A NOVEL STUDY EXAMINING COGNITIVE-MOTOR INTERFERENCE AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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The aim of this study is to assess the feasibility of examining cognitive motor interference (CMi) in athletes following anterior cruciate ligament reconstruction (ACLR) and return to sport through electroencephalography (EEG) and three-dimensional motion capture recordings. A 128-electrode EEG system is used to track brain wave patterns for specific biomarkers of CMi during sitting and balance tasks. An 8-camera Optitrack system is used to obtain three-dimensional kinematics during anticipated and unanticipated drop vertical jumps. Preliminary EEG N200 amplitudes (ACL: -4.99 ± 2.39; Control: -7.75 ± 5.83) and peak knee flexion (ACL: 93.29 ± 12.92°; Control: 92.87 ± 7.17°) during dual-task and unanticipated landings, respectively, demonstrate the feasibility of this study. Future work will continue to assess the effect of CMi on risk factors for secondary ACL injury.

KEYWORDS: Anterior cruciate ligament, return to sport, cognitive-motor interference

INTRODUCTION: The majority of the 200,000 anterior cruciate ligament (ACL) injuries that occur in the U.S. annually are experienced by school-age athletes and at a rate that is increasing by more than 2% every year (Beck et al., 2017). Most ACL injuries occur from noncontact mechanisms during jumping, pivoting, and cutting that result in aberrant neuromuscular control (Hewett et al., 2005). Return to sport (RTS) rates after ACL reconstruction are quite high, yet among those athletes less than 25 years of age who RTS, 24-30% will experience a secondary ACL injury to the ipsilateral or contralateral limb within two years of clearance (Zacharias et al., 2021). Mechanical deficits during landing tasks, including increased hip adduction and knee abduction, and decreased knee flexion angles, persist after RTS and place athletes at an increased risk for secondary ACL injury (Delahunt et al., 2011; Goerger et al., 2015).

Additionally, post-ACLR athletes demonstrate reduced functional brain connectivity between sensory and motor regions (Diekfuss et al., 2019). The cognitive system is of limited-capacity such that when completing two or more tasks concurrently ("dual-tasking"), performance drops because one's available neurocognitive resources are divided between the tasks (Tombu & Jolicœur, 2003). Dual-tasks, which require concurrent cognitive and neuromuscular control, create cognitive-motor interference (CMi) and result in higher-risk landing biomechanics than those which are observed in single-tasks in non-injured athletes (Almonroeder et al., 2018). Biomarkers of CMi are brain wave patterns derived from the electroencephalogram (EEG) and are called event-related potentials (ERPs) (De Sanctis, et al., 2014). These CMi ERPs, such as the "N200" ERP, are reduced in amplitude in dual-tasks compared to single-tasks (De Sanctis et al., 2014). Post-ACLR athletes allocate greater cognitive and neurophysiological supply to simple single-task knee movements (Baumeister et al., 2008, 2011), which aligns with findings of mechanical deficits during traditional single-task jump landings (Goerger et al., 2015; Hewett et al., 2005). Furthermore, post-ACLR athletes demonstrate poorer postural stability compared to controls, which is amplified during dual-task environments (Miko et al., 2021; Mohammadi-Rad et al., 2016). These findings suggest that because post-ACLR athletes experience greater neurophysiological load during simple knee movements they may experience greater CMi than controls and that dual-task landings may provide greater clinical utility for predicting secondary ACL injury risk. As such, the purpose of this study is to assess the feasibility of prospectively examining neurophysiological and biomechanical indices of cognitive-motor interference (CMi) after ACLR and RTS. It is hypothesized that post-ACLR athletes who return to sport experience greater CMi than non-injured controls, as demonstrated by weaker dual-task EEG brain activity during postural stability tasks and poorer dual-task landing biomechanics.

