Age-Related Differences in Neuropsychological Testing Among High School Athletes

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Context: Clinicians have questioned the need to obtain annual baseline neuropsychological tests in high school athletes. If no difference among academic grades exists, annual baseline testing may not be necessary.

Objective: To examine differences at baseline testing on pencil-and-paper neuropsychological tests among grade levels in high school athletes.

Design: Cross-sectional, between-groups design.

Setting: Schools participating in a Georgia high school athletics association.

Patients or Other Participants: High school football players (n = 198) in the 9th through 12th grades, with a mean age of 15.78 ± 1.16 years.

Main Outcome Measure(s): Participants were divided into 4 groups by grade and were administered a symptom checklist and brief neuropsychological test battery. Grade level served as the independent variable. Symptom and individual test scores within the neuropsychological test battery served as dependent variables.

Results: Differences were noted among grades on the Trail Making Test A ($F_{3,194}$ = 3.23, P = .024, η^2 = 0.048), Trail Making Test B ($F_{3,194}$ = 3.93, P = .009, η^2 = 0.057), Symbol Digit Modalities Test ($F_{3,194}$ = 4.38, P = .005, η^2 = 0.064), dominant tap ($F_{3,194}$ = 3.14, P = .026, η^2 = 0.046), and nondominant tap ($F_{3,194}$ = 4.902, P = .003, η^2 = 0.070). Using the Bonferroni correction ($P \le .00625$), we found differences between the 9th grade and 11th and 12th grades.

Conclusions: Baseline neuropsychological test scores in high school athletes improved as a function of age, with differences between the 9th grade and 11th and 12th grades. Because the differences were driven by 9th-grade test scores, baseline testing should be completed, at minimum, upon entrance into 9th and 10th grades; however, annual testing is still recommended until additional research is conducted.

Key Words: concussions, mild traumatic brain injuries, adolescents, cognitive maturity

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Key Points

- Athletes in the 11th and 12th grades performed better on tests of information processing, attention, and motor dexterity than did athletes in 9th grade.
- To reflect cognitive growth, baseline testing of high school athletes should occur at least twice: once when they enter 9th grade and once when they enter 10th; however, annual testing is still recommended.

An estimated 63 000 concussions occur annually in high school athletes.[1] McCrea et al[2] found an incidence rate in high school athletes (15.3%) that was nearly 3 times that originally suggested (5.5%). A variety of theories have been offered to explain why the younger brain is more vulnerable to concussion. Possibilities include less extensive myelination, a greater head-to-body ratio, and thinner cranial bones, all of which provide less protection to the developing nervous system.[3] However, cognitive immaturity has been suspected as the primary factor for increased incidence of concussion in high school athletes.[3,4]

According to the Luria[4,5] theory of brain organization and function, the sequence of cognitive development depends on the changes (both physiologic and functional) that occur with normal maturation of various cortical areas. Progression through each stage is paralleled by qualitative organizational changes in the child's adaptive intellectual abilities. Most researchers have argued that cognitive development of primary, secondary, and tertiary brain regions becomes functional by age 12 years.[5,6] Cognitive maturity, however, continues to develop through adulthood. This cognitive growth period may directly

affect both the recovery rate after injury and the appropriate assessment tools for baseline concussion assessment.

The difference between recovery rates in adults versus adolescents is that in the latter group, injuries occur during times of cognitive growth. Researchers[7,8] have proposed that the younger the brain at initial injury, the more resilient and faster the recovery will be. Recent literature, however, suggests that high school athletes, on average, take longer to recover and report more symptoms after concussion than adults.[9–13] Furthermore, adolescents with concussions show personality changes, headaches, irritability, school learning difficulties, and memory and attention deficits.[14,15] Consequently, it is difficult to assess developmental deficits after concussion, because signs of overt neurologic dysfunction and loss of developmental potential may be lacking. The loss of developmental potential may be demonstrable only at a later time or under specific circumstances.

