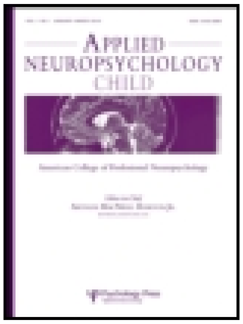

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Cognitive Development and the Immediate Postconcussion Assessment and Cognitive Testing: A Case for Separate Norms in Preadolescents

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With youth sports participation and concern about sports-related concussions both on the rise, it is important to properly measure cognitive function to ensure the clinical utility of baseline testing. Computerized testing batteries are often employed as baseline and postinjury measures of cognitive function, with the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) being the most used of all the current testing platforms. The current study compared 10- to 12-year-old children across the composite scores yielded by the ImPACT and provided normative data on each of the subtests used to calculate the composite scores. Normative data are separated by gender for athletes aged 10 to 12 years old, as this is the current age bracket used by the ImPACT. These norms may be helpful in the interpretation of the ImPACT clinical report and further delineation of areas of neurocognitive dysfunction.

Key words: *cognitive development, concussion, neuropsychology, preadolescent*

INTRODUCTION

Youth incidence of sports-related concussion (SRC) is comparable to that of high school and collegiate athletes (Kontos et al., 2013); 40% of youth athletes presenting to the emergency room with SRC are younger than 14 years old (Bakhos, Lockhart, Myers, & Linakis, 2010). Extrapolation of concussion trends among older athletes to preadolescents suggests that 8- to 12-year-olds demonstrate significantly higher rates of concussion per athletic exposure (Kontos et al., 2013). The incidence of concussion among preadolescent athletes is not surprising given that many athletes participate in sports prior to high school-level competition. In football alone, it is estimated that 3 million children aged 5 to 14 years old participate annually in the sport (Meuller & Colgate, 2013).

Returning an athlete to play from a concussion is a complex and oftentimes difficult decision, especially where children are concerned. Current consensus

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stipulates that an athlete must be symptom-free at rest and symptom-free with cognitive and physical exertion and have so-called normal neurocognitive test results (McCrory et al., 2013b). Return-to-play criteria are designed to ensure recovery to the best extent as the extant literature will allow. The neurocognitive aspect is especially important as it provides the closest approximation to an objective measure as is currently available. Youth athletes are regarded as a particularly vulnerable population to concussion, given evidence that concussed children experience longer recovery times relative to adults (McCrory et al., 2013b; Reddy, Collins, & Gioia, 2008). Current evidence suggests that most older adolescent and young-adult athletes recover from cerebral concussion within 7 to 10 days (McCrea et al., 2003, 2005, 2013; McCrory et al., 2013b; Prichep, McCrea, Barr, Powell, & Chabot, 2013). In older children, the rate of recovery is thought to be longer (McCrory et al., 2013b), though rigorous study in this age group is scant (Giza et al., 2013). A recent systematic review generally supports that younger adolescents and children do take longer to recover, but this lengthened period is merely a matter of days as opposed to weeks (Foley, Gregory, & Solomon, 2014). Even still, returning before recovery is complete can have negative consequences on recovery (Carson et al., 2014; Harmon et al., 2013; Signoretti et al., 2010; Weinstein, Turner, Kuzma, & Feuer, 2013). Longer postinjury recovery periods may increase the risk for a youth athlete returning to play in group, contact, and collision sports to sustain additional head injury prior to full recovery (Collins, Lovell, Iverson, Ide, & Maroon, 2006; Field, Collins, Lovell, & Maroon, 2003; Pellman, Lovell, Viano, & Casson, 2006). Although some contradictory evidence suggests that age is not a modifying factor in recovery from SRC (Lee, Odom, Zuckerman, Solomon, & Sills, 2013; Meehan, Mannix, Stracciolini, Elbin, & Collins, 2013), many of these studies are based on a relatively truncated age range in which preadolescents (i.e., 10- to 12-year-olds) are poorly represented.

Evaluating SRC at all levels of competition is complicated by the lack of overt clinical markers present immediately after injury leaving subject report or observation as the primary means of diagnosis. Dependence on athletes' self-reported symptoms of concussion in isolation is an unreliable measure of recovery given that athletes tend to underestimate the severity of their injuries (Delaney, Lacroix, Leclerc, & Johnston, 2002; Fazio, Lovell, Pardini, & Collins, 2007; Lovell & Solomon, 2013; Sandel, Lovell, Kegel, Collins, & Kontos, 2013). Athletes and their parents primarily focus on physical ailments (e.g., nausea, headache) rather than more subtle symptoms, such as cognitive disturbances (Sandel, Henry, French, & Lovell, 2014; Sandel et al., 2013; P. K. Stevens, Penprase, Kepros, & Dunneback, 2010). Consensus experts advocate for a multidisciplinary approach to concussion diagnosis and management, which includes objective measures of concussion in addition to self-reported symptoms (McCrory et al., 2009, 2013b).

