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Validity of ImPACT for Measuring Attention & Processing Speed Following Sports-Related Concussion

Grant L. Iverson, Ph.D.

University of British Columbia & Riverview Hospital

Mark R. Lovell, Ph.D.

University of Pittsburgh Medical Center

Michael W. Collins, Ph.D.

University of Pittsburgh Medical Center

Author Notes: The authors thank Jennifer Bernardo for assistance with manuscript preparation. Please address correspondence to Grant Iverson, Ph.D., Department of Psychiatry, 2255 Wesbrook Mall, University of British Columbia, Vancouver, B.C. Canada, V6T 2A1.

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Abstract

The purpose of this study was to examine the validity of ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing), a computerized neuropsychological test battery, for measuring attention and processing speed in athletes with concussions. This was accomplished by comparing the computerized testing to a traditional neuropsychological measure, the Symbol Digit Modalities Test (SDMT). Participants were 72 amateur athletes who were seen within 21 days of sustaining a sports-related concussion (Mean = 9.4, SD = 5.4 days). As predicted, the SDMT correlated most highly with the Processing Speed and Reaction Time composites from ImPACT. The composite scores from ImPACT and the SDMT were subjected to exploratory factor analysis, revealing a two-factor solution interpreted as Speed/Reaction Time and Memory. It appears as if the Processing Speed Composite, Reaction Time Composite, and SDMT are measuring a similar underlying construct in this sample of concussed amateur athletes.

Key Words: Concussion, Sports, ImPACT, Validity, Computerized Testing

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Neuropsychological tests are sensitive to the subtleties of cognitive decrements associated with concussions in sports (Barr & McCrea, 2001; Collins et al., 1999; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Kelly, 2001; Macciocchi et al., 1996; McCrea, Kelly, Randolph, Cisler, & Berger, 2002; Randolph, 2001). The general course begins with disruption of cognitive functioning immediately following injury, particularly in the areas of orientation, attention and concentration, mental set shifting, memory, information processing, and executive functioning (Collins et al., 1999; Delaney, Lacroix, Gagne, & Antoniou, 2001; Erlanger et al., 1999; Guskiewicz, Ross, & Marshall, 2001; Johnston et al., 2001; Matser, Kessels, Lezak, & Troost, 2001; Randolph, 2001). Gradual recovery occurs within several hours and full recovery to baseline cognitive and functional status typically is reached within a few days, regardless of concussion severity (Barr & McCrea, 2001; Guskiewicz, Marshall, Broglio, Cantu, & Kirkendall, 2002; Johnston et al., 2001; Lovell et al., 2003; Macciocchi et al., 1996; McCrea et al., 2002; McCrea et al., 2003; Powell & Barber-Foss, 1999).

Individualized approaches to concussion management have recently been implemented by many sports organizations across the United States. Increasingly, organizations are using baseline and post-injury neuropsychological testing. This approach is currently being used clinically with the National Football League (Lovell, 1999), Major League Baseball (Collins, 2001), and it is mandated within the National Hockey League (Lovell & Burke, 2000). With the availability of computerized neuropsychological testing (e.g., Maroon, Lovell, Norwig, Podell, Powell, & Hartl, 2000;

Erlanger et al., 2001), many high schools and colleges are implementing this approach to injury management.

Athletes with concussions show performance decrements on computerized neuropsychological tests (Erlanger et al., 2001; Erlanger et al., 2003; Makdissi et al., 2001; Warden et al., 2001). In essence, demonstrating the sensitivity of computerized testing to the acute effects of concussion is the most important aspect of the test validation process. The following are some recent examples of the sensitivity of computerized neuropsychological testing to concussions in athletes: (a) high school athletes with Grade I ("ding") concussions showed a decline in memory between 1-3 days post injury followed by a return to baseline at 5-10 days post injury (Lovell, Collins, Iverson, Johnston, & Bradley, 2004), (b) some concussed athletes showed a clear increase in simple and choice reaction times at approximately two days post injury with improvement at approximately 6 days post injury (Erlanger et al., 2003), (c) concussed athletes reporting headaches at one week post injury had slower reaction times and lower memory scores than concussed athletes who did not report headaches (Collins et al., in press), and (d) concussed athletes reporting perceived "fogginess" at one week post injury had slower reaction times, reduced processing speed, and lower memory scores than concussed athletes who did not report fogginess (Iverson, Gaetz, Lovell, & Collins, in press).

