The Effects of Sports Related Head Impact on Balance and Neurocognitive Functions

Shaquanda D. Ross-Simmons[1], Michelle L. Vieyra[1], Abhishek Jain[2], Keri Weed[2]

[1]*University of South Carolina Aiken, Department of Biology and Geology, Aiken, SC*
[2]*University of South Carolina Aiken, Department of Psychology, Aiken, SC*

The goal of this study was to investigate the effects of sports-related head injury on balance, attention, and memory. Reliable differences have been found using measures that directly tap into brain functioning, such as the auditory oddball task combined with EEG recording. We hypothesized that athletes reporting a diagnosed concussion or participation in high-risk sports would have compromised balance and neurocognitive functioning compared to athletes in low risk sports. Forty-five undergraduate participants were identified as either concussed, non-concussed in high-risk sports, or non-concussed in low-risk sports using a survey of athletic history, head trauma and demographics. The Biopac MP36 system, a balance board, and the BESS protocol was used to measure balance. E-prime and a 32 channel electrode EEG system was used to conduct an auditory oddball test and a working-memory task. No significant differences were found between groups for balance or accuracy on the oddball test or working memory task. EEG analysis showed no significance differences in latency (response time) but participants who reported a concussion or participation in a high-risk sport did have significantly lower amplitude (response strength) compared to those in low-risk sports. There was also an inverse correlation between errors in the attention task and amplitude. Consistent with prior research, no differences were found using behavioral measures of attention and memory, but more sensitive EEG measures were able to detect subtle differences between groups.

Introduction

Recent attention has focused on the potential long-term detrimental effects of sports-related head injury. Research has documented subtle long-term problems in balance and cognition for athletes who experienced one or more concussions[1]. Additional evidence has suggested that problems may become more pronounced over time, especially when concussions are experienced during adolescence [2]. Research has been less consistent on neurocognitive changes associated with sub-concussive head injuries[3]. Sub-concussive head injuries are head impacts that may cause athletes to experience changes in brain function without clinical presentation of a concussion[4].

According to Broglio et al. (2012), the majority of investigations implementing common behavioral assessment tools have failed to identify differences in cognitive performance in athletes with or without a concussion history. They also stated that it is not clear why some individuals with a concussion history show no persistent functional impairment, whereas others experience cognitive declines and associated brain pathology later in life. Explanations for these inconsistencies may include the sensitivity of measurements used in assessments of impairment[5], how much time has passed between concussion and assessment[1], and individual differences between athletes such as age at concussion[6], risk of head injuries inherent to their sport, and socioeconomic status.

The sensitivity of the measures used to assess impairment is one explanation for inconsistent findings within groups of athletes who experienced sub-concussive head injury[5]. Traditional clinical assessments, such as memory recall tasks and measures of reaction time, sometimes find differences between athletes with and without a history of head injury, but often do not. Balance tests are often more reliable because they measure physiological processes more directly. More consistent differences have been found using measures that directly tap into brain functioning, such as the auditory evoked potential[7]. An auditory evoked potential (AEP) is a specific brain wave pattern produced, and recorded using an EEG, after presentation of an auditory stimulus. One of the waves generated, the P3, is commonly used to assess attention and working memory[8]. AEP is typically assessed while participants engage in an auditory oddball task. This task requires participants to pay attention to two different tones, one of which is presented much more frequently than the other. The task may also include auditory or visual distractors to increase attentional demands. Athletes who have experienced concussions, and those with sub-concussive injuries often show delayed latencies (reaction time) and depressed amplitudes (reaction strength) on the P3 evoked potential, especially when combined with distractors[9].

Another explanation for inconsistent findings in prior studies of head injury focuses on the timing of assessments. As expected, differences between participants with and without concussions are found immediately following an injury, but subsequently disappear anywhere from a few days to a few months after injury. However, long-term follow up studies often report significant negative impacts and suggest that there is often a recovery period where subtle damage may go undetected, with lingering damage worsening over time[1]. In addition, research suggests that damage suffered during periods of rapid brain development (i.e., adolescence) may have more substantial long-term impact than damage received later in life [6].

Inconsistent findings may also be a function of individual differences between athletes[5]. Two players may experience the same head impact but one recovers completely while the other has ongoing deficits. Little has been done to try and identify important individual differences that would explain these differential impacts. Although socioeconomic status (SES) is a powerful predictor of many health outcomes, it has not been considered within the context of sports-related head injury. SES is important because this will determine the likelihood of appropriate medical care following the concussive head injury.

