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Use of Objective Neurocognitive Measures to Assess the Psychological States that Influence Return to Sport Following Injury

Nathan D. Schilaty, **DC, PhD**[1,4], **Christopher Nagelli, MS**[1,5], and **Timothy E. Hewett, PhD**[1,2,3,4,5]

[1]Mayo Clinic, Department of Orthopedic Surgery

[2]Mayo Clinic, Department of Physical Medicine & Rehabilitation

[3]Mayo Clinic, Department of Physiology & Biomedical Engineering

[4]The Ohio State University, Sports Health & Performance Institute

[5]The Ohio State University, Department of Biomedical Engineering

Abstract

There is growing interest in the effects of psychological states on human performance, especially with those that have suffered debilitating injury and are attempting to return to sport (RTS). Current research methods measure psychological states through validated questionnaires; however, these outcomes only allow for subjective assessment and may be unintentionally biased. Application of objective neurocognitive measures correlated with psychological states will advance understanding of injury outcomes by identifying human behavior and avoiding vague assumptions from subjective measures.

1. Introduction

Injury is a potential adverse consequence of participation in sports. The current medical paradigm for treating musculoskeletal injuries is to exclusively address the localized pathology, neglecting the effect of a psychological impact on the athlete. An example of a musculoskeletal injury that follows this model of medical care is anterior cruciate ligament (ACL) tears. ACL injured athletes resort to ACL reconstruction (ACLR) to regain ligamentous integrity and return to sport (RTS) in a timely manner [1]. Post-operative rehabilitation protocols and evidence-based RTS criteria focus on localized acute symptoms that manifest in functional and muscular impairments [2]. An indication of success of the post-injury medical management of ACL-injured athletes is the rate of returning to preinjury level of sport. A review of the current state of play of ACLR athletes reported that less than two-thirds of athletes returned to their preinjury level of sport [3]. Furthermore, the majority

Correspondence: Name: Nathan Schilaty, DC, PhD, Address: 200 First Street SW, Biomechanics Laboratories, R0_GU_01_28BIOM, Rochester, MN 55905, Telephone: 507-284-4937, Fax: 507-266-2533, schilaty.nathan@mayo.edu.

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of athletes have not attempted a return to pre-injury level of competitive sport by 12 months after ACLR [4]. While the majority of athletes eventually return to some form of activity [3,5], residual impairments that are not recognized or addressed by postoperative rehabilitation may significantly limit the athlete's capacity to RTS. The failure of these athletes to return to preinjury level of sport indicates that the current medical paradigm is inadequate [6].

An athlete's *ability* to return to preinjury level of activity may be significantly limited by psychological barriers. Despite the recovery of strength and function of the ACLR knee, the most common reason for reduction in sport participation or complete cessation of athletic activity is the “fear of reinjury” [4,7]. Studies that have compared athletes that have RTS and those that have not observed that athletes that successfully RTS report a lower “fear of reinjury” [8,9]. In addition, a maladaptive psychological *response* to injury may significantly influence whether or not an athlete will RTS [10]. Specifically, a study utilizing the self-determination theory framework (which includes autonomy, competence, and relatedness) to understand how a psychological response may influence outcomes found that athletes that experienced a positive psychological response (i.e. confidence, motivation, and a low kinesiophobia), were more likely to RTS at a quicker rate [10,11]. The initial psychological response of fear of reinjury or movement may be abated by regaining mechanical stability during ACLR [12] and post-operative rehabilitation [13]. Chmielewski et al. [14] observed changes in psychosocial factors are potentially modifiable early after ACLR. However, despite the overall emotional responses of athletes improving during post-operative care, studies have noted that “fear” is the most prominent emotion at the time that athletes are returning to activity [11]. The inability to quantify or objectively measure fear is a significant limitation to rehabilitation, translating into a potentially poor clinical understanding on injured athletes.

The demographic most at risk for suffering ACL injuries are young, active athletes [15]. These athletes may experience a multitude of emotions after injury; the athlete is isolated from their peer group and absent from a significant portion of their season. This is directly evident in lower academic performances in young athletes following ACL injury and ACLR [16]. Athletes avoiding the reintegration to sport despite establishing preinjury level of function in the ACLR knee indicates an underlying psychological issue [5]. Although psychological factors are acknowledged in the literature as a critical measure for RTS, these factors are not commonly addressed in post-operative rehabilitation. The purpose of this article is to highlight the importance of objectively measuring the psychological states of athletes (neurocognition) after injury. As research regarding neurocognition progresses, clinicians will be able to have readily available tools to assess and treat the whole athlete more effectively, producing improved outcomes for RTS with robust evidence-based protocols.

2. Current Sport Psychology Measures

Subjective questionnaires are the current standard for treating clinicians to measure a cognitive or emotional response to an injury. Numerous self-reported outcomes have been developed to efficiently measure symptoms, disability, pain, and emotion following injury.

