

# Individual and Combined Effects of LD and ADHD on Computerized Neurocognitive Concussion Test Performance: Evidence for Separate Norms

R. J. Elbin<sup>1,\*</sup>, Anthony P. Kontos<sup>1</sup>, Nate Kegel<sup>1</sup>, Eric Johnson<sup>1</sup>, Scott Burkhart<sup>1</sup>, Philip Schatz<sup>2</sup>

<sup>1</sup>UPMC Sports Medicine Concussion Program, Department of Orthopaedic Surgery, University of Pittsburgh, PA, USA

<sup>2</sup>Psychology Department, Saint Joseph's University, Philadelphia, USA

\*Corresponding author at: Post-Doctoral Research Fellow, UPMC Sports Medicine Concussion Program, UPMC Center for Sport Medicine, 3200 South Water Street, Pittsburgh, PA 15203, USA. Tel.: +1-412-432-3725; fax: +412-432-3690.

E-mail address: rje13@pitt.edu (R.J. Elbin).

Accepted 29 March 2013

## Abstract

Decreased neurocognitive performance in individuals with self-reported attention deficit hyperactivity disorder (ADHD) and learning disability (LD) is well documented in the neuropsychological research literature. Previous studies employing paper-and-pencil neurocognitive assessments report lower performance in individuals with ADHD and LD. The purpose of the current study was to examine the influence of a self-reported diagnosis of LD, ADHD, and combined LD/ADHD on baseline computerized neurocognitive testing (CNT) used for the concussion assessment. Results revealed athletes with a self-reported diagnosis of LD, ADHD, and/or combined LD/ADHD demonstrated lower performance on baseline CNT and reported larger numbers of symptoms than did control athletes without these diagnoses. These findings provide evidence for the development of separate normative data for athletes with LD, ADHD, and LD/ADHD diagnoses on CNT batteries commonly used for concussion management.

**Keywords:** ADHD; LD; Computerized neurocognitive testing; ImPACT

## Introduction

Computerized neurocognitive testing (CNT) is one component in a comprehensive approach to managing sport-related concussion (along with symptom reports, balance assessment, and vestibular screening), as advocated for in current concussion consensus statements (McCrary et al., 2009). CNT provides objective data that informs clinical management and return-to-play decisions made by the sports medicine practitioner (Broglia, Ferrara, Macciocchi, Baumgartner, & Elliott, 2007; Elbin, Schatz, & Covassin, 2011; Lau, Collins, & Lovell, 2011, 2012; Lau, Lovell, Collins, & Pardini, 2009; Schatz, 2010; Schatz, Kontos, & Elbin, 2012; Schatz, Pardini, Lovell, Collins, & Podell, 2006). Ideally, CNT includes a pre-injury assessment (i.e., baseline), which allows the practitioner to make comparisons between post-concussion and pre-injury cognitive performance (Van Kampen, Lovell, Pardini, Collins, & Fu, 2006). However, baseline data are not always available, necessitating the use of normative CNT values for injured athletes (Echemendia et al., 2012).

Factors such as age (Field, Collins, Lovell, & Maroon, 2003), sex (Covassin, Elbin, Harris, Parker, & Kontos, 2012), and culture (Tsushima, Oshiro, & Zimbra, 2008) have been shown to influence the baseline CNT performance and need to be considered when interpreting comparisons with normative CNT data. Other factors such as attention deficit hyperactivity disorder (ADHD) and learning disability (LD) may also influence the baseline test performance (Silver et al., 2008). In fact, in the most recent Concussion in Sports Consensus Statement (McCrary et al., 2009), both ADHD and LD are referred to as “modifiers” that need to be considered when assessing and managing concussion. Moreover, researchers estimate that between 1.6 and 3.8 million sport-related concussions occur in the USA each year (Langlois, Rutland-Brown, & Wald, 2006), and recent reports

indicate that there are approximately 144,000 annual ER visits for concussion in children ages 0–19 (Meehan & Mannix, 2010). Given that the conservative combined rates of LD and ADHD start at 6.4% (assuming 4% prevalence and a co-morbid overlap of 20%), approximately 102,400 athletes with a sport-related concussion each year may have LD or ADHD. It is therefore surprising that there is limited research on the influence of ADHD and LD on baseline CNT performance and their individual and combined effects on normative data.

ADHD is defined by chronic and impairing behavior patterns characterized by a combination of abnormal levels of hyperactivity, inattention, and impulsivity (Penttila, Rintahaka, & Kaltiala-Heino, 2011). Characteristic symptoms of persons with ADHD include low frustration tolerance (Skirrow, McLoughlin, Kuntsi, & Asherson, 2009), poor self-esteem (Glass, Flory, Martin, & Hankin, 2011), and academic difficulties (Birchwood & Daley, 2012). ADHD affects 4%–10% of all children in the USA (Merikangas et al., 2010). Although typically diagnosed during childhood, recent studies suggest that 65%–85% of children with ADHD continue to meet the diagnostic criteria throughout adolescence and into adulthood (Biederman et al., 2006; McGee, Partridge, Williams, & Silva, 1991; Penttila et al., 2011). There are limited data on the prevalence of ADHD in athletic populations; however, prevalence rates in high school and collegiate athletes are assumed to reflect those in the general population (Putukian et al., 2011).

