

## SYSTEMATIC REVIEW

## THE EFFECTS OF ANTICIPATION ON THE MECHANICS OF THE KNEE DURING SINGLE-LEG CUTTING TASKS: A SYSTEMATIC REVIEW

Thomas G. Almonroeder, DPT<sup>1</sup>Erika Garcia, SPT<sup>2</sup>Malerie Kurt, SPT<sup>2</sup>**ABSTRACT**

**Background:** ACL injuries are common in sports, which has resulted in the development of risk screening and injury prevention programs to target modifiable neuromuscular risk factors. Previous studies which have analyzed single-leg cutting tasks have reported that the anticipation status of the task (pre-planned vs. unanticipated) has a significant effect on the mechanics of the knee.

**Hypothesis/Purpose:** The purpose of this systematic review is to assess the effect of anticipation on the mechanics of the knee in the sagittal, frontal, and transverse planes during tasks which athletes frequently perform during competition.

**Study Design:** Systematic Review

**Methods:** The following databases were searched using relevant key words and search limits: Pub Med, SPORTDiscus, CINAHL, and Web of Science. A modified version of the Downs and Black checklist was used to assess the methodological quality of the articles by two independent reviewers.

**Results:** 284 articles were identified during the initial database search. After a screening process, 34 articles underwent further review. Of these articles, 13 met the criteria for inclusion in this systematic review.

**Conclusions:** It appears that tasks which do not allow a subject to pre-plan their movement strategy promote knee mechanics which may increase an athlete's risk of injury.

**Clinical Relevance:** Clinicians involved in the development and implementation of ACL injury risk screening and prevention programs may want to consider incorporating tasks which do not allow time for pre-planning. These unanticipated tasks may more closely mimic the demands of the sports environment and may promote mechanics which increase the risk of injury.

**Level of Evidence:** Level 1b

**Key Words:** Anterior cruciate ligament, decision-making, knee biomechanics

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## INTRODUCTION

Each year, there are as many as 200,000 anterior cruciate ligament (ACL) injuries in the United States alone, with the majority occurring in young athletes.<sup>1</sup> Unfortunately, the authors of a recent systematic review, which included a meta-analysis, determined that only 63% of athletes will return to their prior level of function and only 44% will return to competitive sports participation following an ACL reconstruction.<sup>2</sup> This is not the only reason for concern, as athletes who have experienced an ACL injury also demonstrate accelerated degenerative changes of the knee even when they have undergone a successful surgical reconstruction.<sup>3</sup> As a result of the high incidence of ACL injury and the potential long-term impact, ACL injury prevention programs which target modifiable neuromuscular risk factors have been developed.<sup>4-6</sup> A recent systematic review was conducted to assess the effectiveness of these programs.<sup>7</sup> Fortunately, this report indicated that three of the eight programs evaluated resulted in a significant reduction in the incidence of ACL injury. However, the potential for these programs to have a meaningful impact on ACL injury rates may still be limited as even the most effective of these programs would require 70 athletes to participate in order to prevent a single non-contact ACL injury, based on the number needed to treat metric. The authors also discussed the large degree of variability in the training components included in these programs. The limited effectiveness and significant variability in ACL injury prevention programs may be due to an incomplete understanding of the important neuromuscular risk factors.<sup>8-10</sup> This creates what has been described as the “ACL injury enigma” as it has been highlighted that an injury cannot be prevented if it is not completely understood.<sup>11</sup>

The identification of biomechanical risk factors for ACL injury has been the result of a combination of studies which have predominantly involved human cadaver specimens,<sup>12-16</sup> biomechanical analyses,<sup>17</sup> or musculoskeletal modeling.<sup>18-20</sup> This work has identified mechanics in the sagittal, frontal, and transverse planes which contribute to ACL injury risk.<sup>21</sup> Understanding these mechanics has allowed for the identification of conditions or circumstances which may promote the risk of ACL injury. For example, both central and peripheral fatigue have been found

to be factors which promote mechanics associated with an increased risk of ACL injury.<sup>22</sup> This is consistent with the observation that the majority of ACL injuries occur at the end of a half or the end of a game when athletes are fatigued.<sup>23-25</sup> It appears that assessing key biomechanical variables can provide insight into the risk of ACL injury.

