The Relationship Between Neurocognitive Function and Biomechanics: A Critically Appraised Topic

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Clinical Scenario: Neurocognitive performance may put individuals at a greater risk for lower-extremity musculoskeletal injuries. Research has observed the relationship between lower-extremity musculoskeletal injury and baseline neurocognitive performance; however, the understanding of this relationship is lacking. Exploring this relationship may give further insight into musculoskeletal injury and provide innovative directions for musculoskeletal injury prevention. **Clinical Question:** Is there a relationship between neurocognitive performance and lower-extremity biomechanics during a jumping or cutting task in healthy adult athletes? **Summary of Key Findings:** The literature was searched for articles that examined the relationship of a baseline neurocognitive test and a biomechanical analysis following a sports-related task. A total of 3 cross-sectional articles were included. All 3 studies concluded that poorer neurocognitive performance was associated with biomechanical faults that are linked to increased risk or rate of lower-extremity musculoskeletal injury. **Clinical Bottom Line:** Based on the evidence included, there is a moderate-level evidence to support the relationship between neurocognition and lower-extremity biomechanics in healthy adult athletes. **Strength of Recommendation:** In accordance with the van Tulder approach, there is a moderate level of evidence due to consistent findings from a combination of high- and limited-quality articles.

Keywords: head, brain, balance, posture

Clinical Scenario

Poor neurocognitive performance may be a risk factor for lower-extremity musculoskeletal injury risk. Previous research has identified poorer baseline neurocognitive function in college athletes who sustained anterior cruciate ligament injuries during an athletic season.¹ Despite these findings, limited research exists attempting to understand the relationship between neurocognitive performance and musculoskeletal injuries. Neurocognitive performance contributes to several aspects of sport performance such as agility, fine motor skills, processing speed and reaction time, and dual tasking.² Successfully integrating cognitive demands during sport participation is critical for rapid decision making, reacting to opponents, and ball handling.^{2,3} A decreased ability to rapidly process cognitive information such as spatial orientation or visual stimuli and make rapid decisions may increase coordination errors and detract from the ability to evade injury.^{2,3} Recent research has assessed the relationship between baseline neurocognitive performance and lower-extremity biomechanics, such as ground reaction forces and knee and hip kinematics during athletic tasks. Understanding the relationship between neurocognition and lower-extremity biomechanics may provide insight into musculoskeletal injury and innovative directions for injury prevention.

Focused Clinical Question

Is there a relationship between neurocognitive performance and lower-extremity biomechanics during a jumping or cutting task in healthy adult athletes?

Search Strategy

The computerized search was conducted in September 2019 (Figure 1). The following search terms were used:

- athlete OR sport
- cogniti*OR neurocogni* OR memory OR reaction time
- biomechanics OR mechanics OR cutting OR landing
- lower-extremity OR lower limb

Sources of Evidence Searched

- EBSCOhost
- MEDLINE
- SPORTDiscus
- Health source—consumer edition
- Additional resources obtained via hand search of reference lists

Inclusion Criteria

- Participants completed at least one neurocognitive test
- Participants completed a sports-related task (ie, jumping/landing, cutting) with lower-extremity biomechanical analysis (ie, kinematics, kinetics)

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Figure 1 — Flow diagram of systematic search of the literature.

- Participants were recreational or competitive athletes with no current injuries
- Studies published in English
- Studies that were level 3 evidence based on Oxford Center of Evidence-Based Medicine
- Studies published within the last 10 years.

Exclusion Criteria

- Studies that examined dual tasks by adding cognitive load to sport-related tasks
- Studies that did not utilize a neurocognitive test
- Reviews of the literature, expert opinions, case studies/series.

Evidence Quality Assessment

The Downs and Black Reduced Checklist^{4,5} was used to critically appraise the included studies. There were 16 components to the checklist. Scores of $\geq 75\%$ (12/16) were considered

high-quality studies. Two authors (K.P. and C.Q.) independently reviewed and scored the included studies. Following independent review, the 2 authors (K.P. and C.Q.) reviewed the completed appraisals and came to a consensus regarding the quality of the studies.