A learning disability is defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM) as learning disorders that are diagnosed when an individual's achievement on individually administered, standardized tests in reading, mathematics, or written expression is substantially below that expected for age, schooling, and level of intelligence (American Psychiatric Association, 2000, p. 49). Recent reports have documented a high co-morbidity rate among LD and ADHD with approximately 19%–26% of children with either disorder in the USA being diagnosed with both disorders (Barkley, 2003a, 2003b). As a result, LD and ADHD have been referred to by researchers as “overlapping spectrum disorders” (Mayes, Calhoun, & Crowell, 2000). Individuals who are diagnosed with one or both of these disorders also tend to demonstrate lower performance on paper-and-pencil-based neurocognitive test batteries (Mayes et al., 2000). However, little is known about the effects of LD and ADHD on CNT.

Researchers have documented executive functioning deficits in the areas of inhibition sustained attention (Barkley, 1997; Pennington & Ozonoff, 1996), complex problem solving, verbal learning, and memory in children, adolescents, and adult populations with diagnosed ADHD (DuPaul et al., 2001; Hoffman & DuPaul, 2000; Johnson et al., 2001; Seidman et al., 2005, 2006). Similarly, poor executive functioning and working memory have been documented in persons diagnosed with LD (Silver et al., 2008). Recent studies have examined the influence of these combined factors on neurocognitive performance and have concluded that both LD and ADHD together present an additive difficulty leading to worse neurocognitive performance on measures of reading, working memory, processing speed, response inhibition, phonological awareness, and set shifting (Purvis & Tannock, 1997; Willcutt et al., 2001). Seidman, Biederman, Monuteaux, Doyle, and Faraone (2001) examined neurocognitive performance in children (ages 6–17) diagnosed with both LD and ADHD and reported significantly more impairment on neurocognitive tests of executive and nonexecutive functioning than ADHD children without LD. These results have been supported in other studies that highlight neurocognitive deficits associated with the combined diagnosis of LD and ADHD (Jakobson & Kikas, 2007).

The effects of LD and ADHD on CNT performance is understudied, but warranted based on previous research evaluating neurocognitive function on paper-and-pencil tests. Collins and colleagues (1999) reported decreased baseline performance on the Trail-Making Test Form B and the Symbol Digit Modalities test for athletes associated with diagnosed LD and a history of concussion. This paper was the first to support the influence that LD and ADHD may have on concussion outcomes including neurocognitive test performance. These researchers suggested that clinicians should consider LD and ADHD status when using neurocognitive testing following concussion. Recent research demonstrates that men and high school athletes with ADHD and LD are more likely to have an invalid baseline (e.g., score below pre-determined cutoffs, reflective of inadequate effort) on computerized neurocognitive batteries (Schatz, Moser, Solomon, Ott, & Karpf, 2012), and other researchers report significant relationships between ADHD and LD to performance on verbal and visual memory in professional football players (Solomon & Haase, 2008). The Zurich Consensus Statement suggested that both LD and ADHD are modifiers that should be considered in concussion management (McCrary et al., 2009). However, there are no empirical data provided in the Zurich Consensus Statement or subsequent literature that examines the role of ADHD and LD alone or combination, in regard to concussion outcomes such as CNT performance.

The purpose of the current study was to compare performance on a CNT battery commonly used for assessing concussion between four groups of athletes: (a) athletes with ADHD, (b) athletes with LD, (c) athletes with both ADHD and LD, and (d) athletes without ADHD and LD (i.e., controls). It was hypothesized that athletes with either ADHD or LD alone would score lower than healthy controls. It was also hypothesized that athletes with both ADHD and LD would score lower than healthy controls and athletes with either ADHD or LD alone. A secondary purpose of the study was to propose new ADHD- and LD-adjusted normative computerized neurocognitive data for a commonly used CNT.

## Methods

### Design

A cross-sectional design was used for the current study. The independent variables were diagnoses of ADHD and/or LD. The dependent variables were CNT scores (i.e., verbal memory, visual memory, reaction time, processing speed) and symptom scores from the Immediate Post-concussion Assessment and Cognitive Test (ImPACT).

