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The Effect of Dual Tasks on the Kinematic Pattern and Kinetics of the Lower Extremities in Athletes: A Narrative Review

Majid Hamoongard[1], Malihe Hadadnezhad[2]

Review Article

Abstract

Introduction: Anterior cruciate ligament (ACL) injury occurs in sports that require rotational and shear movements. Dual tasks during sports maneuvers increase the risk of injuries. The aim of this study was to systematically review the effect of dual tasks on the kinematics and kinetics of the lower extremities in athletes.

Materials and Methods: Articles published between 2000 and 2021 were searched using Google Scholar, and PubMed, Magiran, IranDoc, SPORTDiscus, Institute for Scientific Information (ISI), PEDro, and Scopus databases using a combination of keywords “Biomechanics”, “Landing”, “Dual task”, “Anterior cruciate ligament”, “Divided attention”, “Decision-making”, “Kinetics”, and “Kinematics”. A total of 58 articles were found. After the exclusion of non-English and non-Persian articles and those with damaged samples, 12 articles were reviewed in this study in full text.

Results: In all studies, dual tasks or divided attention were used during jumping, shear, and landing movements, but the type of cognitive and motor interventions and measured variables was different. Adding a secondary task to the movements associated with jumping and landing significantly increased the ground reaction force and dynamic knee valgus (DKV), and reduced hip and knee flexion, which can ultimately increase the risk of ACL injury.

Conclusion: Doing injury prevention exercises with cognitive tasks at the same time may cause variability in the central nervous system (CNS) and reduce the incidence of kinematic and kinetic patterns associated with ACL injury.

Keywords: Anterior cruciate ligament; Dual tasks; Kinematic; Kinetics; Divided attention

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Introduction

Anterior cruciate ligament (ACL) injury is frequent in sports that require cutting, deceleration, and landing from a jump, as well as in people with neuromuscular disabilities (1). Neuromuscular control defects have been defined as inappropriate patterns of activation and low muscle strength and power in the trunk and lower limbs (2, 3). ACL injuries often occur in non-contact conditions, which include biomechanical movement patterns such as a combination of lateral flexion of the trunk, approaching and internal rotation of the thigh, knee extension, external rotation, anterior tibial displacement, and ankle eversion (4). Studies have shown that increasing the vertical component of the ground reaction force (GRF) along with increasing the abduction and external rotational of the tibia increases the stress on the ACL (5).

The sport condition is unpredictable and the athlete needs to quickly choose the right movement strategies in response to sudden changes in the environment; Such as paying attention to the opponent when landing from a jump, which may expose the person to ligament injury (6). For example, a football player during a match and training must perform several tasks, including deceleration, change of direction, etc. at the same time according to the external stimulus (opponent, ball, teammates, etc.), which due to the significant limitation of attention capacity and cognitive demands expose the individual to injury

1- MSc Student, Department of Biomechanics and Sports injuries, School of Physical Education and Sports Sciences, Kharazmi University, Karaj, Iran

2- Assistant Professor, Department of Biomechanics and Sports injuries, School of Physical Education and Sports Sciences, Kharazmi University, Karaj, Iran

Corresponding Author: Majid Hamoongard, Email: majidhamoongard@gmail.com

(7, 8). According to the limited capacity theory of attention, each task requires the use of part of the attention capacity. As a result, if two tasks are performed simultaneously and the attention required to perform two tasks is more than the total capacity of the individual, the performance of one or both tasks will be disrupted (9, 10). Additionally, if two tasks use a common source to process information in the central nervous system (CNS), they will compete with each other for access to information sources, and interference will likely occur between the tasks (9). Therefore, imposing cognitive challenges in the landing mechanism in the event of interference in information processing depends on increasing the load on the ACL and decreasing performance (11). ACL injury often occurs when the athlete's attention to the opponent, the ball, and the target during tasks is associated with jumping and landing, which exposes the individual to injury due to interference with the information process (11, 12). Athletes with less cognitive ability appear to be at risk for non-contact ACL injury (8). Recently, studies have shown that performing a simple cognitive task and divided attention during movements affects knee mechanics during landing (12, 13). It is noteworthy that despite the obvious link between cognitive factors and the occurrence of injury, athletes are not challenged in cognitive processes to assess the risk of injury (13).