The majority of ACL injuries are non-contact in nature and often occur in sports such as basketball and soccer<sup>26</sup> which involve a relatively quick response to an external stimulus such as a ball, teammate, or opponent which cannot be anticipated. In these cases, an athlete is afforded limited time to identify the relevant stimulus and perform the neurocognitive processing required to respond with a motor plan which will allow them to successfully complete a task without putting themselves at risk of being injured.<sup>27</sup> Interestingly, it has been previously reported that relatively poor performance on a test of neurocognitive processing is associated with an increased risk of non-contact ACL injury.<sup>28</sup> Due to the fact that the majority of ACL injuries occur in sports which require landing and cutting in response to unanticipated stimuli and the fact that an athlete's neurocognitive processing appears to play a role in regard to their risk of injury, researchers have begun to investigate the effect of a task's anticipation status (pre-planned vs. unanticipated) on the mechanics of the lower extremity.<sup>27,29-31</sup> Understanding the role that anticipation plays in regard to ACL injury risk is not just of interest to researchers trying to understand the ACL enigma, it is also of great importance to clinicians involved in developing risk-screening and injury prevention programs. If unanticipated conditions promote injury risk in comparison to trials which allow for pre-planning, it is important that these types of unanticipated tasks are integrated into these programs.

Studies investigating the effects of anticipation have used a variety of tasks, subject groups, and methodologies and have also included various dependent variables. This makes a systematic review on this topic of great importance in order to provide an unbiased overview which can help to guide future research and also inform clinicians who are interested in preventing ACL injuries. Therefore, the purpose of this article is to systematically review the literature regarding the effect of anticipation on the mechanics

of the knee in the sagittal, frontal, and transverse planes during tasks which athletes frequently perform during competition.

## METHODS

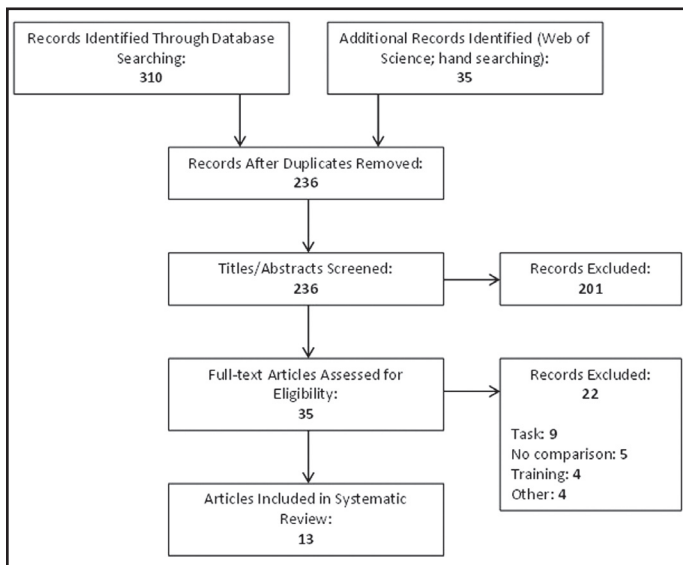
A literature search was performed using the databases, key words and search limits provided in Table 1. Articles which assessed the effect of anticipation on the mechanics of the knee during a single-leg cutting tasks were included in this review. Only studies which included a single-leg land-and-cut or run-and-cut task were included because these movements are common in sports and ACL injuries typically occur during tasks of this nature.<sup>26,32</sup> Some studies also included a crossover cutting task. However, these were not included in this review as this activity is uncommonly performed during sports.<sup>30,33</sup> The authors also chose not to include studies which implemented a training program to alter cutting mechanics as the current review was only intended to describe ACL injury risk and studies that included training did not allow for the delineation of the effects of anticipation independently of any training effects.<sup>34-36</sup> Additional hand searching<sup>37</sup> was conducted throughout the article review process and a search using the Cited Reference Search tool provided by the Web of Science database was also performed.