### Participants

Participants were from a sample of 27,016 athletes (23,089 high school and 3,927 collegiate; 12,258 women and 14,458 men) that completed the baseline ImPACT test battery across the USA over a 2-year period (2009–2011). Any athlete who reported previous history of brain surgery, neurological disorder (e.g., epilepsy and/or seizures), substance abuse, or psychiatric disorder (e.g., depression and/or anxiety) was excluded from the study. The remaining participants ( $N = 2,377$ ) represented 8.8% of the original sample and were grouped into one of four groups: (a) ADHD only ( $n = 882$ ), (b) LD only ( $n = 396$ ), (c) ADHD and LD ( $n = 161$ ), and (d) control ( $n = 938$ ). Of note, the subsample of 938 controls was randomly selected from a larger sample of 23,760, but this group was reduced to create similar sized groups. The representation of these groups to the overall sample is similar to the published rates of ADHD, LD, and combined ADHD/LD in the general U.S. population (DuPaul et al., 2001; Mayes et al., 2000; Merikangas et al., 2010). Demographic data for the ADHD, LD, LD/ADHD, and control groups are presented in Table 1. There was a small but statistically significant between-groups differences with respect to age (Table 1), in which the ADHD and LD groups were younger than the combined LD/ADHD group; as a result, age was used as a covariate (as described in the “Data Analysis” section, below). There were no significant between-groups differences noted on concussion history. There were more men than women within each group (Table 1). However, there were no sex differences between groups. A breakdown of participants by sport for each group is presented in Table 2.

### Measures

**LD and ADHD Status.** For the current study, participants indicated (i.e., yes/no) if they had ever been diagnosed with any LD and/or ADHD on the demographic questionnaire that is administered with the ImPACT test battery.

**Immediate Post-Concussion Assessment and Cognitive Test.** The ImPACT CNT battery was used to assess neurocognitive function and symptoms at baseline. The ImPACT test comprises three general sections that include demographic information, the 22-item Post-Concussion Symptom Scale, and six neurocognitive test modules.

The first module evaluates attention processes and verbal recognition memory. Athletes are presented twice with a list of 12 words that remain on a screen for 750 ms at a time. Athletes are then tested for immediate recall by answering “yes” or “no” when presented a list of 24 words. At the end of the sixth module (~20 min), athletes are presented with the same 24 words and asked to answer “yes” or “no.” This test measures delayed memory of athletes. Tests are scored based on a total percentage of correct answers.

The second module measures visual recognition memory and attentional processes. Athletes are presented with 12 designs that remain on the screen for 750 ms at a time. Athletes are then tested for immediate recall by answering “yes” or “no” when presented

**Table 1.** Demographic data for LD, ADHD, LD/ADHD combined, and control groups

Group	Age* ( $M$ [ $SD$ ])	Concussion History** ( $M$ [ $SD$ ])	Sex	
			Men	Women
Control	15.35 (1.43) <sup>a</sup>	0.10 (0.40)	505 (54%)	433 (46%)
LD	15.47 (1.48) <sup>a</sup>	0.44 (5.30)	243 (61%)	153 (39%)
ADHD	15.32 (1.42) <sup>a</sup>	0.18 (0.59)	343 (73%)	239 (27%)
Combined LD/ADHD	15.80 (1.44)	0.35 (0.88)	110 (68%)	51 (32%)
Total	15.39 (1.44)	0.20 (2.20)	1,501 (63%)	876 (37%)

Notes: LD = learning disability; ADHD = attention deficit hyperactivity disorder.

<sup>a</sup>Significantly different from the combined LD/ADHD group.

\* $p = .001$ .

\*\* $p = .08$ .

**Table 2.** Participants by sport for ADHD, LD, and control groups

Baseline		
Sport	Percent	<i>n</i>
American football	28.2	670
Soccer	16.6	395
Lacrosse	10.3	244
Basketball	7.4	176
Baseball	4.4	104
Wrestling	4.3	103
Track/cross-country	4.0	96
Cheerleading	3.8	90
Volleyball	3.7	89
Softball	3.7	89
Ice hockey	3.0	71
Field hockey	2.8	67
Tennis	1.7	40
Swimming/diving	1.3	30
Other	4.8	113

24 designs. At the end of the sixth module (~20 min), athletes are presented with the same 24 designs and asked to answer “yes” or “no.” This test measures delayed memory and is scored on total percentage correct.

The third module evaluates visual working memory and visual processing speed by using a distractor task (choice reaction time) and memory task (visual memory). Athletes are asked to right click if a red circle is presented and left click if a blue square is presented for the distractor task. Athletes are then presented a random screen of X’s and O’s with three yellow X’s and/or O’s. Athletes are presented the distractor test, followed by the same memory screen minus the yellow X’s and/or O’s. The athlete is asked to click on the three previously illuminated yellow X’s and/or O’s. Athletes complete this module four times. They receive a score for the number of errors on the distractor test, reaction time for the distractor test, and correct identification of yellow X’s and O’s.

The fourth module measures visual processing speed, learning, and memory. Athletes are presented nine symbols matched with nine numbers (1–9) on a screen. Below these pairings, a symbol is randomly presented. The athlete clicks on the matching number as quickly as possible while at the same time remembering the number/symbol pairings. When an athlete clicks on the correct number, the number will light up green. If the number was incorrect it will light up red. The athlete completes 27 trials. The second phase to this test consists of the symbols disappearing from the top grid, and then randomly reappears below the grid. The athletes click on the number that matches the symbol. Athletes receive an average reaction time score and a score for memory recall.

The fifth module measures choice reaction time. Athletes are presented with the words one at a time: red, green, and blue. If the word appears in the correct color, athletes click the left mouse button as fast as they can. Athletes receive a reaction time score and a score for the number of errors.