METHODS: Eligible participants are post-ACLR athletes without associated ligament tears less than 25 years of age who have returned to sport and controls matched for age, sex, sport, leg dominance, and BMI (Table 1). To date, data for two ACLR participants and two matched controls have been collected. Testing includes completion of single- and dual-cognitive-motor tasks during EEG recording and anticipated and unanticipated drop vertical jumps during three-dimensional (3D) motion capture. During 128-electrode EEG (Magstim EGI) recordings (Net Station 5.4), participants complete a Flanker task during randomized blocks of seated (single-task) and single-leg stance on the reconstructed or matched leg (dual-task) positions (Figure 1A). For each, 128 trials of five arrows are rapidly presented and a button-box is used to determine the direction of the middle arrow in congruent and incongruent conditions (Figure 1B), with each condition accounting for 50% of trials.

Table 1. Participant Demographics

	ACLR	Matched Control
Participants (#Females)	2 (2)	2 (2)
Age (years)	21 ± 1.0	21 ± 1.0
Height (in)	67.5 ± 2.5	68.5 ± 1.5
Weight (lbs)	143 ± 7.0	155 ± 5.0
Days Since Injury	535.5 ± 140.5	N/A
Days Since RTS	233.5 ± 113.5	N/A

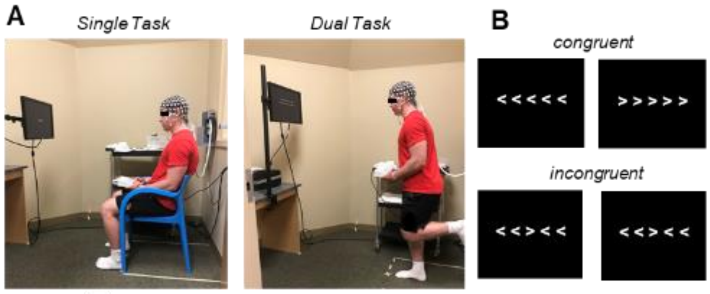

Figure 1. Participant seated and single-leg stance positions with 128-electrode EEG recordings (A) and Flanker test stimuli (B)

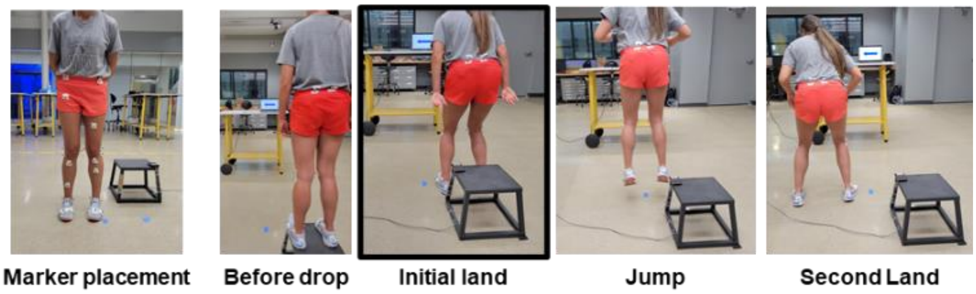

Figure 2. Drop-vertical jump protocol

During biomechanical data collection, an eight-camera 3D motion capture system (OptiTrack PrimeX 13W; Motive 2.3.1) tracks 30-retroreflective markers are placed onto different anatomical landmarks of the participant's lower body using the Rizzoli Lower Body Protocol (Leardini et al., 2007). Retroreflective markers are placed on both affected and unaffected limbs. Participants then complete a drop vertical jump (DVJ) task. The participant is instructed to drop down from a 12-inch plyometric box, land bilaterally, and then complete a

secondary jump in a specific direction (Figure 2). The direction of the jump is presented visually on a monitor by an arrow in either the leftward, rightward, or upward direction (E-Prime 3.0 PST). Participants complete DVJs under two conditions; anticipated (single-task) and unanticipated (dual-task). In the anticipated trials, the direction of the secondary jump is seen prior to the start of the trial. During the unanticipated trials the same drop vertical jump is completed, however the direction of the arrow is not visually presented until 250 ms after the participant's foot has left a foot pedal located on the plyometric box. For each condition, participants complete 15 trials in total, with each direction being presented in both equal amounts (5 times) and random order.
EEG data are processed in EEGLAB and ERPLAB toolboxes. The EEG brain activity evoked after the onset of stimuli are assessed, and ERPs for each correct trial are averaged within condition (congruent, incongruent) and task (single-task, dual-task). Specifically, the N200 peak amplitudes (Negative voltage deflection ≈ 200 ms after flanker onset) within each combination of condition and task are assessed to identify the amplitude of CMi in the dual-task condition relative to single-task condition (De Sanctis et al., 2014). Biomechanical trials in which participants jumped correctly are tracked in Optitrack Motive. Peak knee flexion values are identified, and both hip and knee frontal plane angles are obtained at the time of peak knee flexion. The injured limb was assessed for ACLR and the dominant limb for controls.