Once the literature search was complete, each article title and abstract was screened to determine if they were appropriate for inclusion in this systematic review.<sup>37</sup> The methodological quality of each

article was assessed using items from a version of the Downs and Black checklist which was previously modified for use in non-randomized biomechanical studies.<sup>22</sup> This modified version includes 13 of the 27 items from the original checklist which was developed for use in randomized clinical trials.<sup>38</sup> The wording of some of the questions was also altered in order to provide clearer scoring criteria to improve the consistency among raters. Two reviewers independently evaluated each article. Their scores were compared and a third reviewer was involved in the case of any discrepancies.<sup>37</sup> A data extraction form, developed specifically for this review process, was provided to each reviewer involved in evaluating the articles in order to ensure consistency in identifying the key details (e.g. subject group(s), methods, task, outcomes) which needed to be highlighted within each study. This helped the reviewers determine if an article was appropriate for inclusion in this review and also allowed for analysis of the potential influence of additional factors (i.e. subject group, task) on the results of a study.

Due to the heterogeneity of the tasks, methodology, and outcomes assessed in the studies, it was determined that a meta-analysis was not appropriate.<sup>37</sup> The focus was specifically on the biomechanical variables (joint angles and moments) of the knee as these are thought to have the most relevance to ACL injury. All moments are expressed as externally applied moments as this was the most commonly utilized convention among the articles included.

<b>Database</b>	<b>Key Word Search</b>	<b>Search Limits</b>
PubMed	[ACL OR knee] AND [anticipation OR decision making] AND [biomechanics OR kinematics OR kinetics]	Human subjects, English language
SPORTDiscus (EBSCO)	[anterior cruciate ligament injury OR knee] AND [anticipation OR decision making] AND [biomechanics OR kinematics OR kinetics]	
CINAHL (EBSCO)	[knee OR anterior cruciate ligament OR lower extremity] AND [anticipation OR decision making] AND [biomechanics OR kinematics OR kinetics]	
Web of Science	[ACL OR anterior cruciate ligament OR knee] AND [anticipation OR decision making] AND [biomechanics OR kinetics OR kinematics]	



**Figure 1.** Flow diagram based on the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement.

When summarizing the results of the studies, the focus was on the peak angles and moments as these were most commonly reported. Studies that only looked at muscle activation patterns via electromyography were not included as this was outside the scope of this review.

## RESULTS

### Search Results

The initial database search resulted in the identification of 310 articles, with an additional 35 articles identified using the Cited Reference Search tool and through hand searching. After duplicates were removed, 236 articles remained. The titles and abstracts were screened which resulted in the exclusion of 201 of these articles. The remaining 35 articles were read in full and evaluated for possible inclusion in the review. Thirteen of these articles met the criteria and were included. A flow diagram is provided in Figure 1 in accordance with the PRISMA Statement.<sup>39</sup> This figure also includes the reasons for article exclusion. The primary reasons why articles were excluded were 1) they did not include a single-leg cutting task, 2) they did not directly compare pre-planned and unanticipated trials, and 3) they implemented a training program. One study met all of the criteria for inclusion in this review, but was excluded because subjects were required to carry

loads ranging from 6-40 kg during the trials in order to simulate military field operations.<sup>40</sup>

A summary of the key details of the studies which were included in the current review are provided in Table 2. This includes the participant characteristics, task, and outcomes of interest. The consensus scores for the modified Downs and Black checklist are provided in Table 3. Both the overall scores and the scores for each individual criterion are presented.<sup>37</sup>

### Sagittal Plane Mechanics

The authors of four of the seven studies included in this review, which analyzed the effect of anticipation on the sagittal plane knee angles, reported a statistically significant increase in the peak knee flexion for the unanticipated trials in comparison to the pre-planned trials.<sup>27,30,41,42</sup> The authors of the three remaining studies reported no significant differences.<sup>29,31,43</sup> None of the authors reported a reduction in the knee flexion angle in the unanticipated condition. The effect of anticipation on the sagittal plane moments was fairly inconsistent. The authors of two studies reported a significant increase in the external knee flexion moment in the unanticipated condition,<sup>30,43</sup> Khalid et al<sup>44</sup> reported a significant decrease, the authors of three studies reported no significant difference between the conditions,<sup>29,31,41</sup> and Besier et al<sup>27</sup> reported an increase in the unanticipated condition during a run-and-cut at 30°, but a significant decrease when the angle of the cut was performed at 60°.

