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Brains and Sprains: The Brain's Role in Noncontact Anterior Cruciate Ligament Injuries

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Growing evidence implicates several neuropsychological factors in the mechanism of noncontact anterior cruciate ligament (ACL) sprains.[1–6] Just before the joint loads is a short period of time when sensory integration and complex motor planning must accurately predict impending joint loads.[7] Errors in judgment or unanticipated stimuli may cause a momentary loss of situational awareness or startle responses.[6,8,9] If the brain's executive functioning is unable to successfully negotiate the rapidly changing environmental conditions, then the action-planning networks are disrupted and task uncertainty ensues. The subsequent loss of neuromuscular control and inability to optimally regulate knee-joint stiffness diminishes dynamic stability. This can lead to unconstrained columnar buckling, which is often associated with noncontact ACL injury pathomechanics.[8,10,11] In this article, I briefly review anecdotal, theoretical, and clinical research evidence for the brain's role in maintaining joint stability and neuropsychological factors that may render individuals injury prone.

INJURIES AT THE SPEED OF THOUGHT

Although research on ACL injury pathomechanics has advanced, the underlying reasons for uncoordinated, high-velocity movements observed during noncontact sprains are not well understood. Fundamental neuropsychological characteristics are responsible for situational awareness, sensory integration, motor planning, and coordination, all of which control joint stiffness, and thus, may also profoundly influence one's overall injury-avoidance strategy, regardless of sex.

Yasuda et al[12] suggested that the ACL may tear in less than 70 milliseconds, but the earliest reflexive activity for dynamic restraint requires at least 35 milliseconds to begin developing muscle tension.[13] Additionally, cognitive appreciation of any coordination errors can take up to 500 milliseconds.[12,14] Therefore, the high movement velocities and forces associated with athletics require advanced cognitive planning through feed-forward motor control; otherwise, overreliance on reflexive strategies for dynamic stability may be insufficient to protect the ACL.[15–17]

Formulating these preprogrammed movement patterns, even familiar ones, can take several hundred millseconds.[15,16] We know this because anticipatory postural adjustments are observed 500 milliseconds before athletic maneuvers; to stiffen the knee, preparatory thigh muscle contractions predictably start 150 milliseconds before loading.[7,18] We even know that the reactive muscular contractions typically associated with involuntary reflexes can actually be preplanned in supraspinal regions.[19] This means that the entire sequence of biomechanical events before an injury may have originated from errors or delays in the perception or action neural networks responsible for anticipating movement performance and joint-stability prerequisites.

TUNING MUSCLE STIFFNESS

Bach et al[20] and Nigg and Liu[21] suggested that we continuously adjust the viscoelastic properties of muscle depending on the anticipated functional demands (eg, landing, cutting, decelerating). The neural origin of this "muscle tuning" has a net effect on muscle contractions that can increase joint stiffness 10-fold, maximizing performance while preserving joint equilibrium and stability.[22] To optimize stiffness for each task, the surrounding physical environment must be quickly modeled within the brain before the athletic maneuvers are actually executed. This process is largely unconscious, and in fact, conscious "overthinking" and arousal levels may delay or interrupt routine functional maneuvers.

Several well-known neuropsychological characteristics are important for quick formation of this internal model. Several colleagues and I[1] captured prospective neuropsychological data that included processing speed, reaction time, memory, and visual-spatial abilities from a group of collegiate athletes. The athletes who sustained noncontact ACL tears had decreased scores for each of these characteristics before injury. Although these deficits are common in concussed athletes, recent authors[5,23] have also found direct correlations, suggesting that more musculoskeletal injuries occur after mild head injuries. From these combined results, we may infer that executive-function skills have a substantial role in unintentional (accidental) musculoskeletal injuries such as noncontact ACL sprains.

VISUAL-SPATIAL DISORIENTATION

These mental faculties have critical roles in maintaining overall situational awareness by redirecting attention to important environmental cues and simultaneously choosing the appropriate anticipatory motor program necessary for coordinated movements.[6,24] Visual-spatial disorientation may lead to task uncertainty, attenuated muscle activity, and poor coordination.[6,8,25] Similarly, if the athlete is attempting to mentally negotiate multiple sensory stimuli or motor tasks simultaneously, the additional cognitive load may be enough to slow reaction times and processing speed and to diminish knee-stiffness–regulation strategies.[26]

