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Early Season to End-of-Season Comparisons of Cognitive Performance in College Football Players

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Abstract

Previous research has shown that mild traumatic brain injury (mTBI), is associated with impairments in cognition and emotional attention. In a recent study patients with mTBI utilized more attentional resources and had slower reaction times (RTs) to emotional stimuli than did non mTBI patients. The current study obtained RTs and event-related potential (ERP) recordings to investigate whether a season of football participation might have similar effects. Participants included twelve football athletes and ten male controls. Data were recorded twice for each participant -- at the beginning of the football season and after the season had ended. Participants completed a computerized RT task, in which emotionally relevant trials required the participant to respond either to a neutral cue (e.g., flower as Go signal, spider NoGo signal) or a threat-related cue (e.g., spider as Go signal, flower NoGo signal). During irrelevant trials the participant had to respond to color cues (e.g., red or green as Go signals), regardless of the figure (e.g., spider or flower). We hypothesized that end-of-season football participants would have slower RTs for threat-related stimuli than for neutral stimuli when emotion was relevant. More attentional resources were also expected to be allocated during emotionally relevant trials for football participants than for controls. The possibility of practice effects suggested improved performance in the second test, but we expected less improvement in the football players. As expected, the control group showed a significant improvement in the neutral trials ($t(9) = 3.06$, $p < 0.01$) as well as the threat-related trials ($t(9) = 2.35$, $p = 0.04$), while football participants did not show significant improvement for either the neutral or threat-related trials. ERP results suggest a persisting rapid response to threat-related stimuli at the end of the season. These findings suggest a mild cognitive impairment in the football players, perhaps related to their response to threatening stimuli.

Keywords: mTBI, EEG, sub-concussions

1. Introduction

Concussions are amongst the biggest public health problems today. In the United States, it is estimated, that 83% of the total 200,000 sports-related concussions are due to football[1]. We now know that sustaining multiple severe concussions throughout a lifetime leads to chronic traumatic encephalopathy or CTE[2]. Currently there is no cure for CTE, and research is very limited. Due to the limited literature on the pathophysiology of CTE, most studies today focus on monitoring concussions and how their effects on the brain lead to CTE[2]. Furthermore, there is even less research looking at how sub-concussive blows or mild traumatic brain injuries (mTBIs) – a less severe form of hits to the head – affect the brain. These blows often go undiagnosed since they are not as severe as concussions. However, recent studies, discussed below, show that these “mild” blows to the head may have more impact on the brain than we may have previously thought.

Previously it has been found that we have enhanced emotional attention to unpleasant or threat-related stimuli[3]. Furthermore, studies have shown that mTBIs could be linked to compromised executive functioning and altered emotional activity[4]. A study conducted on patients with mTBIs used EEG measurements and a Go/NoGo task to measure cognitive performance[4]. The Go/NoGo reaction time test requires the use of multiple executive functions, likely used in attention to everyday stimuli. The Go/NoGo task used in this study dealt with threat-related (spider) and neutral stimuli to examine differences in attention to emotion-related stimuli. Because of these features the Go/NoGo task is a good way to measure emotional sensitivity amongst patients with mTBI. The study found that patients with mTBIs had compromised performance in RT tests. RTs for threat-related stimuli are faster than those for neutral stimuli[4]. The study examined the negative N2 wave and the positive P3 to measure differences in ERP results. These researchers found an increased amplitude of the N2-P3 complex in concussion patients.

Many of the symptoms reported by mTBI patients indicate a lack of top-down executive and attentional control processes – patients have difficulty with actions involving response control, memory, and selective attention[3]. Most patients fully recover, though some have symptoms for extended periods of time. In a study conducted on collegiate rugby players it was found that short-term exposure to sub-concussive head trauma has the ability to alter functional connectivity patterns[5]. In another study conducted by Poole et al.[6], on high school athletes, they found that sub-concussive blows were associated with chemical changes that could lead to later neurological problems. Specifically, this study found that undiagnosed mTBIs lead to the accumulation of a number of different chemical changes in the brain. These changes were so diverse that they were often not noticeable, and thus could help mask symptoms of athletes who are injured. Thus, although the chemical changes are numerous, they do not produce symptoms and therefore help mask the degree of injury a player has suffered. Another study[1] was done using fMRI that focused on a default mode network – an active part of the brain when at rest – to measure concussion damage. The study was done in high school players during their football season. Results showed less connectivity of the brain area when the season was over when compared to before the season started[1]. All in all, these studies suggest the need for more research on the effects of sub-concussive blows to the brain.