Numerous position statements regarding concussion assessment have recommended the use of neuropsychological baseline testing.[16–18] Specific guidelines, however, are not available for use in high school athletes. Baseline

Table 1. Neuropsychological Test Age Appropriateness, Administration Time, Reliability, Description, and Domain

Tests	Appropriate Age, y	Administration Time, min	Reliability[21–26]	Description	Domain
Self-report symptoms: 16-item Head Injury Scale	Adolescents	2 to 3	0.84	Presence or absence of 16 symptoms, including duration and severity	Symptomatology
Standardized Assessment of Concussion	11+	5	0.66	Brief assessment of neurologic status	Cognitive function
Hopkins Verbal Learning Test	13+	20	0.54–0.77	The participant learns a list of 12 words from 3 semantic categories; 3 learning trials and 1 delayed trial	Memory/verbal learning
Digital finger tapping test	5+	4	0.58–0.93	Consists of five 10-second finger-tapping trials; average of taps during 5 trials is used for data collection	Motor and dexterity
Trail Making Test Part A	10+	5	0.41	The participant connects the numbers in order, beginning with 1 and ending with 25 in as little time as possible	Information processing
Trail Making Test Part B	10+	5	0.65	Part B requires the participant to connect numbers and letters in an alternate pattern (1-A-2-B-3-C, etc) in as little time as possible	Information processing
Symbol Digit Modalities Test	8+	1.5	0.74	This test involves substituting numbers for random symbols using a reference key	Attention
Digit span test (forward)	8+	<10	0.60	Consists of 7 pairs of random number sequences, increasing in length, that require the athlete to repeat the series verbatim	Concentration and attention
Digit span test (backward)	8+	<10	0.63	Consists of 7 pairs of random number sequences, increasing in length, that require the athlete to repeat the series in reverse	Immediate memory and concentration

testing provides the medical staff evaluating the injured athlete with an individual comparison. Subtle changes in cognitive and motor functions may be detected with effective baseline testing.[18] If cognitive maturity affects neuropsychological testing in adolescent athletes, then comparison with baseline scores older than 1 year may be inappropriate. The purpose of our study was to determine whether differences at baseline testing on traditional pencil-and-paper neuropsychological tests were present among grade levels in high school athletes. We hypothesized that grade-level differences would exist, with adolescents in grades 9 and 10 demonstrating lower baseline neuropsychological test scores than those in grades 11 and 12.

METHODS

Participants

A sample of high school football players (n = 198, mean age = 15.78 ± 1.20 years) from several northeast Georgia high schools were tested before the competitive football season. Included were boys and young men, ages 13 through 19 years, participating in junior varsity and varsity football. Exclusionary criteria included a musculoskeletal injury or head injury within 3 months of testing, English as a second language, or a diagnosed severe psychiatric or learning disability that would hinder testing. All volunteers and guardians read and signed university-approved informed consent and assent forms before the study began.

Data Collection Procedures

All participants completed a health questionnaire designed to elicit demographic information, concussion history, preexisting neurologic conditions, and evidence of other medical conditions. The neuropsychological battery and self-report symptom assessment measures were then administered to all enrolled participants before the start of their competitive season (July through August). Assessments were conducted in a quiet, isolated room by certified athletic trainers who worked with high school athletes and who were trained in test administration by a neuropsychologist.

Neuropsychological Battery

Tests used included measures that have been extensively studied in the sport-related concussion and neuropsychological literature.[11,19,20] These instruments included the Standardized Assessment of Concussion, Trail Making Test Part A, Trail Making Test Part B, digit span, Symbol Digit Modalities Test, Hopkins Verbal Learning Test, finger tapping test, and a self-report symptom checklist (Head Injury Scale; Table 1).[21–26] All tests were administered in the same order to decrease test effects during neuropsychological assessment. Although numerous assessment batteries are available, we chose this traditional pencil-and-paper neuropsychological test battery due to its extensive use in research and age appropriateness of tests.