The neurocognitive approach is related to cognitive processes and the ability dependent on the function of the cortical and subcortical systems of the brain, which includes visual attention, information processing, reaction time, focus of attention, and dual tasks and may be considered as a risk factor for ACL injury due to changes in neuromuscular control (14). Dual tasks are defined as performing two or more cognitive or motor tasks simultaneously (9). The dual task method is based on the theory of limited attention capacity in which the attention capacity of each person is limited and performing each task requires the use of part of the attention capacity (9). Performing dual tasks leads to the increased neurocognitive load on the functional task and increased reaction time compared to performing one task (15). This reduces the time available for movement and may lead to athletes losing their balance during the jump and landing (15, 16). Some researchers believe that the GRF (15) and the probability of ACL damage (17) are higher in dual task conditions. Less cognitive ability is probably associated with an increase in dynamic knee valgus (DKV) (8); So that performing cutting, rotation, and landing movements simultaneously with cognitive challenges, reduces the flexion angle of the knee and thigh, increases the external tibial rotation and finally, increases the load on the ACL and reduces performance (11, 18, 19). Hughes and Dai conducted a narrative review study to investigate the effect of decision-making and divided attention on lower limb biomechanics during jumping and landing. Their subjects were active young people and athletes. The kinematic and kinetic indices associated with ACL injury were examined during decision-making processes (time available for reaction, selection complexity) and divided attention (attention capacity and needs). Decreased knee flexion at initial foot contact with the ground, increased maximal GRF, and decreased stability in decision-making and divided attention during jump and landing maneuvers were reported (20).

Studies examining athletes have found that dual tasks during exercise maneuver expose healthy individuals without cognitive and physical disorders to ACL injury. No study was found that targeted individuals with ligament reconstruction under dual task conditions and in accordance with the inclusion criteria. Therefore, the present study was carried out to review studies that examined the kinematic and kinetic patterns associated with ACL injury under dual-task conditions in athletes. The purpose of this study was to systematically review the existing literature to investigate the effect of dual tasks on the kinematic and kinetic patterns of the lower limb in athletes during the performance of routine movements in sports (jumping and landing, cutting, and rotational movements).

Materials and Methods

This was a review study accomplished in order to collect resources and articles indexed in domestic and foreign databases published between 2000 and 2021. The independent and combined English keywords included "Landing", "Dual-Task", "Anterior Cruciate Ligament", "Divided Attention", "Injury Prevention", "Biomechanics", "Decision-Making", "Kinematics", and "Kinetics". Therefore, the Persian and English language articles indexed in reputable databases including PubMed, Magiran, IranDoc, SportDiscus, Institute for Scientific Information (ISI), PEDro, Scopus, and Google Scholar search engine were collected. In the second step, the references of all review articles was reviewed in a cross-reference manner. In the present review, only studies that directly addressed the effect of divided attention or dual tasks on the kinematics and kinetics of athletes' lower limbs were considered.

According to the definition given by McKinney et al., athletes can be defined (based on intention, volume, and level of exercise) into three categories; A: Elite athletes are athletes who exercise more than 10 hours a week and their athletic performance is at the highest level of competition (including athletes from national, Olympic, and professional teams), B: Competitive athletes are those who exercise more than 6 hours a week and focus on improving performance and participating in official competitions (for example, most college athletes), and C: Recreational athletes, athletes who exercise more than 4 hours per week for pleasure, fitness, or informal and friendly competitions (for example, in-school sports) (21). In the present study, athletes were meant to be subjects who belong to one of the above three categories of athletes (elite, competitive, and recreational).

The study inclusion criteria included valid articles indexed in the abovementioned databases, studies that examined the effect of cognitive tasks on the kinematics and kinetics of the lower limb during cutting and jumping and landing movements, studies that were available in full text, Persian or English studies, and healthy subjects and athletes.