Computer-based neurocognitive testing (CNT) is a widely used objective tool for screening athletes suspected of having sustained a concussion and has been demonstrated to increase diagnostic yield over symptom report alone (Giza et al., 2013; Kelly, Jordan, Joyner, Burdette, & Buckley, 2014; McCrory et al., 2013). Asymptomatic concussed athletes often demonstrate cognitive deficits on CNT and perform more poorly than nonconcussed controls, thereby confirming the added value of using objective measures in injury management (Fazio et al., 2007; Lovell & Solomon, 2013; Van Kampen, Lovell, Pardini, Collins, & Fu, 2006). Most research on the added value of neurocognitive testing has been conducted among adolescents, but based on the elusive nature of many concussion symptoms, it could be expected that objective testing is particularly helpful in evaluating youth who may lack the vocabulary and/or insight to describe more abstract symptoms such as "mental fogginess" or "nervousness" that are often present postinjury (Lau, Kontos, Collins, Mucha, & Lovell, 2011; Lau, Lovell, Collins, & Pardini, 2009). Inclusion of CNT as part of a multidisciplinary evaluation has been shown to reduce the likelihood that an athlete will return to play prior to full recovery (Meehan, d'Hemecourt, Collins, Taylor, & Comstock, 2012; Meehan, Zhang, Mannix, & Whalen, 2012). It is presumed that the sensitivity afforded by CNT in identifying residual cognitive dysfunction increases the time that athletes are held from participation in physical recreation and/or sport.

Several CNT platforms are available for clinical use in screening for concussion (Axon Sports, 2013; CNS Vital Signs, 2015; ImPACT Applications, 2011; Rice et al., 2011). The most commonly used CNT platform among pediatric clinicians is the Immediate Postconcussion Assessment and Testing (ImPACT; Kinnaman, Mannix, Comstock, & Meehan, 2013). The ImPACT is an empirically validated (more than 80% sensitivity; Schatz, Pardini, Lovell, Collins, & Podell, 2006; Schatz & Sandel, 2013) and reliable (≥.60 across all composite scores; Elbin, Schatz, & Covassin, 2011; Nakayama, Covassin, Schatz, Nogle, & Kovan, 2014) tool for detecting concussed athletes from nonconcussed athletes (Broglio, Ferrara, Macciocchi, Baumgartner, & Elliott, 2007; Broglio, Macciocchi, & Ferrara, 2007; Schatz & Ferris, 2013; Schatz & Glatts, 2013; Schatz & Sandel, 2013). Normative data for the test battery are generally stratified based on age and gender for nomothetic comparison if preseason baseline testing is unavailable (Henry & Sandel, 2014; Schatz, Moser, Solomon, Ott, & Karpf, 2012). Current normative data provided by

ImPACT Applications (2011) are banded into three age groups (10- to 12-year-olds, 13- to 15-year-olds, and 16- to 18-year-olds). The youngest age group in particular may not be appropriately grouped given the important neurodevelopmental changes occurring during this critical developmental period.

During this stage of development, maturation and integration of neural networks produce dramatic cognitive gains in reaction time, processing speed, and executive control (Carpenter, Just, & Shell, 1990; Casey, Giedd, & Thomas, 2000; Fry & Hale, 2000; Nagy, Westerberg, & Klingberg, 2004; M. C. Stevens, Skudlarski, Pearlson, & Calhoun, 2009). For instance, comparison of processing speed between 8- to 10-year-olds and 12- to 13-year-olds is greater than 5 standard deviations, with younger children performing more slowly (Kail, 1991). More recent evidence confirms the steady improvement of visual motor speed through development where differences in childhood are greater than in adolescence (Kail, 2007; Kail & Ferrer, 2007). Maturational gains in processing speed are attributed to more efficient networks primarily within the frontal and parietal lobes and contribute to a global improvement in performance across cognitive domains (Carpenter et al., 1990; Casey et al., 2000; Fry & Hale, 2000; Nagy et al., 2004; M. C. Stevens et al., 2009) supported through increased myelination (Cepeda, Kramer, & Gonzalez de Sather, 2001). The functional implications on neurocognition as processing speed increases facilitate improved working memory, which in turn facilitates improvements in reasoning and problem solving (Fry & Hale, 2000; Kail, 2007). The effects of development are not limited only to processing speed. Variability is much higher in both fluid and crystallized intelligence in childhood where gains are exponential through ages 10 to 13 years old relative to more modest gains in adolescence and relative stability in young adulthood (Li et al., 2004). Development is a complex process in itself; how it interplays with brain injury and subsequent recovery is therefore an important question that requires proper assessment as the underlying pathophysiology of brain injury is affected by age and behaves differently in children (McDonald & Johnston, 1990; Pickles, 1950; Reddy et al., 2008).

Such marked differences in neural maturation and cognitive ability among preadolescents raise concerns for the representation of 10- to 12\-year-olds on the ImPACT as a single banded normative age group. Comparison of athletes against this normative sample may decrease the sensitivity and specificity of the test in detecting cognitive deficit or recovery based on within-group differences in individual developmental strides. With such a large number of youth athletes currently playing football, let alone other contact sports (e.g., soccer, wrestling, hockey), it is incumbent upon clinicians to ensure that the tools currently used to assess and manage SRC are properly understood and employed. The goal of the current study was to explore performance differences on the ImPACT between male and female athletes aged 10 to 12 years old to determine whether separate age- and gender-stratified data were warranted for this group. Performance across ImPACT composite scores (Verbal Memory, Visual Memory, Visual Motor Speed, and Impulse Control) was compared between 10-, 11-, and 12-year-olds, and subsequent normative data for the ImPACT composites and contributing neurocognitive subtest scores are provided.