The sixth module measures visual motor response speed and working memory. Athletes are presented with three random letters on the screen. Athletes are then asked to click in backwards order numbers “25” through “1” from a randomized 5 × 5 grid. Athletes are asked to type in the three letters that appeared on the screen before the last number grid. Athletes complete this module five times. Athletes receive a score for the correct number of letters and clicked numbers.

Verbal memory, visual memory, visual processing speed, and reaction time composite scores are provided by ImPACT. The ImPACT test takes approximately 25 min to complete. Reliability data on the ImPACT composite scores range from 0.67 to 0.85 over a 7-day period (Iverson, Lovell, & Collins, 2003) and 0.62 to 0.85 over 1 year (Elbin et al., 2011). However, other researchers have reported lower intraclass correlation coefficients ranging from 0.23 to 0.38 over the course of 45- and 50-day retest intervals (Broglia et al., 2007) and have raised question over incremental validity of these computerized versions (Randolph, McCrea, & Barr, 2005).

### Procedures

University IRB approved this study as an exempt, de-identified medical records research study. Ideally and as recommended for best practice, athletes reported in groups of 10–15 at a time to their own institution’s computer laboratory, where they were explained the standardized test procedures and completed the baseline CNT battery (i.e., ImPACT). However, in practice, the

researchers acknowledge that variations of this recommended best practice may have occurred (e.g., more than 15 students at a session, testing individually).

### Data Analysis

Descriptive analyses (means, *SDs*, frequencies) were used to describe the sample. Prior to statistical analyses, invalid baseline tests as per the test manufacturer's criteria (i.e., impulse control composite score greater than 20) were excluded from the study. A series of analyses of covariance (ANCOVAs; co-varied for age) with Bonferroni correction for multiple comparisons were conducted to compare the neurocognitive performance and total symptom scores for the four groups (i.e., ADD, LD, ADD/LD, control). Post hoc pairwise comparisons were used to determine which groups differed significantly from one another. Statistical significance was set at a multiple comparison corrected  $p \leq .01$  and all statistical analyses were conducted using SPSS 21.0 (IBM Corp., 2012).

### Results

The results of a series of ANCOVAs (co-varied for age) with Bonferroni correction for multiple comparisons revealed significant differences between the four groups on verbal— $F(3; 2,372) = 11.02, p = .001, \eta^2 = 0.014$ —and visual— $F(3; 2,372) = 11.59, p = .001, \eta^2 = 0.014$ —memory, visual processing speed— $F(3; 2,372) = 71.16, p = .001, \eta^2 = 0.08$ , reaction time— $F(3; 2,372) = 37.61, p = .001, \eta^2 = 0.05$ , and total symptoms— $F(3; 2,372) = 16.27, p = .001, \eta^2 = 0.02$ . Examining the post hoc comparisons revealed that the control group demonstrated significantly higher performance on all ImPACT composite scores and reported fewer baseline symptoms than the LD, ADHD, and LD/ADHD groups. Means, standard deviations, and additional post hoc comparisons for all composite scores and baseline symptoms are presented in Table 3.

### Discussion

The primary purpose of the current study was to investigate the individual and combined influence of self-reported diagnosis of LD and ADHD on the baseline administration of the popular neurocognitive test used for concussion assessment and management. The results indicated that groups of athletes who self-reported a diagnosis of LD, ADHD, and/or combined LD/ADHD demonstrated significantly lower baseline performance on all ImPACT composite scores and endorsed a significantly greater number of symptoms than control athletes without these diagnoses. These data are similar to those previously reported by researchers who documented lower neurocognitive performance in individuals with LD and ADHD diagnoses (Seidman et al., 1995, 2001, 2006). The current findings highlight the importance of the baseline or the “pre-injury” assessment when using serial neurocognitive testing for concussion management. Further, the results of the current study provide evidence for the development of separate normative data for athletes with LD, ADHD, and LD/ADHD diagnoses on the ImPACT neurocognitive test battery.

Decreased neurocognitive performance in individuals with ADHD and LD is well established in the neuropsychological literature. Previous studies, employing traditional paper-and-pencil neurocognitive assessments, report lower performance in individuals with ADHD (Barkley, 1997; Seidman, Biederman, Faraone, Weber, & Ouellette, 1997; Seidman et al., 1995, 2005) and LD (Denckla, 1991; Seidman, 2006) on measures of executive functioning, sustained attention, learning, and memory. These

**Table 3.** Comparison of for control, LD, ADHD, and LD/ADHD

	Control		LD		ADHD		LD/ADHD		$\eta^2$
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	
Verbal memory	84.46	9.87	81.54 <sup>a,b</sup>	10.00	83.40 <sup>c</sup>	9.73	81.38 <sup>a</sup>	10.34	0.014
Visual memory	71.90	12.96	68.16 <sup>a</sup>	13.50	69.45 <sup>a</sup>	13.24	67.63 <sup>a</sup>	14.90	0.014
Visual motor <sup>c</sup>	37.05	7.36	31.58 <sup>a,b</sup>	6.64	35.92 <sup>a,c,d</sup>	7.31	32.84 <sup>a,b</sup>	7.95	0.08
Reaction Time	0.59	0.08	0.63 <sup>a,b,d</sup>	0.09	0.60 <sup>a,c,d</sup>	0.09	0.63 <sup>a,b</sup>	0.10	0.05
Symptoms	3.07	4.05	3.94 <sup>a</sup>	4.72	4.50 <sup>a</sup>	4.83	4.45 <sup>a</sup>	4.84	0.02

Notes: LD = learning disability; ADHD = attention deficit hyperactivity disorder. All between-groups post hoc differences at  $p < .01$ .