General questionnaires, such as the Short-Form (SF-36) Health Survey [17], include questions regarding the frequency of an elicited negative emotion following injury. The Emotional Response of an Athlete to Injury Questionnaire (ERAIQ; [18]) has been utilized in an injury cohort to assess the emotional reaction to injury. Other subscales, such as the Knee Osteoarthritis Outcomes Scale (KOOS; [19]) includes questions that address a subject's confidence relating to their knee. Furthermore, the Pain Catastrophizing Scale was developed to quantitatively measure an athlete's pain experience and the thoughts and emotions generated by the pain [20].

Specific to ACL injuries, validated questionnaires used in some clinical practices are the Anterior Cruciate Ligament Return to Sport Index (ACL-RSI) and the Tampa-Scale of Kinesiophobia (TSK-11, shortened version). The ACL-RSI questionnaire developed by Webster et al. was validated as a scale to measure the psychological impact of RTS after an ACLR. The scale consists of 12 questions that focus on three types of psychological responses that have been associated with RTS following an injury: emotion, confidence in performance, and risk appraisal [21]. The ACL-RSI demonstrated acceptable reliability; the athletes that did not resume their respective sport scored lower averages (reflecting a more negative psychological response) than the athletes that did RTS [21]. The TSK was developed to assess the behavior of a patient exhibiting chronic pain, relating “fear” as the means to avoiding painful activity that would cause further injury [22]. This “fear” avoidance model indicates that the recovery from a musculoskeletal injury may be influenced by psychological factors such as kinesiophobia or pain catastrophizing. The original survey of 17 questions utilizes a 4-point Likert scale with options ranging between ‘strongly disagree’ to ‘strongly agree’ [22]. TSK has been predominantly used to study patients recovering from low back pain, but a shortened version of the TSK-11 has been validated to measure kinesiophobia by George et al. to be used in an ACL-injured cohort during postoperative rehabilitation [23]. Recovery from a musculoskeletal injury has been strongly associated with psychological deficits from both the ACL-RSI and TSK-11 scales [21,22].

Although self-administered questionnaires are valuable tools that easily assess the psychological factors impacting an athlete, they may present with significant limitations. An athlete's self-perception is subjective and the absence of objective measures may lead to inadequate clinical interventions. Responses regarding behaviors such as “fear” or “lack of confidence” can be subjectively biased if interpreted with negative connotations, motivation levels, and peer influence. In addition, the athlete can develop symptoms of clinical anxiety and/or depression resulting from injury, further biasing their ability to RTS [10]. Due to the overwhelming subjectivity, the current measures cannot clearly delineate the spectra of various psychological responses an athlete may experience.

3. Future Directions: Neurocognitive Assessment

The psychological state of the individual, when properly measured neurocognitively, will identify characteristics and patterns of brain activity and allow for objective classification improving clinical outcomes [24,25]. Neurocognition refers to correlating emotional / psychological factors and cognitive processing with physiological patterns of neural activity

[25]. Thus, we discuss various neurocognitive methodologies that could be utilized in future research for objectively measuring psychological states of athletes attempting to RTS.

Electroencephalography (EEG) is an inexpensive modality useful in measuring the cortical activity of the brain. Although EEG is limited to measurement of only superficial electrical activity and cannot localize activity to specific brain structures, evoked responses of brainwave patterns are clearly established with the 10/20 electrode placement system and inferences can be made to both cortical and thalamic structures [26]. A recent neurocognitive study demonstrated that when an individual perceives a threat, EEG theta waves follow a pattern by localization to the occipital lobe followed by an increase of theta wave activity in the frontal lobe [27]. Thus, EEG could define neurocognitive patterns of psychological factors (i.e. fear, lack of confidence, anxiety, depression, etc.) despite its inability to specifically localize neural activity. Recent developments of dry electrode sensors with comparative ability to record raw data similar to wet electrodes provides even more accessibility to EEG in research and clinical environments due to rapid setup, signal quality, and ease of data acquisition [28,29]. Wireless, dry electrode systems could assess athletes on the field performing tasks similar to that which they will encounter during play.

Functional magnetic resonance imaging (fMRI) is an expensive modality that could prove useful for observation of localized brain activity and establishment of baseline measures of neurocognitive states from evoked imagery, sounds, or sensations. Although fMRI provides detailed imaging of the brain associated with neurocognitive processes, it is not a plausible modality for observation of an athlete while on the field or while performing a task that challenges the injured region. However, with utilization of previously established baseline measures of specific neurocognitive states (i.e. fear, anxiety, motivation), individuals that have suffered a debilitating injury could be given evoked stimuli to objectively classify their current neurocognitive state regarding their injury. Additionally, fMRI can be corroborated with EEG (known as EEG-fMRI) to further identify how EEG activity relates to specific brain regions [30], thus allowing for the less expensive findings of EEG to be properly correlated with specific brain structures / patterns of behavior.