### Frontal Plane Mechanics

The authors of each of the studies included in the current review reported the effect of anticipation on the mechanics (knee angles and/or moments) of the knee in the frontal plane. The authors of three of the studies included in this review reported a significant increase in the peak knee abduction angle when trials were unanticipated,<sup>30,41,42</sup> while the authors of three additional studies reported no significant difference.<sup>29,31,45</sup> The authors of two studies, which both included NCAA Division I athletes, reported a significant interaction between the effects of fatigue and anticipation on the peak knee abduction angles during a lateral cutting task, as the increase in the peak knee abduction angles for the unanticipated condition became more prominent as the subjects progressed through a general fatigue protocol.<sup>10,43</sup>

<b>Table 2.</b>			
<b>Study</b>	<b>Participant Characteristics</b>	<b>Task</b>	<b>Outcomes of Interest</b>
Besier (2001)	11 male soccer players	Run-and-cut at 30° and 60° Adjusted timing of stimulus to subject	Sagittal angles Sagittal, frontal, and transverse moments
Borotikar (2008)	24 female NCAA athletes (basketball, soccer, volleyball)	Land-and-cut laterally Stimulus presented at 350 ms	Sagittal, frontal, and transverse angles
Brown (2009)	13 males 13 females	Land-and-cut laterally Stimulus presented at 400, 500, and 600 ms	Sagittal, frontal, and transverse angles
McLean (2009)	20 female NCAA athletes (basketball, soccer, volleyball)	Land-and-cut laterally Stimulus presented at 400 ms	Sagittal, frontal, and transverse angles Sagittal, frontal, and transverse moments
McLean (2010)	20 female NCAA athletes (basketball, volleyball, soccer)	Land-and-cut laterally Stimulus presented at 650 ms	Frontal moments
Cortes (2011)	13 female NCAA soccer players	Run-and-cut at 45° Stimulus presented at 450 ms	Sagittal, frontal, and transverse angles Sagittal and frontal moments
Park (2011)	13 female college soccer players	Run-and-cut at 45°	Sagittal, frontal, and transverse angles
Kipp (2013)	12 female recreational athletes 18 female NCAA athletes (basketball, soccer, volleyball)	Land-and-cut laterally Stimulus presented at 350 ms	Frontal angles Frontal moments
Lee (2013)	15 semipro male soccer players 15 amateur male soccer players	Run-and-cut at 45° Stimulus presented 450 ms	Frontal and transverse moments
Weinhandl (2013)	20 female recreational athletes	Run-and-cut at 45° Stimulus presented at 600 ms	Sagittal, frontal, and transverse angles Sagittal, frontal, and transverse moments
Kim (2014)	37 male middle school soccer players	Run-and-cut at 45°	Sagittal, frontal, and transverse angles Sagittal, frontal, and transverse moments
Mornieux (2014)	13 male amateur soccer players	Run-and-cut at 45° Stimulus presented at 850, 600, 500 ms	Frontal moments
Khalid (2015)	6 male soccer players 6 female soccer players	Run-and-cut at 45° Adjusted timing of stimulus to subject	Sagittal, frontal, and transverse moments

The authors of six of the included studies reported a significant increase in the peak knee abduction moment for the unanticipated condition,<sup>27,30,33,44,46,47</sup> while Cortes et al<sup>41</sup> reported a significantly lower peak knee abduction moment in the unanticipated condition, and Brown et al<sup>31</sup> reported that the effect of anticipation was not significant.<sup>31</sup> Kipp et al<sup>45</sup> also reported no significant effect of anticipation on the peak knee abduction moment in either a group of recreational athletes or a group of NCAA Division I athletes. However, they also performed a principal

components analysis<sup>48-50</sup> on the knee moment waveforms and compared the effects of anticipation between the two groups of athletes and found a significant interaction (group x condition) for the fourth retained principal component. This interaction indicated that the magnitude of the abduction moment during early stance (~20%) increased for the unanticipated trials in the recreational athlete group, but not for the group of NCAA Division I athletes. Similar to the results reported for the peak knee abduction angles, McLean et al<sup>43</sup> also reported a significant



