°

Table 2. Joint angles during the sidestep cut

		BASE (M ± SD)	VIS (M ± SD)	p-value	Cohen's *d*
Hip	Flexion angle at IC (°)	40.7 ± 4.9	35.0 ± 7.2	0.020	0.92
	Abduction angle at IC (°)	22.4 ± 4.4	22.9 ± 8.3	n.s.	n.s.
	External rotation angle at IC (°)	1.4 ± 5.1	3.2 ± 6.2	n.s.	n.s.
	Peak flexion angle (°)	45.5 ± 6.9	37.8 ± 9.7	0.001	0.90
	Peak abduction angle (°)	26.7 ± 4.0	25.8 ± 8.0	n.s.	n.s.
	Peak external rotation angle (°)	8.2 ± 9.3	13.2 ±8.8	0.014	0.56
Knee	Flexion angle at IC (°)	30.5 ± 5.0	30.8 ± 6.2	n.s.	n.s.
	Abduction angle at IC (°)	4.3 ± 2.8	4.2 ± 4.3	n.s.	n.s.
	Peak flexion angle (°)	64.1 ± 7.4	59.9 ± 7.5	0.001	0.55
	Peak abduction angle (°)	9.1 ± 4.5	7.9 ± 4.7	n.s.	n.s.
Ankle	Flexion angle at IC (°)	-5.4 ± 6.1	-5.6 ± 7.5	n.s.	n.s.
	Peak flexion angle (°)	13.9 ± 19.7	15.2 ± 20.2	n.s.	n.s.

and an increase in hip internal rotation angle from 4.6° to 6.4°, but this was measured during sidestep cuts of 45°.[28] Comparing kinematics of 45° cuts with 90° cuts, as per the current study, is futile since baseline kinematics differ based on the angle of the cut.[43,55] In addition to the effect of the cutting angle, it has also been shown that the type of visual stimulus matters in altering kinematics during sidestep cutting.[56,57] The differences in findings between the studies, in all three planes, highlight the specificity of task constraints.

Since the subjects were asked to perform the route at near full speed (80-90% of maximum effort), the altered kinematics during the VIS condition, can be linked to the performance-injury risk trade-off hypothesis during sidestep cutting.[58] This hypothesis states that an increase in performance often results in suboptimal kinematics when related to ACL injury risk.[58] It is possible that in the current study these dual-task costs came into effect. In order to maintain performance (i.e. perform the route at 80%-90% of their speed) with the increased dual-task constraints in the VIS condition, the sidestep cutting kinematics changed as a function of the increased visual attentional demands.

Altered higher-risk kinematics are undesirable when related to ACL injury risk, but it has been shown that specifically training sidestep cutting for six weeks can improve both sidestep cutting performance and kinematics in male football players.[53] In semi-elite basketball players it has also been shown that including cognitive-motor dual-task training using LED-displays during dribbling tasks can improve dribbling performance in five weeks of training, to a greater extent than motor training without the cognitive dual task.[59] Furthermore, the cognitive-motor dual-task training also improved cognitive performance by allowing a faster connection between sensory encoding and response execution.[59] These findings indicate that an improvement in cognitive or sidestep cutting performance when trained properly does not have to occur at the expense of sport performance. These promising results may be important for the secondary prevention of ACL injuries, since due to neuroplasticity an ACL reconstructed athlete may shift towards visual-motor control of movement instead of sensory-motor control of movement.[60] This is shown during sidestep cutting when ACL reconstructed basketball players exhibited different hip and knee coordination when a simulated visual attention dual task was added, compared to healthy matched basketball players who did not show altered coordination.[61] These combined findings highlight the importance of including integrated sidestep cutting execution and visual attention in training, in order to improve primary and secondary prevention of ACL injuries.

A strength of the current study is the investigation of the combined effects of unplanned change of direction and a visual attention task on sidestep cutting kinematics in basketball players in a gym environment. Prior research indicates that sidestep cutting kinematics in a laboratory setting differ from actual on field kinematics.[62] Since the current study took place on an indoor basketball court the athlete-environment relationship was preserved resulting in increased ecological validity.[35]

Another strength of the current study was the statistical analysis. The area most of interest in ACL injury risk research is the energy absorption phase during the sidestep cut, which roughly corresponds with the first 50% of the cut.[15,17,18,47,48] Focusing only on kinematic values at IC and peak generally discards a plethora of information in between these timepoints.[36,63] Since this study utilized Statistical Parametric Mapping we were able to statistically analyze the entire stance phase of the sidestep cut instead of being limited to fixed time points only. Analyzing the entire absorption phase allows for a more thorough interpretation of the kinematics, since temporal differences are included.[37]

