

Computer-Based Assessment of Sports-Related Concussion

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Sports-related concussion has received considerable attention from neuropsychologists, athletic trainers, team coaches, physicians, families, and athletes. In this context, researchers have recently developed computer programs for the assessment of sports-related concussion. Computer-based assessment of sports-related concussion saves time, allows for team baseline testing, and can be easily incorporated into the sports medicine environment. This article reviews the advantages and limitations of computer-based assessment of sports-related concussion. Within a well-coordinated concussion management program that includes input from a neuropsychologist, computer-based assessment of sports-related concussion will soon be the most common approach for assessing concussion in athletes.

Key Words: sports-related concussion, mild traumatic brain injury, neuropsychology, computerized neuropsychological assessment

Assessment of sports-related concussion has received increased attention over the past 2 decades. Over this period, neuropsychologists, athletic trainers, and other mental health professionals have attempted to understand and document the behavioral sequelae following cerebral concussions. Within this context, neuropsychological test batteries have been routinely used to determine the effects of cerebral concussion (Zillmer & Spiers, 2001). Much effort has been dedicated to outlining the parameters of neurocognitive changes following sports-related concussions for different settings, including professional football (Collins, 2001) and professional ice hockey (Echemendia & Julian, 2001); as well as for different populations, including college athletes (Barth et al., 1989; Collins et al., 1999; Lovell & Collins, 1998).

Using traditional neuropsychological assessment techniques, single, mild concussions in healthy college-aged athletes have been shown to result in decreased neurocognitive performance, with a relatively rapid recovery curve ranging from 10 days (Barth et al., 1989) up to 1 month postconcussion (Echemendia,

Putukian, Mackin, Julian, & Shoss, 2001). Cerebral concussion in individuals with a history of previous concussion (Moser & Schatz, 2002) or learning disability (Collins et al., 1999) were found to have more enduring cognitive effects. Common to all of the aforementioned studies, cerebral concussions were observed to cause at least mild deficits in attention and concentration.

Computerized testing may play a particularly important role in the sports-concussion arena. Since the neurocognitive sequelae of concussion are often represented by relatively mild symptoms, baseline testing of athletes has been shown to be a powerful assessment tool. By comparing pre- and postconcussion neuropsychological data, the neuropsychologist can differentiate changes in neurocognitive status as a result of the concussion and evaluate the degree of symptom resolution. Given the extremely large number of athletes that may benefit from a baseline-testing paradigm, paper-and-pencil tests may be too time-consuming to allow for a wide-based, baseline-testing program, particularly in high school. To this end, computer programs with accurate timing may be best suited to identify neurocognitive deficits, track progress toward recovery, and assist in return-to-play decisions, especially when postconcussive symptoms include delayed onset of response time and increased decision-making times (i.e.,

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reduced information processing speed). It is the intention of this article to present current trends in computer-based assessment of sports-related concussion.

Advantages and Limitations of Computer-Based Assessment

The American Psychological Association (APA) has established guidelines for computer-based tests and interpretations (APA, 1986). In doing so, the APA recognized a number of potential benefits that can be derived from the proper use of a computer in the delivery of clinical assessment services. Such benefits to the client include an improved ability to capture and engage the interest of the client, the minimization of the client's frustration and loss of dignity when working on properly constructed and presented software-based tasks, and an experience of mastery and sense of control gained by the client within the context of learning to use the computer. Benefits to the examiner include the freedom to increasingly focus on treatment or qualitative assessment gained by the automation of data collection, precise measurement of multiple domains of performance (response latency or response time in milliseconds) not possible by the human observer, and more efficient task performance such as randomization of trials or rapid modification of stimuli.

Computerized versions of tests have been found to be psychometrically equivalent when compared to traditional versions (Campbell et al., 1999; Elwood & Griffin, 1972). In the computer-based form, however, assessment measures have features that may be either absent or less accurate than when administered through traditional pencil-and-paper-based forms. These features include timing of responses and latencies, automated analysis of response patterns, transfer of results to a database for further analysis, and the ease with which normative data can be collected in a group setting (Wilson & McMillan, 1991). Computerized or automated assessment measures are, by nature, highly sensitive to subtle changes in attention, concentration, and response latency. Precise control over the presentation of test stimuli can be established, thereby increasing the reliability of computer-based tests. With computerization, the ability to control visual and auditory stimulus characteristics and features such as color, animation, and sound can be easily incorporated into all aspects of the assessment process, including the presentation of on-screen instructions (Wilson & McMillan, 1991). Thus, on general performance test measures, the speed and accuracy of differentiating vi-

sual stimuli may be superior to examiner based testing. Many of these advantages cannot be achieved with conventional testing (Kane & Reeves, 1997; Mead & Drasgow, 1993).

