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Effects of Playing Positions on Memory and Auditory Comprehension in High School Football Players with a Mild Concussion

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Purpose: This study examined whether different playing positions of high school football players are associated with impaired memory and auditory comprehension at a sentence level after a concussion. The specific research questions are 1) whether there are significant differences in memory on the Immediate Postconcussion Assessment Cognitive Test (ImPACT) between a speed-positions group and a non-speed positions group, and 2) whether there are significant differences in auditory comprehension on Subtest VIII of the Computerized-Revised Token Test (CRTT) between the speed-positions group and the non-speed positions group.

Methods: 36 acutely concussed high school football players (Age: $M=14.61\pm1.96$, Education: $M=8.36\pm1.92$) were administered the ImPACT and Subtest VIII of the CRTT which requires auditory comprehension ability at a sentence level. A group of 36 players was selected from an extant database. The group was divided into two groups based on their reported playing positions: speed-position ($N=18$) and non-speed-position ($N=18$), and matched by age and education. The speed-positions were; quarterback, running back, wide receiver, ends, defensive back, safety, and linebacker. The non-speed position group was composed of defensive and offensive linemen. IBM SPSS Statistics 24 was used to compare the two speed groups across the ImPACT and CRTT variables.

Results: The results revealed that at post-concussion assessment high school athletes who play non-speed positions perform significantly poorer than a matched group of high school athletes who play speed positions on verbal memory and auditory comprehension abilities.

Keywords: Sports-related concussion (SRC), Playing position, Memory, Language, Football players

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INTRODUCTION

According to a Gallup poll in 2017, football is the most popular sport in United States (Retrieved from http://news.gallup.com/poll/224864/football-americans-favorite-sport-watch.aspx) [1] with 37% of US adults picking football as their favorite sport. The popularity of football spans the generations including high school teenagers. According to a report by the National Federation of State High School Associations [2], football is the number 1 participatory sport for boys at the high school level and is the leading cause of injuries in high school players.

Unfortunately, there is a relative paucity of evidence on the cognitive behaviors (i.e., memory and language) of concussed high school football players, and specifically the impact of the playing positions on memory and language at the high school level is unknown [3].

There is a growing body of evidence that some playing positions have a higher risk of concussion for professional players [4-6]. Non-speed positions such as offensive linemen are reported to have significantly more concussions and sub-concussive hits than other positions [6,7].

Non-speed positions are also reported to have significantly more symptoms than other positions on a self-report questionnaire from a group of 730 National Collegiate Athletic Association Division 1 Football Championship Series athletes [6]. These findings suggest that offensive linemen experience frequent head impacts with low-magnitude, and report more frequent post-impact symptoms than other positions. However, the report of these symptoms is not associated with the diagnosis of concussion. For the non-speed positions, the consequences of recurrent hits are damaging to their frontal lobe white matter [4]. Furthermore, non-speed positions players with a history of three or more concussions exhibited lower white matter fractional anisotropy and lower blood oxygen level during a working memory task than did those players with zero or one concussion [4].

However, there is limited information as to the consequences of positions on the cognitive-communication behavioral changes in high school football players, even though a recent study [8] reported that Chronic Traumatic Encephalopathy (CTE) was found even in high school players. In this study three of the 44 high school players in the sample of brain donors were diagnosed with mild CTE at autopsy.

Dysfunctions of memory and language are frequently reported clinical features of CTE [8-10]. Memory was reported as an issue in 73% of the brain donors with a mild CTE, and in 92% of the donors with severe CTE. Language was also reported as a clinical symptom in 39% of the sample of brain donors with mild CTE, and in 66% of the donors with severe CTE [8]. The report by Mez et al. [8] implies that even high school players are at risk for CTE.

Considering that a decline in cognitive and language functions are the most representative symptoms in CTE [8-10], it is crucial to examine whether high school football players would exhibit significantly poorer performance in cognitive-communication behavior as a function of what position they play.

A recent study (Montenigro et al. [7]) investigated whether cumulative head impact exposure predicts later-life depression, apathy, executive dysfunction, and cognitive impairment in former high school and college football players. They found that the results demonstrated a threshold dose-response relationship between the repeated head impacts and all the variables tested including risk of later-life cognitive impairment. Interestingly, the dose-response threshold for the cognitive function was much higher relative to other outcome variables, and they speculated that cognitive changes reflect the development of CTE. This speculation is consistent with previous findings that cognitive changes appear in the later stages of CTE, and the advancing pathological stages of the disease are related to increased severity of cognitive abnormalities [9,10].

