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Title: Effects of Age, Sex, Learning Disability, and Attention-deficit/Hyperactivity Disorder on the Neuropsychological Test Performances of High School Athletes

Abstract

Purpose: Computerized neuropsychological testing has emerged as a vital approach in the assessment and management of sports-related concussion. Despite a growing body of research on the utility of neuropsychological testing of athletes, limited and conflicting findings are available about the effects of age, sex, learning disability, and attention-deficit/hyperactivity disorder on the scores of a neuropsychological test battery when administered to high school athletes.

Methods: The participants, 5741 high school athletes (3313 males, 2428 females) in 65 high schools, underwent baseline neuropsychological testing before the start of their sport season. Multivariate analyses of variance were calculated to examine the effects of age, sex, learning disability, and attention-deficit/hyperactivity disorder on the neuropsychological test scores and total symptom score.

Results: The neuropsychological test scores of the 16 to 18 age group were significantly better than the 13 to 15 age group on all 5 neuropsychological tests. Girls performed significantly better than boys on 3 of the 5 neuropsychological tests. Girls also reported more symptoms than boys. The athletes with a history of learning disability scored significantly poorer than those without a history of learning disability on 3 of the 5 neuropsychological tests and had higher total symptom scores. Those with a history of attention-deficit/hyperactivity disorder obtained significantly lower scores than those without a history attention-deficit/hyperactivity disorder on 1 of the 5 neuropsychological tests, while obtaining higher total symptom scores.

Conclusions: The findings support the current use of age and sex norms in the interpretation of neuropsychological test scores, and suggest that learning disability and attention-deficit/hyperactivity disorder need to be considered when examining the neuropsychological test results of high school athletes.

Keywords: neuropsychological, age, sex, learning disability, attention-deficit/hyperactivity disorder

ABBREVIATIONS

ANAM: Automated Neuropsychological Assessment Metrics; **ImPACT:** Immediate Post-Concussion Assessment and Cognitive Testing; **LD:** learning disability; **ADHD**: attention-deficit/hyperactivity disorder; **MANOVA:** multivariate analysis of variance.

INTRODUCTION

In the past decade, an increasing body of medical research, media coverage and legislative interests has focused on sports-related concussion, with growing concerns for the accurate diagnoses and effective management of sport concussions.[1,2,3] Every state in the United States has passed laws mandating that concussed athletes undergo qualified health care evaluations before returning to participate in sports. While customary neurodiagnostic methods, such as x-rays, CT scans and MRIs, have limited roles in the assessment of concussions, the use of neuropsychological testing, according to the 4th International Conference on Concussion in Sport, is recognized as a valued approach in the evaluation of neurocognitive changes in the concussed athlete.[4] The interest in neuropsychological techniques developed because of head injuries in contact sports, like football, at the high school, college and professional levels. In 2007 the National Football League required baseline and post-injury neuropsychological assessments for its players,[5] and other professional sports, including ice hockey, soccer, rugby, Australian Rules football, skiing, and motor sports, have also implemented neuropsychological testing of their participants.[6,7]

In recent times, traditional paper-and-pencil neuropsychological tests have been replaced in the athletic context by practical user-friendly computerized neurocognitive testing methods.[8] The advantages of the computer-based neuropsychological test methods include ease of administration, shorter testing time, accessibility to group testing, and cost effectiveness. Sports medicine researchers attest to the utility of computer-based neuropsychological test batteries, such as the Automated Neuropsychological Assessment Metrics (ANAM),[9] Cog Sport[10] and the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).[11] For high school athletes, ImPACT has emerged as one of the most widely used neurocognitive tools for the assessment of mild traumatic brain injury. A substantial body of research has revealed the usefulness of this computerized test battery,[12] but others also cited some of its drawbacks, e.g., its lack of reliability and validity data.[13] In addition, limited information is available as to the potential influence of demographic and learning factors, such as age, sex, learning disability (LD), and attention-deficit/hyperactivity disorder (ADHD), on neuropsychological test scores.