The purpose of this study was to compare the effects of a reported sports-related concussion during adolescence to non-concussed adolescent participation in high-risk and low-risk sports on balance and neurocognitive functioning. This study included several measures of impairment that varied in sensitivity. Balance was measured using a force plate that automatically recorded sway in all four directions. An auditory oddball task was used to collect both behavioral measures (i.e., attention and working memory) and P3 evoked potential. Former high school athletes who participated in high risk and low risk sports were recruited from a college psychology class. This strategy ensured that there was a period of at least six months between the time of injury and the neurocognitive assessments. Socioeconomic status was also examined to see if there was any correlation between SES and the effects of injury or sports participation.

We hypothesized that high school athletes who experienced one or more concussions would have compromised balance and neurocognitive functioning compared to high school athletes who had not experienced a concussion. Also, we expected high school athletes who participated in high risk sports to have compromised balance and neurocognitive functioning in comparison to athletes who played low risk sports. Differences between groups of high school athletes were expected to be more pronounced on more sensitive AEP and balance measures than less sensitive behavioral measures. In addition, neighborhood SES was expected to moderate deficits associated with head injury.

Methods

Participants

Sixty undergraduates were recruited through the SONA on-line system for Introductory Psychology students managed by the Psychology Department at the University of South Carolina Aiken. All participants were awarded one hour of research participation credit. There were 40 women and 18 men with an age range from 18 to 25. The majority of participants were White (66.5%), with 27.6% Black and 6.9% Hispanic. Forty of the participants were identified as middle class and 20 were identified as upper class based on the neighborhood poverty rate of the community they lived in while attending high school. The study was approved by the IRB board at USC Columbia and all participants were fully informed of the research protocol as indicated by signed informed consent.

Participants were classified into one of three groups:

1. **Concussed** (*n* = 19; 30.5%). This group included participants who participated in at least one high risk sport (e.g., football, basketball, baseball, soccer, equestrian[10]) as a teenager and who experienced at least one serious head injury. Of the 19 concussed participants, 58% reported experiencing one concussion, 21% reported experiencing two concussions, and 21% reported experiencing three concussions between the ages of 13 and 17. Only 1 participant reported that their concussion was from a non-sports related accident.
2. **High risk** (*n* = 28; 47.5%). This group included participants who played at least one high risk sport as a teenager, and reported having no serious head injuries either associated with sports participation or not.
3. **Low risk** (*n* = 13; 22%). This group included participants who played at least one low risk sport (e.g., tennis, swimming, track, golf) as a teenager, and who reported no serious head injuries.

Procedure and Measures

When participants arrived for the study, eligibility was verified and informed consent obtained. Participants taking any medications for depression, anxiety, or attention deficit disorder were excluded from participation. Participants first completed the BESS balance assessment. Following the balance task, measurements were taken of the participants' head in order to determine the correct size EEG cap. As the EEG cap was fitted and electrodes applied, music was played to make the participants comfortable. As one experimenter applied electrodes, a second experimenter administered a questionnaire on socioeconomic status, history of sports participation and head injury. After all impendences had reached below a single digit number, the auditory oddball task was administered. Upon completion of this task, the EEG cap was removed and the participants were thanked for their cooperation.

Socioeconomic Status (SES)

SES was measured by the percentage of homes below poverty level within the surrounding neighborhood of participants' residences at age 17. The measure was derived using census data from the Federal Financial Institutions Examination Council (FFIEC) Geocoding System (https://geomap.ffiec.gov/FFIECGeoMap1.aspx).

Sport and Injury History

Participants were classified into concussed, high risk, or low risk groups based on responses during a semi-structured interview about their history of sports participation and injuries experienced during and outside of play. Questions for this interview were constructed by the experimenters for this study. Participation in all sports since the age of 14 was queried. Follow up questions asked for the context of participation (e.g., school team, community organization), length of participation, and frequency of participation. For each sport identified, participants were asked about the number of serious injuries sustained. Follow up questions focused on head injuries in particular such as medical care following each serious injury. Finally, participants were queried about any head injury received unrelated to sports participation with similar follow up questions about access to medical care following the injury.

Balance

Balance was assessed with a modified version of the Balance Error Scoring System (BESS)[11]. Participants were assessed during 3 stances: feet side-by-side with hands on hips, standing on one foot with hands on hips, and a tandem stance. Each of the 3 stances was performed once on a firm surface and once on a foam surface with eyes closed for a 30 second time period. Participants were observed and deviations from stance positions were marked by the experimenter. The force plate automatically recorded postural sway deviations from side-to-side and from front-to-back. From these measurements total sway was computed and used in subsequent analyses. The BESS has been shown to have adequate reliability and to discriminate individuals with sports-related concussions from non-concussed participants[11].