Results of Search

Summary of Search, Best Evidence Appraised, and Key Findings

- The literature was searched for studies that correlated performance on neurocognitive tests to lower-extremity biomechanics during a jumping or cutting task.
- The search returned 100 results. After review of the titles and abstracts, 83 articles were excluded, and the remaining 17 articles underwent review of the full text. Two articles met the inclusion/exclusion criteria, and 1 article was added from a hand search for a total of 3 articles to be included in this critically appraised topic (CAT).
- Two of the studies^{2,6} compared the lower-extremity biomechanics in high and low neurocognitive performance groups. The remaining study⁷ explored the relationship between neurocognitive performance and knee biomechanics when ball handling and nonball handling.
- All 3 studies^{2,6,7} concluded that poorer neurocognitive performance was associated with biomechanics linked to elevated lower-extremity musculoskeletal injury risk following a jump-landing/cutting task, such as increased knee valgus and ground reaction force.

Results of Evidence Quality Assessment

The Downs and Black Reduced Checklist^{4,5} was used to critically appraise the included studies. Monfort et al⁷ received a 13/16, Herman and Barth² received a 11/16, and Shibata et al⁶ received a 13/16 (Table 1). Among the limitations of the quality assessments were the lack of blinding of those measuring the main outcomes in each of the included studies. Another limitation was the lack of described confounders. While Herman and Barth² and Monfort et al⁷ clearly describe the method of their outcome measures in detail, they failed to include or report the accuracy, reliability, and validity of the measures. Herman and Barth² did not report actual probability values for all main outcomes. Finally, a point was deducted from Shibata et al⁶ for lack of adjustments for the potential confounders in the analysis from which the main findings were drawn.

Clinical Bottom Line

An adaptation of the van Tulder approach was used to determine the strength of recommendation for the clinical question. According to the van Tulder approach,⁸ the strength of recommendation can be strong, moderate, limited, or conflicting based on the consistency and quality of evidence. Based on the 3 articles included (Table 2), there was a moderate-level evidence to support the relationship between neurocognition and lower-extremity biomechanics in healthy adult athletes. This recommendation was selected because there were consistent findings from a combination of high- and limited-quality articles.

Table 1 Summary of Evidence

Level of evidence	Study design	Number located	Author
3B	Cross-sectional	3	Monfort et al ⁷ Herman and Barth ² Shibata et al ⁶

Implications for Practice, Education, and Future Research

Evidence has demonstrated that there is a relationship between neurocognitive performance and biomechanical function following a jumping or cutting task. This relationship was identified despite the variability in the biomechanical assessments, neurocognitive testing, and patient population across the included studies. Despite moderate evidence and low sample sizes reported, these findings may have implications for clinical practice because baseline neurocognitive testing is currently utilized in many athletic settings and may provide novel insights into musculoskeletal injury prevention and rehabilitation.

All 3 studies identified increased peak knee valgus angle and moment, and increased ground reaction forces in individuals with poorer neurocognitive performance. Monfort et al⁷ studied knee valgus angle, knee valgus moment, and ground reaction force during a cutting motion with ball handling and nonball handling. Herman and Barth² and Shibata et al⁶ both started the participants on a 30-cm box, jumping to the ground with both feet, followed by an unanticipated 45° cutting or vertical landing task. For the variables used to investigate the relationships, Herman and Barth² reported ground reaction force, knee abduction moment, and knee adduction–abduction joint angles. Shibata et al⁶ reported knee valgus angle, knee valgus moment, and ground reaction force.

Despite variance in the tasks, all 3 studies identified alterations in biomechanics associated with poorer neurocognitive performance. Monfort et al⁷ reported confidence intervals in the comparison of ball handling versus nonball handling and peak knee valgus angle. As the 95% confidence interval did not encompass 0, this provided additional confidence in the results. In addition, Herman and Barth² reported differences between the high- and low-performing groups and noted significant group differences. However, it should be noted that knee valgus, knee moment, knee flexion, hip adduction, and ground reaction forces did not reach a level of statistical significance in the investigation by Shibata et al.⁶ To further examine the results of Shibata et al,⁶ effect sizes were utilized to further examine the trends in the data. The effect sizes associated with most of these outcomes in the Shibata et al⁶ study were moderate to large indicating clinically relevant differences may be present between the high and low cognitive performance groups. This can be attributed to the small sample size limiting the ability to detect statistically significant differences. Despite the variability in the biomechanical assessments across studies, the authors can conclude that biomechanical patterns exhibited by poor cognitive performers were not a result of the testing methods.