<sup>a</sup>Different from Control.

<sup>b</sup>Different from ADHD.

<sup>c</sup>Different from LD.

<sup>d</sup>Different from LD/ADHD.

<sup>e</sup>Visual Processing Speed composite score.



earlier studies have substantiated the effects of ADHD and LD on neurocognitive performance on paper-and-pencil tests. The current study extended these findings to a CNT (i.e., ImPACT) designed specifically for the assessment of sport-related concussion.

In the current study, the presence of LD alone, or in conjunction with ADHD (i.e., overlapping diagnosis), was associated with lower neurocognitive performance on ImPACT when compared with athletes with only ADHD. The current finding is supported by previous research (Jakobson & Kikas, 2007; Seidman et al., 1995; Silver et al., 2008) in which individuals with co-morbid LD and ADHD performed worse on the Rey–Osterrieth Complex Figure and the Stroop test than individuals with ADHD only (i.e., without LD; Seidman et al., 1995). More recently, Seidman and colleagues (2001) reported that children with co-morbid LD and ADHD diagnoses performed worse than children with ADHD without LD on measures of executive and non-executive functions. These previous finding, together with the current results, support the hypothesis proposed by Seidman (2006) that suggests that co-morbid ADHD and LD diagnoses lead to more severe deficits in executive functioning, including memory and attentional dysfunction.

In addition, to the decreased performance on the neurocognitive domains of ImPACT, athletes with LD, ADHD, and ADHD/LD endorsed a significantly greater number of baseline concussion symptoms than controls. Literature on the relationship between LD and ADHD and baseline concussion symptoms has been understudied. Perhaps, these increased baseline concussion symptoms are reflective of heightened awareness of “state-like” feelings associated with the LD and ADHD diagnoses. Previous studies corroborate the influential relationship that LD and ADHD have on neurocognitive performance (Collins et al., 1999; Seidman et al., 1995, 1997); however, little research has examined symptom reports and LD and ADHD. Nonetheless, these findings should be interpreted cautiously and require replication in future research.

The current research represents the first study to examine the individual and combined influence of ADHD and LD on performance on a commonly used CNT and symptom report. The current findings, which are in agreement with previous studies using paper-and-pencil neurocognitive tests (Seidman et al., 1995, 2001), should be used to inform baseline neurocognitive test administration and interpretations. Baseline CNT has been recommended as best practice by recent concussion position statements and consensus papers (Guskiewicz et al., 2004; McCrory et al., 2009; Putukian et al., 2011). Baseline CNT provides the sports medicine professional with a direct intra-individual comparison of pre- to post-injury performance. Although normative data for age and gender for tests such as the ImPACT test used in the current study have been published (Iverson et al., 2003), other variables such as LD and ADHD have not been examined previously. The results of the current study suggest that LD and ADHD, and in particular LD, may confound post-injury test interpretation if not accounted for through an adjusted baseline comparison. Although researchers have recently questioned the utility of baseline computerized neurocognitive assessments (Echemendia et al., 2012) over post-injury normative comparisons, they failed to acknowledge how LD and ADHD might adversely affect post-injury only performance. The current study’s findings provide evidence that warrants consideration of LD, ADHD, and combined LD/ADHD when interpreting neurocognitive test results.

### Limitations

There are several limitations to the current study that should be acknowledged and addressed in future studies. The current data were compiled from a retrospective medical-records review of computerized neurocognitive baseline data. Although invalid baselines were discarded, the authors recognize that variability in testing environment (i.e., group vs. individual testing) may have influenced the results. In addition, the diagnosis of LD, ADHD, and LD/ADHD was based on self-reported data collected during baseline testing. Future studies should corroborate such diagnoses with additional documentation (e.g., parent/guardian corroboration, clinical exam/interview, medical records review) and consider examining the influence that the subtypes of ADHD (e.g., inattentive, hyperactive) and LD (e.g., reading, arithmetic) may have on neurocognitive performance. Examining sex differences on these ADHD and LD subtypes also warrants future study as previous research has documented that sex differences likely play a role in ADHD and LD subtypes (Bauermeister et al., 2007; Gross-Tsur et al., 2006). Additionally, this study did not account for the effect medication and other treatments may have had on the neurocognitive performance of the ADHD group. Previous work by Biederman and colleagues (2008) reported that attentional performance was higher in a sample of 15–25-year olds with ADHD who took stimulant medication compared with those who did not. Future research should consider the effect of ADHD medication including dosage schedule on computerized neurocognitive performance. Finally, the current study did not delineate between subtypes of LD such as reading and arithmetic subtypes.