Due to the recent evidence regarding the effects of mTBIs, this study is focused on executive functioning and altered emotional activity of football players using EEG recordings. Because patients with mTBIs show altered attention to emotion, we predicted that in football players there would be changes in the amplitudes and timing of the N2-P3 peak to the task at the end of the season relative to early in the season. Since previous research has found that we respond faster to threat signals, we predicted that in both the football and the control group there would be faster RTs for threat-related than neutral stimuli. Finally, we expected that due to expected sub-concussive blows throughout the season, football players would not improve as significantly as the controls on the Go/NoGo task from early to end-of-season.

2. Methodology

2.1 Participants

Participants were obtained on a volunteer basis from Bethel College, a small private school in Kansas. Football athletes were recruited at the beginning of the season through the Athletic Training Department. Athletes were chosen on the basis of not having sustained a concussion within the past month. In exchange for their participation, participants were entered in a drawing to win a $25 gift card to a coffee shop on campus. Twelve healthy males were offered extra credit for participating in the study. The twelve males of the control group were obtained from multiple psychology courses early on in the semester.

At the end of the football season participants were asked to return for a second recording. Football participants were paid $5 for the completion of the study. The control group was offered additional extra credit for returning to complete the study. Two controls were excluded from the results due to incompletion of the study.

2.2 Study Design

Participants in the football group were asked to complete a Go/NoGo task (Figures 1 & 2) along with EEG recordings before the football season started for a baseline recording. The task along with the EEG recordings took about 40 minutes to complete. At the end of the season the football group returned to complete the same Go/NoGo task as in the beginning of the season. Participants in the control group completed only the Go/NoGo early in the semester and again at the end of the semester.

2.3 Go/NoGo task and EEG recordings

A Go/NoGo RT task to measure attention to emotional stimuli was adapted from the study conducted by Mäki-Marttunen et al[4]. The Go/NoGo task consists of a short series of stimuli presented on a computer screen. In this task, a triangle was shown on a screen pointing upward or downward, and participants had to respond with a button press on which way the triangle was pointing. Following the triangle was a dot on the center of the screen and a box of red or green color, with either a threat-related (spider) or neutral (flower) symbol in the middle (Figures 1 & 2). Participants were asked to respond using the button box on which way the triangle was pointing on the Go signal of each block. Participants were required to withhold responses on trials in which the NoGo signals occurred (Table 1).

Blocks of 64 trials (32 Go, 32 NoGo) were randomized for each participant, and trials within blocks were also randomized. Each participant completed 2 sets of the 4 kinds of blocks (Table 1) in random order, i.e., a total of 512 trials. A 32-trial practice block, for which data were discarded, preceded these 8 blocks. Note that in the data analysis, blocks were grouped on the basis of emotion being relevant (Blocks 3 & 4) or irrelevant (Blocks 1 & 2). Participants used a button box for responding to each trial. There were two versions of the task, each corresponding to different responses on the button box. In script 1, pressing the yellow button was required if the triangle was pointing up, and the green button was to be pressed if it was pointing down. In script 2, these button-color-triangle-direction requirements were reversed. Half of each group was assigned to script 1 and half to script 2. Each response had a corresponding RT that was used to measure differences amongst participants.

In addition, we obtained electroencephalographic (EEG) recordings to measure brain activity throughout the completion of the task in football players; EEG data were not collected for control participants. We used a 32-electrode cap to obtain event-related potential (ERP) measurements for the football players. EEG recordings were obtained for football players in order to see changes in brain activity across the football season.