Montenigro et al. [7] also computed weighted mean impacts per season by playing position, and found that offensive and defensive lineman showed much higher mean scores than players at line backer, wide receiver, and quarterback positions. In contrast, Montenigro et al. [7] reported that 16% of former athletes diagnosed with CTE had no reported history of concussion [9]. These findings suggests that sub-concussive impacts may eventually lead to a diagnosis of CTE. Furthermore, given that lineman are at risk for a higher number of sub-concussive impacts than those of speed positions, investigating the effects of playing positions on the cognitive behaviors in high school players may have important clinical implications for the prevention and care of these young people.

The present study investigated whether playing positions was associated with adverse consequence on a players' memory and language performance. The specific research questions are: 1) Are there significant differences in memory on the Immediate Post-concussion Assessment Cognitive Test (ImPACT) [11] between the speed position-group and the non-speed position-group? and 2) Are there significant differences in auditory comprehension on Computerized-Revised Token Test (CRTT) [12] between the speed position-group and the non-speed position-group?

Our hypothesis is that the non-speed position group would demonstrate significantly lower memory and language scores than the scores of the speed-position group, and would exhibit slower processing speed in response time measures than the speed position group. The rationale for the hypothesis is that non-speed positions are more exposed to recurrent sub-concussive hits/impacts than the speed positions. If the sub-concussive hits affect the cognitive and language behaviors, and the non-speed positions players are at risk for more frequent sub-concussive hits we predict they would demonstrate slower and poorer performance on memory and language tasks than the speed positions players.

METHODS

Participants

A total of 36 concussed high school football players (Mean Age: 14.61±1.96) completed both the ImPACT and Subtest VIII of the CRTT, which requires auditory comprehension at the sentence level.

All athletes were referred by their team trainers or physicians to the Concussion Management Clinic in the Department of Rehabilitation Science at the University of Texas at El Paso.

Participants were divided into two groups based on their reported playing positions: speed-position ($N=18$) and non-speed-position ($N=18$) groups. The speed-positions were; quarterback, running back, wide receiver, ends, defensive back, safety, and linebacker. The non-speed positions were defensive and offensive linemen. This classification system of playing positions replicates that reported in previous studies on playing positions in football players [4,5,13].

The estimation of the number of required subjects for this study was calculated using the sample size software, G-Power analysis. Statistical power was set at 0.80, and alpha level was set at 0.05 for the calculation. The calculated sample size was a total of 32 subjects with the medium effect size Cohen's *f*2, 0.02, based on the Cohen's guideline [14]. Therefore, data from a total 36 subjects were collected in the study based on the crossed check on the results of the sample size calculation.

The Verbal Memory Composite, Visual Memory Composite, Visual-Motor Speed (Processing Speed) Composite scores from the ImPACT were initially included as well as the CRTT accuracy and CRTT Efficiency Scores (ES) from the CRTT Subtest VIII. IBM SPSS Statistics 24 was utilized to compare two groups across the ImPACT and CRTT variables. These initial variables were tentative to choose each variable from each task based on the variable selection analysis[1)] using a Principal Component Analysis (PCA).

All participants met the following selection criteria: (a) they were native American English speakers; (b) reported no history of speech-language therapy; (c) reported no history of learning disability and other special education issues; (d) reported no history of other neurological disease; (e) were referred for post-concussion assessment. Table 1 provides the demographic information for all participants in this study.

Table 1. Demographic information

	All athletes	Speed position-group	Non-speed position-group
Number of subjects	36	18	18
Age	14.61 (1.96)	14.72 (1.41)	14.5 (2.2)
Education	8.36 (1.92)	8.61 (1.38)	8.1 (2.2)
Reported concussion history	1.44 (0.69)	1.56 (0.78)	1.33 (0.59)

Materials

The current study used two computerized neurocognitive test batteries: ImPACT Version 2 which incorporates measures of memory and CRTT Subtest VIII as a language measure.

ImPACT: ImPACT is a computer-administered neuropsychological test for the post-concussed population [11], and takes approximately 20 minutes to complete. ImPACT measures multi aspects of cognitive functioning including attention span, working memory, reaction time, verbal and visual memory, response variability, non-verbal problem-solving. There are 6 individual test modules: 1) Word Memory: Immediate and delayed memory for words, 2) Design Memory: Immediate and delayed memory for designs, 3) X's and O's: Attention, concentration, working memory, reaction time, 4) Symbol Match: Visual processing speed, learning and memory, 5) Color Match: Focused attention, response inhibition, reaction time, and 6) Three Letters: Attention, concentration, working memory, visual-motor speed. The results from each module are automatically computed into composite scores. This study used the Verbal Memory Composite, Visual Memory Composite, and Visual-Motor Speed (Processing Speed) Composite scores from ImPACT.