A limitation of the current study is that some caution is warranted when interpreting the kinematic results. IMU based 3D motion capture systems allow for sport specific on field measurement, but are less accurate than gold standard infrared optoelectronic 3D measurement systems.[38,39,64] IMU based systems are quite accurate at capturing movement in the sagittal plane, however, the accuracy of IMU based systems is acceptable in movements in the frontal plane, and questionable in the transverse plane.[38,64] During change of direction, IMU based knee abduction/adduction angles could be up to 11° off and hip rotation angles could be more than 8° off compared to optoelectronic measurement systems.[38,39] During the current study these movements had ranges of motion of 5.0 degrees and 7.5 degrees respectively. Since the ranges of motion of these movements are relatively small and measurement errors can be relatively large, caution is warranted when interpreting the outcomes of the current study with regards to these movements. IMU-based motion capture was chosen to accommodate the on-court movements needed for an ecologically valid task, but may have only maintained accuracy in the study of sagittal plane movements.

Another limitation of the current study lies within the practical design of the measurements. In the VIS condition subjects did not know the route which they had to follow, the FitLights dictated this such that they had to scan their environment. Some routes would be eligible for capturing the sidestep cutting kinematics and other distractor routes would not be eligible. To guarantee that the subject would not know the route beforehand, these distractor routes were added. The ratio between actual recording routes and distractor routes was 2:1 respectively. We limited the current study to a ratio of 2:1 so that fatigue would not be a factor within the design. However, there was still a possibility that subjects would be able to guess the route beforehand, although the authors saw no signs of this.

Additionally, while the current study did analyze the duration of the sidestep cut in the BASE and VIS conditions, timing gates were not utilized to analyze the approach speed of the participants.

Caution is warranted with generalizing the results of the current study to other populations as the participants were all male and did not differ greatly in skill level. Finally, it could be that the sample size was too limited (small) to uncover more nuanced effects on sidestep cutting execution. The sample size in the current study was similar to comparable research[27] and was calculated on the basis of the power analysis with medium to large effects, as found in the hip and knee. While adequate for medium to large effects, the current sample size could be too small to uncover more nuanced kinematic changes.[46] Finally, caution is warranted with generalizing the results of the current study to other populations as the participants were all male and did not differ greatly in skill level.

Consistent with the findings of this study, as a practical implication, it can be advised that sidestep cutting execution with cognitive load should be incorporated in injury prevention practices. There are several ways to incorporate visual attention in sport specific prevention training. For example, cognitive load can be added by performing unanticipated cutting on the sports field by tasking the athlete with mirroring or chasing a leading teammate. A teammate can also approach the athlete and when together, the teammate decides to cut to the left or right, and the athlete must cut the opposite direction. Third, the teammate approaches the athlete dribbling with a ball and when together, the teammate decides to cut to the left or right with the ball, and the athlete cuts and tries to intercept the ball. And lastly, the teammate passes a ball (direction and speed self-chosen) and the athlete has to change direction to chase for the ball. In these examples, temporal variability (timing of stimuli), spatial variability (location of stimuli) and complexity of stimuli can be decreased or increased, thus less or more mirroring the demands of the actual sports environment.[65,66]

Future research could study the effect of specifically training sidestep cutting with increased visual attentional demands on performance and kinematics, in order to generate methods to improve ACL injury prevention. Furthermore, future research could study the effect of variability (e.g. timing, location, type, complexity) of the visual stimuli on sidestep cutting performance and kinematics. In line with this, future research could investigate whether questionnaires more suited to monitoring the attentional demand could provide more information. Finally, future research could study the possible mediating impact of skill level, alongside the possible effects of age and gender, on the effect of increased visual attentional demands and study the effect of dribbling during sidestep cutting as this is a common ACL injury mechanism in basketball.[14]

CONCLUSION

The results of the current study demonstrate that the addition of a visual attention dual-task alters sidestep cutting kinematics in male basketball players. Increased visual attentional demands primarily result in less hip and knee flexion during the absorption phase and the increased cognitive demand could lead to an increased ACL injury risk. Professionals in sports and healthcare are encouraged to consider implementing visual attention in their injury prevention paradigms in order to improve ecological validity and facilitate transfer to the actual sports environment.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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