Age

As the cognitive abilities of children continue to develop through adolescence, the effect of age on neuropsychological functioning in the general population is well-documented over a wide range of neuropsychological test instruments.[14,15] On the other hand, research findings on the impact of age in the neuropsychological assessment of adolescent athletes are notably inconsistent. Several sports medicine investigations confirm the established patterns of older adolescents scoring better on neuropsychological tests than their younger counterparts.[16-20] However, in other studies of youth athletes, no age differences were observed on varied neuropsychological tests.[21-23] To further obfuscate age effects, a comparison of athletes 13-16 year old and 18-22 year old found that the older group performed better on reaction time, while the younger group did better on visual motor speed.[24] Varying research methodologies, such as different test instruments and sample sizes, probably explain the conflicting research evidence of age factors in the neurocognitive test performances in young athletes, with results that call for further examination of this relevant demographic variable.

Sex

Sex differences in certain cognitive functions among children have been demonstrated. For example, girls achieve higher scores on verbal tests, while boys obtain higher scores on visuospatial tests.[14] Likewise, among young athletes, sex differences have been noted, with girls performing better than boys on measures of processing speed and verbal production,[21] as well as reaction time and verbal memory.[25] Female athletes also obtained higher symptom scores.[22,23,26] In contrast, no sex differences were found in other studies of youth athletes' scores on neurocognitive tests.[19,20,22,23] In view of these inconsistent findings, further comparison of young male and female athletes is desirable.

LD/ADHD

Despite the notable presence of LD and ADHD among school children, few studies have examined these factors in high school sports.[27] In 2 investigations, no differences on neuropsychological testing were found among high school athletes with and without a history of LD.[21,22] However, 2 recent studies found that athletes with a history of LD, ADHD, and/or combined LD/ADHD demonstrated poorer performances on ImPACT tests of verbal memory, visual memory, visual processing speed, reaction time, and total symptoms than a control group of athletes without LD or ADHD.[27,28] How student athletes with LD or ADHD perform on neuropsychological tests remains uncertain and deserves further exploration.

We designed the present research to fill important gaps in our knowledge of the possible effects of demographic and learning factors on neurocognitive measures, by obtaining ImPACT baseline test scores of a large sample of high school athletes. We specifically examined the effects of age, sex, LD, and ADHD. Based on prior neuropsychological studies, we hypothesized that age, sex, LD, and ADHD would significantly affect ImPACT scores.

MATERIALS AND METHODS

Participants

Participants for this normative study were 5741 English speaking athletes (3313 males, 2428 females) in 65 high schools, grades 8 to 12. The mean age of the participants was 15.06 years (*SD* = 1.21). Athletes included 1383 8th graders, 1507 9th graders, 1517 10th graders, 944 11th graders, and 71 12th graders (219 had missing data for their grade). Seventy athletes (1.22%) reported a history of LD and 149 (2.59%) had a history of ADHD.

The numbers of athletes in the varied sports were football (*n* = 1954), soccer (*n* = 1049), basketball (*n* = 804), volleyball (*n* = 709), cheerleading (*n* = 390), softball (*n* = 150), baseball (*n* = 127), and others (*n* = 140) (418 had missing data for their sports). Six hundred forty eight athletes reported having a previous concussion, including 474 with one concussion, 114 with two concussions, and 60 with three or more concussions.

ImPACT

The participants underwent baseline testing with the computerized ImPACT battery prior to their respective seasons. ImPACT is a web-based computerized neuropsychological test battery developed for the assessment of sports-related concussion in youth, collegiate, and professional athletes. The test, which takes about 30 minutes to complete, was administered in small groups of about 20, monitored by certified athletic trainers trained in the standardized administration of the examination.

The ImPACT provided neurocognitive test scores and a total symptom score, along with relevant biopsychosocial information. ImPACT yielded five composite scores, including Verbal Memory, Visual Memory, Visual Motor Speed, Reaction Time, and Impulse Control. The testing also provided a Total Symptom score, based on the Post-Concussion Symptom Scale which consists of 22 commonly reported post-head injury symptoms (e.g., headaches, dizziness).[11] A partial list of biopsychosocial data included age, sex, years of education, native language, sport played, prior concussion, and history of seizures, psychiatric illness, learning disability, attention-deficit disorder, psychiatric illness or seizures. A total of 600 (9.46%) athletes were excluded from the study because of invalid profiles that were automatically identified by the online ImPACT version that incorporates various validity criteria, such as Impulse Control scores that were $\geq$30.