The Verbal Memory Composite Score utilized is comprised of the average of the following scores: Word Memory total percentage correct (immediate+delay)/2 from Module 1, Symbol Match (hidden symbols)/9*100 from Module 4, and Three letters Total letters correct from Module 6.

The Visual Memory Composite Score is average of the following scores: X/s and O's Total correct (memory)/12/100

[1)] PCA was performed in order to reduce the number of variables, and also to select the best representative variable of each test based on the nature and the interrelationships among variables.

from Module 3, and Design memory-total percentage correct (immediate+delay)/2 from Module 2.

The Processing Speed Composite Score is average of the following scores: X's and O's total correct (during interference) total/4 from Module 3, and Three letters average accounted correctly*3 from Module 6.

CRTT Subtest VIII: Following the administration of the ImPACT, CRTT Subtest VIII was performed as a language measure, specifically as a measure for the auditory comprehension. The auditory comprehension performance has been highlighted as a predictor variable for the treatment effect and recovery in stroke survivors with aphasia [15-17], and it has been commonly used as one of the important subtests in standardized batteries like the Western Aphasia Battery (WAB [18]) to measure general language processing ability.

The CRTT is the computerized version of the Revised Token Test (McNeil & Prescott [19]), the validity and reliability were established (McNeil et al. [12]) and standardized on healthy controls, people with aphasia, people with right-hemisphere lesions, and concussed athletes [3].

The CRTT consists of 10 subtests and each subtest consists of 10 imperative sentences. The command in the CRTT Subtest VIII begins with the word "put" and the length of each sentences vary with critical lexical items of color (blue, green, red, white, and black), shape (square and circle), and size (small and big) [12]. Subtest VIII includes prepositional phrases such as above, in front of, behind, below, to the left, or to the right. Some examples of commands from the CRTT Subtest VIII are "Put the big blue square above the small black circle" or "Put the big red circle below the small white square". Participants listened to these commands presented by the CRTT software through the computer and responded with the mouse to the stimuli shown on the computer screen. The average words per minute (wpm) per sentence was 183, and the average syllables per minute (spm) was 210. It takes less than 10 minutes to complete the CRTT Subtest VIII [3].

The CRTT software calculates the scores automatically using a multidimensional scoring system. The multidimensional scoring system is specifically designed to capture underlying deficits and behaviors in people with brain damages [12]. The specific scoring system is modeled after the Porch Index of Communication Ability (PICA) [20].

According to the multidimensional scoring system [3,12], the range of the accuracy scores is from 1 to 15. Score 15 (Complete) is when the patient made a correct response. Scores 14 (Rehearsal) is a manually entered score when a subject repeats command. Score 13 (Delay) is when there is a delay with a correct response. Score 12 (Immediacy) is when a response occurs before the command ends. Score 11 (Self-Correction) is when there is self-correction for a command. Score 10 (Reversal) is when the elements are reversed in the response for the two parts commands. Score 9 (Repeat) is when a repeat of the command had to be generated either automatically or manually by an examiner. Score 8 (Cue) is when the response is made after the repeat. Score 7 (Error) is when the response is incorrect. Score 6 (Perseveration) is when a subject exhibits the same error as the previous response. Score 5 (Rejection) is when the patient rejects the command. Score 4 (Unintelligible) is when the response was unintelligible. Score 3 (Unintelligible Perseveration) is given only when the current item within a subtest is scored a 4 and the preceding command within the subtest was also assigned a score of 4. Score 2 (Omission) is when elements are missing in the response. Score 1 (No Response) is when there is no response for the command.

The CRTT accuracy and CRTT ES are calculated by the software program for CRTT Subtest VIII and were reported for the current study. CRTT efficiency score was added as a unique feature of CRTT from the original RTT [12]. According to personal communication with Dr. Malcolm McNeil, "the intent of the ES was to design a metric that would capture the accuracy of the response that is conditioned by/relative to the time spent on the task. Additionally, it was designed to minimize ceiling effects for normal subjects and high functioning individuals with impairments on the CRTT." The CRTT ES is computed based on the following formula:

$$\mathrm{ES} = \mathrm{CRTT}\ (t^{*}/mt^{**})$$

t^{*} = length of time

mt^{**} = the maximum time assigned for each command

Data analysis

Three variables from the ImPACT (Verbal Memory Composite score, Visual Memory Composite score, and Visual-Motor Speed Composite ([Processing Speed, PS] score) and the two CRTT Subtest VIII variables CRTT accuracy, and CRTT ES measures were initially computed for a Pearson correlation coefficient to assess the relationships among the variables. In addition, exploratory PCA was computed to identify the nature and interrelationships among the variables and also to reduce the number of variables based on the nature and the interrelationships. After the PCA, a Between Groups MANOVA was performed to compare the two participant groups across the selected ImPACT and CRTT variables based on the PCA results using IBM SPSS Statistics 24.

