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Neurocognitive and Symptom Predictors of Recovery in High School Athletes

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Objectives: The purpose of this study was to identify specific symptom and neuropsychological test patterns that might serve as prognostic indicators of recovery in concussed high school football players. The recently proposed simple versus *complex* concussion classification was examined and specific symptom clusters were identified.

Design: Case–control study.

Setting: High school football.

Participants: Subjects were 108 recently concussed male high school football athletes between the ages of 13 and 19 (mean = 16.01) years.

Assessment of Risk Factors: Participants were evaluated by utilizing the Immediate Postconcussion Assessment and Cognitive Testing computer-based neurocognitive test battery at before injury and within an average of 2.23 days of injury. All athletes were followed until they met criteria for clinical recovery.

Main Outcome Measures: Symptom ratings and neurocognitive test performance.

Results: Both neurocognitive test results and self-reported symptom data had prognostic value in determining time to clinical recovery. Self-reported cognitive decline, Immediate Postconcussion Assessment and Cognitive Testing reaction time, and migraine headache symptoms were associated with longer time to clinical recovery. Overall, these difficulties were predictive of concussions that were retrospectively classified as complex.

Conclusions: Specific symptom clusters and neurocognitive test results may have predictive value to classifying and managing concussions.

Key Words: concussion, complex, neurocognitive, symptoms, simple

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INTRODUCTION

The management of concussion is currently a hotly debated subject in sports medicine circles, and there has been a sharp increase in research regarding this topic over the past decade. One specific area of research has focused on the relative contribution of self-reported symptoms (eg, headaches, dizziness, and nausea) versus more objective neurocognitive test results in making return-to-play decisions. Based on research to date, it is clear that concussed athletes may present clinically with a myriad of symptoms and every injury must be considered in and of itself.[1]

Despite the increased focus on sports concussion, relatively few studies have evaluated the relative occurrence of specific symptom clusters and their importance in predicting eventual resolution and return to sports. This study is designed to evaluate the predictive value of specific symptom and neurocognitive performance in a group of recently concussed high school football players. This study is also designed to investigate the relationship of these symptom patterns to the *simple–complex* classification recently proposed by the Prague International Concussion Symposium.[2]

According to the Prague statement, complex concussions are classified at the time of injury or retrospectively when 1 of the following 4 criteria are met: a concussive convulsion, loss of consciousness for more than 1 minute, patient has a history of multiple previous concussions, or has not recovered after 10 days. Concussions that resolve within 10 days and do not meet the other 3 criteria are considered simple. Therefore, athletes are often not classified until after 10 days.[2]

To our knowledge, there has only been 1 study to date designed to evaluate the simple–complex dichotomy. This study by Iverson[3] utilized the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) test battery to evaluate *cognitive* and noncognitive aspects of recovery.[3] He found that within 72 hours of injury, high school athletes with complex concussions performed worse on 3 of 4 cognitive composite scores (visual memory, processing speed, and reaction time) compared with athletes with simple concussions.

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AU1

The following describes the commercial interest of Drs. Mark Lovell and Michael Collins in the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) software that was used as an outcome measure in the study. Drs. Mark Lovell and Michael Collins are part owners of ImPACT Applications, the company that distributes the ImPACT program. As such, they have a financial interest in the company. Dr. Lovell is the software developer of this program. Dr. Jamie Pardini and Brian Lau are not employees, owners, or shareholders in ImPACT Applications and have no financial interest in ImPACT or ImPACT Applications.
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AU2

In addition to investigating the validity of simple versus complex distinction, Iverson also evaluated whether concussion history was associated with the occurrence of complex concussions.[3] Iverson found that athletes with 1 or 2 previous concussions did not take longer time to recover than those experiencing their first injury.[3] Therefore, this study did not support the importance of number of prior concussions in making the simple versus complex distinction.

METHODS

Subjects

The subject sample for this 5-year study (2002-2006 seasons) consisted entirely of male participants of Pennsylvania high school football programs. All teams play a total of 9 regular season games during a season. This study only included athletes who had suffered concussions during preseason and regular season football activity and did not include athletes who were injured in postseason play-offs.

Study Protocol

To be included in this study, athletes must have undergone initial on-field evaluation by a certified athletic trainer and must have completed both neurocognitive testing and postinjury symptom assessment. This study was approved by the University of Pittsburgh Institutional Research Board.