Auditory Oddball Task

An auditory oddball task was used to derive several neurocognitive measures. A series of tones was presented and participants were asked to respond with a key press whenever they heard a tone, distinguishing between a frequent and rare tone. The frequent tone was presented approximately 85% of the time while the rare tone was presented 15% of the time. In addition, the task included an occasional visual distractor, a picture of a basket, that the participant was asked to attend to and later report how many times the visual distractor appeared. Attention was measured by the number of key press errors for frequent and rare tones during all trials. Working memory was measured by over and under reporting of baskets counted during the task.

EEG

P3 amplitude and latency measures were derived from electroencephalograph (EEG) recording while participants responded to the auditory oddball task. A 32-channel ActiChamp electrode cap was used to collect brain waves. Four additional electrodes were added around the eyes to measure blinks: left horizontal, right horizontal, right upper vertical, and right lower vertical. Participants were instructed to control blinking, told to remove any gum, and asked to disable any electrical devices that may interfere with experiment. Participants sat in a comfortable chair with a tray approximately 1.5 feet away from a screen centered vertically and horizontally to the eyes. The keyboard was placed on the tray. EEG recordings were analyzed though Brain Analyzer Pro software. P3 waves were extracted separately for correct responses to frequent and rare tones. Each set of waves, pertaining to the corresponding tone, was segmented by individual trial, followed by a baseline removal, and then averaged over all of the trials. Prior to averaging, waves were subjected to a semi-automatic artifact rejection followed by a manual artifact rejection to remove error trials and other artifacts not caught by the automatic artifact rejection. Trials during which participants blinked were also removed. The averaged wave for frequent tones was then subtracted from the averaged wave for rare tones and filtered which created a P3 wave that represented brain response to an infrequent stimulus. BrainAnalyzer software was used to locate the peak amplitude of the averaged wave form between 250 and 450 milliseconds following stimulus presentation. Both amplitude and latency of the resulting P3 wave were used in subsequent analyses.

Results

Balance, attention, and memory variables were analyzed using one-way analysis of co-variance (ANACOVA) in SPSS. Group membership was the independent variable, and percentage of neighborhood poverty was the covariate. P3 amplitude and P3 latency were analyzed with a 3 (group: concussed, high risk, low risk) by 3 (brain site: Fz, Cz, Pz) repeated measures ANACOVA. Distribution of variables was first inspected for outliers and extreme scores were adjusted to within 3 standard deviation of the mean. Due to equipment malfunctions, not all participants are included in all analyses.

Balance

The low-risk group on average had better balance scores (less sway) than the other two groups but there was no significant differences in sway between the three groups, $F(2, 48) = 1.44$, $p = .25$. As shown in Figure 1 average total sway for the groups were as followed: concussed group was 69.76 (SD = 25.74), high risk group was 64.20 (SD = 23.83), and low risk group was 53.36 (SD = 20.17).

Attention Task – Attending to Tone Switch

Trends for the auditory oddball task were as expected with the concussed group having the most errors on average. These differences were not significant however. Rare tone errors during the auditory oddball task data showed no significance between groups, $F(2, 34) = .87$, $p = .48$. Average amount of errors of rare tones for the concussed group was 9.00 (SD = 5.55), for the high risk group was 7.38 (SD = 3.72), and for the low risk group was 7.13 (SD = 5.57). Figure 2 displays the differences between the three groups in rare tone errors. Frequent tone errors during the auditory oddball task data showed no significance between groups, $F(2, 34) = .40$, $p = .67$. Average errors of the frequent tones for the concussed group was 15.93 (SD = 18.21), for the high risk group was 13.81 (SD = 11.09), and for the low risk group was 12.13 (SD = 14.94).

Memory Task – Counting Baskets

Participants in high-risk sports did the worst on the working memory task on average, although differences between groups were not significant, $F(2, 33) = .48$, $p = .63$. Average working memory errors for the concussed group was 2.08 (SD = 1.55), for the high risk was 2.71 (SD = 1.76), and for the low risk 1.71 (SD = 2.50). Figure 3 displays the differences between the three groups in working memory errors.

EEG

EEG data did show significant differences in the P3 wave between the three groups. P3 latency (relating to reaction time) for the low risk was the slightly higher than for the other two groups but these differences were not significant, $F(2,20) = .96$, $p=.4$. EEG data of the P3 wave showed significant differences in the amplitude of the wave (relating to reaction strength) between groups, $F(2, 20) = 3.635$, $p = .045$. The low risk group showed the largest amplitude, followed by the high risk group, and the concussed group having the lowest amplitude. Figure 4 displays the differences in P3 amplitude between the three groups at three different central locations of the brain (Fz, Cz, Pz). A significant inverse correlation was found between errors in the attention task and amplitude. Higher wave amplitude was associated with fewer errors in reporting when stimuli changed from the frequent to rare tone.