RESULTS

Correlation Results: Pearson Correlation *r*

The results of Pearson Correlation analyses were summarized in Table 2. The variables from the ImPACT were significantly positively correlated to each other and the CRTT variables were also significantly and positively correlated to each other.

Variable Selection Process: PCA

Five variables were initially included for the data collection, and two variables were chosen based on the PCA. The PCA with varimax rotation was performed for five variables to identify the variables with the greatest shared variance. Two factors were extracted from the PCA results. Interestingly, all three variables from the ImPACT were highly loaded on one factor, and the two variables from the CRTT were highly loaded on a second factor. Table 3 summrizes the coefficients for the two components.

The criteria for choosing the variables based on the PCA results were as follows: 1) The variable with the highest value was chosen as the dependent variable from each factor, 2) The variable that was not highly loaded on the second factor was chosen as the dependent variable. Two variables were chosen from each factor based on these criteria. The Verbal Memory variable from ImPACT was the highest value from the first factor out of two factors, and CRTT Efficiency was the highest value in the second factor out of two factors. Therefore, the Verbal memory Composite Scores and the CRTT Efficiency Scores were choosen as the dependent variables because each variable represents each factor as well as each test, ImPACT and CRTT.

MANOVA results

The Multivariate Analysis of Variance (MANOVA) was conducted to assess the difference on the two selected dependent variables, the Verbal Memory Composite scores and the CRTT Efficiency Scores, compared between the speed and non-speed groups. The multivatriate effect was significant by groups, $F(2, 33)=5.64$, $p=0.008$, Wilk's $\Lambda=0.745$, partial $\eta^2=0.26$. Univariate tests showed that there were significant differences across two groups on the Verbal Memory Composite scores, $F(1, 34)=6.37$, $p=0.016$, partial $\eta^2=0.16$ and the CRTT ES $F(1, 34)=4.58$, $p=0.04$, partial $\eta^2=0.12$.

The followed ANOVAs with post hoc tests showed that the non-speed group composite scores were significantly lower than the speed group on the Verbal Memory Composite scores (Non-speed players: $Mean=76.67$ [$SD=13.04$], Speed players: $Mean=86.61$ [$SD=10.04$], $F(1, 34)=6.37$, $p=0.016$), and the CRTT Efficiency Score was also significantly lower than the speed position group (Non-speed players: $Mean=11.61$ [$SD=$

Table 3. Coefficients derived from the PCA Rotated Component Matrix

	Factor 1	Factor 2
Verbal Memory Composite Scores	**0.938**	0.037
Visual Memory Composite Scores	0.826	0.131
Visual-Motor Speed Composite Scores	0.752	0.083
CRTT Accuracy Scores	0.181	0.902
CRTT Efficiency Scores	0.012	**0.921**

Coefficients bolded are those selected to represent each factor.

Table 2. Correlations results among variables

Variables	Verbal memory composite scores	Visual memory composite scores	Visual-motor speed composite scores	CRTT accuracy scores	CRTT efficiency scores
Verbal memory composite scores	1	0.731**	0.623**	0.173	0.086
Visual memory composite scores	0.731**	1	0.352*	0.319	0.065
Visual-motor speed composite scores	0.623**	0.352*	1	0.159	0.141
CRTT accuracy scores	0.173	0.319	0.159	1	0.681**
CRTT efficiency scores	0.086	0.065	0.141	0.681**	1

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).

1.48], Speed players: *Mean* = 12.51 [*SD* = 0.98], $F(1, 34) = 4.58$, $p = 0.04$). However, the significance of the CRTT Efficiency Score variable is not valid based on the *p* value (corrected new *p*-value = 0.025) with a Bonferroni Correction. The significance of the Verbal Memory Composite scores is still valid for the multiple comparisons.

The number of prior concussions reported by the athletes was also compared between the speed and the non-speed position groups. The analysis revealed that there was no significant difference in the number of prior concussions reported by the groups (Speed players: *Mean* = 1.56, *SD* = 0.78, Non-speed players: *Mean* = 1.33, *SD* = 0.59, $F(1, 34) = 0.92$, $p > 0.05$)

DISCUSSION

The primary goal of the current study was to investigate whether playing positions (Speed vs. Non-speed positions) showed significant differences on high school football athletes' memory and language performance following a sport-related concussion (SRC).