A related modality to fMRI is magnetoencephalography (MEG). This modality allows for EEG-like signals to be localized in the brain. Similar to fMRI, baseline readings and re-testing after injury could be performed to classify neurocognitive states, defining psychological patterns with evoked stimuli to specific brain regions. Although this modality improves localization of neural activity, it is inherently expensive to implement, especially with longitudinal studies that would be required for baseline measurements and successive examination post-injury. In addition, other than comparison of evoked responses, this modality cannot be utilized in the athletic environment or field-of-play.

Functional near-infrared spectroscopy (fNIRS) allows for viewing of the hemodynamic responses similar to fMRI and positron emission tomography (PET), but can be portable and wireless similar to EEG. It has improved temporal resolution (msec vs sec) from fMRI and no ionizing radiation exposure [31] like PET. This technology could provide objective insight into the neurocognitive state similar to fMRI by demonstrating increases in blood flow to specific structures after stimuli. Unfortunately, similar to EEG, fNIRS is limited to the superficial cortical structures and cannot provide resolution for deeper brain structures.

Electrocorticography (ECoG) is an invasive modality in which an electrode array is embedded directly to the brain, thus improving localization of EEG signals. Although its use is not feasible on most human subjects, some individuals with epileptic episodes or those involved in neuroprosthetic research with implanted ECoG may consent to undergo research regarding various neurocognitive states. These neurocognitive results could then be re-tested with EEG to observe similarities of signal localization. However, behavioral animal research utilizing ECoG [32] is most reasonable to expand and correlate non-invasive EEG to specific brain regions, especially with advances in animal research in which various neurocognitive states can be evoked from various stimuli.

The above techniques could further be coupled with real-time measures of stress such as electrodermal activity (EDA; a measure of the sympathetic nervous system) [33,34] or serum/salivary cortisol levels [35] before, during, and after an anticipated kinesiophobic event. This correlated data would further identify when an individual is truly experiencing kinesiophobia or reinjury anxiety. EDA and salivary cortisol levels are relatively inexpensive and easy to implement and could assess responses at various time points throughout the rehabilitation process.

Transcranial magnetic stimulation (TMS) utilizes a non-invasive electromagnetic coil to stimulate neurons in regional sections of the brain [36]. Similar to MRI, the depth of the electric induction in the brain can be controlled. TMS is currently utilized to study neural excitability in ACLR athletes [37] and could be used therapeutically to study neurocognitive states. For example, TMS is currently used to augment fear extinction with those suffering from post-traumatic stress [38]. Therefore, TMS could be utilized at specific brain regions to mitigate the effects of kinesiophobia, thus providing insight into the neural activation patterns surrounding neurocognitive states of dysfunction.

Neurofeedback is a modality that allows individuals to manipulate their own brainwave activity. With neurofeedback, EEG waveforms are recorded, processed, and analyzed by a computer in real-time and displayed to the individual in the form of a game. The individual must utilize the specified brainwave pattern to achieve success with the game [39,40]. Thus, neurofeedback provides an individual with the ability to manipulate their own brain activity toward a specific goal. A recent study utilized neurofeedback as a means for improving sport performance [24]. Thus, as a result of one learning to control their own brain patterns, this modality could provide improvement for individuals to RTS caused by neurocognitive deficits.

We have highlighted various methods of measuring neurocognitive states that can be applied to injured athletes. All of these modalities, when utilized within their respective strengths to assess the neurocognitive states of injured athletes, will provide important objective data regarding the psychological factors that influence RTS. Although there are limitations for clinical utilization of some of these modalities, continued research will result in increased understanding of neurocognitive states and the advancement of technology. These advancements will open new frontiers of assessing neurocognitive states and applying therapy to injured athletes in the clinic. As a result, clinical scientists will be able to develop and utilize robust evidence-based RTS rehabilitation protocols that address athletes holistically.

4. Conclusion

The current subjective measures for determining psychological states following injury are limited by personal interpretations of life experience, and may differ from one individual to another. Consequently, it is imperative that objective neurocognitive measures be applied to future study of psychological states in association with the existing subjective questionnaires. The current evidence-based RTS criteria is limited to only assessing the physical readiness of the athlete, even though psychological factors can impact performance and injury risk [41]. Thus, objective neurocognitive measures will improve understanding of psychological states and advance evidence-based rehabilitation protocols.

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Key Points

1. There is increasing evidence that psychological factors may negatively influence the recovery and return to sport outcomes following musculoskeletal injury.
2. Self-reported questionnaires are the current clinical standard for evaluating psychological factors following injury; however, these outcomes are subjective measures that may lead to inadequate clinical interventions.
3. Neurocognitive measures provides an objective approach to understand the psychological factors of injury and its effect on physiological patterns of neural activity, advancing and merging the field of sports medicine and sports psychology.