### Clinical Implications

Clinicians should be aware of premorbid factors such as ADHD or LD. Individuals who sustain a concussion often exhibit acquired neurocognitive deficits (e.g., inattention, slowed processing, executive dysfunction) that present in a similar manner

to a clinical diagnosis of ADHD or LD (Yeates et al., 2005). On an individual level, those with ADHD and LD tend to be fairly heterogeneous in their clinical presentation, making baseline neurocognitive testing a valuable resource in clinical evaluation of concussion. The current findings highlight the importance of gathering a detailed premorbid history during the clinical interview and utilizing baseline neurocognitive testing. Furthermore, this study provides an important first step in examining the effects of LD and ADHD on computerized neurocognitive performance. The magnitude of the effect sizes in this paper is very modest, and the extent of potential clinical significance is simply unknown at this time. Knowing that an athlete has a history of LD or ADHD may be an important factor in determining prognosis, recovery time, and making safe return-to-play decisions.

## Conclusion

Athletes diagnosed with ADHD and/or LD performed significantly worse on CNT measures and endorsed more symptoms at baseline compared with the control group. As a result, comparing these athletes to the current standard normative data can result in more difficult return to play decision-making (e.g., preventing athletes from returning due to lower neurocognitive test scores). With specific baseline normative data for those diagnosed with ADHD and/or LD, treating clinicians will hopefully have a more accurate understanding of their true neurocognitive abilities. Despite this, one should always use neurocognitive test results as one of several important factors in return to play decisions. Results of the study also underscore the importance of individual baseline testing especially within a population(s) in which more variability is expected at baseline. As a result, clinicians will hopefully improve their accuracy regarding return to play decisions for these athletes post-injury.

## Conflict of Interest

Dr Schatz has served as a consultant to the International Brain Research Foundation, the Sports Concussion Center of New Jersey, and ImPACT Applications Inc. ImPACT had no role in the conceptualization of the study, the management or analysis of data, the writing of the article, or the decision to submit it for publication.

## References

- Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, *121* (1), 65–94.
- Barkley, R. A. (2003a). Issues in the diagnosis of attention-deficit/hyperactivity disorder in children. *Brain and Development*, *25* (2), 77–83.
- Barkley, R. A. (Ed.). (2003b). *Attention-deficit/hyperactivity disorder* (2nd ed.). New York: Guilford Press.
- Bauermeister, J. J., Shrout, P. E., Chavez, L., Rubio-Stipec, M., Ramirez, R., Padilla, L., et al. (2007). ADHD and gender: Are risks and sequela of ADHD the same for boys and girls? *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *48* (8), 831–839.
- Biederman, J., Monuteaux, M. C., Mick, E., Spencer, T., Wilens, T. E., Silva, J. M., et al. (2006). Young adult outcome of attention deficit hyperactivity disorder: A controlled 10-year follow-up study. *Psychological Medicine*, *36* (2), 167–179.
- Biederman, J., Seidman, L. J., Petty, C. R., Fried, R., Doyle, A. E., Cohen, D. R., et al. (2008). Effects of stimulant medication on neuropsychological functioning in young adults with attention-deficit/hyperactivity disorder. *Journal of Clinical Psychiatry*, *69* (7), 1150–1156.
- Birchwood, J., & Daley, D. (2012). Brief report: The impact of attention deficit hyperactivity disorder (ADHD) symptoms on academic performance in an adolescent community sample. *Journal of Adolescence*, *35* (1), 225–231.
- Broglio, S. P., Ferrara, M. S., Macciocchi, S. N., Baumgartner, T. A., & Elliott, R. (2007). Test-retest reliability of computerized concussion assessment programs. *Journal of Athletic Training*, *42* (4), 509–514.
- Collins, M. W., Grindel, S. H., Lovell, M. R., Dede, D. E., Moser, D. J., Phalin, B. R., et al. (1999). Relationship between concussion and neuropsychological performance in college football players. *Journal of the American Medical Association*, *282* (10), 964–970.
- Covassin, T., Elbin, R. J., Harris, W., Parker, T., & Kontos, A. (2012). The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *American Journal of Sports Medicine*, *40* (6), 1303–1312.
- Denckla, M. B. (1991). Attention deficit hyperactivity disorder-residual type. *Journal of Child Neurology*, *6* (Suppl.), S44–S50.
- American Psychiatric Association. (2000). *Diagnostic and Statistical Manual of Mental Disorders*, (4th ed., text rev.). Washington, DC: Author.
- DuPaul, G. J., Schachar, R. H., Weyandt, L. L., Tripp, G., Kiesner, J., Ota, K., et al. (2001). Self-report of ADHD symptoms in university students: Cross-gender and cross-national prevalence. *Journal of Learning Disabilities*, *34* (4), 370–379.
- Echemendia, R. J., Bruce, J. M., Bailey, C. M., Sanders, J. F., Arnett, P., & Vargas, G. (2012). The utility of post-concussion neuropsychological data in identifying cognitive change following sports-related MTBI in the absence of baseline data. *Clinical Neuropsychology*, *26* (7), 1077–1091.
- Elbin, R. J., Schatz, P., & Covassin, T. (2011). One-year test-retest reliability of the online version of ImPACT in high school athletes. *American Journal of Sports Medicine*, *39* (11), 2319–2324.
- Field, M., Collins, M. W., Lovell, M. R., & Maroon, J. (2003). Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *Journal of Pediatrics*, *142* (5), 546–553.
- Glass, K., Flory, K., Martin, A., & Hankin, B. L. (2011). ADHD and comorbid conduct problems among adolescents: Associations with self-esteem and substance use. *Attention Deficiency Hyperactivity Disorders*, *3* (1), 29–39.