The results revealed that athletes who played non-speed positions performed slower and poorer on memory and auditory comprehension than those athletes who played speed positions. Specifically, the non-speed players were significantly poorer than the speed players on the Verbal Memory Composite Scores from the ImPACT, and the Efficiency Scores from the CRTT Subtest VIII.

The results of this study show that the non-speed players are more vulnerable in verbal memory and language behaviors, specifically auditory comprehension at a sentence level, than the speed players. This vulnerability may be due to the non-speed players' increased risk for sub-concussive impacts since the frequency of self-reported concussions was not different between groups [6]. Sub-concussive recurrent hits may cause the significant differences in the performance for memory and language by playing positions found in this study.

While the current study found evidence of cognitive behavioral changes by playing positions, Clark et al. [4] provided evidence of change in functional brain structures by playing positions. Specifically, while Clark et al. [4] reported that non-speed players exhibited more damaged white matter then speed players, the current study found that the non-speed players exhibited poorer behavioral performance in verbal memory and auditory comprehension than speed players.

The current study supports and extends the effects of playing positions on behavior performance findings in collegiate athletes [4] to the high school players in this current study.

The correlation results and PCA results across initial variables provided useful information on the nature and relationships among variables. The two tasks, the ImPACT and CRTT were separated in the results. The ImPACT was included as a memory measure, and the CRTT was included as a language measure, specifically for the auditory comprehension at a sentence level. In the results of the PCA, three variables from the ImPACT were highly loaded in the 1st factor, while the two variables from the CRTT were highly loaded in the 2nd factor. In the correlation results, the variables within each task were positively correlated. Therefore, the variable selection from each task was made based on the most highly loaded in each factor because the highest variable was assumed to be the most representative for each task. These results can suggest an option for the possibility of a variable selection out of many potential variables in concussion research.

The results of this study also suggest several interesting possibilities or speculation regarding the recent CTE literature. First, exhibiting significant differences in auditory comprehension performance, the CRTT ES, might indicate an early symptom of a decline in language function in people with the CTE. According to Mez et al. [8], CTE was reported even in high school players. As described in the introduction, 7% of the participants diagnosed with mild CTE (3 out of 44) only played football up to the high school level (21%). According to the literatures [8-10], cognitive features, specifically language, have been reported to appear in the later stages of the CTE disease. The current study results add further support to the specific differences in the auditory comprehension. This suggests that the language deficits might begin in the early stages of the CTE and continue to develop slowly and then show up clearly in the late stage as CTE becomes progressively worse. If this is true, testing language measures such as the CRTT ES might be useful to detect the early symptoms of the CTE since the CRTT ES was designed to detect the ceiling effects and early dysfunctional performance in mildly impaired individuals.

Further investigation of auditory comprehension in a sample of individuals showing potential signs and symptoms of CTE may help validate the above speculation. Based on the findings of the current study, we can assume that playing position is potentially a significant factor in detecting those individuals with an increased risk for developing CTE.

The comparison of the number of prior concussion self-reported by each group was not statistically different between the two groups and therefore cannot explain the differences between the speed position and the non-speed position groups. Furthermore, given that the two groups were matched for age and years of education, these two variables cannot explain the current findings. Therefore, the source of differences between the two speed groups carrying out spoken commands may suggest the possibility that the non-speed position players potentially experienced more sub-concussive hits. The higher rate of sub-concussive hits experienced by high school athletes in non-speed positions may put them at greater risk for developing CTE given the dysfunction of verbal memory and auditory comprehension found in this sample of high school athletes.

This study has limitations, which indicate the need for further investigations. We did not test different domains or levels of language such as syntax, phonology, or word level vs. sentence level. These aspects of language processing require further investigation.

Another limitation of the study was the lack of data on the frequency of sub-concussive hits experienced by the participants. The current study was not designed to investigate the relationship between the recurrent hits and the cognitive performance. Previous studies have provided information on the relationship between playing positions and the number of recurrent hits. In the future, an investigation of the effect of recurrent sub-concussive and concussive hits can be carried out to assess the impact on cognitive communication variables such as auditory comprehension, by playing positions.

This current study used a relatively small number of participants so generalization to a population is limited. However, this study did indicate the young athletes' cognitive communication performance may be adversely impacted based on the position they play in the game of football. Future studies with a larger dataset are suggested to investigate the cognitive communication differences by playing positions and to replicate the results of the current study.

CONCLUSIONS

The current study examined how playing positions may impact a high school athletes' memory and language performance following a sports-related mild concussion. The findings exhibit that playing positions in high school football athletes can significantly affect cognitive communicative behaviors such as verbal memory and auditory comprehension of sentences.

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