From a financial perspective, computer-based assessment can show cost-benefit gains over traditional administration procedures (French & Beaumont, 1987), as well as increased security of test data and patient records through computerized storage (Barak, 1999). The time and staffing requirements needed to administer and analyze a standardized battery of neurocognitive measures to an entire team of athletes can be significant. Since computer-based measures can be easily administered to groups of athletes and are scored automatically, they provide a useful tool for the consulting practitioner, team physician, or athletic trainer.

Computer-based neuropsychological test administration is not free from criticism or limitations. Test developers have often failed to meet established testing standards of reliability and validity established by the APA. Poorly designed interfaces can contribute to test anxiety on the part of the examinee. And, reductions in the amount of face-to-face interaction between the clinician and examinee can lead to misdiagnosis (Space, 1981). Furthermore, some researchers and clinicians suggest that computer-based assessment can never be equivalent to traditional methods of psychological testing, as the mode of administration creates a markedly different experience for the examinee (Honaker, 1988). In addition, computer-interface interaction may be more taxing cognitively to the concussed athlete, who may already be experiencing difficulty with attentiveness and concentration as a result of his or her injury. Thus, factors extraneous to paper-and-pencil assessments, which are introduced during computer-based assessment, must be identified and evaluated with respect to their potentially disruptive effects (Bennett, 1999).

Timing of the synchronization between the computer's microprocessor and monitor cannot occur without a measurable amount of error or delay in timing, and it can be difficult to standardize or control this delay with any degree of consistency. As a result, inaccurate timing procedures have been found in software used to assess human performance. This potentially serious technical deficiency has been well documented (Reed, 1979; Westall, Perkey, & Chute, 1986). Researchers have since developed software solutions that provide near-millisecond accuracy (Westall, Perkey, & Chute, 1989). In fact, clinicians wishing to obtain a gross measure of reaction time or response onset latency may not even require such accuracy. However,

medical research efforts employing the use of functional magnetic resonance imaging (fMRI) to observe brain-behavior relationships require synching between stimuli presentation and scan acquisition within very specific time intervals (Gur et al., 2000; Gur et al., 2001). As such, fMRI technology is currently being incorporated into psychometric validation research using postconcussion and brain imaging data (Marion et al., in press) to allow accurate timing to the millisecond.

Computer-Based Neuropsychological Assessment of Sports-Related Concussion

Recently, researchers have developed computer programs for the assessment of sports-related concussion. The focus of the subsequent research has been on the utility and validation of comprehensive neuropsychological test batteries for the assessment and tracking of cognitive deficits related to sports-related concussion. Three computerized assessment approaches to assess sports-related concussion have emerged from these efforts: CogSport, HeadMinder, and the Immediate Post Concussion Assessment and Cognitive Testing (IMPACT). Comparisons among these three measures on factors such as administration time and cost, computer

requirements and available technological support, data storage, and report generation procedures are presented in Table 1.

CogSport. CogSport (CogState, 1999) is a stand-alone software product that measures reaction time and accuracy to evaluate simple and complex attention, working memory, short-term memory and new learning, incidental memory, adaptive problem solving, continuous performance, and spatial abilities. CogSport task stimuli take the form of playing cards, which are presented either individually or grouped, with specific response requirements. Test takers respond to tasks by pressing either the D or the K on the computer’s keyboard. Administration takes approximately 15 to 20 min, and results are submitted to CogState for scoring and analysis. Optional services include customized reports, custom data for import into popular statistical packages, assistance in interpretation of results for publication or presentation, assistance in the preparation of research protocols or IRB submissions, storage and retrieval of data and results, and mirroring of stored data for increased security.