METHOD

Participants

The current retrospective sample included 2,732 male and female athletes aged 10 to 12 years old. An athlete was excluded from the current study if he or she reported a diagnosed learning disability, attention-deficit or attention-deficit hyperactivity disorder, and/or psychiatric disorder (e.g., depression, anxiety). Other excluding criteria included other traumatic brain injury, seizure disorders, or pervasive developmental disorders. IQ was not measured specifically, but all participants attended regular school classes with no reported educational supports. Additionally, athletes with a reported history of more than two diagnosed concussions were excluded. The logic for excluding those participants with two or more concussions was based on the extant literature that has shown that persisting neurocognitive or neurophysiological alterations are not typically apparent until after the third injury (Bruce & Echemendia, 2009; Collins et al., 2002; De Beaumont, Beauchemin, Beaulieu, & Jolicoeur, 2013; De Beaumont, Lassonde, Leclerc, & Theoret, 2007; Iverson, Brooks, Lovell, & Collins, 2006; Macciocchi, Barth, Littlefield, & Cantu, 2001). In an effort to be abundantly cautious with the current sample, we excluded any participant with more than a single concussive injury. For those who did have a history for previous concussions, none reported a concussion within the previous 12 months. To be included in the study, athletes were required to be playing a sport at the time of baseline testing.

A total of 147 athletes fell beyond 3 standard deviations on at least one composite score, had an invalid baseline based on ImPACT validity criteria, or had clearly implausible scores. Certified athletic trainers (ATCs) were primarily responsible for the administration of the ImPACT. Although ATCs are trained to follow best practices as recommended in the technical manual (ImPACT Applications, 2011), it is unknown to what extent the guidelines were followed. These athletes were excluded, leaving a total of 2,585 athletes in the database. From here, the total number of participants per sex was calculated for each year of age to determine which group had the smallest membership (10-year-old girls, $n = 31$). In the interest of creating evenly sized groups, 70 participants per sex by each year of age for 11- and 12-year-old participants were randomly selected for inclusion in the current study. The final sample consisted of 370 (171 female, 199 male) English-speaking athletes aged 10, 11, and 12 years old from across the United States. Athletes were split as evenly as possible between age and genders (140 per year of age with 70 boys and 70 girls for ages 11 and 12 years old, and 90 participants in the 10-year-old group with 59 boys and 31 girls) using a randomized method. The smaller number of 10-year-old athletes did truncate the size and gender ratio in this group.

Procedures

Written informed assent and consent were obtained from each participant and his/her parent or legal guardian, respectively. Data were subsequently deidentified, and institutional review board approval for retrospective analysis of date was obtained from Saint Joseph's University and the University of Pittsburgh. Baseline testing was conducted on desktop computers with an external mouse under the supervision of an ACT. Neurocognitive performance was measured using the online version of the ImPACT, a brief computerized test battery yielding four neurocognitive composite scores, including Verbal Memory, Visual Memory, Visual Motor Speed, and Reaction Time, and a validity composite score (Impulse Control), derived from six neurocognitive modules. The Word Memory test visually presents 12 words. Patients are then presented with a new list of words, some of which appeared in the first set (respond "yes") and some of which did not (respond "no"). A delayed recognition trial is also presented at the end of the test. The Word Memory test is designed to measure verbal recognition, learning, and retention. Analogous to this test, the Design Memory test presents 12 different simple line drawings and again includes an immediate and delayed recognition trial. The Design Memory test is intended to measure spatial recognition, learning, and retention. For the X–O and Interference subtest, a field of Xs and Os are presented, with three highlighted in yellow. Participants are asked to remember where these are located. Next, participants are asked to respond to a visual stimulus (a red circle or a blue square) by pressing the P key or Q key on the keyboard, respectively, as quickly and accurately as possible. Then, the field of Xs and Os reappears and participants select the Xs or Os they recall being highlighted. The memory portion of this test assesses visual working memory, while the interference task measures processing speed and reaction time. The Symbol Match test is essentially a digital version of the Symbol Match Modalities Test where numerals 1 through 9 each have a corresponding symbol. Patients are asked to fill in the corresponding number on a grid where the symbols are presented. After three trials, the symbol-digit key disappears and patients are asked to match each symbol to the corresponding number. This test measures implicit verbal learning and reaction time. The Color Match subtest is a digitized version of a Stroop test where patients respond as quickly as possible if the word and color of the text correspond (i.e., green is displayed in the color green, red in red, or blue in blue). This test measures response inhibition and reaction time. Finally, for the Three Letters subtest, patients are presented with three letters and are told to remember them. Next, the letters are removed from the screen and a 5 × 5 grid containing the randomly placed numerals 1 through 25 is presented. Patients are asked to count backward from 25 as quickly as possible before the number grid disappears. Then, patients are asked to type in the three letters that they saw presented. There are five memory trials (total percent correct out of 15) and five counting trials. The memory portion of this task is designed to measure verbal memory while the counting aspect is designed to measure processing speed. The ImPACT composite scores are summary scores of two or three subtest scores (see Table 1). Impulse Control is often interpreted as a test of validity rather than an assessment of neurocognitive functioning (ImPACT Applications, 2011). The ImPACT battery also includes a demographic section and the Postconcussion Symptom Scale for athlete