Usually athletes cope with sport-specific situational demands and adjust their attention to focus on the appropriate environmental cues, so they can plan movements accordingly.[27] However, during high-speed, complex athletic maneuvers, cognitive faculties are under even greater stress and may be unable to reconcile the overabundant somatosensory information with the biomechanical demands of a rapidly changing physical environment. Unexpected joint loads during this planning period may be inconsistent with the brain's internal model of anticipated events. Such is the case for noncontact ACL injuries, during which the anticipated and real-life conditions are unexpectedly incompatible. This leads to incorrect, preprogrammed knee-stiffness–regulation strategies and movement errors.[16] Moreover, if sudden, unanticipated environmental stimuli occur, the involuntary startle response may be provoked, superseding routine preprogrammed motor patterns.[28]

UNANTICIPATED EVENTS

It is well documented that unanticipated events can provoke a universal startle response within the central nervous system, resulting in a brief, involuntary, and widespread change in neuromuscular activity.[9,28] In terms of reliance on visual information, athletes may suffer a brief episode of "inattentional blindness" and fail to recognize important visual cues simply because they were not expecting them. Unanticipated images, even friendly faces, can provoke startle responses, but the most common research model uses acoustic stimuli.[29] In recent research,[9] colleagues and I provoked a startle response during the preparatory phase, 100 milliseconds before a simple knee perturbation. Knee-extensor moment increased briefly after the startle response, but then knee stiffness diminished. If this rapid sequence occurs during functional activities, the temporary increase in the knee-extensor moment might straighten the knee, but then a precipitous drop in knee stiffness would leave the capsuloligamentous structures exposed to excessive loads and columnar buckling beyond the joint's normal arthrokinematics.[11] If the immediate physical surroundings are not correctly anticipated or suddenly change at an inopportune time, such as during the preparatory phase of landing or cutting, then normal stiffness-regulation strategies can be disrupted and dynamic restraint will be compromised.

FUTURE DIRECTIONS

These preliminary theories may guide researchers to pursue studies in several areas related to ACL injury prevention. More data are needed to establish the precise periods of time when individuals are vulnerable due to cognitive demands such as sensory integration, decision making, and motor planning. Sport-specific situations that may disrupt situational awareness in athletes can be explored, with particular focus given to visual attention in high-intensity, dynamic, complex environments. Mapping the specific neural networks used throughout the critical interval of time when joint loading occurs also requires investigation, especially among those individuals who have sustained bilateral ACL injuries and in case-control participants who remain injury free despite exposure to high-risk sports. Lastly, additional neuropsychological characteristics that may influence one's ability to avoid injury deserve attention; these include locus of control, sensation seeking, kinesiophobia, stress, and emotional regulation.

SUMMARY

Small mental errors in judgment or coordination at ill-timed phases of movement planning could lead to the rapid, premature onset of large joint forces during sports. If these loads are not fully anticipated, then preprogrammed muscle contractions may be insufficient for stiffness levels to provide dynamic restraint, regardless of sex. This sequence of events would limit the capacity of muscles to act in a load-compensating manner, thereby exposing capsuloligamentous structures to failure. The importance of various neuropsychological characteristics in injury proneness should be explored to enhance prevention and rehabilitation strategies.

REFERENCES

1. Swanik CB, Covassin T, Stearne DJ, Schatz P. The relationship between neurocognitive function and noncontact anterior cruciate ligament injuries. *Am J Sports Med*. 2007;35(6):943–948.
2. Louw Q, Gillion N, van Niekerk SM, Morris L, Baumeister J. The effect of vision on knee biomechanics during functional activities - a systematic review. *J Sci Med Sport*. 2015;18(4):469–474.
3. Baumeister J, Reinecke K, Weiss M. Changed cortical activity after anterior cruciate ligament reconstruction in a joint position paradigm: an EEG study. *Scand J Med Sci Sports*. 2008;18(4):473–484.
4. Hutchison M, Comper P, Mainwaring L, Richards D. The influence of musculoskeletal injury on cognition: implications for concussion research. *Am J Sports Med*. 2011;39(11):2331–2337.
5. Pietrosimone B, Golightly YM, Mihalik JP, Guskiewicz KM. Concussion frequency associates with musculoskeletal injury in retired NFL players. *Med Sci Sports Exerc*. In press.
6. Pashler H. Dual-task interference in simple tasks: data and theory. *Psychol Bull*. 1994;116(2):220–244.
7. DeMont RG, Lephart SM, Giraldo JL, Swanik CB, Fu FH. Muscle preactivity of anterior cruciate ligament-deficient and -reconstructed females during functional activities. *J Athl Train*. 1999;4(2):115–120.
8. Woo E, Burns Y, Johnston L. The effect of task uncertainty on muscle activation patterns in 8–10-year-old children. *Physiother Res Int*. 2003;8(3):143–154.
9. DeAngelis AI, Needle AR, Kaminski TW, Royer TR, Knight CA, Swanik CB. An acoustic startle alters knee joint stiffness and neuromuscular control. *Scand J Med Sci Sports*. 2015;25(4):509–516.
10. Dunning A, Ghoreyshi A, Bertucco M, Sanger TD. The tuning of human motor response to risk in a dynamic environment task. *PLoS One*. 2015;10(4):e0125461.
11. Boden BP, Sheehan FT, Torg JS, Hewett TE. Noncontact anterior cruciate ligament injuries: mechanisms and risk factors. *J Am Acad Orthop Surg*. 2010;18(9):520–527.
12. Yasuda K, Erickson AR, Beynnon BD, Johnson RJ, Pope MH. Dynamic elongation behavior in the medial collateral and anterior cruciate ligaments during lateral impact loading. *J Orthop Res*. 1993; 1(3):190–198.
13. Shultz SJ, Perrin DH, Adams MJ, Arnold BL, Gansneder BM, Granata KP. Neuromuscular response characteristics in men and women after knee perturbation in a single-leg, weight-bearing stance. *J Athl Train*. 2001;36(1):37–43.