After injury, participants were managed clinically using international return-to-play standards.[2,22,23] Once an athlete reported being completely symptom free while at rest, he was progressed through a graduated exertional activity schedule, progressing from light activity (eg, walking) through heavy exertion (eg, running wind sprints). These activities were monitored by their athletic trainers, and athletes were not returned to practice or game situations until they met specific return-to-play criteria. No athlete was returned to play before undergoing a clinical evaluation.

In addition to the resolution of subjective symptoms such as headache, photophobia, and dizziness, athletes were also required to obtain satisfactory neurocognitive test performance compared with their baseline scoring (77.4% of participants completed baseline testing preseason). When baseline data were not available, their scores were compared with age-specific normative data.

Three specific criteria were used to clear athletes to return to play.[3]

1. The athlete's total score on the postconcussion scale (PCS) must have been less than 7. Because the PCS contains many symptoms that are not specific to concussion, even noninjured athletes are not necessarily expected to report no symptoms at the time of baseline testing. In a prior study that examined noninjured high school males, the mean symptom score for males in this age range was 5.8, although 76% scored 6 or less with a large portion scoring 0 (40.5%).[24] Regardless of their postconcussion symptom score, no athletes were returned to play if they were experiencing headache or other symptoms such as dizziness or balance dysfunction that was clearly linked to their diagnosed concussion.
2. In addition to the above criteria, the athlete must not have had more than 1 ImPACT neurocognitive composite score that was statistically worse than their baseline performance. A prior study had indicated that having 1 composite score below baseline was not uncommon but having 2 scores below baseline was extremely uncommon, occurring in only 3.6% of a noninjured sample of athletes.[24] Reliable change was determined based on the results of a previous study by Iverson et al[24] of high school and collegiate athletes. The values needed for a score to be significant at the 80% confidence interval were as follows: 9 points for Verbal Memory composite, 14 points for Visual Memory composite, 0.06 seconds for the Reaction Time composite, and 3 points for the Processing Speed composite.
3. Finally, the athlete must have had all his neurocognitive composite scores above the 10th percentile for his age, which broadly represents the normal range.

It is important to note that the athlete's symptoms and cognitive scores were tracked until time of recovery and that the classifications into simple and *complex* were made retrospectively after the athlete had been followed throughout the recovery process.

Concussions were diagnosed by athletic trainers and/or physicians present on the sidelines after an on-field collision. The basis for diagnosis was on-field presentation of 1 or more of the following signs or symptoms after impact to the head: (1) any noticeable change in mental status or consciousness; (2) loss of consciousness, disorientation, posttraumatic amnesia, or retrograde amnesia; or (3) any self-reported symptoms that appeared after a collision on the field. Typically, these symptoms were headache, dizziness, balance dysfunction, or visual changes (eg, visual blurring, diplopia, and "seeing stars").

Outcome Measures

The neuropsychological testing modules of ImPACT comprised a series of 6 tests to yield 4 composite scores: *Verbal Memory, Visual Memory, Processing Speed*, and *Reaction Time*. The individual tests and the construction of composite scores are summarized in Table 1. T1

In addition, ImPACT includes a 22-item symptom inventory. The concussion symptom inventory includes a 7-point Likert-type scale on 22 concussive symptoms in which 0 is complete absence of symptoms and 6 as most severe.[23,25,26]

Table 2 lists the symptom inventory. T2

Following referral to the University of Pittsburgh Sports Concussion Program, athletes continued to be evaluated using the ImPACT test battery throughout their recovery. Postconcussion symptoms were also monitored utilizing the PCS that is included in the ImPACT test battery.[2,23,27] Both preinjury baselines and all postconcussion evaluations were collected using the same version of the ImPACT test battery.

Statistical Analysis

To objectively compare data for the 4 symptom domains and the 4 ImPACT composite scores, a series of standardized Z scores were calculated with a mean of 0 and an SD of 1. These scores were derived by dividing the difference between

