



The Impact of High-Contact Sports on Memory and Auditory Comprehension in Young Athletes following Sports-Related Concussions

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Purpose: we investigated whether memory and language abilities differ by sports played (football, basketball, and ice hockey) following Sport-Related Concussions (SRCs).

Methods: A total of 74 young athletes with mild TBI were enrolled in this study and all participants specifically from Sports-Related Concussions. The group of 74 participants with mTBI from SRCs was divided into three groups by the sports played: football (N=35), basketball (N=19), and ice hockey (N=20).

Results: The Multivariate Analysis of Variance (MANOVA) was conducted on the two selected variables, verbal memory composite scores and CRTT-Efficiency Scores. The results of the MANOVA demonstrated that there were no significant differences across three sports group.

Conclusions: The primary goal of the current study was to investigate whether measurement of cognitivelinguistic function across three different high-contact sports showed significant differences on young athletes' memory and language performance following sport-related concussions (SRCs). The results revealed that verbal memory and auditory comprehension at a sentence level were not statistically significantly different across three main high-contact sports following SRCs.

Keywords: mild traumatic injury, sports-related concussions, high-contact sports, memory, auditorycomprehension



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INTRODUCTION

The Centers for Disease Control and Prevention reported that more than 3 million sports-related concussions occur per year [1]. Among young athletes, a high incidence of concussion in high school sports has been reported in football, ice hockey, and basketball [2,3]. Hootman & Agel [4] and Gessel et al. [5] also reported an increased incidence of sports-related concussions in high school (8.9%) and in collegiate (18%) athletes who play football, soccer, and ice hockey.

According to a poll by Gallup in 2017 [6], football is the most popular sport across the United States (US), and it is the number one participatory sport for boys at the high school level. Basketball is also listed as a popular participatory sport, according to the report of the National Federation of State High School Associations (<http://www.nfhs>).

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org) [7]. Participation in these contact sports with high incidence of concussion could be a leading cause of neurocognitive impairments in the school-aged population [8-9]. Studies of this population typically involve neurocognitive testing of high school and collegiate athletes with Sports-Related Concussions (SRCs) in order to examine the cognitive impact of concussion. One of the representative tools for the post-concussion assessment is ImPACT [10].

There are relatively well-established literatures in language processing of traumatic brain injury (TBI), however, there are few studies investigating the language function after SRCs. This is because a SRC is mild traumatic brain injury (mTBI) and people easily assume that mTBI would not bring language processing decline. Contrary to people's general guess, the impact of SRCs on language system has shown interesting results [11]. According to one recent study's neuroimaging results [11], there were structural and functional changes in the frontotemporal language network after SRCs. The long-term alteration has shown with the event-related brain potentials (ERPs) in the language network including the N400 and P600 and the neurocognitive changes were induced by the SRCs.

Considering that there is evidence to support that playing certain positions in football can lead to changes in the brain structures [12], and also in cognitive functions such as memory and language [13], different sports may affect the neurocognitive performance differently after SRCs. Verbal memory and auditory comprehension at a sentence level in high school athletes with SRCs were tested in a few previous studies [13,14]. Salvatore et al. [14] found that individuals with a concussion perform significantly worse than individuals without a concussion on the ImPACT measures and auditory comprehension skills as assessed by the CRTT-Subtest VIII. Yoo & Salvatore [13] found that the verbal memory and auditory comprehension abilities were dependent on the speed positions in football. More specifically, the players in the non-speed positions scored significantly lower than the speed-position players. These results, however, are limited to football among several high-contact sports, and it is still unknown whether athletes who play other high-contact sports also exhibit verbal memory and auditory comprehension issues as much as football athletes after a concussion.

Therefore, we are motivated to investigate whether memory and language abilities differ by sports played (football, basketball, and ice hockey) following Sport-Related Concussions (SRCs). We hypothesize that memory and auditory comprehension performance in athletes with SRCs would be different

depending on the sports that they play. Specifically, we expect that football players with SRCs would have the lower cognitive-linguistic performance than other two contact sports athletes because football is the most popular and representative high-contact sport.

METHODS

Participants

A total of 74 young athletes with mild TBI were enrolled in this study and all participants specifically from Sports-Related Concussions (Mean Age: 17.04, SD=3.27, Mean Years of Education: 10.54, SD=2.96, and Mean Number of Concussions: 1.6, SD=0.84): The group of 74 participants with mTBI from SRCs was divided into three groups by the sports played: football (N=35), basketball (N=19), and ice hockey (N=20). Age, education years, and the number of concussions were not significantly different among the three groups (Table 1).

The Institutional Review Board (IRB) of the University of Texas at El Paso approved this study, and informed consent was received from all participants.