- Gross-Tsur, V., Goldzweig, G., Landau, Y. E., Berger, I., Shmueli, D., & Shalev, R. S. (2006). The impact of sex and subtypes on cognitive and psychosocial aspects of ADHD. *Developmental Medicine and Child Neurology*, 48 (11), 901–905.
- Guskiewicz, K. M., Bruce, S. L., Cantu, R. C., Ferrara, M. S., Kelly, J. P., McCrea, M., et al. (2004). National Athletic Trainers' Association Position Statement: Management of sport-related concussion. *Journal of Athletic Training*, 39 (3), 280–297.
- Hoffman, J. B., & DuPaul, G. J. (2000). Psychoeducational interventions for children and adolescents with attention-deficit/hyperactivity disorder. *Child and Adolescent Psychiatric Clinics of North America*, 9 (3), 647–661, ix.
- IBM Corp. (2012). IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.
- Iverson, G. L., Lovell, M. R., & Collins, M. W. (2003). Interpreting change on ImPACT following sport concussion. *Clinical Neuropsychology*, 17 (4), 460–467.
- Jakobson, A., & Kikas, E. (2007). Cognitive functioning in children with and without Attention-deficit/Hyperactivity Disorder with and without comorbid learning disabilities. *Journal of Learning Disabilities*, 40 (3), 194–202.
- Johnson, D. E., Epstein, J. N., Waid, L. R., Latham, P. K., Voronin, K. E., & Anton, R. F. (2001). Neuropsychological performance deficits in adults with attention deficit/hyperactivity disorder. *Archives of Clinical Neuropsychology*, 16 (6), 587–604.
- Langlois, J. A., Rutland-Brown, W., & Wald, M. M. (2006). The epidemiology and impact of traumatic brain injury: A brief overview. *Journal of Head Trauma Rehabilitation*, 21 (5), 375–378.
- Lau, B. C., Collins, M. W., & Lovell, M. R. (2011). Sensitivity and specificity of subacute computerized neurocognitive testing and symptom evaluation in predicting outcomes after sports-related concussion. *American Journal of Sports Medicine*, 39 (6), 1209–1216.
- Lau, B. C., Collins, M. W., & Lovell, M. R. (2012). Cutoff scores in neurocognitive testing and symptom clusters that predict protracted recovery from concussions in high school athletes. *Neurosurgery*, 70 (2), 371–379; discussion 379.
- Lau, B. C., Lovell, M. R., Collins, M. W., & Pardini, J. (2009). Neurocognitive and symptom predictors of recovery in high school athletes. *Clinical Journal of Sport Medicine*, 19 (3), 216–221.
- Mayes, S. D., Calhoun, S. L., & Crowell, E. W. (2000). Learning disabilities and ADHD: Overlapping spectrum disorders. *Journal of Learning Disabilities*, 33 (5), 417–424.
- McCrary, P., Meeuwisse, W., Johnston, K., Dvorak, J., Aubry, M., Molloy, M., et al. (2009). Consensus statement on concussion in sport—the 3rd International Conference on concussion in sport, held in Zurich, November 2008. *Journal of Clinical Neuroscience*, 16 (6), 755–763.
- McGee, R., Partridge, F., Williams, S., & Silva, P. A. (1991). A twelve-year follow-up of preschool hyperactive children. *Journal of the American Academy of Child and Adolescent Psychiatry*, 30 (2), 224–232.
- Meehan, W. P., 3rd, & Mannix, R. (2010). Pediatric concussions in United States emergency departments in the years 2002–2006. *Journal of Pediatrics*, 157 (6), 889–893.
- Merikangas, K. R., He, J. P., Brody, D., Fisher, P. W., Bourdon, K., & Koretz, D. S. (2010). Prevalence and treatment of mental disorders among US children in the 2001–2004 NHANES. *Pediatrics*, 125 (1), 75–81.
- Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 37 (1), 51–87.
- Penttila, J., Rintahaka, P., & Kaltiala-Heino, R. (2011). The significance of attention-deficit hyperactivity disorder for the future of the child and the young. *Duodecim*, 127 (14), 1433–1439.
- Purvis, K. L., & Tannock, R. (1997). Language abilities in children with attention deficit hyperactivity disorder, reading disabilities, and normal controls. *Journal of Abnormal Child Psychology*, 25 (2), 133–144.
- Putukian, M., Kreher, J. B., Coppel, D. B., Glazer, J. L., McKeag, D. B., & White, R. D. (2011). Attention deficit hyperactivity disorder and the athlete: An American Medical Society for Sports Medicine position statement. *Clinical Journal of Sport Medicine*, 21 (5), 392–401.
- Randolph, C., McCrea, M., & Barr, W. B. (2005). Is neuropsychological testing useful in the management of sport-related concussion? *Journal of Athletic Training*, 40 (3), 139–152.
- Schatz, P. (2010). Long-term test-retest reliability of baseline cognitive assessments using ImPACT. *American Journal of Sports Medicine*, 38 (1), 47–53.
- Schatz, P., Kontos, A., & Elbin, R. (2012). Response to Mayers and Redick: “Clinical utility of ImPACT assessment for postconcussion return-to-play counseling: Psychometric issues”. *Journal of Clinical and Experimental Neuropsychology*, 34 (4), 428–434; discussion 435–442.
- Schatz, P., Moser, R. S., Solomon, G. S., Ott, S. D., & Karpf, R. (2012). Prevalence of invalid computerized baseline neurocognitive test results in high school and collegiate athletes. *Journal of Athletic Training*, 47 (3), 289–296.
- Schatz, P., Pardini, J. E., Lovell, M. R., Collins, M. W., & Podell, K. (2006). Sensitivity and specificity of the ImPACT Test Battery for concussion in athletes. *Archives of Clinical Neuropsychology*, 21 (1), 91–99.
- Seidman, L. J. (2006). Neuropsychological functioning in people with ADHD across the lifespan. *Clinical Psychology Review*, 26 (4), 466–485.
- Seidman, L. J., Benedict, K. B., Biederman, J., Bernstein, J. H., Seiverd, K., Milberger, S., et al. (1995). Performance of children with ADHD on the Rey-Osterrieth complex figure: A pilot neuropsychological study. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 36 (8), 1459–1473.
- Seidman, L. J., Biederman, J., Faraone, S. V., Weber, W., & Ouellette, C. (1997). Toward defining a neuropsychology of attention deficit-hyperactivity disorder: Performance of children and adolescents from a large clinically referred sample. *Journal of Consulting and Clinical Psychology*, 65 (1), 150–160.
- Seidman, L. J., Biederman, J., Monuteaux, M. C., Doyle, A. E., & Faraone, S. V. (2001). Learning disabilities and executive dysfunction in boys with attention-deficit/hyperactivity disorder. *Neuropsychology*, 15 (4), 544–556.
- Seidman, L. J., Biederman, J., Monuteaux, M. C., Valera, E., Doyle, A. E., & Faraone, S. V. (2005). Impact of gender and age on executive functioning: Do girls and boys with and without attention deficit hyperactivity disorder differ neuropsychologically in preteen and teenage years? *Developmental Neuropsychology*, 27 (1), 79–105.
- Seidman, L. J., Biederman, J., Valera, E. M., Monuteaux, M. C., Doyle, A. E., & Faraone, S. V. (2006). Neuropsychological functioning in girls with attention-deficit/hyperactivity disorder with and without learning disabilities. *Neuropsychology*, 20 (2), 166–177.
- Silver, C. H., Ruff, R. M., Iverson, G. L., Barth, J. T., Broshek, D. K., Bush, S. S., et al. (2008). Learning disabilities: The need for neuropsychological evaluation. *Archives of Clinical Neuropsychology*, 23 (2), 217–219.
- Skirrow, C., McLoughlin, G., Kuntsi, J., & Asherson, P. (2009). Behavioral, neurocognitive and treatment overlap between attention-deficit/hyperactivity disorder and mood instability. *Expert Review of Neurotherapeutics*, 9 (4), 489–503.