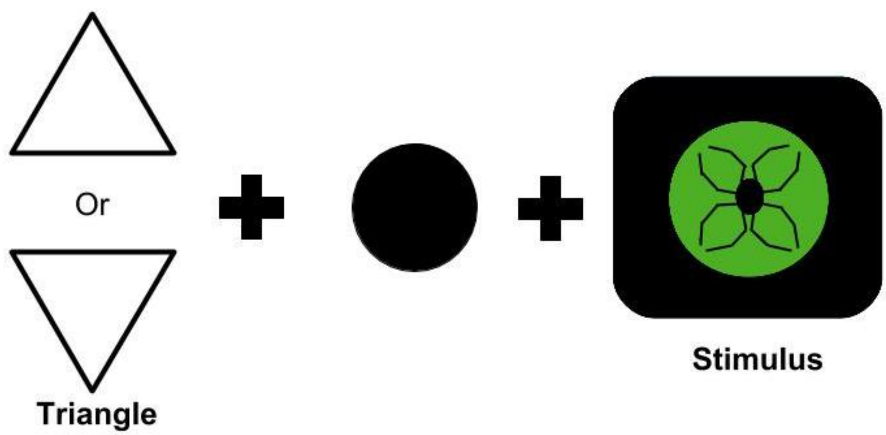

Figure 1. Example of a trial

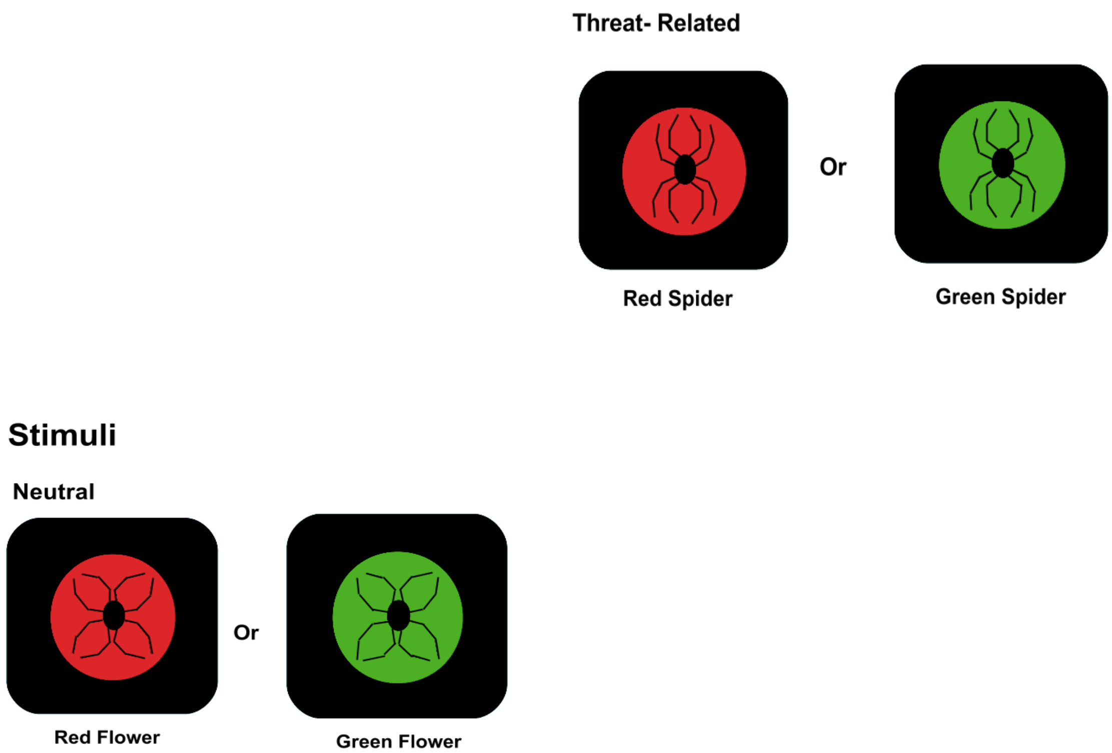

Figure 2. Stimuli presented in each block

Table 1. Block Setup, Go signals and NoGo signals of each block. A Go signal meant the participant needed to respond on which way the triangle was pointing. When a NoGo signal was shown, participants were required to withhold their response.