Statistical Analysis

Before the study, we calculated a power analysis for the univariate analysis of variance using a significance level of $\alpha = .05$, power = 0.80, and a moderate effect size of 0.75, which suggested a sample size of 26 participants per group.[27] All raw neuropsychological test data were reviewed for test scores that deviated by 2 SDs from the mean.[28] No test fit this criteria; therefore, the data from all 198 participants were included in the analyses. A total of 198 volunteers were classified into groups by grade: 9th (n = 43), 10th (n = 49), 11th (n = 55), and 12th (n = 51). All statistical techniques were computed using SPSS (version 15.0; SPSS Inc, Chicago, IL). To examine differences

Table 2. Participant Demographic Information

Grade	Age, Mean ± SD, y	Mass, Mean ± SD, kg	Height, Mean ± SD, cm	Ethnicity, % White	No Previous History of Concussion, %	No Self-Reported Learning Disability, %
9th	14.15 ± 0.68	69.83 ± 7.21	168.30 ± 1.20	92.3	76.9	75.0
10th	15.22 ± 0.42	75.43 ± 6.28	177.4 ± 0.78	92.6	88.9	66.7
11th	16.25 ± 0.44	75.28 ± 7.47	176.9 ± 0.86	100.0	72.7	80.0
12th	17.09 ± 0.61	76.93 ± 8.95	179.90 ± 0.96	72.7	62.5	92.7
Total sample	15.78 ± 1.16	74.15 ± 7.75	175.60 ± 1.20	91.0	75.6	91.0

among groups, we calculated a 1-way multiple analysis of variance for the outcome measures. The Bonferroni correction was conducted to examine differences among grades. Significance was set a priori at .05 for main effects and at .00625 after the Bonferroni correction for 8 dependent variables.

RESULTS

Differences were noted among ages within grade levels ($F_{3,194} = 332.92$, $P < .001$; Table 2). Groups were not different in terms of ethnicity (χ^2 [3, n = 198] = 5.798, $P = .760$), previous history of concussion (χ^2 [3, n = 198] = 4.716, $P = .194$), or learning disabilities (χ^2 [3, n = 198] = 0.102, $P = .992$) and, thus, were included in the analysis.

We found differences among grades for the Trail Making Test A ($F_{3,194} = 3.23$, $P = .024$, $\eta^2 = 0.048$), Trail Making Test B ($F_{3,194} = 3.93$, $P = .009$, $\eta^2 = 0.057$), Symbol Digit Modalities Test ($F_{3,194} = 4.38$, $P = .005$, $\eta^2 = 0.064$), dominant tap ($F_{3,194} = 3.14$, $P = .026$, $\eta^2 = 0.046$), and nondominant tap ($F_{3,194} = 4.902$, $P = .003$, $\eta^2 = 0.070$). Consequently, older participants tended to perform better than younger participants on tests of information processing and motor speed (Table 3). Nonsignificant test results are shown in Table 4.

The Bonferroni correction adjusts the observed significance level for multiple comparisons. We found differences among grades for the Trail Making Test B (mean difference from 9th grade to 11th grade = 15.732, $P = .004$), Symbol Digit Modalities Test (mean difference from 9th grade to 11th grade = 6.754, $P = .005$), and nondominant tap (mean difference from 9th grade to 11th grade = 5.487, $P = .002$).

DISCUSSION

Baseline neuropsychological test scores were different among grade levels in high school athletes. We noted differences on tests of information processing (Trail Making Test), attention (Symbol Digit Modality Test), and motor dexterity (finger tap test) between the 9th- and 11th- grade and 9th- and 12th-grade athletes. Furthermore, post hoc calculations showed that the differences were the result of differences between 9th-grade participants and those in all other grades. Although some individual

variability exists regarding the age of cognitive maturity, neuropsychological test scores in these test domains differed at 15.22 years of age, or the 10th grade.

According to the Luria theory of cognitive development, most cognitive units are functional by age 12 years but continue to develop through early adulthood.[5] Information processing speed, attention, and motor tests showed a general improvement in time to completion, which appears to support the theory of cognitive maturity. Although much of cognitive development is present at age 12 years,[29] incomplete cognitive maturity in high school student-athletes may explain the differences in neuropsychological test performance using the battery of tests described in this study.