TABLE 1. Cognitive Tests That Comprise ImPACT Composite Scores

Composite Score	Tests Included
Verbal Memory	Average percent correct on
	Word memory
	Three-letter memory
	Symbol match
Visual Memory	Average percent correct on
	Design memory test
	X's and O's topographical memory
Processing Speed	Weighted number correct
	X's and O's distracter
	Reverse-number clicking component of X's and O's
Reaction Time	Weighted average reaction time
	Symbol match
	Color match
	X's and O's distracter

baseline and postinjury composite scores by the baseline standard deviation. *Z* scores were constructed to allow direct comparison of changes in neurocognitive and symptom scores across time utilizing the same metric. The individual symptom scores were then collapsed into 4 separate symptom factors derived through a previously published factor analysis.[28] This prior study revealed that self-reported symptoms may be subcategorized into 4 different factors with satisfactory internal consistency: a *migraine* headache factor (α = 0.87), a cognitive factor (α = 0.89), a sleep factor (α = 0.79), and a neuropsychiatric factor (α = 0.78). Therefore, this study evaluated both individual symptoms and these symptom clusters. To develop standardized factor scores, the *Z* scores of the individual symptoms in each factor were summed and then divided by the number of symptoms in each group to provide a mathematically averaged change score for each factor.

TABLE 2. Postconcussion Scale: 22 Self-Reported Symptoms and Their Classification into 4 Factors

Factors
Headache (M)
Nausea (M)
Vomiting (M)
Balance problems (M)
Dizziness (M)
Sensitivity to light (M)
Sensitivity to noise (M)
Numbness or tingling (M)
Visual problems (M)
Fatigue (C)
Drowsiness (C)
Feeling slowed down (C)
Feeling mentally "foggy" (C)
Difficulty concentrating (C)
Difficulty remembering (C)
Sleeping more than usual (C)
Irritability (P)
Sadness (P)
Nervousness (P)
Feeling more emotional (P)
Trouble sleeping (S)
Sleeping less than usual (S)

Each symptom graded on scale between 0 and 6 (0 being none and 6 being the worst possible).

C, cognitive; M, migraine; P, neuropsychiatric; S, sleep.

To statistically evaluate potential differences in neuropsychological functioning in the simple and complex groups, performances on the 4 ImPACT composite scores were assessed using multivariate analysis of variance (MANOVA) with univariate analysis (when appropriate). The 4 ImPACT composite scores constituted the dependent variables whereas the simple versus complex variable constituted the independent variable.

RESULTS

During this study, 177 athletes sustained a concussion and 108 were eventually returned to play. There was a group of 69 nonrecovered athletes who did not meet criteria for recovery or return-to-play status. These athletes will be the subjects of an additional study.

Table 3 presents demographic information for the subjects. T3

Of the 108 high school athletes cleared to return to play, 47 (43.5%) were retrospectively classified as simple concussions and 61 (56.5%) were classified as complex. Athletes who were classified in the simple group recovered in an average of 5.7 (SD = 2.4) days and complex group recovered in an average of 29.2 (SD = 43.5) days. The average age for the combined simple and complex groups was 16.1 (range = 13–19) years, and the number of years of school completed was 9.6 (range = 8–11 completed). The simple and complex groups did not differ significantly with regard to either age ($F = 1.3$, $P < 0.3$) or education ($F = 3.04$, $P < 0.08$). The simple group was an average age of 16.2 (SD = 1.2) years and education of 9.8 years compared with 15.9 years old and 9.5 years of education for the complex group. The average time between injury and first evaluation for the entire sample was 2.2 (range = 0–12) days. The complex group was evaluated an average of 2.4 days post injury (range = 0–12 days) and the simple group an average of 2.0 days post injury (range = 0–5 days). The median time to first evaluation was identical for the 2 groups (2 days). Therefore, regardless of their eventual classifications as a simple or complex injury, all athletes were initially evaluated within the same time frame post injury.

A relatively small number of athletes reported learning disabilities (n = 6), a history of receiving special education services (n = 10), repeating a grade (n = 8), or a history of diagnosed Attention Deficiency Hyperactivity Disorder (n = 6). Sixteen athletes reported a history of receiving speech therapy services. Fifteen subjects reported a history of pre-injury migraine headache, and 23 subjects reported a history of headaches (either migraine or other type). The history of a psychological condition was reported in 2 subjects and a history of alcohol abuse was reported by 1 subject. Fifty AU3

TABLE 3. Subject Demographics. All Male Pennsylvania High School Football Players

AU10

Description	N	Mean	STD
Average age, y	177	16.01	1.2
Average grades of education*	177	9.63	1.004
Years of higher secondary football experience	174	1.58	1.19
Total concussed subjects	177		
Total not fully recovered	69		
Total fully recovered†	108		
Within 10 days (simple)	47		
After 10 days (complex)	61		
		Simple† (<10 d)	Complex† (>10 d)
Learning disability		1	1
Age, y		16.2	15.9
Education, y		9.8	9.5
Received special education services		1	4
Received speech therapy services		5	4
Attention deficiency hyperactivity disorder		1	3
Repeated a grade		3	3
History of headache		4	11
History of migraine‡		3	8
History of seizure		0	0
History of brain surgery		0	0
History of psychological conditions		1	0
History of meningitis		0	0
History of alcohol abuse		0	0
Days first evaluated post injury		2.0	2.4
History of previous concussion			
None (0)		35	44
1		6	13
2		5	4

Participants may be included multiple times if sustained multiple concussions that were each tracked by trained specialist at UPMC. Subjects may also appear in 1 or more categories.