TABLE 1
ImPACT Composite Scores Calculated by Taking the Mean Value from Each of the Contributing Subtest Measures

Composite Score	*Contributing Scores/Formula (Average of Scores Presented)*
Verbal Memory	Word Memory: total percent correct Symbol Match: total correct (hidden)/9 × 100 Three Letters: percentage of total letters correct
Visual Memory	Design Memory: total percent correct Xs and Os: total correct (memory)/12 × 100
Visual Motor Speed	Xs and Os: total correct (interference)/4 Three Letters: average counted correctly × 3
Reaction Time (RT)	Xs and Os: average correct RT (interference) Symbol Match: average correct RT (visible)/3 Color Match: average correct RT
Impulse Control	Xs and Os: total incorrect (interference) Color Match: total commissions

Note. In some cases, either multiplication or division of certain measures as specified in the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) technical manual.

self-report of symptoms. Athletes completed a baseline ImPACT as part of standard presport participation evaluations. Athletes' reported histories of neurological or psychological disorders were collected via embedded questions in the demographic section of the ImPACT battery.

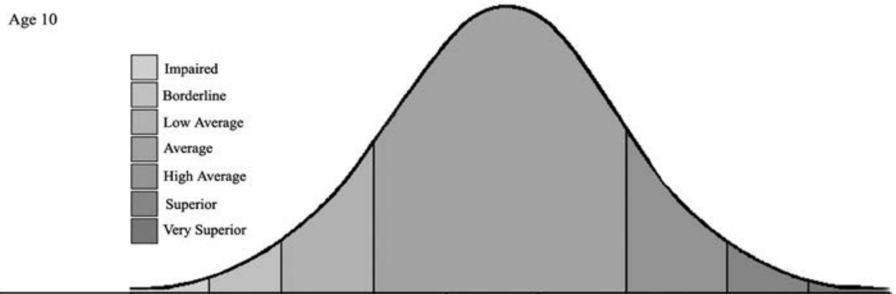
Athletes were excluded from the study if they had an invalid baseline test, as defined by ImPACT Validity Indicators (2012) or clearly implausible scores (e.g., Color Match average Reaction Time = 0). The criteria set for neurocognitive performance included having all four clinical composite scores (Verbal Memory, Visual Memory, Visual Motor Speed, and Reaction Time) within 3 standard deviations of the age- and gender-based mean. This criterion served to eliminate any test taker who failed to follow the directions properly, for instance, on the X–O interference task (i.e., confusing the visual cues) and those who counted upward as opposed to backward on the Counting subtest of the Three Letters module.

Data Analysis

Data analyses included univariate analyses of variance (ANOVAs) conducted for each composite score from the ImPACT with Bonferroni corrections for multiple comparisons. Means and standard deviations were calculated for boys and girls within each age group. Standardized z scores for each ImPACT composite and subscale score were calculated using the following formula: $z = \left(\frac{x-\mu}{\sigma}\right)$. The data are presented by age (Figures 1–3).

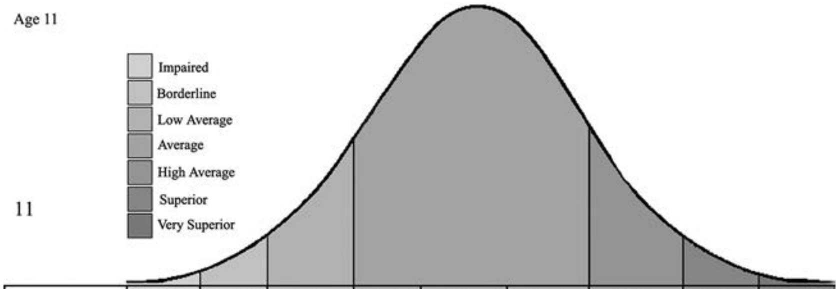
RESULTS

Descriptive statistics for both genders at each year of age are reported in Table 2. One-way between-subjects