These data represent a cross-sectional glimpse of the effect of cognitive maturity within high school athletes on baseline neuropsychological test scores. A distinct separation is seen among age groups within the normative test data for information processing, attention, and motor ability, with performance improving as age increases on both traditional pencil-and-paper and publicly available computerized neuropsychological test scores.[30–33] All normative data for the significant tests in this study, however, reflected a difference between adults (those 15 years of age and older) and adolescents (Table 5).[30–33] Although this sample was local, means and SDs were similar to normative test data and previously published research, which also suggests that these data are generalizable to other high school athletes.[22,24,34,35] A longitudinal study should be performed to confirm this finding.

Executive function has been associated strongly with the prefrontal cortex, which is one of the slowest-developing brain areas.[6,29,36] Executive function appears to be the last to mature, reaching cognitive maturity as late as 24 years of age.[36] This finding suggests that within a common neuropsychological test battery, some domains (information processing, attention, motor) might require additional assessment and, potentially, reevaluation if administered during times of cognitive growth. Several theories may explain why test results in other domains within the concussion assessment battery were not different: perhaps the domains obtained cognitive maturity before 9th grade, reliability of the neuropsychological tests was poor, or the test did not stress the specific circumstances under which a deficit within the domain would be demonstrated.

Table 3. Neuropsychological Test Results That Were Different Across Grade Levels (Mean ± SD)

Grade	Trail Making Test A	Trail Making Test B	Symbol Digit Modalities Test	Nondominant Tap Test	Dominant Tap Test
9th	39.84 ± 12.76	79.84 ± 25.24	47.44 ± 9.39	48.81 ± 6.53	53.85 ± 8.47
10th	33.47 ± 14.71	70.82 ± 20.46	53.08 ± 11.80[a]	51.97 ± 7.34	57.56 ± 7.56
11th	32.37 ± 10.13[a]	64.10 ± 17.63[a]	52.72 ± 9.42[a]	50.76 ± 7.20	56.13 ± 8.95
12th	35.78 ± 12.54	70.89 ± 26.27	54.19 ± 7.56[a]	54.30 ± 7.39[a]	59.01 ± 8.72[a]

[a] Higher score than in 9th-grade participants.

Table 4. Neuropsychological Test Results That Were Not Different Across Grade Levels (Mean ± SD)

Grade	Standard Assessment of Concussion (Total Score)	Hopkins Verbal Learning Test (Total of Trials 1–3)	Digit Span Test, Forward (Total Score)	Digit Span Test, Backward (Total Score)	Head Injury Scale (No. of Symptoms Reported)
9th	25.69 ± 2.20	23.09 ± 4.35	8.39 ± 1.98	5.95 ± 2.17	1.46 ± 2.26
10th	26.16 ± 2.11	23.00 ± 4.43	8.04 ± 1.93	5.77 ± 1.96	2.57 ± 3.23
11th	26.58 ± 2.00	24.05 ± 4.59	8.32 ± 1.83	6.76 ± 2.27	2.67 ± 3.45
12th	26.39 ± 1.93	24.33 ± 4.46	8.52 ± 1.59	6.58 ± 2.21	2.41 ± 3.46

Neuropsychological tests for children tend to be less-sophisticated versions of adult batteries. Adult batteries may not be appropriate for children because the domains being tested might require different demands on the child's cognitive system.[36] Additionally, various factors affect neuropsychological test scores, including previous concussion history, educational background, premorbid level of function, cultural background, age, test anxiety, distractions, sleep deprivation, medication, psychiatric disorders, learning disabilities, and previous exposure to neuropsychological testing.[36] Obtaining a thorough health history may help the clinician to choose a suitable test battery and perform testing in an optimal environment for adolescents with any of these factors. Using appropriate concussion assessment batteries and testing regimes is necessary for all clinicians working with the adolescent population.