In addition to utilizing different biomechanical tasks, the relationship between neurocognition and biomechanics remained true despite the included studies utilizing different methods to test

neurocognition. Monfort et al⁷ utilized a computerized test, the Immediate Post-Concussion Assessment and Cognitive Testing, for the neurocognitive test. The Immediate Post-Concussion Assessment and Cognitive Testing provides a composite score for 4 different domains including visual memory, verbal memory, reaction time, and processing speed,⁹ and despite its popularity and common clinical uses, the test has been reported to have low to moderate test–retest reliability in a healthy sample (intraclass correlation coefficient = .39–.61).¹⁰ Herman and Barth² utilized a computerized neurocognitive test, known as the concussion resolution index which included 6 domains that were broken down into the following 3 groups: simple reaction time, complex reaction time, and processing speed. In previous investigations, the concussion resolution index has demonstrated low to moderate test–retest reliability in healthy individuals (intraclass correlation coefficient = .03–.66).¹⁰ Shibata et al⁶ utilized a pen and paper neurocognitive test known as the Symbol Digit Modalities Test. The Symbol Digit Modalities Test examined psychomotor speed, visual short-term memory, attention, and concentration.¹¹ To the authors' knowledge, the reliability and validity have not been reported in a healthy, athletic population.

Following testing, Herman et al² and Shibata et al⁶ split their participants into high- or low-performing groups. Herman and Barth² used the results of multiple constructs to form a group of high and low performers. Shibata et al⁶ took a more basic approach, looking at the average achievement rate, then using the median as a cutoff between groups. While these 3 tests all have different components, price range, and time demands, they all effectively challenged neurocognitive function. This indicates that various baseline neurocognitive testing may be able to provide insight into lower-extremity biomechanical patterns that may predispose individuals to injury.

The patient population was also diverse across the 3 studies. Monfort et al⁷ included all males, Shibata et al⁶ included all females, and Herman and Barth² included both male and female participants. It did not appear that gender played a role in the outcome of the studies. In addition, the type of athletic participation varied in the participants included across all of the studies. Monfort et al⁷ recruited athletes from the men's college club soccer team, Herman and Barth² and Shibata et al⁶ included nonspecific athletes who participated in jumping/cutting sports with recreational and university club athletics, respectively. While the level of participation was similar, the sports they participated in represented a more diverse sample. Despite these differences in sports participation, all 3 studies came to the same conclusion regarding the relationship between neurocognition and biomechanics. This suggests that the findings of the CAT may have application to a wide array of athletic settings, however, limited to college-aged athletes.

Currently, it is common practice to administer baseline concussion testing for athletes before beginning sports participation. Using these baseline scores, it may be possible to identify individuals with poor neurocognitive test results for further assessment of biomechanics for the purposes of musculoskeletal injury prevention. However, there is a wide range of tools used to measure neurocognitive performance. While many generate a percentile score that could quantify poor, average, or good neurocognitive test results, this may not be the case for all testing batteries. Future research should determine the best way to systematically define poor performers, whether this entails the use of a single-standardized test or defining cutoff scores for multiple tests.