Block	Go Signal	NoGo Signal
One	Red (Spider or Flower)	Green (Spider or Flower)
Two	Green (Spider or Flower)	Red (Spider or Flower)
Three	Flower (Red or Green)	Spider (Red or Green)
Four	Spider (Red or Green)	Flower (Red or Green)

2.4 Data Analysis

2.4.1 behavioral analysis

Due to significantly slower RTs in the beginning of each block, the first two trials of each block were excluded from analysis. There were four conditions for each block: Red Flower, Red Spider, Green Flower, Green Spider. Excel spreadsheets were used to find median RTs for each participant in correct Go trials (of course, no reaction time data are generated on NoGo trials) for each of the four blocks. Paired t-tests, analyses of variance (ANOVA), and Wilcoxon signed rank tests were conducted using R Statistical Software[9,10]. Statistical significance was defined as a p-value ≤ 0.05.

2.4.2 EEG analysis

All EEG data were imported into EEGLAB software[7]. Preliminary analyses indicated a high number of movement-related artifacts in NoGo trials, so our analyses were based on Go trials only. The first two trials of each block were deleted much as had been done for reaction times. Using the ERPLAB plugin for EEGLAB[8], we extracted epochs for four categories of trials in which the Go signals were as follows: red (NoGo = green; emotion cue irrelevant), green (NoGo = red; emotion cue irrelevant), flower (NoGo = spider -- i.e., emotion cue relevant), spider (NoGo = flower -- i.e., emotion cue relevant). Epochs were from 200 ms prior to stimulus onset to 600 ms after the onset of the Go signal. Green and red trials were also recategorized according to which irrelevant emotion cue was present (flower or spider).

Epochs with artifacts were rejected using ERPLAB, which identified epochs with 100 microvolt or greater shifts across 100 ms windows. Epoched data were subjected to independent component analysis in EEGLAB, and eye movement components were removed. Artifact-free data were averaged across trials within each category for each participant. Grand average ERPs were created by averaging across participants, but separately for early season and end-of-season phases of the study. Latencies and amplitudes of peaks were measured using ERPLAB, and the resulting data were analyzed using R[9] and R Commander[10].

3. Results

3.1 Behavioral Results

Figure 3 shows a significant decline in RTs from early season to end-of-season ($F(1,20) = 14.18$, $p=0.0012$). There were significantly slower RTs for emotion relevant cues than for emotion irrelevant cues ($F(1,20) = 84.16$, $p < 0.001$). There was less improvement observed in the football group than in the control group. The improvement in the control group was significant in neutral trials ($t(9) = 3.06$, $p < 0.01$), and in the threat-related trials ($t(9) = 2.35$, $p = 0.04$).

Groups responded faster to spider cues than to flower cues; this difference was barely significant ($F(1,20) = 4.48$, $p = 0.047$). Groups also responded significantly faster to red cues than to green cues ($F(1,20) = 11.19$, p = 0. 002). This difference was more noticeable in the early-season for the control group than the football group. There was a significantly different response to emotion cues between the two groups ($F(1,20) = 5.68$, $p = 0.027$). Specifically, in the early season there was a faster response amongst the control group to spiders when emotion was relevant when compared to the football group. The football group had slower median RTs for the green spider trials than the controls. The football group had even slower RTs in the red spider trials. When comparing the end-of-season trials to the early season trials, these differences were much smaller, with the RTs being slightly faster overall for both groups. In the early season emotion irrelevant blocks, the football group had slower median RTs for the red flower and spider trials. In addition, the football group had faster RTs for the green flower and spider trials than the controls. There was an overall improvement in RTs from early season to end-of-season in both groups.

