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Factor Structure of ImPACT® in Adolescent Student Athletes

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Abstract

Objective: ImPACT® (Immediate Post-Concussion Assessment and Cognitive Testing) is a computerized neuropsychological screening battery, which is widely used to measure the acute effects of sport-related concussion and to monitor recovery from injury. This study examined the factor structure of ImPACT® in several samples of high school student athletes. We hypothesized that a 2-factor structure would be present in all samples.
Method: A sample of 4,809 adolescent student athletes was included, and subgroups with a history of treatment for headaches or a self-reported history of learning problems or attention-deficit hyperactivity disorder were analyzed separately. Exploratory principal axis factor analyses with Promax rotations were used.
Results: As hypothesized, both the combination of Verbal Memory and Visual Memory Composite scores loaded on one (Memory) factor, while Visual Motor Speed and Reaction Time loaded on a different (Speed) factor, in the total sample and in all subgroups.
Conclusion: These results provide reasonably compelling evidence, across multiple samples, which ImPACT® measures 2 distinct factors: memory and speed.

Keywords: Cognitive; Concussion; Sports; Memory; Factor analysis; Concussion

Introduction

ImPACT® (Immediate Post-Concussion Assessment and Cognitive Testing) is a computerized neuropsychological screening battery, which is widely used to measure the acute effects of sport-related concussion and to monitor recovery injury. It includes six modules of cognitive tests that are combined into five composite scores. It also contains a 22-item self-report post-concussion symptom scale. The test yields five primary summary scores: Verbal Memory, Visual Memory, Reaction Time, Processing Speed, Impulse Control, as well as the Post-Concussion Scale total score. The Impulse Control scale is not used in routine clinical interpretation; rather, it is used to assess whether a person might have invalid results (e.g., as a result of right–left confusion during responding to one of the tests).

Over the past decade, the reliability (Elbin, Schatz, & Covassin, 2011; Iverson, Lovell, & Collins, 2003; Nakayama, Covassin, Schatz, Nogle, & Kovan, 2014; Schatz, 2010; Schatz & Ferris, 2013), validity (Allen & Gfeller, 2011; Iverson, Lovell, & Collins, 2005; Maerlender et al., 2010, 2013), and sensitivity and specificity (Broglio, Macciocchi, & Ferrara, 2007;

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Schatz, 2010; Schatz & Sandel, 2013) of ImPACT® have been documented and debated (Mayers & Redick, 2012; Randolph, Lovell, & Laker, 2011; Randolph, McCrea, & Barr, 2005; Resch et al., 2013; Schatz, Kontos, & Elbin, 2012) in the literature. Across this same time period, the factor structure of ImPACT® has not been well described in the manual or in publications, but it appears as if a two-factor model might appropriately represent the underlying factor structure (Iverson et al., 2005; Schatz & Maerlender, 2013). However, when 11 subscores were factor-analyzed in a sample of 104 college students, a five-factor model emerged (Allen & Gfeller, 2011). The largest and the most elaborate study to date illustrating the two-factor structure was conducted by Schatz and Maerlender (2013). They conducted exploratory factor analysis (EFA) on the four primary ImPACT® scores in a sample of more than 21,000 healthy athletes and identified a two-factor solution labeled "Memory" (Verbal and Visual Memory) and "Speed" (Visual Motor Speed and Reaction Time). This factor structure was replicated in the same article on a large sample of athletes who were tested following a concussion. Additionally, the use of the two-factor solution was associated with greater test–retest reliability (Bruce et al., 2016) in professional ice hockey players. The purpose of this study was to replicate and extend the work of Schatz and Maerlender (2013) by examining the factor structure of ImPACT® in several samples of high school student athletes stratified by characteristics, such as gender or having comorbid conditions, which were excluded in the study by Schatz and Maerlender (2013): developmental problems (e.g., learning problems or attention-deficit hyperactivity disorder [ADHD]), history of concussion, or history of medical treatment for headaches. The goal of this stratification was to examine whether the factor structure of ImPACT® is similar across these subpopulations, which would provide support for measurement invariance, a property that is necessary if we wish to interpret ImPACT® scores in a similar manner for different subpopulations. We hypothesized that the two-factor structure would replicate in all samples.