*Number of grades completed (ie, 9 = completed ninth grade).

†The classification of simple or complex only used length of recovery and not the other 3 criteria.

‡Eleven also have history of headache.

participants reported sustaining 1 or more concussion before their involvement in this study. This information is presented in Table 3.

T4 T5 Tables 4, 5 display the neurocognitive and symptom scores for the simple and complex concussed groups, respectively.

The overall MANOVA was significant ($F = 2.69$, $P = 0.04$), and therefore, additional univariate analyses were completed to further evaluate group differences on specific ImPACT composite scores. Univariate analysis revealed that the Visual Memory ($F = 6.78$, $P = 0.016$) and Processing Speed ($F = 7.92$, $P = 0.007$) composite scores were significantly worse in complex concussions compared with simple concussions. The Reaction Time and Verbal Memory composite scores were not significantly different between groups ($F = 3.00$, $P = 0.088$ and $F = 0.07$, $P = 0.796$, respectively).

Next, we evaluated differences between the simple and complex groups with regard to the 4 symptoms factors. An analysis of variance (ANOVA) revealed that athletes with complex concussions had significantly higher total symptom scores on the PCS ($F = 10.19$, $P = 0.002$). To evaluate group difference with regard to the 4 symptom factors, a MANOVA was completed with the 4 factors entered as dependent variables and the simple and complex designations entered as independent variables ($F = 3.29$, $P = 0.01$). As this analysis was statistically significant, additional univariate ANOVAs were completed. Significant differences were found between simple and complex concussions for the migraine ($F = 10.30$, $P = 0.0019$), sleep ($F = 6.4$, $P = 0.0133$), and cognitive ($F = 5.31$, $P = 0.0238$) factors. The neuropsychiatric factor was not significant ($F = 0.41$, $P = 0.511$).

In addition to the overall analysis of symptom constellations, we also evaluated the relative prevalence between the means of the individual standardized symptom scores to provide an assessment of the relative frequency of individual symptoms in each group (Table 5).

The symptoms were subjective fogginess (Z score difference = 4.30), difficulty concentrating (Z score difference = 2.46), vomiting (Z score difference = 2.391), and dizziness (Z score difference = 2.09).

In the study, only 20 participants had experienced a loss of consciousness. A MANOVA revealed that the LOC and no LOC groups did not differ with regard to either neuropsychological performance or symptoms ($F = 1.49$, $P = 0.2169$ and $F = 0.66$, $P = 0.6102$, respectively). AU4

Finally, we conducted an analysis to evaluate the potential role of concussion history in neuropsychological performance for the simple and complex groups. With regard to concussion history, 25.5% of those with simple concussions and 27.9% with complex concussions had 1 or more previous concussions. A MANOVA did not reveal any differences between simple and complex groups on the ImPACT composite Z scores ($P = 0.7564$). Athletes with the presence of previous concussion did not have significantly worse scores on the 4 standardized symptom factors—migraine, cognitive, sleep, and neuropsychiatric (all effects: $P = 0.2526$)—and/or standardized total symptoms (all effects: $P = 0.7910$) as assessed by MANOVA and ANOVA, respectively.

DISCUSSION/CONCLUSIONS

This study was designed to investigate the predictive utility of self-reported symptom and neuropsychological performance after concussion in a group of football athletes. Prior research by Iverson[3] had suggested that athletes who had been designated as having complex concussions did have higher overall postconcussive symptoms scores when compared with athletes whose concussions had been designated as simple.