Table 2 Characteristics of Studies Selected

	Monfort et al⁷	Herman and Barth²	Shibata et al⁶
Study design	Cross-sectional	Cross-sectional	Cross-sectional
Study title	Visual-spatial memory deficits are related to increased knee valgus angle during a sport-specific sidestep cut	Drop-jump landing varies with baseline neurocognition: implications from ACL injury risk and prevention	The influence of differences in neurocognitive function on lower limb kinematics, kinetics, and muscle activity during an unanticipated cutting motion
Participants	15 male athletes (mean age 20.7 [2.0] y, height 1.78 [0.07] m; weight 76.5 [8.9] kg)	37 athletes (age 18–30) High-performance group: mean age 21.05 (1.54) y; height 1.73 (0.07) m; weight 68.68 (9.26) kg Low-performance group: mean age 20.81 (1.68) y; height 1.71 (0.12) m; weight 70.11 (10.12) kg	15 female athletes (mean age 20.1 [1.3] y; height 1.67 [0.7] m; weight 60.6 [6.9] kg)
Inclusion/exclusion criteria	Inclusion: current members of the male college club indoor soccer team or had been members in the past 2 mo; no history of traumatic (resulting in surgery and time loss) knee/ankle injury or minor injuries (hindering but not resulting in time loss) in the past 3 mo that limited their participation; Tegner Activity Scale ≥ 7 and Marx Activity Scale ≥ 12 Exclusion: no specific exclusion criteria were noted	Inclusion: recreational athletes who participate in jumping/cutting sports at least 3 times a week OR participate in these sports at least once a month and previously participated in high school varsity or college club levels Exclusion: did not meet age criteria, did not meet the activity-level criteria, had a lower-extremity injury that prevented participation for longer than 2 wk over the previous 6 mo, possessed cardiovascular, respiratory, neurological, or other conditions that prevented them from participating at maximal effort, had suffered a concussion within the last year	Inclusion: play sports including jumping/cutting motions; practicing 2–3 h a day, 5–6 d a week Exclusion: injuries in the lower limb, a concussion within the past 6 mo, any disorder of the peripheral sensory system, past history of surgery in the lumbar spine or lower limbs
Methods	Participants completed the ImPACT cognitive assessment that includes visual memory, verbal memory, reaction time, and processing speed. BH, followed by NB handling maneuvers were collected while running 6 m, planting on the nondominant limb, then cutting 45° in a single step. They performed BH at the fastest speed while maintaining dribbling control, and then the NB trials were completed within a 10% mean speed of the BH trial. Eight trials were collected for each condition. Retroreflective markers were placed on the pelvis and lower-extremity and shoes. The marker data was collected using a motion capture system. Ground reaction forces were sampled using force platforms.	Participants completed the CRI that included 6 subset domains: the reaction time, the cued reaction time, the animal decoding, the visual recognition 1 and 2, and the symbol scanning subsets. They were then separated into HP and LP. Participants stood on 30-cm box placed at a distance measuring one-half of the subject's height away. The subject stands on the box, jumps forward off the box with both feet, lands on the target, then jumps at maximum effort to the second target. The second target was revealed after leaving the 30-cm box, pointing 1 of 3 directions (left 45° angle, vertical, right 45° angle). 16 retroreflective markers were placed over the trunk, pelvis, and lower-extremity. The marker data was collected using a motion analysis system. Ground reaction forces were obtained using force plates, in conjunction with the motion capture data.	Participants were administered the SDMT and grouped into a HP or LP group based on their achievement rate. Participants jumped off a 30-cm high box, then performed a random task according to a command on a personal computer monitor immediately after leaving the box. The tasks included a side-step cutting 45°, single-leg landing, and forward stepping using the dominant limb. 35 retroreflective markers were placed over the whole body. A motion analysis system was used to capture the motions. Ground reaction forces were obtained using a force platform that was synchronized with the kinematic data. Surface EMG was recorded using a 7-channel EMG system and collected synchronously with motion and force plate data.
Outcome measures	Biomechanical outcomes - Ground reaction force - pKVA - pKVM	Biomechanical outcomes - Ground reaction force - Knee adduction–abduction moment - Knee flexion and adduction–abduction joint angles - Hip flexion and adduction–abduction joint angles - Trunk flexion and lateral bending angles	Biomechanical outcomes - Ground reaction force - Surface EMG - Hip flexion, adduction, internal rotation angle - Knee flexion and valgus angle - Hip flexion and adduction moment - Knee flexion and abduction moment

(continued)

Table 2 (continued)