Lack of access to the full text of the article, history of injury (including knee ligament injury, especially ACL) or lower limb surgery, examining kinematics and kinetics of the lower limb during walking and balance movements, articles published in non-English and non-Persian languages, and duplicate studies (obtained from other databases) were considered as the exclusion criteria. The variables studied in the present study were kinematics of hip, knee (joint angles), and kinetics (torque of joint forces and GRF) in frontal, sagittal, and transverse planes.

Results

In all studies, dual tasks or divided attention were used during jumping, cutting, and landing movements, but the type of cognitive and motor interventions and measured variables were different. All subjects in the present study were athletes. 9, 2, and 1 studies respectively used jumping and landing movements (6, 13-15, 22-26), rotational and cutting movements (12, 27), and jumping and landing with cutting movements (28) to evaluate performance. For the subjects' divided attention while performing the movements, 4 studies used calculating and counting numbers and colors (22-24, 26) and two studies used motor tasks (12, 27), predicted conditions along with decision making (6, 13), visual stimulus using a device (14, 28), and reaction time (15, 25) (Figure 1).

In the present narrative review, 3, 8, and 1 studies used kinetics (22, 25, 26), kinetics and kinematics (6, 12-15, 24, 27-29), and the Tuck Jump test scoring system (23), respectively. In terms of examining the measured variables, GRF (12-15, 22, 27-29), thigh and knee torque and flexion angle (6, 12-15, 24, 27-29), DKV, knee abduction and external rotation (6, 12-15, 23, 27-29) were examined in 9 studies. Moreover, 7 studies examined the knee abduction force torque and internal and external rotation (6, 12-14, 27-29) and one study examined center of pressure (COP) displacement and stabilization time (26), trunk flexion angle and anterior tibial shear force (14), ankle inversion and plantar flexion (6), and activity of the rectus femoris, vastus lateralis, biceps femoris, and gastrocnemius muscles (22). As a result of the search based on the strategy of the present study, a total of 58 articles were found, of which the full text of 32 studies was reviewed based on the title, abstract, and methodology of the articles. Out of the 32 studies reviewed, 19 cases (9 unrelated articles, 7 cases of injured subjects, and 4 articles with different methodology) were excluded from the study. Finally, based on the inclusion criteria, 12 articles were reviewed. These articles were published between 2010 and 2021 (Table 1).

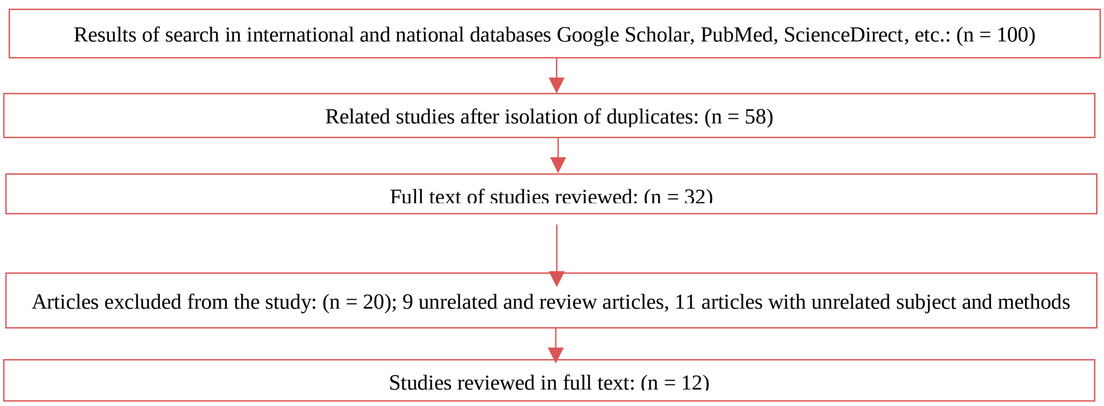

Figure 1. Results of selection of articles considered for review

Table 1. Studies related to the effect of dual tasks on the kinematic and kinetic patterns of the lower limb