	Z = -2.0	Z = -1.5	Z = -1.33	Z = -.67	Z = 0	Z = .67	Z = 1.33	Z = 1.5	Z = 2.0
Verbal Memory Composite	64.33	68.85	70.39	76.36	82.42 (9.04)	88.49	94.45	95.99	**100**
Word Memory total percent correct	70.72	75.46	77.07	83.32	89.67 (6.64)	96.01	**100**	**100**	**100**
Symbol Match total correct (hidden)	2.60	3.52	3.84	5.05	6.29 (1.84)	7.52	8.74	9	9
Three Letters pct. of total letters correct	59.86	66.12	68.24	76.50	84.89 (12.51)	93.27	**100**	**100**	**100**
Visual Memory Composite	42.96	48.90	50.92	58.76	66.71 (11.87)	74.67	82.50	84.52	90.46
Design Memory total percent correct	51.38	57.63	59.76	68.01	76.39 (12.5)	84.77	93.02	95.14	**100**
X-O total correct (memory)	1.86	3.11	3.53	5.18	6.84 (2.49)	8.51	10.16	10.58	11.82
Visual Motor Speed Composite	15.07	17.73	18.63	22.15	25.72 (5.33)	29.29	32.80	33.71	36.37
X-O total correct (interference)	77.21	81.74	83.28	89.26	95.33 (9.06)	101.41	107.39	108.93	113.46
Three Letters avg. counted correctly	3.09	4.62	5.14	7.15	9.20 (3.06)	11.25	13.264	13.78	15.31
Reaction Time Composite	0.96	0.91	0.89	0.82	0.75 (0.11)	0.68	0.61	0.59	0.53
X-O avg. correct RT (interference)	0.84	0.80	0.78	0.72	0.65 (0.10)	0.59	0.52	0.51	0.46
Symbol Match avg. correct RT (visible)	2.68	2.47	2.40	2.12	1.84 (0.42)	1.56	1.28	1.21	1.00
Color Match avg. correct RT	1.136	1.26	1.23	1.11	0.98 (0.19)	0.85	0.73	0.69	0.60
Impulse Control Composite	21.71	18.62	17.56	13.48	9.33 (6.19)	5.19	1.10	0.05	**0**
X-O total incorrect (interference)	18.79	16.17	15.27	11.81	8.29 (5.25)	4.77	1.30	0.41	**0**
Color Match (total commissions)	5.97	4.74	4.32	2.69	1.04 (2.46)	**0**	**0**	**0**	**0**

FIGURE 1 Norms and standard deviations for 10 year old children across composite scores and subtest on the Immediate Post-concussion and Cognitive Testing (ImPACT) battery.



	Z=-2.0	Z=-1.5	Z=-1.33	Z=-.67	Z=0	Z=.67	Z=1.33	Z=1.5	Z=2.0
Verbal Memory Composite	66.23	70.61	72.10	77.89	83.76 (8.77)	89.63	95.42	**96.91**	**100**
Word Memory total percent correct	83.28	86.10	87.07	90.80	94.58 (5.65)	98.37	**100**	**100**	**100**
Symbol Match total correct (hidden)	2.90	3.79	4.09	5.26	6.45 (1.78)	7.64	8.82	**9**	**9**
Three Letters pct. of total letters correct	58.17	64.87	67.15	76.00	84.98 (13.4)	93.96	**100**	**100**	**100**
Visual Memory Composite	45.35	51.72	53.88	62.29	70.82 (12.73)	79.35	87.75	89.92	96.29
Design Memory total percent correct	57.31	63.23	65.24	73.06	81.00 (11.84)	88.93	96.75	98.76	**100**
X-O total correct (memory)	2.50	3.70	4.11	5.69	7.29 (2.40)	8.90	10.48	10.89	**12.00**
Visual Motor Speed Composite	18.95	21.68	22.61	26.21	29.87 (5.46)	33.53	37.13	38.06	40.79
X-O total correct (interference)	84.02	88.47	89.99	95.87	101.84 (8.91)	107.82	113.70	115.22	119.67
Three Letters avg. counted correctly	4.79	6.45	7.01	9.20	11.42 (3.32)	13.65	15.84	16.40	18.06
Reaction Time Composite	0.86	0.82	0.80	0.74	0.68 (0.09)	0.62	0.56	0.54	0.50
X-O avg. correct RT (interference)	0.83	0.77	0.75	0.68	0.60 (0.12)	0.52	0.44	0.43	0.37
Symbol Match avg. correct RT (visible)	2.35	2.17	2.10	1.86	1.62 (0.37)	1.37	1.13	1.07	0.89
Color Match avg. correct RT	1.16	1.10	1.07	0.99	0.90 (0.13)	0.81	0.73	0.70	0.64
Impulse Control Composite	20.15	17.32	16.36	12.64	8.85 (5.65)	5.07	7.35	0.37	**0**
X-O total incorrect (interference)	18.54	15.95	15.06	11.64	8.16 (5.19)	4.68	1.25	0.37	**0**
Color Match (total commissions)	2.96	2.39	2.20	1.45	0.70 (1.13)	**0**	**0**	**0**	**0**

FIGURE 2 Norms and standard deviations for 11 year old children across composite scores and subtest on the Immediate Post-concussion and Cognitive Testing (ImPACT).

ANOVAs were conducted to compare the effects of age and gender on ImPACT composite scores: Verbal Memory, Visual Memory, Visual Motor Speed, Reaction Time, and Impulse Control. Results that yielded a significant main effect for age were further analyzed using appropriate corrections for multiple comparisons (i.e., comparison of 10-year-olds to 11-year-olds, 10-year-old to 12-year-olds, and 11-year-olds to 12-year-olds).