All participants met the following selection criteria: (a) They were native speakers of American English; (b) They did not have history in speech-language therapy; (c) They did not have learning disability and other special education issues; (d) They did not have other neurological diseases; (e) They were referred by team coaches, trainers or medical doctors for a post-concussion assessment at the Concussion Management Lab at the University of Texas at El Paso. All participants visited the lab for the first evaluation within 72 hours following SRCs. The second and third evaluations were administered after 2-3 weeks after the initial visit. The data for this study included only the initial evaluation for the acute mild traumatic brain injury.

Materials & Procedures

The current study utilized two computerized neurocognitive test batteries: The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) Version 2 as a memory mea-

Table 1. Descriptive information of participants

Sports	N	Age	Years of education	Number of concussion
Football	35	16.83 (3.31)	10.29 (2.99)	1.47 (0.68)
Basketball	19	16.47 (4.15)	10.32 (3.83)	1.52 (1.06)
Ice hockey	20	18.56 (0.98)	11.77 (0.88)	2.22 (1.17)

measure, and the Computerized-Revised Token Test (CRTT)-Subtest VIII as a measure of auditory comprehension of language at the sentence level.

ImPACT: ImPACT is a computer-based neuropsychological test for the post-concussed population [15], and it tests cognitive functions of attention, memory, processing speed, verbal and visual memory, response variability, non-verbal problem solving, sorting performance in each area into composite scores. This study included the verbal memory composite, visual memory composite, and visual-motor speed (processing speed) composite scores from the ImPACT.

CRTT-Subtest VIII: The CRTT is the computerized version of the Revised Token Test [16] and the reliability and validity were established [17]. This test is standardized on healthy controls and pathologic populations such as people with aphasia, right-hemisphere lesions, and concussions [14]. The example of the verbally presented command from the CRTT-Subtest VIII is “Put the big blue square above the small red circle”. Participants are required to listen to the auditorily presented command through the computer and respond by moving the token with the mouse to the stimuli on the computer screen (Figure 1).

The CRTT-Subtest VIII is a language measure, specifically assessing auditory comprehension at a sentence level. Auditory comprehension abilities have been identified as a predictor variable for the treatment effect and recovery in population with a brain injury such as a stroke with aphasia [18-20]. This is because auditory comprehension ability is a measure of the general language processing ability. According to Schuell [20], good auditory comprehension is crucial for successful outcomes in their rehabilitation in stroke survivors with aphasia. Therefore, testing of auditory comprehension has been widely included as the subtests of the standardized

measures for the populations with brain injuries, such as Western Aphasia Battery (WAB) [21].

As a new version of the CRTT compared to the RTT, CRTT-ES (efficiency score) was added in the original RTT [17]. The intent of the ES was to design a metric capturing the accuracy of the response relative to the time spent on the task [13]. Thus, CRTT-ES is the more time sensitive measure for the auditory comprehension performance, and the CRTT software automatically calculates CRTT-ES with the following formula [17].

$$ES = CRTT * (T/MT)$$

CRTT: CRTT scores

T = Length of Time taking to complete the command

MT = The Maximum Time assigned for each command (30 seconds)

The following tentative variables were chosen initially as main outcome variables for the ImPACT and CRTT: verbal memory composite scores, visual memory composite scores, and visual-motor speed composite scores (processing speed) from ImPACT, and the CRTT-Accuracy and CRTT-Efficiency Scores (CRTT-ES) from the CRTT-Subtest VIII.

Data analysis

All data analyses were conducted with IBM SPSS Statistics 24. First, exploratory principal component analysis (PCA) was computed to reduce the number of variables from the initial tentative outcome measures. Second, the Multivariate Analysis of Variance (MANOVA) was conducted to assess the difference on the two selected dependent variables across three sports groups: 1) verbal memory composite scores and 2) CRTT-ES.

RESULTS

PCA

A PCA with varimax rotation was performed for the ImPACT and CRTT variables in order to identify the greatest shared variance among the initially chosen main variables, and also to reduce the variables. As the results, two factors were extracted as shown in Table 2. Table 2 summarizes the coefficients derived from the PCA rotated component matrix.