Study	Subjects	Methodology	Measured variables	Results
Wilke et al. (26)	21 competitive athletes (15 women) with an average age of 25 years	Jumping and landing on the force plate in such a way that during the landing, the subjects had to maintain the number of shirts that were displayed randomly and announce them 10 seconds after landing.	Kinetics (time of stabilization, displacement of the COP and GRF)	Increased internal/external displacement of the COP was observed, but the time of stabilization and GRF did not change significantly.
Amoli et al. (22)	20 male (elite) volleyball players aged 18 to 24	Performing a simulated volleyball defense followed by a single-leg landing. Numbers were used to impose the cognitive task.	Kinetics (muscle activity and GRF)	Decreased activity of the rectus femoris and vastus lateralis muscles and increased activity of biceps femoris and internal gastrocnemius muscles were observed. Besides, the GRF was less in cognitive task conditions compared to non-cognitive task conditions.
Schnittjer et al. (23)	20 recreational athletes (10 women) with an average age of 22 years	Performing the Tuck jump test in three conditions without cognitive load, with simple cognitive load, and with difficult cognitive load	Scoring system based on the Tuck jump test (DKV)	A significant increase in scores was observed by adding cognitive homework to the Tuck jump test. The differences between the simple and difficult cognitive tasks were not significant, but there were significant differences in DKV.
Kajiwara et al. (15)	20 competitive athletes (10 women) with an average age of 20 years	Performing single-leg jumping and landing task while at the same time cognitive task was imposed on the person using the Stroop effect (a kind of interference in reaction time).	Kinetics (GRF, muscle activity) and kinematics (DKV and knee flexion angles)	Increase in tibia internal rotation angle and peak GRF were observed. The increase in rectus femoris muscle activity was not significant compared to hamstring. The knee flexion and DKV angles and anterior tibial shear force did not change significantly.
Almonroeder et al. (12)	20 healthy women aged 18 to 25 years with experience in playing basketball (competitive)	Performing cutting movements in three conditions with passing, carrying the ball, and cutting movement alone.	Kinetics (knee abduction torque, GRF) and kinematics (knee and hip flexion and knee abduction)	The athletes showed less flexion and more knee abduction in conditions with divided attention (chest pass). The GRF did not change significantly.
Mejane et al. (28)	19 female (recreational) athletes with an average age of 25 years	Performing jumping and landing tasks with cutting movements in conditions with and without perceptual cognitive task and in conditions with and without perceptual cognitive task with the addition of kinetic muscle fatigue protocol	Kinetics (knee abduction and internal rotation) and kinematics (angles of flexion, abduction, and internal rotation of the knee)	Muscle fatigue led to a significant increase in the maximum force of abduction and internal rotation of the knee and a decrease in knee flexion compared to conditions without cognitive-perceptual tasks. Knee abduction in cognitive task conditions with muscle fatigue increased significantly in 12 athletes.
Almonroeder et al. (13)	20 female athletes (recreational) aged 18 to 25 years	Jumping and landing task with cognitive load, without decision-making with overhead target, with decision-making and without overhead target, with decision-making and overhead target	Kinetics (GRF and knee abduction torque) and kinematics (knee abduction and flexion angles)	In the conditions of attention to the overhead target compared to jumping and landing alone, the maximum GRF was higher and the knee flexion angle was lower. Compared to the control group, the knee abduction force was higher in the conditions associated with decision-making and overhead target.

Table 1. Studies related to the effect of dual tasks on the kinematic and kinetic patterns of the lower limb (continue)