Statistical Analyses

We performed a multivariate analysis of variance (MANOVA) to identify between-group differences. The independent variables were age, sex, LD, and ADHD. The dependent variables were the ImPACT composite scores (Verbal Memory, Visual Memory, Visual Motor Speed, Reaction Time, and Impulse Control) and Total Symptom score.

We applied a Bonferroni correction to all analyses to account for multiple comparisons (0.05/6), resulting in an alpha of P = .008. Partial eta squared (η^2) was calculated as a measure of effect size, with 0.01 constituting a small effect, 0.06 a medium effect, and 0.14 a large effect.[29]

Approval for the use of the research data was granted by the State of Hawaii Department of Education. The study was reviewed by the Hawaii Pacific Health Research Institute and was determined to be exempt from institutional review board review.

RESULTS AND DISCUSSION

We present in Table 1 the means and standard deviations for each of the ImPACT scores of the athletes by age, sex, LD, and ADHD groups. The results of the MANOVA are also shown.

Age

A MANOVA was conducted examining the effects of age on the 6 ImPACT dependent variables. Using Pillai's trace, there was a significant effect of age on the ImPACT variables, $V = .039$, $F(6, 5732) = 38.41$, $P < .001$. The tests of between-subjects showed a statistically significant effect of age on five composite scores, with the 16-18 age group scoring higher than the 13-15 age group in Verbal Memory (F [1,5737] = 29.42, $P < .001$, partial $\eta^2 = .005$), Visual Memory (F [1,5737] = 8.54, $P = .003$, partial $\eta^2 = .001$, and Visual Motor Speed (F [1,5737] = 190.75, $P < .001$, partial $\eta^2 = .032$); athletes 16-18 scored lower (i.e., better) than athletes 13-15 in Reaction Time (F [1,5737] = 64.97, $P < .001$, partial $\eta^2 = .011$) and Impulse Control (F [1,5737] = 43.20, $P < .001$, partial $\eta^2 = .007$)S. The two age groups did not differ significantly Total Symptom scores.

Sex

MANOVA revealed a significant effect of sex on the ImPACT variables, $V = .037$, $F(6, 5732) = 36.36$, $P < .001$, as girls performed significantly higher than boys on Visual Motor Speed (F [1,5737] = 129.73, $P < .001$, partial $\eta^2 = .022$), and lower than boys on Reaction Time (F [1,5737] = 8.39, $P = .004$, partial $\eta^2 = .001$ and Impulse Control (F [1,5737] = 38.55, $P < .001$, partial $\eta^2 = .007$. Girls also reported significantly higher Total Symptom scores than boys (F [1,5737] = 9.03, $P = .003$, partial $\eta^2 = .002$). No sex differences were seen in Verbal and Visual Memory.

LD/ADHD

MANOVA showed a significant effect of LD on the ImPACT variables, V =.008, F (6, 5734) = 7.27, P <.001. Those with a history of LD obtained 4 ImPACT scores that were significantly different than those without a history of LD: lower Verbal Memory (F [1,5739] = 8.51, P = .004, partial η^2 = .001), lower Visual Motor Speed (F [1,5739] = 29.42, P < .001, partial η^2 = .005), slower Reaction Time (F [1,5739] = 8.80, P = .003, partial η^2 = .002), and higher Total Symptom (F [1,5739] = 16.40, P < .001, partial η^2 = .003). No significant difference was seen for Visual Memory and Impulse Control.

MANOVA indicated a significant effect of ADHD status on the ImPACT variables, V = .006, F (6, 5734) = 5.50, P <.001. The athletes with a history ADHD obtained scores that were statistically different than the scores of those reporting no history of ADD/ADHD, with lower Visual Motor Speed (F [1,5739] = 13.20, P < .001, partial η^2 = .002) and higher Total Symptom (F [1,5739] = 18.45, P < .001, partial η^2 = .003). There were no differences found with Verbal Memory, Visual Memory, Reaction Time, and Impulse Control.