**Table 3.** (+) study met criteria (-) study did not meet criteria

Modified Downs and Black Criteria	Besier (2001)	Borotikar (2008)	Brown (2009)	McLean (2009)	McLean (2010)	Cortes (2011)	Park (2011)	Kipp (2013)	Lee (2013)	Weinhandl (2013)	Kim (2014)	Mornieux (2014)	Khalid (2015)
Clear Aim	+	+	+	+	+	+	-	+	+	+	+	+	+
Outcomes described	+	+	+	+	+	+	+	+	+	+	-	+	+
Subjects described	-	+	-	+	+	+	+	+	+	+	-	+	+
Task(s) described	+	+	+	+	+	+	-	+	+	+	+	+	-
Main findings clearly described	+	+	+	+	+	+	+	+	+	+	+	+	-
Measures of random variability	-	+	+	+	+	+	+	+	+	+	+	+	+
Reporting of probability values	-	-	+	-	+	+	+	-	+	+	+	+	+
Subjects represent population	-	-	-	-	-	-	-	-	-	-	-	-	-
Included subjects represent population	-	-	-	-	-	-	-	-	-	-	-	-	-
Planned analysis	+	+	+	+	-	+	-	+	+	+	+	+	+
Appropriate statistics	+	+	+	+	+	+	+	+	+	+	+	+	+
Accuracy of outcome measures	-	+	+	+	+	+	-	+	+	+	+	+	+
Sample size calculation	-	+	+	+	+	-	-	-	+	-	-	+	-
<b>Total Score</b>	<b>6</b>	<b>10</b>	<b>10</b>	<b>10</b>	<b>10</b>	<b>10</b>	<b>6</b>	<b>9</b>	<b>11</b>	<b>10</b>	<b>8</b>	<b>11</b>	<b>8</b>

interaction between fatigue and anticipation as the increase in the peak knee abduction moment in the unanticipated condition became more prominent as subjects progressed through a fatigue protocol.

### Transverse Plane Mechanics

The effect of anticipation on the mechanics of the knee in the transverse plane was less commonly analyzed than the effects in the sagittal and frontal planes. However, the authors of four of the studies included in this review reported a statistically significant increase in the peak knee internal rotation angles for the unanticipated trials,<sup>10,30,42,43</sup> while the authors of two studies reported that anticipation had no effect on the transverse plane kinematics of the knee.<sup>29,31</sup> Also, the authors of four of the included studies reported an increase in the peak internal rotation moment of the knee for the unanticipated condition,<sup>27,31,43,44</sup> while the authors of two studies reported the opposite effect.<sup>30,47</sup>

### DISCUSSION

In general, anticipation had a prominent effect on the mechanics of the knee during the cutting tasks, which would likely result in an increase in the risk of an ACL injury. This finding was consistent with observational studies whose authors' have reported that the majority of injuries occur during a landing and cutting task<sup>32,51</sup> performed while competing in sports such as basketball and soccer which do not allow for pre-planning.<sup>26,52</sup>

The implications of the effects of anticipation on the mechanics of the knee in the sagittal plane were difficult to ascertain. An increase in the external knee flexion moment would likely require a greater internal knee extension torque, mainly from the quadriceps musculature. This could potentially increase the risk of injury as force from the quadriceps has been shown to increase ACL strain by promoting anterior translation of the tibia relative to the femur.<sup>12,13</sup> In fact, DeMorat et al.<sup>12</sup> reported that the application of a single quadriceps force of 4500 N at 20° of knee flexion resulted in a rupture of the ACL in over half of the cadaver specimens they included in their analysis. However, many have begun to question how this cadaver work translates to sports-related tasks as the authors of multiple musculo-skeletal modeling studies have reported that sagittal plane mechanics alone cannot produce forces which are high enough to rupture the ACL during landing and cutting.<sup>53,54</sup> This is primarily due to the large posteriorly directed ground reaction force vector during the initial landing phase which effectively limits the force which is transmitted to the ACL, as this vector passes behind the knee joint and limits anterior translation of the tibia. Also, the increase in the knee flexion angle reported in the unanticipated trials would most likely counteract the increase in the force produced by the quadriceps. This is due to the fact that the hamstring musculature becomes more effective at assisting the ACL in limiting the anterior translation of the tibia as the knee flexion angle

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increases.<sup>13,20,55</sup> However, Weinhandl et al<sup>29</sup> used a musculoskeletal modeling approach to estimate the forces acting on the ACL and reported that anticipation significantly increased ACL loading (combined sagittal, frontal, and transverse plane forces). Interestingly, the increase in the ACL force was primarily due to an increase in the loading in the sagittal plane. It seems that further analysis is required in order to truly understand how the sagittal plane mechanics of the knee contribute to ACL injury risk.