- Solomon, G. S., & Haase, R. F. (2008). Biopsychosocial characteristics and neurocognitive test performance in National Football League players: An initial assessment. *Archives of Clinical Neuropsychology*, *23* (5), 563–577.
- Tsushima, W. T., Oshiro, R., & Zimbra, D. (2008). Neuropsychological test performance of Hawai'i high school athletes: Hawai'i ImPACT normative data. *Hawaii Medical Journal*, *67* (4), 93–95.
- Van Kampen, D. A., Lovell, M. R., Pardini, J. E., Collins, M. W., & Fu, F. H. (2006). The “value added” of neurocognitive testing after sports-related concussion. *American Journal of Sports Medicine*, *34* (10), 1630–1635.
- Willcutt, E. G., Pennington, B. F., Boada, R., Ogline, J. S., Tunick, R. A., Chhabildas, N. A., et al. (2001). A comparison of the cognitive deficits in reading disability and attention-deficit/hyperactivity disorder. *Journal of Abnormal Psychology*, *110* (1), 157–172.
- Yeates, K. O., Armstrong, K., Janusz, J., Taylor, H. G., Wade, S., Stancin, T., et al. (2005). Long-term attention problems in children with traumatic brain injury. *Journal of the American Academy of Child and Adolescent Psychiatry*, *44* (6), 574–584.