Clinical Relevance

The National Athletic Trainers' Association[16] position statement on concussion recommends baseline testing of athletes; however, we realize that time and resource constraints present certain challenges to implementing this recommendation. Although baseline testing for concussion has been recommended, the appropriate frequency of baseline testing has not been established for high school or collegiate athletes.[16–18]

Our research appears to suggest that differences exist among grades, with younger participants performing differently on tests of information processing, attention, and motor speed: the older the athlete, the better the performance on information processing, attention, and motor tests. Results on baseline neuropsychological test scores administered in 9th grade do not remain the same in subsequent high school grades. Differences among grades would support an effect of cognitive maturity on neuropsychological test scores in high school athletes.

Baseline testing of high school athletes, consistent with our findings, should occur at least twice: once during their initial entrance into high school athletics (9th grade) and again upon entering 10th grade. Retesting upon entrance into the 10th grade provides the opportunity to update test scores during cognitive growth. The trend for improved performance for upper classmen, at least on tests of information processing, attention, and motor abilities, would suggest the need for retesting upon entering 10th grade. Although scores appear to remain stable after 10th grade, we still recommend testing annually until additional research is conducted to confirm these findings. Furthermore, we recommend that if the athlete becomes injured during the season, retesting be conducted to establish a new baseline for the next season to account for any cognitive changes after a concussive injury.

The study has several limitations. First, this was a cross-sectional study of high school athletes evaluated by grade level. Longitudinal studies within the high school population need to be conducted to determine the rate of cognitive maturity and the effect of concussive injuries at critical moments in a high school athlete's cognitive development. Second, the number of participants was not equal across grades. More participants were evaluated in the 10th and 11th grades than in the 9th and 12th grades. Although this imbalance appears to be standard for high school participation in athletics, equal numbers per grade might affect the results. Third, confounding variables were not evaluated and controlled within this study. As previously mentioned, different factors affect neuropsychological test scores. Evaluation of and attempts to eliminate the interactions among these variables within the high school population are necessary to obtain generalizable data.

Future longitudinal research should be conducted using both traditional pencil-and-paper and computerized neuropsychological tests to identify the proper baseline testing regimes and determine the true effect of cognitive maturity.

Table 5. Normative Values Available for Males by Age on Trail Making Test Parts A and B, Symbol Digit Modalities Test, and Finger Tap Test (Mean ± SD)

Age[30–32]	Trail Making Test A Time to Completion, min	Trail Making Test B Time to Completion, min	Symbol Digit Modalities Test, No. Correct	Finger Tap Test, No. of Taps
12	16.6 ± 5.9[a]	39.6 ± 13.3[a]	37.58 ± 9.87	41.00 ± 6.34
13	16.0 ± 10.1[a]	34.0 ± 12.4[a]	41.69 ± 9.18	45.80 ± 3.99
14	16.0 ± 12.0[a]	28.6 ± 12.0[a]	45.49 ± 8.49	47.30 ± 7.13
15	25.7 ± 8.8[b]	49.8 ± 15.2[b]	48.73 ± 9.69	NA
16	25.7 ± 8.8[b]	49.8 ± 15.2[b]	49.27 ± 11.08	NA
17	25.7 ± 8.8[b]	49.8 ± 15.2[b]	53.01 ± 12.27	NA
18	25.7 ± 8.8[b]	49.8 ± 15.2[b]	…	NA
20–29	…	…	…	48.50 ± 6.50

Abbreviations: …, data not applicable; NA, data not available.

[a] Scores for Trail Making Test Parts A and B for participants under the age of 15 years were obtained using the Trail Making Intermediate Test. A direct comparison with participants older than 15 years cannot be made, because they were administered the adult version of the test.

[b] Data were extrapolated from a reported group of males, aged 15 through 19 years.

At this time, however, yearly retesting is still optimal pending more conclusive and consistent data. Additional investigation is required to determine the best concussion assessment tools for high school athletes. Furthermore, longitudinal studies are required to determine the critical moments of cognitive maturation to help us understand when to avoid excessive mental exertion, strenuous activity, or contact in order to prevent long-term consequences after concussion.

ACKNOWLEDGMENTS

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