All three variables from the ImPACT were loaded on the first factor, and the two variables from the CRTT were loaded on the second factor (Table 2). The variables with the highest value were selected from each factor. Therefore, the Verbal Memory variable was selected because the eigenvalues of the verbal memory variable explained 90% of variance of the fac-

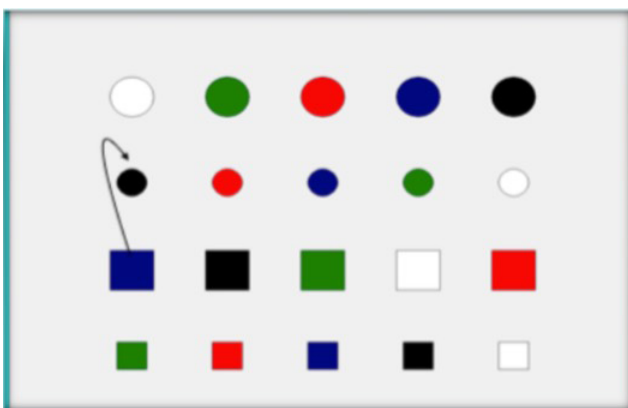


Figure 1. Example of CRTT computer screen and command

Table 2. Coefficients derived from the PCA rotated component matrix

Variables	Eigenvalues	
	Factor 1	Factor 2
Verbal Memory	0.899	0.002
Visual Memory	0.855	0.140
Processing Speed	0.713	0.297
CRTT-ACC	0.200	0.893
CRTT-ES	0.080	0.915

tor 1. According to the PCA results, we assumed that the verbal memory was the most representative memory measure among the ImpACT variables, especially compared to visual memory. Also, the CRTT-ES variable was chosen because the CRTT-ES variable's eigenvalues explained 91.5% of variance of the factor 2. We assumed that the CRTT-ES represents better for the CRTT-Subtest VIII than the CRTT-ACC variable.

MANOVA

The Multivariate Analysis of Variance (MANOVA) was conducted on the two selected variables, verbal memory composite scores and CRTT-ES. The results of the MANOVA demonstrated that there were no significant differences across three sports group ($F(4, 140)=1.43, p=0.23$), verbal memory composite Scores ($F(2, 71)=0.51, p=0.61$), and CRTT-ES ($F(2, 71)=2.59, p=0.082$) (Table 3).

DISCUSSION

The primary goal of the current study was to investigate whether the specific high-contact sport played has any impact on young athletes' memory and auditory comprehension performance following sport-related concussions (SRCs). Specifically, we examined whether verbal memory and sentence auditory comprehension measures differ by sports played (football, basketball, and ice hockey) in young athletes following Sport-Related Concussions (SRCs).

The results reveal that there was no significant difference across three sports groups on the verbal memory composite scores and CRTT-ES following SRCs. This finding indicates that verbal memory and auditory comprehension at a sentence level are not different across sports among young athletes with SRCs. The scores of the football group were overall lower than other two groups, even though there were no statistically significant differences except the processing speed scores.

Table 3. Coefficients derived from the PCA rotated component matrix

Sports	Verbal Memory	CRTT-ES
Football	81.72 (11.82)	11.74 (1.85)
Basketball	83.26 (15.35)	12.7 (0.71)
Ice Hockey	84.95 (15.03)	12.27 (1.06)

The pattern of the results raises a possibility that the characteristics of sports might affect the results. Notably, football players tend to be diagnosed with more sub-concussive injuries than athletes in the other two sports. The literature suggests that the non-speed positions in football (e.g., linemen) experience more sub-concussive hits, whereas speed positions (e.g., receivers) experience higher overall rates of concussion [21]. Hockey and basketball have less-clearly delineated speed vs. non-speed positions, and while the overall rate of concussion is similar, the rate of sub-concussive injury is lower in these two sports. However, there might be other potential factors affecting the results such as performance at baseline; hence, our speculation requires further studies in the future.

In addition, there was no significant difference in language function across sport groups. The results were surprising because football has been considered as the highest contact sport and we have assumed that language functions in the football group would be significantly lower than other two contact sports. The results might indicate that all three high-contact sports would have the similar level of vulnerability in language, specifically for sentence level auditory comprehension abilities. This, however, does not imply that all three groups are not impaired in auditory comprehension abilities compared to athletes without concussions because the previous study [14] showed that individuals with a concussion performed significantly more poorly on the auditory sentence comprehension when compared to individuals without concussions [14].

These results might also be because language deficits appear later than memory deficits [23-25]. According to the studies on chronic traumatic encephalopathy (CTE) deficits [23-25], language deficits appear at later stages as a symptom.

The pattern of the results might also be due to the limitation of language profiles tested in the current study. In this study, auditory sentence comprehension was examined as a language measure. Other modalities, domains, and tasks of language such as reading, naming, story retelling, and narrative discourse could exhibit significant differences. Therefore, fu-

tures studies are required with different modalities, domains and tasks of language.

CONCLUSION

The primary goal of the current study was to investigate whether measurement of cognitive-linguistic function across three different high-contact sports showed significant differences on young athletes' memory and language performance following sport-related concussions (SRCs). The results revealed that verbal memory and auditory comprehension at a sentence level were not statistically significantly different across three main high-contact sports following SRCs.

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