14. Swanik CB, Lephart SM, Swanik KA, Stone DA, Fu FH. Neuromuscular dynamic restraint in women with anterior cruciate ligament injuries. *Clin Orthop Relat Res*. 2004;425:189–199.
15. Dunn TG, Gillig SE, Ponsor SE, Weil N, Utz SW. The learning process in biofeedback: is it feed-forward or feedback? *Biofeedback Self Regul*. 1986;11(2):143–156.
16. Ghez C, Krakauer J. The organisation of movement. In: Kandel ER, Schwartz JH, Jessell TM, eds. *Principles of Neural Science*. Vol 4. New York, NY: Elsevier Science Publishing; 1991:653–673.
17. Lephart SM, Swanik CB, Huxel K. Reestablishing neuromuscular control. In: Prentice WE, ed. *Rehabilitation Techniques in Sports Medicine*. Vol 4. New York, NY: McGraw-Hill; 2003:100–120.
18. Bouisset S, Zattara M. Biomechanical study of the programming of anticipatory postural adjustments associated with voluntary movement. *J Biomech*. 1987;20(8):735–742.
19. Santello M, McDonagh MJ, Challis JH. Visual and non-visual control of landing movements in humans. *J Physiol*. 2001;537(pt 1): 313–327.
20. Bach TM, Chapman AE, Calvert TW. Mechanical resonance of the human body during voluntary oscillations about the ankle joint. *J Biomech*. 1983;16(1):85–90.
21. Nigg BM, Liu L. The effect of muscle stiffness and damping on simulated impact force peaks during running. *J Biomech*. 1999;32(8): 849–856.
22. Markolf KL, Graff-Radford A, Amstutz HC. In vivo knee stability: a quantitative assessment using an instrumented clinical testing apparatus. *J Bone Joint Surg Am*. 1978;60(5):664–674.
23. Hutchison M, Comper P, Mainwaring L, Richards D. The influence of musculoskeletal injury on cognition: implications for concussion research. *Am J Sports Med*. 2011;39(11):2331–2337.
24. Consiglio W, Driscoll P, Witte M, Berg WP. Effect of cellular telephone conversations and other potential interference on reaction time in a braking response. *Accid Anal Prev*. 2003;35(4):495–500.
25. Ford KR, Myer GD, Toms HE, Hewett TE. Gender differences in the kinematics of unanticipated cutting in young athletes. *Med Sci Sports Exerc*. 2005;37(1):124–129.
26. Kim AS, Swanik CB, Higginson C, Thomas SJ, Kaminski TW. Reactive knee stiffening is diminished under cognitive loads [abstract]. *J Athl Train*. 2010;45(suppl 4):S47.
27. Nideffer RM. Comparison of self-report and performance measures of attention: a second look. *Percept Mot Skills*. 1977;45(3, pt 2): 1291–1294.
28. Davis M. The mammalian startle response. In: Eaton RC, ed. *Neural Mechanisms of Startle Behavior*. New York, NY: Plenum; 1984:287–351.
29. Lang PJ. The emotion probe: studies of motivation and attention. *Am Psychol*. 1995;50(5):372–385.

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