	Monfort et al ⁷	Herman and Barth ²	Shibata et al ⁶
Results	Worse visual-spatial memory was associated with a greater pKVA ($R^2 = 52\%$, adjusted $R^2 = 48\%$, $P = .008$). Visual memory composite score was the strongest predictor for change in pKVM but did not reach statistical significance after controlling for multiple comparisons ($R^2 = 27\%$, adjusted $R^2 = 21\%$, $P = .049$). BH had a significant group effect on pKVA ($P = .02$), having a decrease in pKVA (mean: -1.6° ; 95% CI, -3 to -0.3 ; Cohen d : 0.67) compared with NB. No significant effect was observed for pKVM.	The LP group demonstrated significantly lower CRI scores in all domains compared with the HP group. Processing speed was a 20.3% difference, simple reaction time was 42.6% difference, and complex reaction time was 47.1% difference. The LP group had a 31% higher peak vertical ground reaction force and 26% higher peak proximal anterior tibial shear force. The LP group also had a difference of 4.8° in knee abduction angle.	The average SDMT achievement rate was 65.0% (6.8%). The top 7 were placed in the HP group (achievement rate 70.8% [5%]), the remaining 8 were placed in the LP group (60.0% [3.1%]). The knee extensors (QUAD) activity was larger in the LP group compared with the HP group at 50 ms before initial contact (pre-IC) and the first 50 ms of the cutting phase (post-IC). The CCR was larger at pre-IC and significantly larger at post-IC. When looking at the P value for peak kinematics and kinetics, it showed no statistical significance. However, the effect size for knee valgus was 0.49 and the effect size for knee moment, knee flexion, and hip flexion were 0.77, 0.90, and 0.96, respectively.
Conclusion	Neurocognitive test scores on visual-spatial memory were associated with neuromuscular control during a dripping task, more specifically increased knee valgus. Assessing this neurocognitive domain may be useful in identifying athletes with reduced neuromuscular control.	Athletes who performed poorer on baseline neurocognitive assessments also demonstrated knee kinetics and kinematics that are related to ACL injury. Assessing neurocognitive performance may aid in the identification of those are elevated injury risk.	Lower performance on the SDMT was associated with quadriceps dominant muscle activity that has been reported to increase the load on the ACL, presenting a potential increased risk.
Level of evidence	3B	3B	3B
Validity scores	13/16	12/16	13/16
Support for the answer	Yes	yes	yes

Abbreviations: ACL, anterior cruciate ligament; BH, ball handling; CCR, co-contraction ratio; CRI, concussion resolution index; EMG, electromyography; HP, high performance; ImPACT, Immediate Post-Concussion Assessment and Cognitive Testing; LP, low performance; NB, nonball ; pKVA, peak knee valgus angle; pKVM, peak knee valgus moment; SDMT, Symbol Digit Modalities Test.

Future research should examine changes in biomechanics following neurocognitive training. As previously mentioned, there are different ways to effectively measure neurocognitive performance; therefore, there are also different means of challenging neurocognition. This preventative approach could challenge aspects such as reaction time, visual memory, and processing speed. Wilkerson et al¹² assessed and trained visuomotor reaction time in college football players. Assessment and training were completed using a visuomotor reaction time system (VMRT) with 64 target buttons to press when illuminated, tracking the average number of target hits, and the amount of elapsed time between hits.¹² First, after administering preseason baseline testing then tracking injuries over the course of the season, 52% of the slower players sustained a strain or sprain versus 32% of the faster players.¹² In addition, after implementing a visuomotor training program during the postseason, there was an improvement in reaction time performance in the slow performers group but not in the fast performers group.¹² This may suggest that VMRT may be a modifiable risk factor to injury, but there may be a cap on the maximum level of performance improvements. These results identify an area for further investigation to identify how this translates to injury risk, prevention, and rates as it is an intervention that can be widely applied. Similar methods could be employed to track the implementation of a neurocognitive training. As previously mentioned, neurocognition takes many forms. This training program could employ similar reaction time methods as Wilkerson et al,¹² it could come in the

form of memory training games, or it could challenge processing speed. To take it a step further, if the primary neurocognitive test could identify which portion of neurocognition players are weakest in, the training could be more focused. However, these interpretations must be made with caution as it is unknown if biomechanical faults improve or if injury rates improve following training.

Based on the literature reviewed in this CAT, a relationship between neurocognition and lower-extremity biomechanics has been repeatedly demonstrated. With different methods utilized for biomechanical assessment, neurocognitive evaluation, and patient recruitment, all 3 articles included in this CAT yielded similar results. Education about neurocognitive testing and standardizing the results needs to be further developed before intervention strategies can be implemented. Future research should look at the effects of neurocognitive intervention on biomechanics.

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