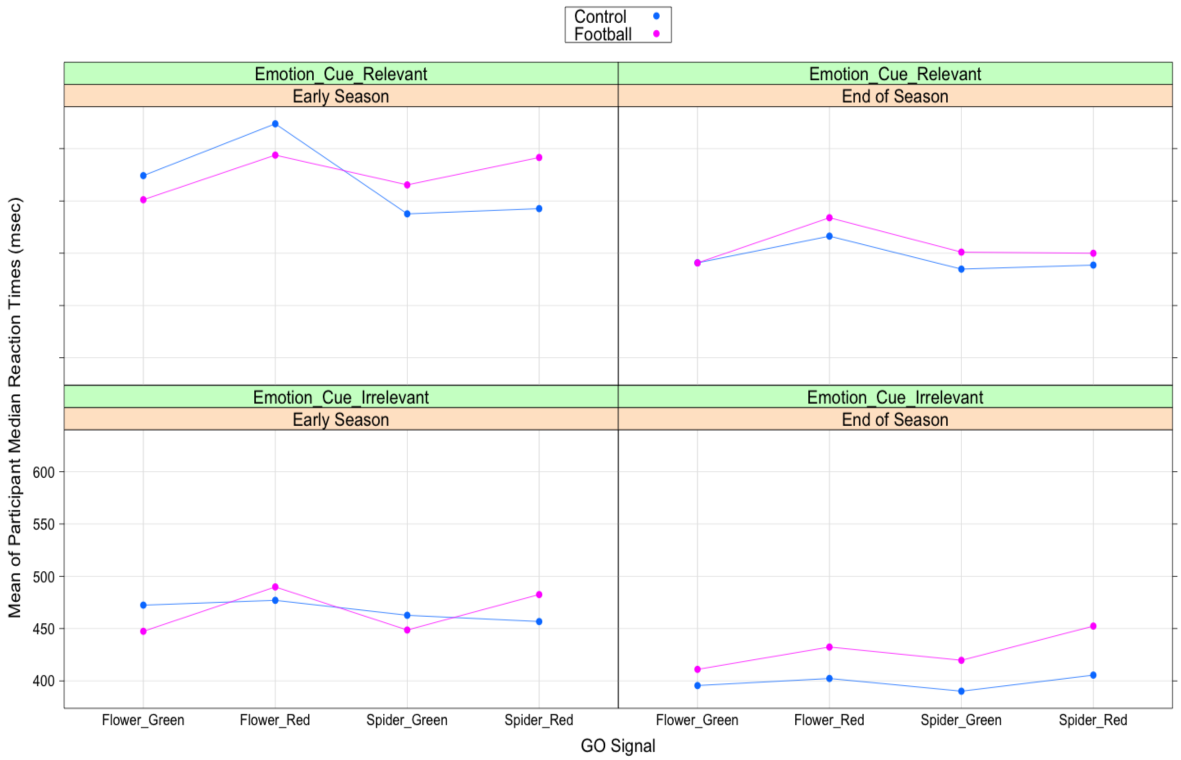

Figure 3. Mean of the median RTs for football players vs controls from early season to end of season. The graphs show the RTs for all four conditions between the two groups.

3.2 ERP Results

Results from the ERP analyses show the N2-P3 complex across all four conditions that was found in previous studies[4]. For the emotion irrelevant conditions in early season (Figure 4), the P3 peak for the Go green rule is larger than the peak of the Go red. Differences in P3 amplitude were clearly evident in the early season and were less pronounced in the end-of-season (Figure 5). When looking at the emotion relevant condition, the peak of the P3 wave for spiders came before the peak for flowers. This difference was evident in both early season and end-of-season.

When comparing emotion relevant (spiders or flowers) to emotion irrelevant (color) in both the early season and end-of-season there were shorter peak latencies for the emotion irrelevant trials. This difference reflects the faster RTs found for emotion irrelevant than emotion relevant trials (Figure 3). The latency for the spider peak is shorter than the latency for flowers. This latency difference was significant in early season (Wilcoxn Signed Rank, ($V = 68$, $p = 0.021$) and in end-of-season ($V = 72$, $p = 0.0068$).