In the frontal plane, the effects of anticipation were relatively consistent as the results of multiple studies demonstrated an increase in the peak knee abduction angle and peak knee abduction moment. This is concerning as these mechanics have been previously shown to increase ACL strain<sup>18,19,56</sup> and have also been reported to prospectively predict ACL injury when observed during a land-and-jump task.<sup>17</sup> The frontal plane mechanics of the knee for the unanticipated trials also appear to be influenced by the athletes' level of fatigue. In fact, some have proposed that unanticipated tasks, performed when an athlete is fatigued, represent the "worst case scenario" in regard to ACL injury risk.<sup>10,43</sup> The effects of fatigue appear, at least in part, to affect central control mechanisms (suprapinal and spinal components) as McLean et al<sup>43</sup> utilized a single-leg progressive fatigue protocol and found an interaction between the effects of anticipation and fatigue for the frontal plane mechanics of the knee. The nature of the interaction indicated that the difference between pre-planned and unanticipated trials became more prominent with fatigue. Interestingly, they also found similar results in the non-fatigued limb. The authors concluded that this inter-limb crossover supports the premise that the effects of fatigue are centrally mediated. While the effects of central fatigue can occur anywhere in the nervous system from the cerebral cortex to the neuromuscular junction,<sup>57-59</sup> future studies would likely benefit from attempting to more precisely explain the mechanism behind the relationship between fatigue and anticipation. This is important as combating the effects of fatigue at the spinal level would likely require different intervention approaches than at the supraspinal level.

Similar to the frontal plane, anticipation was reported to have significant effects on the mechanics of the

knee in the transverse plane. The most consistent finding was an increase in the internal rotation moment in the unanticipated condition. This is also concerning as Flemming et al<sup>56</sup> found that applying an internal rotation torque to the knee increased the ACL strain in a group of 11 subjects who had a transducer implanted arthroscopically into their ACL. It has also been reported that the effects of loading in the frontal and transverse planes can have a combined effect<sup>19,60</sup> which may result in ACL strains which are high enough to result in a rupture of the ligament.<sup>19</sup> In regard to ACL injury risk, it appears that the most prominent effects of anticipation may occur in the frontal and transverse planes of motion.

From a research perspective, the results of this systematic review indicate that when performing a study to investigate possible risk factors for ACL injury, the demands of the task must be carefully considered, as anticipation appears to be a significant independent risk factor and may interact with other risk factors for ACL injury. Also, if incorporating an unanticipated task, it is important to consider the timing of the stimulus provided, as there appears to be a cutoff point (between 600-800 ms) in regard to the presentation of the stimulus to the time in which the subject must complete the task (i.e. cut), where knee joint kinematics and kinetics are affected. Times which are greater than this threshold are thought to allow participants time to successfully develop a motor plan which will not increase their risk of injury.<sup>33</sup> However, the specific cutoff point may depend on the complexity of the task and the subject sample (recreational vs. elite athletes).<sup>31</sup> Finally, some have advocated for the implementation of stimuli which better reflect the sports environment in an effort to improve the ecological validity.<sup>41,47</sup> While most studies used a relatively simple stimulus (e.g. alternating colors, arrows, etc.) to direct movement<sup>10,27,29,43,46</sup> others have begun to incorporate different stimuli which may more closely mimic sport participation.<sup>41,47</sup> For example, Lee et al<sup>47</sup> compared a traditional arrow stimulus to a stimulus which required subjects to respond to a video of a soccer defender and found that while both significantly influenced knee mechanics, the game-like soccer simulation had a more prominent effect. While this is certainly a worthwhile endeavor, all

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of the methods used to assess the effects of anticipation are still relatively controlled in comparison to the demands of the sports environment as most involve only two or three choices. Finally, studies that include a run-and-cut task should be carefully designed to control for the approach speed as two of the studies reported significant differences between the pre-planned and unanticipated trials.<sup>27,41</sup>

