

New Technology and Sports-Related Concussion

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Specialists study the connection of orthopedic injuries and concussion in athletes.

Despite considerable controversy and debate over the past two decades, recovery from sports-related concussion remains poorly understood. Much of the current confusion regarding this issue revolves around continued questions regarding when brain function returns to normal following injury. To date, most scientific information regarding recovery from concussion has been based on animal research. However, the relevance of this line of research to athletes has been questioned. This article will review new developments in research regarding recovery from sports-related concussion with a specific emphasis on functional brain imaging and computer-based neuropsychological testing technologies. In addition, this article will discuss the implications of this new research for return to play strategies in sports medicine.



ADVERSE CONSEQUENCES

The growing awareness of the potential adverse consequences of concussion has resulted in the implementation of baseline neuropsychological testing by the majority of National Football League (NFL) teams, the entire National Hockey League (NHL), and hundreds of colleges and high schools. This technology has evolved to provide a practical and inexpensive method of identifying athletes whose level of neurological functioning has not returned to normal. The Pittsburgh Steelers were the first NFL team to implement baseline neuropsychological testing in 1993. The Steelers conducted preseason baseline testing utilizing standard "paper and pencil" procedures. If an athlete was injured during the season, he was retested and a direct comparison was made to his preseason level of functioning. Due to concerns regarding concussion within the National Hockey League, the NHL developed and implemented league-wide baseline neuropsychological testing for all athletes in 1997. More recently, both the Indy Racing League (IRL) and the Championship Auto Racing Teams (CART) have mandated neuropsychological testing programs to assist in making return to competition decisions.

THE PITTSBURGH STEELERS PROGRAM

Although representing a large step forward in the development of more effective concussion management techniques, traditional neuropsychological testing has proven to be time-consuming, costly, and of insufficient sensitivity to detect mild injuries. As a result of these inherent limitations and in parallel to the widespread proliferation of the microcomputer, Pittsburgh Steelers medical staff began to develop computer-based neuropsychological testing procedures in the mid 1990s.

When compared to more traditional neuropsychological testing, computer-based testing procedures have a number of advantages. First, the use of computers allows the evaluation of large numbers of athletes with minimal manpower. This promotes the assessment of an entire football team within a reasonable time period and is therefore less disruptive to the team's schedule. Second, data acquired through testing can be easily stored in a specific computer or computer network and can therefore be more easily accessed at a later date (eg, following injury). Third, the use of the microcomputer promotes the more accurate measurement of cognitive processes such as reaction time and information processing speed. In fact, computerized assessment allows for the evaluation of response times that are accurate to 1/100 of a second while traditional testing allows for accuracy only to 1 to 2 seconds. Fourth, the utilization of the computer allows for the randomization of test stimuli that should help to improve the stability or reliability of test results across multiple evaluations of the athlete, minimizing the "practice effects" that naturally occur as an athlete becomes more accustomed to taking a specific test. These practice effects have clouded the results of research studies and have also presented an obstacle for the clinician evaluating the true degree of neurocognitive deficit following injury. Finally, computer-based evaluation promotes the unbiased evaluation of cognitive processes by eliminating error due to scoring or inter-rater reliability issues.

NEW DEVELOPMENTS IN IMAGING

Although neuropsychological testing has increasingly been utilized as a tool throughout the field of sports medicine, additional technologies have evolved that are helping to answer basic questions about the neurological consequences of concussion. In particular, new functional brain imaging techniques such as functional magnetic resonance imaging (fMRI) have emerged and are rapidly adding to our knowledge base regarding recovery from concussion. The development of fMRI for the evaluation of athletes has grown out of an awareness of the lack of sensitivity of more traditional anatomic brain imaging techniques such as computed tomography (CT) and magnetic resonance imaging. Although useful in identifying brain injury in more severe cases, CT and MRI scans are not often helpful in identifying more subtle brain-related changes that are thought to occur on a metabolic rather than an anatomic level.

fMRI has only recently developed as a viable tool for the assessment of neurological processes following mild traumatic brain injury. The technology is based on the measurement of specific correlates of brain activation such as cerebral blood flow and oxygenation. fMRI involves no exposure to radiation and repeat evaluations can be undertaken with minimal risk. This allows the evaluation of changes in brain function that may occur with mild concussion and makes it possible to track the recovery process. Although a promising tool, fMRI has yet to be widely implemented in clinical settings. This is no doubt a function of the sophisticated technology needed to acquire and analyze the images and the current considerable expense of the procedure. At the current time, only a few laboratories are actively investigating the use of fMRI in sports-related head injury, although this is likely to change within the next few years. In the United States, the laboratory at the University of Pittsburgh represents one of only a handful of programs that is structured to collect both neuropsychological and fMRI data in athletes. This multiyear, federally funded study relies on the prior baseline neuropsychological testing of a very large group of athletes who have all completed baseline testing prior to their injury. Although still preliminary, our initial data have been highly encouraging and have demonstrated a correlation of fMRI abnormalities and recovery with our computerized neuropsychological test results.

As an example of the potential usefulness of fMRI and computerized neuropsychological testing technology, we present a case of a 17-year-old female high school athlete who suffered

a concussion (See Fig 1, upper image). The initial signs of injury did not include loss of consciousness or noticeable amnesia. Rather, the athlete exhibited a brief period of confusion (approximately 30 seconds), accompanied by dizziness and sensitivity to light (photosensitivity). No immediate treatment was pursued. The following morning, however, this individual complained of a right temporal headache, as well as mild fatigue. An evaluation was subsequently conducted through the University of Pittsburgh Medical Center Sports Medicine Concussion Program during which both computerized neuropsychological testing and an fMRI were completed. The scan (Fig 1, lower image) shows the initial fMRI data at 48 hours after injury. This scan reveals an abnormal pattern of brain activation in posterior brain areas. The athlete was also evaluated 8 days postinjury at which time both fMRI and neuropsychological testing were conducted. The subject's fMRI scan at this time had normalized as evidenced by activation of expected brain areas in the frontal and temporal lobes. Her computerized neuropsychological test results were congruent with this resolution of abnormal patterns visible through fMRI, demonstrating initial decline at 48 hours after injury and a return to prebaseline levels at 8 days postinjury.

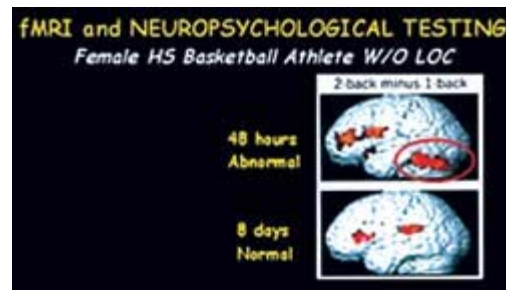


Figure 1. Functional MRI of the brain at 48 hours and 8 days post-injury. At 48 hours, the athlete demonstrates abnormal activation in the cerebellum. Brain activity returns to normal by 8 days, as does neuropsychological test performance.

CONCLUSIONS AND FUTURE DIRECTIONS

This article has focused on new developments in the management of sports-related concussion. Specifically, we have emphasized that the clinical management of concussion is evolving rapidly and we still have much to learn about both the short- and long-term consequences of injury. It is likely that the new development of functional MRI will help to answer some of the current questions that exist regarding when the brain returns to normal following concussion. However, fMRI will most likely remain primarily a research tool. The development of computer-based neuropsychological testing holds great promise regarding the clinical management of sports-related concussion.

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