Relatively, little has been published regarding specific symptom patterns after concussion, although a number of

TABLE 4. ImPACT Composite Score and Symptom Factor Raw and *Z* Score Means

	Simple		Complex		
ImPACT Composite	**Raw Scores (SD)**	***Z* Score**	**Raw Scores (STD)**	***Z* Score**	**Cohen *D* (Between Groups)**
Verbal*	72.21 (13.169)	−1.51	75.20 (13.808)	−1.43	0.221 (small)
Visual†	71.28 (11.985)	−0.63	62.155 (15.348)	−1.37	0.663 (medium)
Reaction Time*	0.6134 (0.1039)	−0.85	0.69 (0.193)	−0.081	0.838 (large)
Processing Speed‡	37.469 (7.125)	0.11	30.61 (9.120)	−2.22	0.466 (medium)
Symptom factors					
Migraine§	5.26 (5.571)	−1.40	11.02 (8.177)	−3.02	0.551 (medium)
Cognitive¶	7.109 (7.436)	−2.22	11.82 (9.181)	−3.67	0.441 (medium)
Sleep†	0.74 (1.512)	−0.16	2.02 (3.122)	−1.05	0.465 (medium)
AU12 Neuropsychiatric*	1.61 (2.728)	−0.36	1.77 (2.534)	−0.54	0.018 (small)

Group differences in performance on the ImPACT composite scores and symptom factors are displayed in raw and standard (*Z*) scores separately for the simple and complex groups. Standard scores were calculated by dividing the difference between mean group scores and postinjury scores divided by standard deviation. Standard scores have a mean of 0 and an SD of 1.

Effect sizes were calculated by dividing the mean raw score differences of the simple and complex groups by the pooled standard deviation of the 2 groups. The pooled standard deviation is defined as $\sqrt{[(\delta_1^2+\delta_2^2)/2]}$. By convention, Cohen *D* values at 0.2 are small, 0.5 are medium, and greater than 0.8 are large.

ANOVA, analysis of variance; ImPACT, Immediate Postconcussion Assessment and Cognitive Testing.
*Differences are nonsignificant.
†Univariate ANOVA significant at the *P* = 0.01 level.
‡Univariate ANOVA significant at the *P* = 0.007 level.
§Univariate ANOVA significant at the *P* = 0.001.
¶Univariate ANOVA significant at the *P* = 0.02.
||Univariate ANOVA significant at the *P* = 0.05.

researchers have discussed this over the past decade.[2,26] Currently, the question remains: Are there specific symptoms or symptom clusters that are associated with prolonged recovery from concussion? The answer to this question is potentially an important one as the early identification of relatively important symptoms early on in the treatment of the concussed athlete would be of value not only to the athlete and his or her medical team but also might provide valuable information to the athlete, the family, and his or her coaches. Specifically, the identification of prognostic indicators could help to set realistic expectations for safe return to sport.

The relationship between neuropsychological testing results and self-reported symptoms has recently been debated in the literature and continued research in this area is needed. Although some researchers have suggested that neuropsychological testing should not be utilized only after symptoms have resolved,[35] others[1,36] have suggested that there is "value added" in conducting testing earlier in the recovery process.

The results of this current study lend support to the continued use of both symptom and neuropsychological test data in the management of concussion as both types of information were "predictive" of recovery. With regard to cognitive functioning, we found the largest effect size for the ImPACT reaction time composite score with the complex group exhibiting substantially slower reaction time in comparison to the simple group. In addition, of the symptom factor scores, the cognitive and migraine factors were significantly different for the simple and complex groups. This suggests that athletes who perceive that they are having cognitive issues are (at least to some extent) accurately reporting these difficulties on the symptom scale that accompanies ImPACT. Furthermore, the relative importance of the migraine symptom factor is also not surprising given the prominent role that headaches play in concussion and return to sport.[20]

Although preliminary, the findings of this study and future studies of this nature may have direct relevance for the clinical management of concussed football athletes. The early identification of prognostic symptom factors might help physicians and other professionals identify athletes who require the services of specialists (eg, neurologists and neuropsychologists). In addition, the identification of these symptom factors might eventually be helpful in suggesting pharmaceutical intervention in specific patients (eg, triptan medications for athletes with migraine headache).

This study provides some support for the retrospective use of the simple–complex dichotomy in sports concussion research. As a group, the complex concussion group did perform more poorly on neuropsychological testing and also reported more symptoms on the symptom inventory that accompanies the ImPACT computer-based concussion system. However, it is important to note that the clinical utility of the simple–complex classification has yet to be validated. When an athlete sustains a concussion, this injury requires immediate diagnosis and management and decisions regarding return to play must often be made within a day or 2 days of injury. Therefore, there is the possibility that an injury that initially seems to be a simple concussion can later evolve into a complex concussion. It is also possible that our simple and complex groups differed with regard to their symptom status immediately post injury based on factors other than injury severity (eg, perhaps, there were athletes who were more vocal in reporting symptoms and therefore more cautious in eventually returning to play).