Materials and Methods

Participants

In 2010, 5,494 students from student athletic programs in Maine completed baseline, preseason testing with ImPACT®, a computerized program measuring symptom ratings and neurocognitive functioning. A demographics and history questionnaire is embedded in the ImPACT® program. The health survey asked the student whether he or she has had a variety of health conditions, and these questions required a Yes or No response. Participants were excluded on the basis of an invalid baseline score ($n = 279$) based on scoring below predetermined cutoffs documented in the ImPACT® interpretation manual (Lovell, 2007), a history of treatment for seizures or brain surgery ($n = 58$), a concussion within the past year ($n = 326$), and age outside the range of 13 and 19 years ($n = 77$). Therefore, the final sample included 4,754 adolescent and young adult students between the ages of 13 and 19 (Mean = 15.9, standard deviation [*SD*] = 1.3) years. There were 2,624 (55.1%) boys and 2,132 girls (44.8%). These students were from 49 schools across the state, with no school contributing more than 5% of the total sample. The students completed baseline testing prior to participating in their first sport for that school year (some students participated in several sports during the year). Institutional review board approval for the use of this de-identified database was obtained from the academic institutions of the study investigators.

Measures

ImPACT® is a brief computer-administered neuropsychological test battery, which consists of six individual test modules that measure aspects of cognitive functioning including attention, memory, reaction time, and processing speed. Each test module may contribute scores to multiple composite scores. The Verbal Memory composite score represents the average percent correct for a word recognition test, a symbol number match test, and a letter memory test with an accompanying interference task. These tests are conceptually similar to traditional verbal learning (word list) tasks and the auditory consonant trigrams test (i.e., the Brown–Peterson short-term memory paradigm; L.R. Peterson & M.J. Peterson, 1959), although the information is presented visually on the computer and not auditorily by an examiner. The Visual Memory composite score comprised the average percent correct scores for two tests: a recognition memory test 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 first test taps immediate and delayed memory for visual designs, and the second test measures short-term spatial memory (with an interference task). 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 (which is similar to a traditional digit symbol task). Because a smaller reaction time indicates greater speed, reaction time was multiplied by −1 to make it directionally similar to speed for the ease of interpretation. The "Processing Speed" composite represents the weighted average of the three tests 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 (see the test manual for a more complete description; Lovell, 2007). 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, and “fogginess”). The dependent measure is the total score derived from this 22-item scale.

Statistical Analyses

A total of five scores from ImPACT® were included in the factor analyses: Verbal Memory Composite, Visual Memory Composite, Visual Motor Speed, Reaction Time, and Total Symptom Score. Factor scores were generated in accordance with the procedures outlined by Schatz and Maerlender (2013). Means and *SD*s from baseline ImPACT® data were used to calculate *z*-scores. For each factor (i.e., Memory and Speed), *z*-scores were calculated by subtracting the athletes’ score from the mean of the baseline sample and dividing by the *SD* of that sample. The *z*-score for Memory was obtained by taking the average of the combined *z*-scores for the Verbal Memory and the Visual Memory composite scores, and the *z*-score for Speed was obtained by taking the average of the combined *z*-scores for the Visual Motor Speed and the Reaction Time composite scores. Of note, *z*-scores for Reaction Time data were inverted, because higher scores reflect slower/worse performance. Based on the prior study (Schatz & Maerlender, 2013), we hypothesized that the data would fit a two-factor structure composed of a memory factor and a speed factor, and that inclusion of the Total Symptom Score would yield a third independent factor. To test these hypotheses, we ran factor analyses assuming two different models: (a) a four-item two-factor model (using the four primary cognitive composite scores) and (b) a five-item three-factor model (using all five scores). Prior to factor analyses, the composite scores were examined for normality and found not to be reasonably normally distributed both by visual inspection and by the Shapiro–Wilk test for normality. Exploratory factor analyses were performed using R version 3.01 (R Core Development Team, 2012) and the psych package (Revelle, 2013) using principal axis factoring with a Promax rotation. Promax is an oblique factor rotation method that allows for factors to be correlated with one another rather than requiring that they be uncorrelated. Principal axis factor analysis is done via an eigenvalue decomposition of the reduced correlation matrix and has no requirement of multivariate normality. The Promax rotation is computed first by solving for a varimax orthogonal rotation followed by a second rotation step to minimize the loadings of the lowest loading item on each factor, creating correlated factors. Although we had an a priori hypothesized factor structure for which confirmatory factor analysis (CFA) is generally the preferred approach, CFA was not used for mathematical reasons: a model composed of two factors and only four items are under-determined. Rather, we sought to determine, through EFA, whether the two-factor structure would emerge. We chose to retain an item on a factor if its loading was 0.4 or higher, in line with convention in the psychology and the education literature (Henson & Roberts, 2006).