The purpose of this study was to examine the construct validity of ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing; (Maroon et al., 2000), a computerized neuropsychological test battery, for measuring attention and processing speed in athletes with concussions. This was accomplished by comparing the

computerized testing to a traditional neuropsychological measure, the Symbol Digit Modalities Test (SDMT; Smith, 1982). The SDMT has been routinely used in sport concussion research (e.g., Collins et al., 1999; Erlanger et al., 2003; Hinton-Bayre, Geffen, McFarland, 1997; Guskiewicz, Marshall, Broglio, Cantu, & Kirkendall, 2002; Macciocchi, Barth, Littlefield, & Cantu, 2001; McRea et al., 2003; Mrazik et al., 2000; Zillmer, 2003). It is believed to measure scanning and tracking aspects of attention and speed of processing (Spreen & Strauss, 1998). It was hypothesized that the SDMT would be more highly related to the Processing Speed and Reaction Time composites on ImPACT than the two memory composites.

Method

Participants & Procedures

Participants were 72 amateur athletes who were seen within 21 days of sustaining a sports-related concussion (Mean = 9.4, Median = 9, SD = 5.4 days). The breakdown of athletes by concussion severity, based on the American Academy of Neurology guidelines, was as follows: Grade 1 = 33%, Grade 2 = 49%, and Grade 3 = 18%. Their average age was 17.1 years (SD = 1.9), and their average education was 10.5 years (SD = 1.8). The majority of athletes were male (83.8%). The breakdown of athletes by sport was as follows: football = 58.3%, hockey = 11.2%, soccer = 9.7%, basketball = 6.9%, wrestling = 5.6%, and other sports = 8%. This was the first documented concussion for 59% of the sample. Twenty-one percent reported one previous concussion, 14% reported two previous concussions, and 6% reported three or more previous concussions.

Measures

Version 2.0 of ImPACT is a computer administered neuropsychological test battery that consists of six individual test modules that measure aspects of cognitive functioning including attention, memory, reaction time, and processing speed. Version 1.0 of the battery has been used in multiple studies relating to outcome from concussion (Collins et al., in press; Iverson, Gaetz, Lovell, & Collins, 2002; Iverson, Gaetz, Lovell, Collins, & Maroon, 2002; Lovell et al., 2003; Lovell, Collins, Iverson, Johnston, & Bradley, in press). Five composite scores were used for this study. In general, the test battery is designed to yield multiple types of information within a brief period of time. Each test module may contribute scores to multiple composite scores. The Verbal Memory composite score represents the average percent correct for a word recognition paradigm, a symbol number match task, and a letter memory task with an accompanying interference task. The Visual Memory composite score is comprised of the average percent correct scores for two tasks; a recognition memory task that requires the discrimination of a series of abstract line drawings, and a memory task that requires the identification of a series of illuminated X's or O's after an intervening task (mouse clicking a number sequence from 25 to 1). The Reaction Time composite score represents the average response time (in milliseconds) on a choice reaction time, a go/no-go task, and the previously mentioned symbol match task. The Processing Speed composite represents the weighted average of three tasks that are done as interference tasks for the memory paradigms. The Impulse Control composite score represents the total number of errors of omission or commission on the go/no-go test and the choice reaction time test. This composite is used to identify athletes who are not putting forth maximum effort or

who are seriously confused about test instructions. This composite was not one of the dependent measures for this study. In addition to the cognitive measures, ImPACT also contains a Post-Concussion Symptom Scale that consists of 22 commonly reported symptoms (e.g. headache, dizziness, "fogginess") that is utilized throughout organized sports (Lovell & Collins, 1998; Aubry, 2001). The dependent measure is the total score derived from this 22-Item scale.

Most research to date has used version 1.0 of the program. ImPACT 2.0 is very similar to the original version. However, there are some significant changes. Version 2.0 includes an additional test module (design memory). In addition, one of the working memory tasks (X's and O's) was expanded and modified, making it more difficult than the previous version. Version 2.0 also yields two memory composite scores (Verbal Memory and Visual memory) while Version 1.0 contains only one memory composite score. Version 2.0 has been shown to be sensitive to the acute effects of concussion (Iverson, Lovell, & Collins, 2004).

The Symbol Digit Modalities Test (Smith, 1982) was developed in the 1960s. The manual was first published in 1973, and was last revised in 1982 (although it is now in its 8th printing, as of March of 2000). The SDMT requires the examinee to quickly substitute a number for a randomized series of geometric figures. The target number is presented at the top of the page with each corresponding geometric figure. The test items present the geometric figures only, and the examinee must quickly write in the target number that goes with each figure. The total number of correctly completed numbers in 90 seconds is the score derived from this test. The SDMT has been used extensively, over several decades, in dozens of studies with diverse clinical groups.