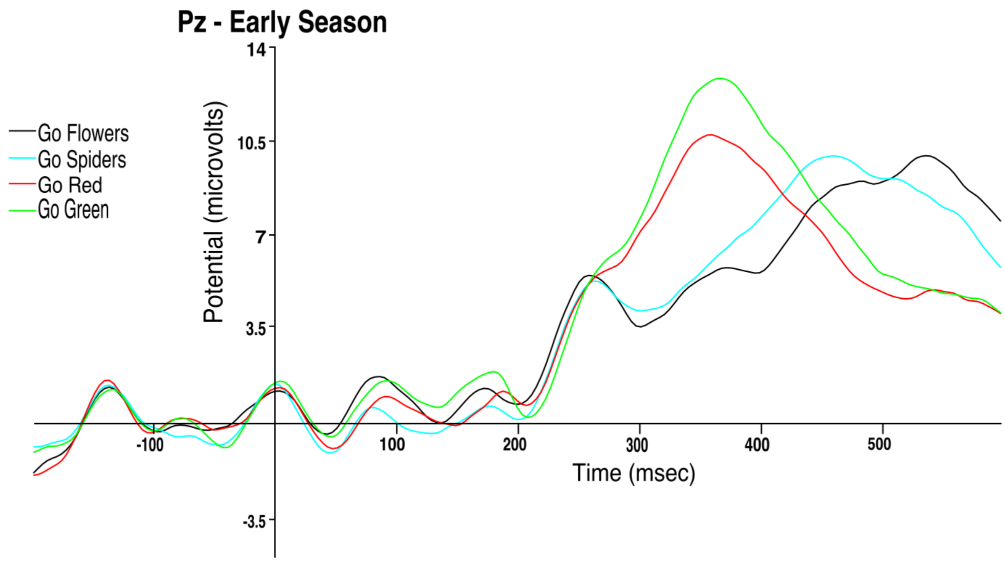

Figure 4. Early season: Pz electrode for all four conditions. The curves display grand average potentials (i.e., averaged across trials and then across the 12 participants) for spiders vs flowers and for green vs red as Go Signals.

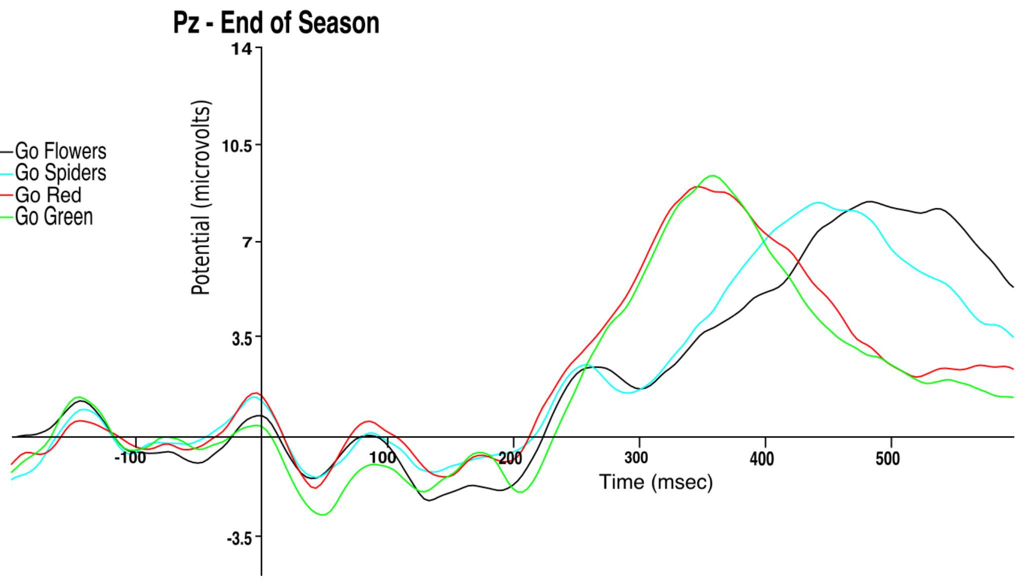

Figure 5. End-of-season: Pz electrode for all four conditions. The curves display grand average potentials for spiders vs flowers and for green vs red as Go Signals.