Verbal Memory

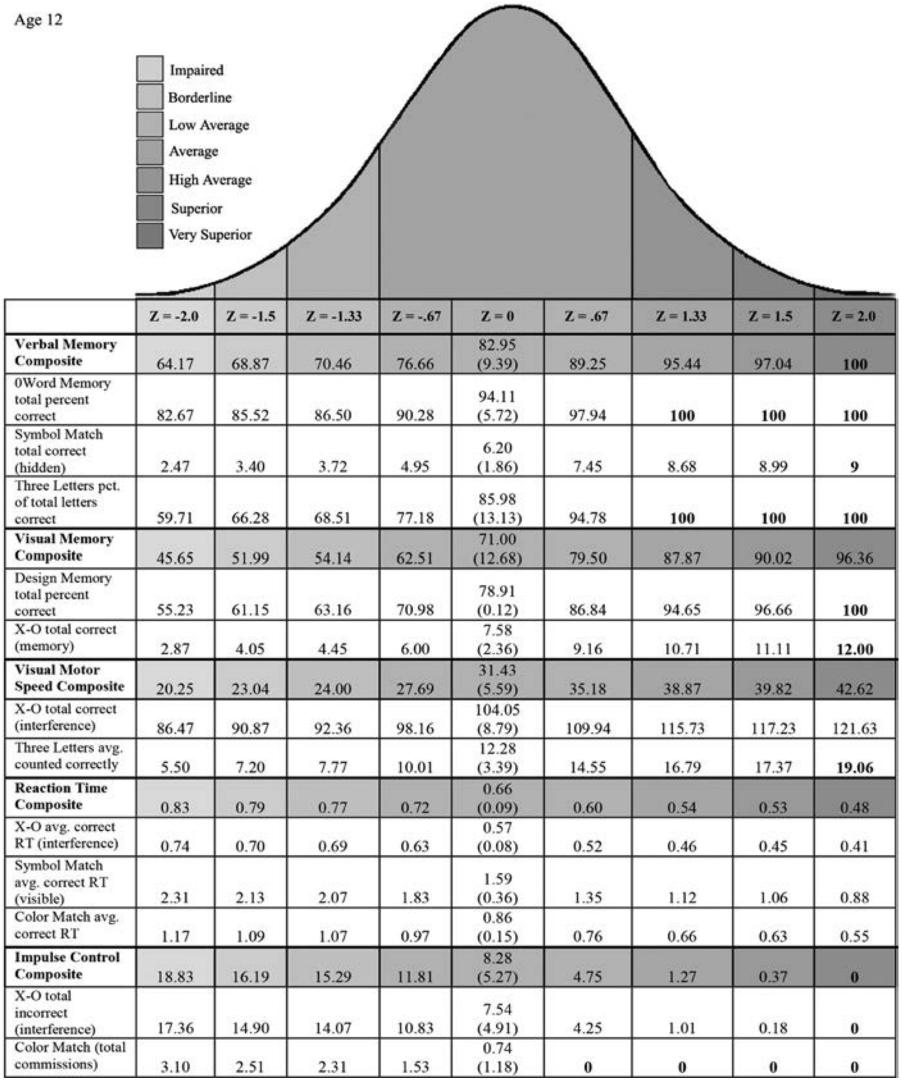
Results of the ANOVA revealed no interaction effect between age and gender on Verbal Memory scores, $F(2, 359) = 1.96$, $p = .146$, $\eta^2 = .012$. There were no main effects of age, $F(2, 359) = 1.96$, $p = .146$, $\eta^2 = .011$, or gender, $F(2, 359) = 0.26$, $p = .872$, $\eta^2 = .000$ (Table 2).

Visual Memory

There was no interaction between age and gender on Visual Memory scores, $F(2, 359) = 1.37$, $p = .255$, $\eta^2 = .008$, but there was a main effect of age, $F(2, 359 = 8.443$, $p = .000$, $\eta^2 = .045$. As Levene's test of equal variances was significant ($p = .027$), the simple effects of age are reported using a Games-Howell correction. Results showed significant differences between 10-year-old athletes and both 11-year-old ($p = .028$) and 12-year-old ($p = .000$) athletes on the Visual Memory composite. There was no main effect of gender on Visual Memory, $F(1, 359) = 0.38$, $p = .845$, $\eta^2 = .00$ (Table 2).

Visual Motor Speed

There was no interaction effect between age and gender on Visual Motor Speed, $F(2, 359) = 1.77$, $p = .171$, $\eta^2 = .010$, but again, there was a main effect of age, $F(2, 359) = 31.63$, $p = .000$, $\eta^2 = .150$. There was no main effect of gender, but results did show a strong statistical trend, $F(1, 359) = 3.09$, $p = .08$, $\eta^2 = .009$. Levene's test