CogSport was designed to evaluate changes in cognitive function, and was originally validated on approximately 300 professional Australian football play-

Table 1. *Neuropsychological Test Measures for the Computer-Based Assessment of Concussion*

Dimension	CogSport	CRI	Impact
Administration Time	15–20 min	20–25 min	20–25 min
Subtests/Tasks	Simple/Choice/Complex RT, Monitoring, One Back, Matching, Incidental & Associate Learning	Simple RT, Cued RT, Visual Recognition, Symbol Scanning, Decoding	Word Discrimination, Visual Working Memory, Sequencing, Visual Attention Span, Symbol Matching, Choice RT
Operating System	Windows 95/98/2000/NT Macintosh OS 8.6, 9, X	Internet-based: Windows- IE 5 and 6 Macintosh- Netscape 4.7	Windows 95/98/2000/NT
Administration Costs	Free to download and test \$50 per report Volume discounts available for large scale projects.	High Schools \$495/campus (250 baseline, 25 post-trauma) Universities \$995 per campus (500 baseline, 25 post-trauma) Prof. Teams/Hospitals \$1,995 (100 baseline, 25 post-trauma)	High Schools \$995.00/institution (unlimited use) Universities \$1,245/institution (unlimited use) Professional/other \$1,495/institution (unlimited use)
Tech Support	Unlimited online support	Free online support (up to 10 e-mails); \$295 for Phone support (first year)	Unlimited online and Phone support
Report Generation	\$50 per athlete per year (Discounts available for bulk testing)	No additional cost Baseline comparison reports generated automatically	No additional cost Baseline comparison reports generated automatically
Data Storage	Results stored locally on user’s computer or remotely on CogState’s server	Results stored remotely on HeadMinder’s server	Results stored on local server

Note: CRI = Concussion Resolution Index.

ers and hundreds of healthy controls across a wide range of ages (Makdissi et al., 2001). The authors indicated good test-retest coefficients and external validation with the Trail Making and Digit Symbol Substitution Tests (Collie, Darby, & Maruff, 2001). More recently, scores of 60 healthy controls on the CogSport simple and choice reaction-time tasks were compared with performance on the Digit Symbol Substitution Test and the Trail Making Test, and resultant correlation coefficients were significantly high (A. Collie, personal communication, September 2002).

Concussion Resolution Index. HeadMinder Inc., offers online neurocognitive and neurobehavioral assessment tools in the form of the Concussion Resolution Index (CRI) and Sideline Assistant (Erlanger, Feldman, & Kutner, 1999). The CRI is Internet-based, and all subtests are administered online via an Internet browser. As a result, the program is computer platform independent. Test measures are scored online, and results are accessible only to the test administrator who is responsible for interpreting and discussing test results with that athlete. The CRI is currently used by numerous professional, semipro, club, college, and high school athletic organizations on three continents.

The CRI subtests measure reaction time and speeded decision-making, and report strong concurrent validation with the Symbol Digit Modalities Test, Wechsler Adult Intelligence Scale—Third Edition Digit Symbol and Symbol Search, Grooved Pegboard, and Trail Making Tests (Erlanger et al., in press). The CRI has been found to be sensitive in identifying postconcussive symptoms, while remaining resistant to retest effects (Erlanger et al., 2001; Erlanger et al., in press). The CRI also includes an internal symptom validity measure to screen for chance responding or significantly decreased baseline test performance. The Sideline Assistant is a personal digital assistant based software application containing a roster of all athletes and pertinent medical and contact information, as well as an electronic version of the Standardized Assessment of Concussion (McCrea, Kelly, Kluge, Ackley, & Randolph, 1997).

Immediate Post Concussion Assessment and Cognitive Testing. ImpACT (Lovell, Collins, Podell, Powell, & Maroon, 2000) is a computer-based neuropsychological test battery that measures attention, memory, processing speed, and reaction time to 1/100th of a sec. The Windows-based program also consists of a selfreport symptom questionnaire and a concussion history form. Approximately 200 high

schools, intercollegiate athletic programs, and professional teams currently use ImpACT. In college football, ImpACT is utilized by 9 of the 11 Big Ten football teams, as well as teams in the Pacific-10, Southeastern Conference, and Big XII. At the professional level, ImpACT is currently in use by teams in the National Football League, Major League Baseball, the umpires of Major League Baseball, and the National Basketball Association. In addition, the Championship Auto Racing Teams and the United States Olympic Women's Hockey Team are using ImpACT.