RESULTS & DISCUSSION: Preliminary EEG and kinematic data and were collected. Given the small sample size and preliminary status of this study, data are presented graphically and descriptively to demonstrate study feasibility. Table 2 illustrates N200 amplitude differences between groups for the single- and dual-task Flanker conditions (Figure 3, Table 2).

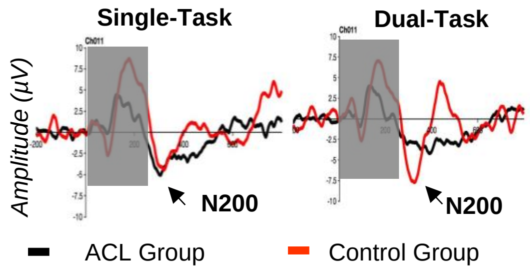

Table 2. Average N200 amplitude across incongruent Flanker trials

Group	Single Task	Dual-Task
ACL	-6.0 ± 0.25	-4.99 ± 2.39
Control	-4.6 ± 2.65	-7.75 ± 5.83

Figure 3. N200 brain biomarker of cognitive-motor interference in single- and dual-task conditions

Hip and knee kinematic differences between both groups for the single- and dual-task DVJ are presented in Figure 4.

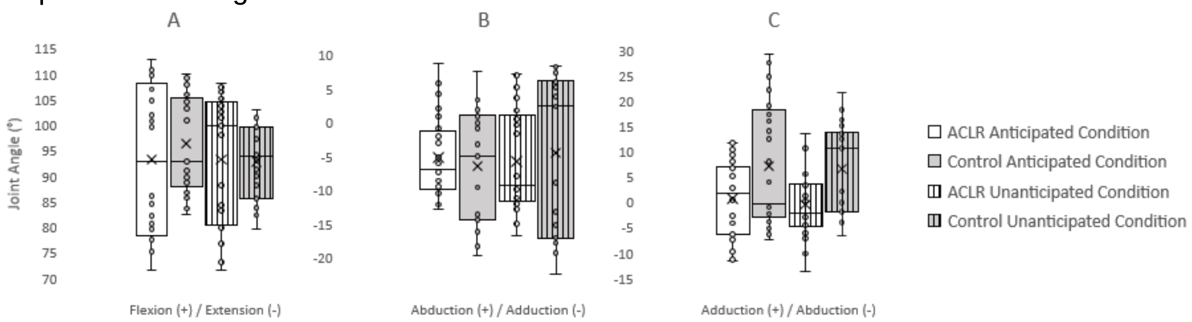

Figure 4. Peak knee flexion (A), hip frontal plane angle at time of peak knee flexion (B), and knee frontal plane angle at time of peak knee flexion (C) in anticipated and unanticipated conditions. Horizontal lines represent median values, and (x) markers represent mean values.

These preliminary data demonstrate the feasibility of using ERP and three-dimensional motion capture approaches to examine markers of CMi after ACLR.

CONCLUSION: EEG recordings can be used to obtain N200 amplitudes and assess CMi induced by dual-tasks in individuals post-ACLR. Additionally, three-dimensional motion capture can be used to assess hip and knee kinematic differences for anticipated and unanticipated landings post-ACLR. This preliminary data demonstrates the feasibility of a study that combines EEG recordings and 3D kinematics to examine the effect of CMi after ACLR. As this study continues, N200 and hip and knee kinematic differences will be quantitatively and prospectively analyzed to assess their contribution toward risk for secondary ACL injury.

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