	Z = -2.0	Z = -1.5	Z = -1.33	Z = -.67	Z = 0	Z = .67	Z = 1.33	Z = 1.5	Z = 2.0
Verbal Memory Composite	64.17	68.87	70.46	76.66	82.95 (9.39)	89.25	95.44	97.04	**100**
0Word Memory total percent correct	82.67	85.52	86.50	90.28	94.11 (5.72)	97.94	**100**	**100**	**100**
Symbol Match total correct (hidden)	2.47	3.40	3.72	4.95	6.20 (1.86)	7.45	8.68	8.99	**9**
Three Letters pct. of total letters correct	59.71	66.28	68.51	77.18	85.98 (13.13)	94.78	**100**	**100**	**100**
Visual Memory Composite	45.65	51.99	54.14	62.51	71.00 (12.68)	79.50	87.87	90.02	96.36
Design Memory total percent correct	55.23	61.15	63.16	70.98	78.91 (0.12)	86.84	94.65	96.66	**100**
X-O total correct (memory)	2.87	4.05	4.45	6.00	7.58 (2.36)	9.16	10.71	11.11	**12.00**
Visual Motor Speed Composite	20.25	23.04	24.00	27.69	31.43 (5.59)	35.18	38.87	39.82	42.62
X-O total correct (interference)	86.47	90.87	92.36	98.16	104.05 (8.79)	109.94	115.73	117.23	121.63
Three Letters avg. counted correctly	5.50	7.20	7.77	10.01	12.28 (3.39)	14.55	16.79	17.37	**19.06**
Reaction Time Composite	0.83	0.79	0.77	0.72	0.66 (0.09)	0.60	0.54	0.53	0.48
X-O avg. correct RT (interference)	0.74	0.70	0.69	0.63	0.57 (0.08)	0.52	0.46	0.45	0.41
Symbol Match avg. correct RT (visible)	2.31	2.13	2.07	1.83	1.59 (0.36)	1.35	1.12	1.06	0.88
Color Match avg. correct RT	1.17	1.09	1.07	0.97	0.86 (0.15)	0.76	0.66	0.63	0.55
Impulse Control Composite	18.83	16.19	15.29	11.81	8.28 (5.27)	4.75	1.27	0.37	**0**
X-O total incorrect (interference)	17.36	14.90	14.07	10.83	7.54 (4.91)	4.25	1.01	0.18	**0**
Color Match (total commissions)	3.10	2.51	2.31	1.53	0.74 (1.18)	**0**	**0**	**0**	**0**

FIGURE 3 Norms and standard deviations for 12 year old children across composite scores and subtest on the Immediate Post-concussion and Cognitive Testing (ImPACT).

of equal variances was nonsignificant ($p = .351$). Simple effects were tested using a Bonferroni correction for multiple comparisons. Results once again revealed differences between 10-year-old and 11-year-old ($p = .000$) and 12-year-old ($p = .000$) athletes as well as significant differences between 11-year-old and 12-year-old ($p = .008$) athletes (Table 2).

TABLE 2
Results of Univariate Analyses of Variance

	Age × Sex Interaction		*Age*		*Sex*	
Domain	F	p	F	p	F	p
Verbal Memory	2.235	.109	1.936	.146	0.026	.872
Visual Memory	1.371	.255	8.443	.000	0.038	.845
Visual Motor Speed	1.777	.171	31.63	.000	3.090	.080
Reaction Time	1.592	.205	38.385	.000	0.525	.469
Impulse Control	4.144	.017	6.802	.001	1.87	.172

Note. F values and significance (*p* values) are shown for each of the five composite scores yielded from the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) battery including Verbal Memory, Visual Memory, Visual Motor Speed, Reaction Time, and Impulse Control. Significant results are bolded.

Reaction Time

There was no interaction between age and gender, $F(2, 359) = 1.59$, $p = .205$, $\eta^2 = .009$. While there was a main effect for age, $F(2, 359) = 38.39$, $p = .000$, $\eta^2 = .176$, gender did not exert an effect, $F(1, 359) = 0.53$, $p = .469$, $\eta^2 = .001$. Levene's test of equal variances was significant; thus, a Games-Howell correction was employed to analyze the simple effects. Ten-year-olds showed differences from 11-year-olds ($p = .000$) and 12-year-olds ($p = .000$), and 11-year-olds were also different than 12-year-olds ($p = .001$; Table 2).

Impulse Control

Finally, results of the ANOVA revealed an interaction effect between age and gender on Impulse Control, $F(2, 359) = 4.14$, $p = .017$, $\eta^2 = .023$, as well as a significant main effect of age, $F(2, 359) = 6.82$, $p = .001$, $\eta^2 = .037$, but not gender, $F(1, 359) = 1.87$, $p = .172$, $\eta^2 = .005$. Levene's test of equal variances was significant; thus, a Games-Howell correction was employed to analyze the simple effects. Ten-year-olds did not differ from 11-year-olds ($p = .714$) but did differ from 12-year-olds ($p = .002$), and 11-year-olds were also different than 12-year-olds ($p = .013$; Table 2).

DISCUSSION

To investigate age and gender differences among preadolescents on the ImPACT, a retrospective sample of 370 male and female athletes aged 10 to 12 years old was compared across sex and age. Results of one-way ANOVAs with age and gender as between-subjects factors revealed significant main effects of age on the Visual Memory, $F(2, 359) = 8.443$, $p = .000$, $\eta^2 = .045$, Visual Motor Speed, $F(2, 359) = 31.63$, $p = .000$, $\eta^2 = .150$, Reaction Time, $F(2, 359) = 38.39$, $p = .000$, $\eta^2 = .176$, and Impulse Control, $F(2, 359) = 6.82$, $p = .001$, $\eta^2 = .037$, composite scores. Further exploration of the effect of age using correction factors for multiple comparisons revealed that 10-year-olds significantly differed from both 11- and 12-year-olds, and 11-year-olds and 12-year-olds were also significantly different on measures of Visual Memory, Visual Motor Speed, Reaction Time, and Impulse Control. No significant effect was found on the Verbal Memory composite for age. These results are consistent with prior research showing that maturation during preadolescence contributes to dramatic changes in reaction time, processing speed, and executive control (Carpenter et al., 1990; Casey et al., 2000; Fry & Hale, 2000; Nagy et al., 2004; M. C. Stevens et al., 2009). There is some precedence to the effect of age on Visual Memory as well with previous work showing similar findings (Ardila & Rosselli, 1994; Sheingold, 1973; Wilson, Scott, & Power, 1987). The results also confirm our original hypothesis that normative data for the 10- to 12-year-old age group on the ImPACT should be separated by individual ages rather than banded into a single group due to the variation in performance within this group. Age-specific data will serve as a better representation for performance comparison among 10- to 12-year-olds, particularly in the nonverbal and speed domains assessed by the ImPACT.