As was the case with the Iverson's study,[3] this study did not find significant differences in either symptom reporting or

TABLE 5. Individual Symptom Scores Raw and *Z* Score Means

Variables	Simple		Complex		*Z* Score Difference Between Simple and Complex
	Raw Scores (STD)	*Z* Score	Raw Scores (STD)	*Z* Score	
Total Symptom	14.60 (14.998)	−1.78	27.13 (19.855)	−3.71	1.93
Headache (M)	1.30 (1.171)	−1.59	2.73 (1.67)	−3.30	1.71*
Nausea (M)	0.74 (1.08)	−4.23	1.07 (1.247)	−6.19	1.96*
Vomit (M)	0.130 (0.453)	−0.069	0.32 (0.833)	−2.46	2.391*
Balance (M)	0.522 (0.809)	−1.00	1.03 (1.288)	−2.53	1.53
Dizziness (M)	0.83 (1.141)	−1.50	1.88 (1.462)	−3.59	2.09*
Fatigue (C)	1.28 (1.486)	−0.92	2.03 (1.746)	−1.40	0.48
Trouble sleeping (S)	0.43 (0.910)	−0.129	1.25 (1.856)	−1.36	1.231*
Sleeping more (C)	0.63 (1.323)	−0.65	0.78 (1.462)	−0.60	−0.05
Sleeping less (S)	0.30 (0.910)	−0.20	0.77 (1.489)	−0.72	0.52*
Drowsiness (C)	1.283 (1.500)	−2.88	1.77 (1.711)	−3.38	0.5
Light sensitivity (M)	0.89 (1.418)	−1.66	1.72 (1.757)	−3.18	1.52
Noise sensitivity (M)	0.46 (0.912)	−0.64	1.40 (1.564)	−2.16	1.52
Irritability (*P*)	0.74 (1.290)	−0.79	0.93 (1.582)	−1.09	0.3
Sadness (*P*)	0.217 (0.629)	−0.08	0.18 (0.504)	−0.17	0.09
Nervousness (*P*)	0.39 (0.856)	−0.47	0.37 (0.712)	−0.44	−0.03
Emotional (*P*)	0.26 (0.800)	−0.09	0.283 (0.761)	−0.46	0.37
Numbness (M)	0.196 (0.500)	−0.56	0.35 (0.799)	−2.02	1.46
Slowness (C)	0.87 (1.185)	−2.15	1.68 (1.600)	−3.68	1.53*
Fogginess (C)	0.98 (1.164)	−5.04	1.92 (1.690)	−9.34	4.3*
Difficulty concentrating (C)	0.93 (1.272)	−2.21	1.98 (1.836)	−4.67	2.46*
Difficulty remembering (C)	1.13 (1.392)	−1.70	1.65 (1.812)	−2.63	0.93
Visual problems (M)	0.39 (0.954)	−0.76	0.87 (1.455)	−1.73	0.97

Individual symptom differences in performance on the ImPACT displayed in raw and standard (*Z*) scores separately for the simple and complex groups. Standard scores (*Z* scores) were calculated by dividing the difference between mean group scores and postinjury scores divided by standard deviation. Standard scores have a mean of 0 and an SD of 1. Standard scores allow direct comparison between different variables, and the *Z* score difference between simple and complex was determined by subtracting complex standard scores from simple standard scores.

AU11 ImPACT, Immediate Postconcussion Assessment and Cognitive Testing.

*Symptoms with the largest contributions to differences between simple and complex in each symptom factor.

neuropsychological test performance in athletes with and without a history of concussion.

This study is not without limitations. First of all, our subject pool consisted completely of injured high school football athletes, and therefore, the findings cannot be generalized to athletes in other sports or to collegiate/professional athletes or female athletes.

In addition, this study is based on the analysis of a group of participants from 13 different high schools within western Pennsylvania and all analyses were retrospective. This particular database was selected because it utilized a homogeneous sample, and all athletes received clinical on-field and postinjury management that was highly consistent between schools. Therefore, these data were not gathered as part of a prospective study. This creates the possibility that athletes retrospectively classified as complex injuries had simple injuries but were not cleared until after 10 days post injury.

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