Initial psychometric research on the ImpACT system reveals strong reliability data and validation research is in progress (Maroon et al., 2000). To date, the test developers have collected baseline data on over 5,000 athletes and have collected concussion data on approximately 340 athletes. More detailed research outlining the basic psychometrics of ImpACT (i.e., normative, reliability, and validity data) is forthcoming in the medical literature.

Discussion

When computers were first used in the 1980s for computer-based administration of psychological measures, there was much criticism directed at this new initiative. Since then, computer administered psychological tests have become more refined. As a result, psychologists have come to appreciate the many benefits of psychological tests that incorporate computer-assisted testing and interpretation (Zillmer, 1991). It seems particularly practical to use computerized neuropsychological testing for the assessment of sports-related concussions, first-and foremost, because of the number of athletes to be tested. It is now understood that a neuropsychological baseline assessment paradigm facilitates the detection and management of mild neurocognitive changes in athletes who have sustained a concussion. The generation of objective pre- and postconcussion data is particularly important because of the transient medical symptoms often seen in this population, as well as the ambiguity of determining the severity and symptom resolution of a concussion in the absence of objective neuropsychological data. In addition, computerized testing is easy, has inherent psychometric strengths, can minimize practice effects on serial assessments, is relatively inexpensive, provides accurate reaction time measurement, and can be administered in group settings. Because of these advantages, computerized testing programs can be more easily initiated in college and high school athletic

programs that often have hundreds of participants involved in sports. Because of its objectivity, computerized testing for sports-related concussions appears to have also been well received by professional teams and professional leagues within professional football, minor league hockey, and professional soccer. The future of this approach may very well be that athletic trainers and sports medicine specialists will include neuropsychological assessment in their existing protocol for the medical management of their athletes.

Most neuropsychologists critical of computerized testing will argue that such an approach removes the neuropsychologist from the scene. There certainly is some truth to this, since a comprehensive neuropsychological evaluation is best carried out in the presence of an experienced neuropsychologist (Zillmer & Ball, 1987). If one uses the forensic setting as the golden standard, perhaps because it is the most contentious, any conscientious neuropsychologist would spend considerable time with the client to obtain a neuropsychological profile. We argue, however, that the use of a widespread computerized assessment program to assess sports-related concussions will actually increase the awareness of neuropsychological services and, as a result, referrals to the neuropsychologist. Computerized assessment in sports-related concussions are very much like sophisticated screening tests; they may not provide a comprehensive evaluation of abilities, but they do provide objective evidence of neurocognitive strengths and weakness, and a pre-post comparison.

In addition, computerized tests facilitate the creation of data banks as a means of studying concussions and thus may very well prove to be a terrific vehicle for the assessment and management of this complex injury. The biggest challenge to the computerized testing approach will be on the psychometric issue of validity: "Do these tests really measure what they purport to measure?" Thus, test validity should be the most important consideration at all stages of computerized test development and test evaluation. Needless to say that a test is only as good as is its standardization. In addition, computerized tests are, of course, canned and therefore do not allow for a flexible approach to neuropsychological testing. Comprehensive neuropsychological testing may be appropriate when concussion-based symptoms do not resolve or additional emotional features arise from the injury and compromise the athlete's neurocognitive status. Finally, a standard, serial, postconcussion assessment schedule has yet to have been agreed on by researchers. The computerized testing approach would benefit from an agreed-on test retest schedule. Re-

searchers and test authors are encouraged to examine this important variable.

The goal of this article was to introduce the practicing neuropsychologist to the culture of computerized neuropsychological testing, specifically as it applies to the assessment of sports-related concussions. We believe that the advantages of such an approach far outweigh its limitations. The future of sports-related concussion assessment should and will include the use of computerized baseline assessment of athletes. We introduced the three main programs that are currently on the market, although it was not our goal to provide a specific critique of each assessment approach. Documenting the reliability and validity of assessment measures may represent the most critical issue for the long-term success of computer-based assessment of sports-related concussion, in addition to establishing their utility and sensitivity to the sequelae of concussion.

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