For professionals interested in ACL risk screening and injury prevention, the results of this review support the integration of tasks that specifically target central control mechanisms. Authors have previously proposed the use of decision-making tasks,<sup>27,45</sup> neurocognitive training,<sup>45</sup> virtual reality training,<sup>31,43</sup> and mental imagery<sup>43</sup> as approaches which could potentially allow athletes to reduce their risk of injury in the dynamic sports environment. The potential for training is supported by the findings of Kipp et al<sup>45</sup> where recreational athletes demonstrated greater differences between their pre-planned and unanticipated trials than NCAA Division I athletes. These authors proposed that this is likely due to the fact that the NCAA Division I athletes had improved their ability to perform in dynamic conditions as they may have more exposure to tasks which do not allow for pre-planning. However, it is impossible to determine from their cross-sectional design whether the elite athletes improved performance under unanticipated conditions was experience-driven or whether their innate ability had contributed to them reaching their athletic status. Nonetheless, intervention studies do support the fact that the effects of anticipation may be modifiable with appropriate training.<sup>34-36</sup> Current training programs typically involve exposing athletes to unanticipated run-and-cut or land-and-cut tasks, similar to those included in the studies which have analyzed the effects of anticipation. The basic premise of this approach is that this training can improve an athlete's neurocognitive processing within a relatively controlled environment and that the effects of this training will translate into improvements in motor control within the sports environment. Training studies have not typically involved any type of progression. However, altering the timing of the stimulus and/or increasing the number of response options seem like viable options. Other approaches

which target neurocognitive processing should also be investigated (e.g. mental imagery, choice reaction tasks, dual task training) as these interventions would likely be very easy and relatively inexpensive to implement on a wide scale.<sup>46</sup> Developing programs which do not require trained personnel and costly equipment may play a key role in reducing the rate of ACL injury. This is an area of research that certainly merits further study.

This systematic review does have some limitations, which need to be carefully considered. First, as with all systematic reviews there is a significant risk of publication bias, as studies demonstrating statistically significant differences in outcomes are more likely to be published. No attempt was made to contact the authors of the studies in this review in order to address this limitation. Second, while the methodological quality of the articles included in this review was assessed using a previously modified version of the Downs and Black checklist, no articles were excluded based on quality. Unfortunately, there is not a well-developed checklist to evaluate the methodological quality of studies which are not randomized control trials. While the authors of this paper do have experience using these types of rating systems, there is no training program available to ensure consistency as there is with other scales. Further development of tools to assess the methodological quality of non-randomized trials, including the Downs and Black checklist, appears warranted. Finally, while this review only analyzed the effects of anticipation on the mechanics of the knee, the mechanics of the hip and the ankle may also be affected<sup>29,41,47</sup> and may contribute to the risk of ACL injury.

It is also important to note that a similar systematic review, which included a meta-analysis, was recently performed by Brown et al.<sup>61</sup> However, these authors only included articles which assessed a run-and-cut task where the approach speed was between 3.0 to 5.5 m/s in an attempt to allow for a comparison among studies. However, in doing this they excluded any study which used a land-and-cut task. The articles that Brown et al excluded provided valuable information within the current review and landing and cutting is also a common task involved in sports. As a result, they only included three of the thirteen articles that were included in the current review.



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They also did not address how anticipation can interact with fatigue and how there appears to be some experience-driven adaptations. Both of these factors have important implications for both researchers and clinicians and should be included in a review of this nature. Finally, their systematic review was limited in regard to their analysis of the effects occurring in the frontal and transverse planes by only including a single study which analyzed the effect of anticipation on frontal and transverse plane kinematics.

## CONCLUSION

In conclusion, the results of this systematic review indicate that anticipation has a significant effect on the mechanics of the knee in the sagittal, frontal, and transverse planes during cutting tasks. It appears that tasks which do not allow an athlete to pre-plan their movement promote mechanics which may increase the risk of ACL injury. This has important implications for both researchers and clinicians involved in the development of ACL risk screening and injury prevention programs. Researchers must carefully consider the demands of the tasks they include in their protocols and clinicians may benefit from implementing activities which involve cutting in response to a stimulus that cannot be anticipated.

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