4. Discussion

Results did show an improvement from early season to end-of-season in both groups. This finding is likely due to practice effects. This was a significant improvement only in the control group. Results in the end-of-season RTs for football players showed slower RTs than controls across all conditions (Figure 3). These results were only found in the end-of-season data, suggesting that there may be some factor football players acquired that interfered with their ability perform as well as in the beginning. This interference may be due to repeated blows to the head although we cannot be sure. The possibility that the reported p-values based upon t-tests are misleadingly low because of multiple comparisons must also be considered. Nonetheless, these results confirmed the theoretical expectations of impairment in the football group and should not be neglected.

Both groups had slower RTs to red than to green cues regardless of the figure. This finding may be due to the fact that we normally experience green as a Go signal and red as a stop or NoGo signal. RTs for spiders were found to be slightly faster than those for flower stimuli in both groups. For the football group however, this difference was found to be less true (see description of group by emotion cue interaction). The football group responded more slowly to red spiders than to any of the other conditions. This finding suggests that football players focused more on threat-related stimuli than neutral stimuli. Instead of getting accustomed to the spider condition after repeated exposures, the football group seemed to be just as sensitive to the condition as in the beginning. It is as though the football group had an increased sensitivity to threat-related stimuli than the controls.

In the ERP analyses, this study found a N2-P3 complex, which has been found in other studies[4]. Unlike the study of Maki et al., which found no significant differences in the amplitudes of the N2-P3 complex, our study found that the P3 wave appeared sooner for threat-related stimuli than for neutral stimuli. We also found a significant difference between the latency of the P3 wave for spiders than that for flower stimuli in early season. This latency difference appeared again in the end-of-season ERPs. In both early and end-of-season, there were shorter peak latencies for the emotion relevant when compared to the emotion relevant conditions (Figure 4 & 5). This difference was also evident through the RT (Figure 3); overall this suggests that participants responded more quickly to color than to figure stimuli.

The current study focused on football players in their late teens to early twenties. It may be that at this age there is a difference between the N2-P3 amplitudes. Furthermore, we measured football participants relatively soon after the sub-concussive blows they may have received. It is possible that if measurements were done a month or two months afterwards, the differences in N2-P3 amplitudes may become significant. Additionally, differences found in groups could be due to the individual differences amongst the control and the football group. On the other hand, it is possible that differences were missed because of low statistical power arising from our small sample sizes. Future studies could look at the relationship between errors made and NoGo trials to see whether brain inhibition was different for controls or football players. The differences found in football players for the end of season, along with the slower RTs in emotion irrelevant trials for football players strongly suggest the need for future studies to see if these differences are maintained. Although the Go/NoGo task was chosen for its ability to detect sensitivity to emotional stimuli amongst mTBI patients[4], the effects produced in this study appear to be small. However, the finding that amongst football players there seems to be a continued sensitivity to threat-related stimuli when compared to controls suggests a strong need for more evaluation.

5. Conclusion

Repeated blows to the head may be more dangerous than we had previously thought[5]. The current study found increased recruitment of attentional resources for processing threat-related stimuli. We also found less attentional resources were used when processing emotion-related stimuli. In the football group we found an inability to ignore emotion-related stimuli when they were irrelevant. Overall, the football group did not show as much improvement from early to end-of-season performance. Lastly, differences in ERP data further show the differences from playing a season of football. Finally these findings may suggest that repeated blows to the head could have an effect on performance in a RT task. These findings suggest the possibility of cognitive impairment due to blows to the head amongst football players. It is of crucial importance to pay more attention to athletes who receive multiple blows to the head such as football players for they may also have a higher risk of obtaining CTE than previously thought. Paying more attention to sub-concussive blows or mTBIs is a huge step towards learning how to prevent greater brain damage and decrease the risk of CTE before it is too late.

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