Internal consistency reliability was measured using coefficients Alpha (α) (Cronbach, 1951), Omega Hierarchical (ω_H), and Omega Total (ω_T) (Zinbarg, Revelle, Yovel, & Li, 2005). In some circumstances, Omega coefficients represent a better measure of internal consistency than α (Zinbarg et al., 2005), but they are frequently not reported in the literature. Internal consistency estimates the proportion of variance explained by a test, and it is expected to be adversely affected in this instance by the small number of scores that are being analyzed and the assumption that different constructs are being measured. Coefficient α is concerned with a general test factor rather than accounting for variance driven by particular factors, and it represents a lower bound of internal consistency in multidimensional tests. Omega coefficients can account for variance in the test due to both a single common factor, ω_H, and the variance explained by all common factors, ω_T, making them appropriate for investigating internal consistency in multidimensional measures (Zinbarg et al., 2005). Reliability for the individual factors was not explored, because we assumed that the two subscales do not operate independently of one another. A correlated factor structure would support this assumption.

These analyses were initially performed for the whole sample and then separately for stratified subsamples. The whole study sample was stratified under four different schemes: (a) gender, (b) headache history (i.e., those reporting a history of medical treatment for headaches or migraines), (c) concussion history (i.e., those reporting a lifetime history of one or more concussions), and (d) history of developmental problems (i.e., learning disability, repeating a grade, or ADHD; Table 1). The factor analyses were performed under each of these stratification schemes by running the analyses in each subgroup separately. The purpose was to look for the evidence of configural invariance and ensure that the hypothesized constructs were similar across groups.

Results

As hypothesized, both the Verbal Memory Composite and the Visual Memory Composite loaded mostly on one factor, whereas Visual Motor Speed and Reaction Time loaded on a different factor. Factor 1 is considered a Memory Factor and

Table 1. Factor structure of ImPACT® in multiple groups

	Model A: two factors		Model B: three factors		
Item	Factor 1	Factor 2	Factor 1	Factor 2	Factor 3
Verbal Memory					
Total sample (n = 4,809)	**0.73**	−0.11	**0.74**	−0.11	0.03
Boys (n = 2,664)[a]	**0.73**	−0.10	**0.74**	−0.10	0.02
Girls (n = 2,145)[a]	**0.69**	−0.10	**0.69**	−0.10	0.02
No headache (n = 4,341)[a]	**0.71**	−0.10	**0.73**	−0.11	0.03
Headache (n = 468)[a]	**0.84**	−0.12	**0.84**	−0.12	0.01
No concussion (n = 4,317)[a]	**0.72**	−0.11	**0.73**	−0.11	0.03
Prior concussion (n = 492)[a]	**0.77**	−0.10	**0.78**	−0.10	0.02
No academic issues (n = 4,133)[a]	**0.74**	−0.11	**0.76**	−0.12	0.03
Academic issues (n = 398)[a]	**0.63**	−0.04	**0.62**	−0.04	0.02
ADHD (n = 278)[a]	**0.70**	−0.07	**0.70**	−0.07	0.01
Visual Memory					
Total sample	**0.56**	0.02	**0.55**	0.03	−0.04
Boys	**0.58**	0.02	**0.57**	0.02	−0.02
Girls	**0.58**	0.01	**0.57**	0.01	−0.03
No headache	**0.57**	0.00	**0.56**	0.01	−0.04
Headache	**0.42**	0.22	**0.42**	0.22	−0.02
No concussion	**0.56**	0.01	**0.55**	0.02	−0.04
Prior concussion	**0.57**	0.04	**0.56**	0.05	−0.03
No academic issues	**0.52**	0.03	**0.50**	0.05	−0.05
Academic issues	**0.60**	0.07	**0.62**	0.05	−0.03
ADHD	**0.76**	−0.06	**0.75**	−0.06	−0.01
Visual Motor Speed					
Total sample	0.22	**0.52**	0.21	**0.53**	0.01
Boys	0.20	**0.54**	0.20	**0.54**	−0.01
Girls	0.21	**0.52**	0.21	**0.53**	0.02
No headache	0.24	**0.50**	0.23	**0.51**	0.01
Headache	0.03	**0.66**	0.03	**0.66**	0.01
No concussion	0.23	**0.51**	0.22	**0.52**	0.01
Prior concussion	0.15	**0.56**	0.15	**0.56**	0.01
No academic issues	0.19	**0.53**	0.18	**0.54**	0.01
Academic issues	0.08	**0.69**	0.10	**0.66**	0.02
ADHD	0.31	**0.42**	0.31	**0.42**	0.00
Reaction Time[b]					
Total sample	−0.12	**0.86**	−0.12	**0.86**	0.00
Boys	−0.11	**0.86**	−0.11	**0.86**	0.01
Girls	−0.11	**0.84**	−0.11	**0.83**	−0.01
No headache	−0.11	**0.87**	−0.12	**0.87**	0.00
Headache	−0.12	**0.79**	−0.12	**0.79**	0.00
No concussion	−0.11	**0.87**	−0.12	**0.86**	0.00
Prior concussion	−0.12	**0.84**	−0.12	**0.84**	0.00
No academic issues	−0.12	**0.86**	−0.13	**0.86**	0.00
Academic issues	−0.05	**0.70**	−0.06	**0.72**	−0.01
ADHD	−0.10	**0.89**	−0.10	**0.88**	0.00
Symptom Score					
Total sample			0.01	0.00	**1.00**
Boys			0.01	0.01	**1.00**
Girls			0.00	0.00	**1.00**
No headache			0.01	0.00	**1.00**
Headache			0.01	0.00	**1.00**
No concussion			0.01	0.00	**1.00**
Prior concussion			0.01	0.00	**1.00**
No academic issues			0.02	0.00	**0.99**
Academic issues			0.00	0.00	**1.00**
ADHD			0.00	0.00	**1.00**