The advantages of computerized neuropsychological testing over traditional paper-and-pencil test procedures, such as ease of test administration and cost effectiveness, have resulted in its wide use in the sports arena, as well as extensive research evidence regarding the neurocognitive functioning of concussed athletes. However, the limited and conflicting information available regarding the influence of factors, such as age, sex, LD, and ADHD, prompted the present investigation that provided a range of findings pertaining to these important variables. Our data revealed that, with increasing age in high school, there were better performances on Verbal Memory, Visual Memory, Visual Motor Speed, Reaction Time, and Impulse Control. The results reflected the progressive development of neurocognitive abilities during adolescence and is consistent with the established evidence on age differences in neuropsychological testing[14,15] and in sports neuropsychology findings.[16-20] When evaluating high school athletes' performances on neuropsychological measures, clinicians should recognize age factors in test results. Sex comparisons found girls performing better than boys on Visual Motor Speed, Reaction Time, and Impulse Control. Girls also reported more concussion symptoms than boys, who may ignore or minimize their symptoms in order to continue participating in their sport. [23] The present findings on sex differences were similar to results from neuropsychological research and with prior reports of high school and collegiate athletes.[21,25]

We obtained significantly poorer ImPACT scores from athletes with a history of LD or ADHD, as compared to those with no prior history of LD or ADHD. The lower ImPACT performances associated with LD or ADHD have been cited in previous sports-related investigations.[22,27,28] It should be noted that the effect sizes of the differences found with age, sex, LD, and ADHD were relatively small. With large sample sizes, as in this study, small between group differences can yield significant *P*-values while representing small effect sizes.[29]

The strengths and weaknesses of the current work are worthy of note. The sample size in this study comprised one of the largest number of participants in a study of this nature. The investigation, however, was compromised by self-reported personal data, such as history of LD and ADHD, which were not independently verified. Invalid ImPACT profiles were excluded, but there was no formal effort testing to assure optimal level of test performance by the athlete. Research indicates that 11% of high school football players provide baseline scores that represent insufficient effort on neuropsychological tests.[17]

CONCLUSIONS

The findings of this research revealed that factors, such as age, sex, LD, and ADHD, can affect the neuropsychological test scores of high school athletes. The results support the current use of separate age and sex norms in the interpretation of ImPACT test scores. Users of neuropsychological test instruments in sports need to acknowledge the influence of the aforementioned variables on test results.

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Reaction Time	0.64	0.11	0.61	0.09	8.8	0.003*
Impulse Control	7.9	5.4	7.57	5.15	0.28	0.599
Total Symptom	13.33	17.29	7.79	11.29	16.4	0.001*
	ADHD		No ADHD			
	M	*SD*	*M*	*SD*	*F*	*p*
Verbal Memory	81.06	10.57	82.17	9.94	1.82	0.177
Visual Memory	71.22	13.92	71.83	12.96	0.322	0.571
Visual Motor Speed	33.16	7.53	35.28	6.99	13.2	0.001*
Reaction Time	0.62	0.09	0.61	0.09	0.25	0.617
Impulse Control	8.52	6.35	7.55	5.12	5.09	0.024
Total Symptom	11.81	13.68	7.75	11.31	18.5	0.001*

*Significant < 0.008

Table 1. Means and standard deviations of ImPACT scores for age, sex, LD, and ADHD groups

	Ages 16-18		Ages 13-15			
	M	*SD*	*M*	*SD*	*F*	*p*
Verbal Memory	83.39	10.08	82.46	10.15	29.42	0.001*
Visual Memory	74.24	12.71	73.84	12.56	8.54	0.003*
Visual Motor Speed	38.53	6.61	34.88	6.19	190.75	0.001*
Reaction Time	0.6	0.09	0.61	0.07	64.79	0.001*
Impulse Control	5.98	4.53	8.42	5.87	43.2	0.001*
Total Symptom	6.57	9.8	8.74	12.85	0.23	0.632
	males		females			
	M	*SD*	*M*	*SD*	*F*	*p*
Verbal Memory	82.06	9.93	82.26	9.98	1.77	0.183
Visual Memory	72.28	12.88	71.19	13.1	6.49	0.011
Visual Motor Speed	34.37	7.14	36.39	6.67	129.73	0.001*
Reaction Time	0.62	0.09	0.61	0.09	8.39	0.004*
Impulse Control	7.95	5.4	7.07	4.76	38.55	0.001*
Total Symptom	7.42	11.13	8.45	11.73	9.03	0.003*
	LD		No LD			
	M	*SD*	*M*	*SD*	*F*	*p*
Verbal Memory	78.7	10.82	82.19	9.94	8.51	0.004*
Visual Memory	68.46	14.18	71.86	12.96	4.75	0.029
Visual Motor Speed	30.71	7.05	35.28	7	29.42	0.001*