Study	Subjects	Methodology	Measured variables	Results
Herman and Barth (14)	37 athletes (recreational) aged 18 to 30 years	The neurocognitive function was assessed using magnetoencephalography (MEG). The task involved horizontal jumping on the force plate and then performing an immediate rebound to the secondary target, which was provided 250 milliseconds before landing.	Kinetics (GRF, knee abduction and extensor torque) and kinematics (flexion and abduction angles of the knee, trunk flexion)	In people with poorer neurocognitive function, an increase was reported in maximum GRF, anterior shear forces and abduction torque of the knee along with a decrease in trunk flexion. The knee flexion angle did not change significantly.
Meyer (24)	26 athletes (recreational) (9 females) with an average age of 21 years	Performing the jumping and landing task without cognitive task by counting down loudly at intervals of one second from a random number, counting down loudly at intervals of seven seconds from a random number	Kinetics (GRF) and kinematics (knee flexion)	A decrease was observed in knee flexion angle and an increase in GRF along with a decrease in performance under dual task conditions.
Mache et al. (6)	29 athletes (recreational) (13 women) with an average age of 22 years	The jumping and landing task was performed in pre-predicted conditions and conditions with decision-making.	Kinetics (torque adduction and internal rotation of the hip) and kinematics (hip and knee flexion, abduction, and adduction, ankle plantar flexion and inversion)	Less flexion of the hip and knee with more abduction and external rotation of the knee, more plantar flexion and less internal rotation and adduction torque in conditions with decision-making were observed.
Shinya et al. (25)	20 male (recreational) athletes with an average age of 24 years	Performing the jumping and landing task with the cognitive task that the subjects had to press the left or right button of the device as soon as the signal was presented.	Kinetics (GRF) and accelerometer	Maximum GRF and acceleration after touching the button under dual task conditions were higher than jumping and landing alone.
Fedie et al. (27)	38 basketball players (competitive) (19 women); The average age of men and women was 19 and 20 years, respectively	Performing cutting movements alone, cutting movements with passing, cutting movements with deception (the second examiner performed the passing action by showing a predetermined sign and the subject had to intercept the ball path by recognizing the signal as deceptive or real.)	Kinetics (GRF, torque of abduction and hip and knee adduction) and kinematics (hip and knee flexion and abduction angles)	The women showed less knee and hip flexion and more knee abduction in the three conditions of cutting movements compared to the men. Decreased knee flexion and increased hip adductor torque in both men and women with divided attention compared to cutting movements alone exposed the person to ACL injury.

DKV: Dynamic knee valgus

Discussion

The aim of this study was to investigate the effects of dual-tasks on the kinematic and kinetic patterns of the lower extremities in athletes. The results suggested that the divided attention process during the rotational, cutting, and landing movements changed the mechanics of the knee, the activity of the lower limb muscles, and GRF, which can ultimately increase the risk of ACL injury.

It is necessary to consider the role of cognitive abilities in neuromuscular control and the risk of injury (8). So, conducting a review study to examine the effect of dual tasks during exercise and its effect on the risk of ACL injury seemed necessary. Of the 12 studies included in this study, 5 stated that performing dual tasks during jumping and cutting maneuvers increased the GRF (13-15, 24, 25) and 2 studies showed that the imposition of cognitive load did not significantly affect the GRF (12, 26). This is probably due to the cognitive error of the subjects due to insufficient attention to the cognitive task, which leads to paying more attention to the kinematics of the lower limb during landing, and consequently, the maximum GRF does not change significantly (26). Overall, performing dual tasks during exercise maneuvers appears to increase the GRF and ultimately increase the risk of ACL injury.

In all studies, an increase in the DKV angle was observed during dual tasks (6, 12-15, 23, 27-29), which increases the risk of ACL injury (12, 24). The increased knee abduction and external rotation (6, 28) are considered as predicting factors for ligament injury. Given the present review, the subjects showed an increase in DKV angle and hip abduction and external rotational torques (6, 13, 23, 14, 27-29), which exposes the subjects to ACL injury (30). 7 studies examined the hip and knee flexion angle and torque and stated that the application of cognitive load during jumping and landing reduces the hip and knee flexion angle and torque (6, 12, 13, 24, 27-29), which can increase the GRF and the risk of ACL damage (24, 31). When there is a need for divided attention, the processing of sensory information (such as visual and auditory inputs) is disrupted, resulting in the athlete not being able to accurately schedule the prediction of the GRF and reduces the knee flexion at the initial contact of the foot with the ground that increases the risk of ACL injury (20).

It has been suggested that the rigid landing pattern, i.e. the limitation of the trunk flexion, hip, and knee along with the increase of DKV, leads to an increase in the vertical component of the GRF and an increase in the risk of injury (12, 13, 32). The soft landing pattern absorbs the GRF by the muscles and reduces the tension on the ligaments (22). Increasing the quadriceps muscle torque causes anterior tibial displacement and increases the pressure on the ACL (33). Furthermore, increasing the hamstring muscle torque counteracts the force produced by the quadriceps muscle, reduces anterior tibial displacement, and ultimately reduces the risk of injury (1).