Numbers in bold denote the correlation of that item to the factor.

[a] A common stratification scheme. All subgroups with the same letter should have sample sizes that sum to the total sample size for the study.

[b] Negatively correlated because less time indicates more speed.

Factor 2 a Speed Factor. The correlation between these two factors was 0.56, suggesting that an oblique factor rotation was appropriate. The Tucker–Lewis index of factoring reliability was quite good at 1. Including the total symptom score led to a three-factor solution with the same two factors as were found in the two-factor model and a third factor comprised the total symptom score by itself. This third factor had a low correlation with the other two factors (−0.04 and −0.09). The Tucker–Lewis index of factoring reliability was quite good for this model as well at 1. Factor loadings can be seen in Table 1 for both the two- and three-factor models for the total sample and for several subgroups. The factor structure remained the same across all subsamples in both Model A and Model B as can be seen in Table 1, supporting the presence of configural invariance. Loadings were also relatively similar in the subsamples.

Internal consistency was measured for a general factor underlying all items. Coefficient α for the test as a whole was modest at 0.64 for Model A (the model based on the four neurocognitive composite scores) and 0.56 for Model B (the model that included the total symptom score as a fifth item) in the total sample. Internal consistency based on Omega coefficients was also modest based on a single common factor, as measured by ω_H: 0.52 for Model A and 0.48 for Model B. However, when accounting for all common factors (as measured by ω_T), internal consistency was good: 0.72 for Model A and 0.76 for Model B.

Discussion

This study builds on prior literature suggesting that the four primary cognitive composite scores from ImPACT® may be interpreted as a two-factor scale measuring memory and speed in both healthy student athletes and in athletes who have been concussed (Iverson et al., 2005; Schatz & Maerlender, 2013). Moreover, Schatz and Maerlender (2013) reported that the two factors have comparable or better test–retest reliability and sensitivity to the acute effects of concussion compared to the four primary composite scores. These results indicate that this two-factor solution is valid for boys, girls, and those with a headache history, learning problems, or ADHD. Internal consistency estimates (using α, ω_H, and ω_T) suggest that a two-factor solution is needed for the reliability of measurement, and the variance is not sufficiently well explained by a single general factor. When the total symptom score was included in the factor analysis, it loaded in its own unique factor and correlated minimally with memory and speed factors. The independence of symptom scores from the memory and speed factors validates the unique role of self-reported symptoms on preseason baseline testing. Future research can establish the correlation between symptom scores and factor scores in a sample of concussed athletes.

It could be of value to clinicians and researchers if the test publisher provided normative data for the two-factor scores and included them in the clinical interpretation report. The Verbal and Visual Memory scores represent recall of information that has been presented visually, with Verbal Memory stimuli (i.e., words and letters) more easily verbally encoded than Visual Memory stimuli (i.e., more ambiguous line drawings and symbols). The Reaction Time represents a tangible measure of the time required to respond to binary (i.e., go/no-go) and complex (i.e., sequential clicking, coding) stimuli, and the Visual Motor Speed represents the decision time and speed of conceptualization of responses. Given the similar mechanism of visual presentation of both verbal and visual stimuli, as well as the inherent timing within the Visual Motor Speed and Reaction Time stimuli, combining these indices that share similar constructs and variance seems reasonable. However, if the test publisher creates two new factor scores, the two-factor structure does not mean that the four existing composite scores should be abandoned. Those scores provide additional and more specific information about test performance, which helps the clinician to better understand the new factors' scores. Moreover, there are now algorithms for identifying cognitive impairment based on the combination of low scores across the four primary composites (Iverson, 2011; Iverson & Schatz, 2015). Additional research is needed to identify an optimal psychometric methodology for identifying cognitive impairment and monitoring recovery from injury on ImPACT® using the two factors and four primary composite scores. It is anticipated that this research will lead to a simplified, more reliable, and more robust clinical methodology for interpreting ImPACT®.

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