Results

Descriptive statistics for the measures are provided in Table 1. The Pearson correlations between the ImPACT composite scores and the SDMT also are presented in Table 1. The SDMT correlated more highly with the Processing Speed and the Reaction Time composites than with the memory composites or total symptoms score.

Insert Table 1 About Here

Exploratory principal components factor analysis was conducted using the five ImPACT composite scores and the SDMT. The subject to variable ratio was 12:1. The communalities for the seven variables were high, ranging from .70 to .95. With the eigenvalues set at .5, three components were extracted accounting for 81.9% of the total variance. The first component accounted for approximately 55.1%, the second component for 15.6%, and the third component for 11.3% of the variance. A varimax rotation with Kaiser normalization was applied to the components. The rotated components were interpreted as follows: (a) Speed/Reaction Time: SDMT .87, Processing Speed Composite .85, and Reaction Time Composite -.76; (b) Memory: Verbal Memory Composite .87 and Visual Memory Composite .80; and (c) Total symptoms .93.

Discussion

The validation of neuropsychological tests is a gradual process, involving numerous studies over extended periods of time. One aspect of validity is to correlate computerized test scores with traditional test scores to better understand the presumed

underlying constructs being measured by the computerized tests. As predicted, the SDMT correlated most highly with the Processing Speed and Reaction Time composites from ImPACT. Exploratory factor analysis revealed a two-factor solution interpreted as Speed/Reaction Time and Memory. The total symptoms score was extracted as a unique component, but as a single variable it should not be considered a factor. It appears as if the Processing Speed Composite, Reaction Time Composite, and SDMT are measuring a similar underlying construct in this sample of concussed amateur athletes.

Similar results were obtained by Erlanger and colleagues (2003), who compared the Concussion Resolution Index to the Symbol Digit Modalities Test and other traditional neuropsychological measures. The Concussion Resolution Index is a web-based, online, computerized neuropsychological assessment comprised of six cognitive subtests. They found that the Processing Speed Index correlated .66 with the SDMT. The correlations between the SDMT and the Simple Reaction Time ($r = .31$) and the Complex Reaction Time ($r = .39$) Indexes were smaller.

The ongoing validation of a test relates to its clinical use, not to the test itself. Our goal should be to validate the clinical inferences we derive from tests (Franzen, 1989, 2000). By focusing on the validity of inferences, we focus on the decision-making process of the clinician. Toward that end, ImPACT has been used in multiple studies of athletes with concussions. The composite scores, especially the memory and symptoms composites from Version 1 (Collins et al., 2003; Iverson et al., in press; Lovell et al., 2003; Lovell et al., in press) and the Verbal Memory, Reaction Time, and symptoms composites from Version 2 (Iverson et al., 2004), are very sensitive to the initial effects of concussion in amateur athletes.

Current ongoing research at the University of Pittsburgh Medical Center employing ImPACT and functional magnetic resonance imaging (fMRI) can also be conceptualized as validity work. The physiological changes following concussion at the cellular level have been clarified over the past 15 years, through animal and in vitro modeling (e.g., see Gaetz, 2002; Giza & Hovda, 2004; ADD 2 others for reviews). Essentially, it is believed that cerebral concussion triggers a multilayered neurometabolic cascade of physiological changes at the cellular level (Giza & Hovda, 2004). It is these physiological changes that are believed to underlie the symptoms reported by athletes in the initial hours and days post injury, as well as the decrements in neuropsychological test performance. Conducting baseline and serial postconcussion evaluations with ImPACT, in tandem with fMRI, might (a) help us better understand the underlying physiological constructs being measured by the test, and (b) facilitate decision making regarding the clinical management of athletes with concussions. Initial results from this work will be forthcoming in the near future.

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Table 1. Descriptive statistics and correlations.

Measure	Mean	SD	Range	r
Verbal Memory	81.2	12.4	46 – 100	.46**
Visual Memory	72.3	14.9	29 – 95	.37**
Procession Speed	35.6	8.3	16.1 – 53.8	.70**
Reaction Time	.58	.12	.41 – 1.04	-.60**
Total Symptoms	17.4	16.3	0 – 60	-.29*
SDMT	58.0	10.0	39 – 83	---

$p < .05$, $**p < .01$