Cognitive factors may play an important role in increasing or decreasing muscle activity and GRF. Adding cognitive task to the simulated defense of volleyball increased the activity of the biceps femoris and internal gastrocnemius muscles, and decreased the activity of the rectus femoris and vastus lateralis muscles, in addition to reducing the GRF (22). This is an important factor in limiting anterior displacement and external rotation of the tibia, which reduces the risk of ACL injury (5).

The results of this study (22) were not consistent with other studies that predicted an increased risk of injury in conditions of imposing cognitive load. Elite athletes are able to perform movement patterns automatically and without the need for attention (34). These athletes are able to manage cognitive information (spectator, coach, and teammate voice) well during special sports maneuvers and show a high level of performance (34, 35). Probably the reason for the decreased ACL injury in the study by Amoli et al. was that most of the athletes were elite volleyball players. A plausible explanation for this finding is the advanced ability of these athletes to effectively manage cognitive factors during single-leg jumping and landing, which reduces the incidence of kinetic and kinematic patterns associated with ACL injury. Elite athletes with involuntary high-level neuromuscular control change patterns of muscle activation in response to dangerous jumps and landings that are simultaneously combined with cognitive tasks and land with the correct movement pattern (22). This interpretation is confirmed by the findings of previous studies that described the existence of differences in the mechanism of injury of volleyball players at different levels of competition (36)

Finally, it can be concluded that the effect of cognitive load on the biomechanics of jumping and landing may depend on the ability of athletes to subconsciously change movement patterns in hazardous conditions (22). Therefore, adding cognitive processes to training protocols may have a positive effect on lower limb mechanics, and incorporating cognitive processes during movements will help simulate athletes' dynamic movements in competition conditions (13).

Exercises combined with dual tasks increase the ability of individuals to overcome the limitations of CNS processing (37). The ability to maintain dynamic stability of the knee joint during cognitive challenges is a very important factor in preventing ACL injuries (38). Neuromuscular training increases joint stability, improves joint posture, and improves neuromuscular control (39). Biomechanical studies have confirmed that the use of neurocognitive approaches in combination with neuromuscular training can reduce neuromuscular defects (40). It seems that the combination of exercises aimed at preventing injury and cognitive exercises reduces divided attention and increases automation, similar to what happens in elite athletes.

Limitations

Among the limitations of the present study was the exclusion of non-English and non-Persian non-linguistic studies published in conferences, which may affect the results of the study. In the present study, gray literature such as dissertations and abstracts presented in congresses were not examined.

Recommendations

It is suggested that in future studies, the effect of dual tasks on static, dynamic stability and balance variability in athletes should be considered. Additionally, the systematic review of the present study should be carefully examined.

Conclusion

The results of the articles reviewed in the present study indicated that performing dual tasks or divided attention process during sports maneuvers significantly increases the GRF and DKV, and also reduces the torque of flexion angle of the hip and knee, which may increase the risk of ACL injury. Therefore, in designing and implementing valid training protocols that aim to prevent injury, the needs of cognitive tasks should be considered. Thus, the effectiveness of these programs may be improved, at least in preventing ACL damage.

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Authors' Contribution

Majid Hamoongard: study design and ideation, manuscript preparation, approval of the content of the final version of the manuscript for submission, specialized evaluation of the manuscript in terms of scientific concepts; Malihe Hadadnezhad, preparation of the manuscript, analysis and interpretation of results, rewriting the manuscript, approving the content of the final manuscript for submission, specialized evaluation of the manuscript in terms of scientific concepts.

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Conflict of Interest

Authors do not have a conflict of interest. Dr. Malihe Hadadnezhad is an associate professor at Kharazmi University of Tehran, School of Physical Education and Sports Sciences, Department of Biomechanics and Sports Pathology. Majid Hamoongard has been a master's degree student in sports pathology and corrective exercises at Kharazmi University of Tehran since 2020.

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