Gender effects were also explored in this study to evaluate whether boys and girls within the 10- to 12-year-old age group differed on the ImPACT composite scores. The same one-way ANOVAs for age and gender showed no interaction effects for the Verbal Memory, Visual Memory, Visual Motor Speed, or Reaction Time composites (see Table 2). Impulse Control, by contrast, evidenced a significant interaction effect for age and gender. However, no main effects for gender were found for any of the ImPACT composite scores, suggesting that gender does not modify baseline performance within this age group. The absence of gender findings on cognitive testing at this age is not unusual (Sheppard & Vernon, 2008) as sex differences in cognition reach peak magnitude in middle school- and high school-aged adolescents (Camarata & Woodcock, 2006) where girls show superior performance until young adulthood. Our findings are generally consistent with the literature where no/minimal sex differences have been found at baseline (Covassin, Schatz, & Swanik, 2007; Kontos et al., 2012). The extant literature does show prolonged recovery from concussion in girls (Covassin et al., 2007; Covassin, Swanik, & Sachs, 2003; Farace & Alves, 2000; Reddy et al., 2008).

Because of the consistent age differences but lack of gender differences on the ImPACT composite scores, normative data provided in the current study are split across age groups but are combined on gender. Subtest normative data were provided to enrich the clinical interpretation of ImPACT test performance and provide alternative interpretive information to aid clinical judgment. These data may be particularly helpful when interpreting postinjury data. For example, a 10-year-old boy sustains a concussion while playing ice hockey. He presents for evaluation 5 days after injury with the following composite scores on the ImPACT (Z scores from the current 10- to 12-year-old age band presented in parentheses): Verbal Memory, 85 (0.33); Visual Memory, 75 (0.26); Visual Motor Speed, 19.63 (−2.75); and Reaction Time, 0.9 (−1.75). During the course of the next 25 days, he exhibits consistent improvement and reports being asymptomatic by 3 weeks postinjury. At that time, he obtains the following composite scores on the ImPACT: Verbal Memory, 95 (1.33); Visual Memory, 85 (1.00); Visual Motor Speed, 23.58 (−2.6); and Reaction Time, 0.77 (−0.75). Based on the current norms, Visual Motor Speed in particular would appear persistently low and this athlete might be withheld from competition longer despite otherwise meeting criteria for return to play (symptom-free at rest and with both cognitive and physical exertion). Using the norms in this study, the interpretation might be different. Consider the speed scores in particular. Immediately after injury, his Visual Motor Speed Z score would have been −1.14, or near the 14th percentile, and his Reaction Time would have been −1.43, near the 8th percentile. Such scores would still appear concerning to a neuropsychologist and might preclude the patient from returning to play. By contrast, his composite Z scores at apparent recovery would have been −0.4, or near the 34th percentile, for Visual Motor Speed and −0.21, or near the 45th percentile, for Reaction Time. The perception of whether the patient appears ready to return to play may shift substantially in such a case, with all other factors being equal. At apparent recovery, his scores appear typical (i.e., within the average range), thereby alleviating concern about returning this athlete back to the ice. It is important to note that neurocognitive scores should not be interpreted in isolation of other important information gleaned from clinical interviews and/or assessments using other objective measures. Neurocognitive data such as that from the ImPACT are useful as a screening tool that can provide rich information regarding cognitive performance, but there are other facets (e.g., reported symptoms, vestibular-ocular performance) that should be considered when determining whether an athlete is fully recovered (Collins, Kontos, Reynolds, Murawski, & Fu, 2014).

The current study is not without limitations. The normative data presented were collected from a retrospective sample; thus, environmental conditions and input of demographic data were not observed by the investigators of the study. Accordingly, administration may not have been standardized. However, as the ImPACT is a standalone computerized test battery that randomly selects test stimuli and requires limited interaction from the test administrator, the effects of such a confound are minimized. We took further steps to mitigate any undue effect of nonstandard administration on performance by eliminating very extreme or implausible scores. Nonetheless, athletes' performance on the ImPACT could have been biased by a variety of unforeseen factors such as a distracting environment. Maturational differences impact test performance, and therefore, when conducting research on younger age groups, large sample sizes are preferable. Although within the acceptable size for statistical analysis, future studies of ImPACT performance in this age group (especially 10-year-olds) should aim for a larger sample size. Further, future research investigating baseline and postinjury neurocognitive performance in this age group will provide important clinical support for the use of CNTs within this age cohort. The current data provide more information about test performance in this age group but should not be interpreted as a definitive normative sample given the number of 10-year-olds. Regardless, this study does provide sufficient statistical evidence for meaningful differences in this age cohort. Other studies focusing on special populations such as children with learning disabilities or disorders of attention will also be important as there are little to no normative data in this group, much less postinjury data.

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