SES

There were no significant correlations between SES and performance on balance or memory tasks however SES was correlated with errors in detecting the rare tone in the auditory oddball task, $F(1,37) = 4.77$, $p = .04$.

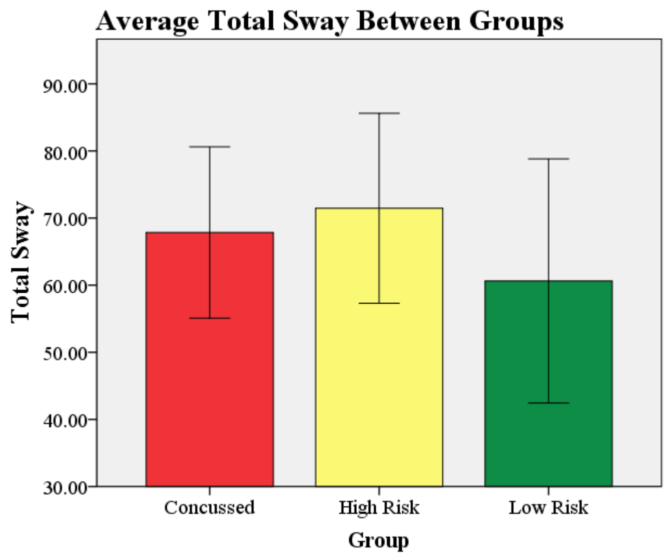

Figure 1. Average total sway scores from performance on BESS task for each group (n=48). Low-risk group had the best overall balance between groups.

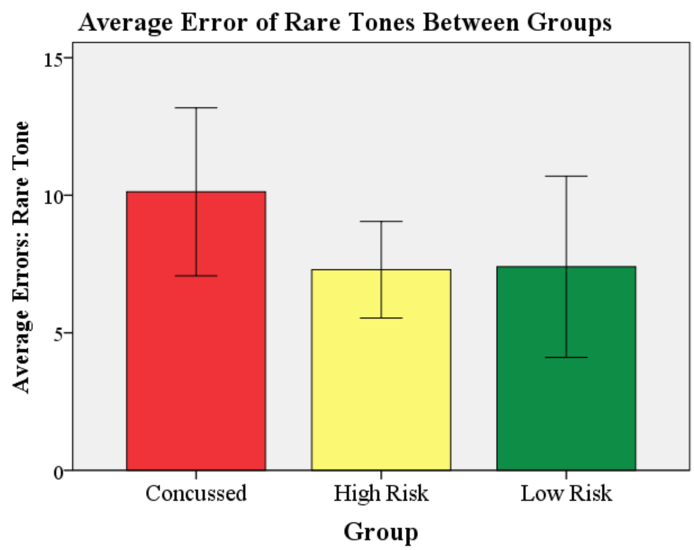

Figure 2. Average total error of rare tone from auditory oddball task for each group (n=38). concussed group made more errors in detecting the change of stimuli.

Discussion

This study investigated the effects of sports-related head injury and participation in high- and low-risk sports experienced during high school on balance, attention, and memory. No significant differences were found between groups in relation to balance, memory, and attention tasks although trends were as expected with the low-risk group having better balance and making fewer errors on average than the other two groups. There was a significant difference found between groups for P3 amplitude measured with an EEG with the low-risk group showing a much greater reaction strength. This supports the idea that subtle differences in cognitive function may not be measurable by standard clinical assessments, like attention and memory tasks, but require more sensitive measures like EEG[1,4,7].

Individual differences between the participants may have confounded our experiment. The length of time between head injury and our assessment of impairment varied greatly, from 6 months to 4 years, and based on the work of Broglio et al. (2011), this likely affected the results of the study. There was a significant effect of SES on detection of the rare tone. This may reflect the likelihood of receiving adequate medical care after an injury, a variable not assessed in this study. Alternatively, a greater awareness of the negative consequences of head injuries in the last decade may have led to more appropriate medical care following concussion. The Affordable Care Act may also have alleviated some of the high costs of receiving that medical care.

The small and unequal size of the groups recruited and ultimately assessed for this study was also a limitation. Various equipment issues with the EEG resulted in smaller than ideal sample sizes, especially for analysis of P3 latency and amplitude. Significant findings in the balance, attention and memory tests may have been obtained in a study with larger group sizes.

The results of this study suggests a relationship between a decline in cognitive function and participation in high-risk sports even when no

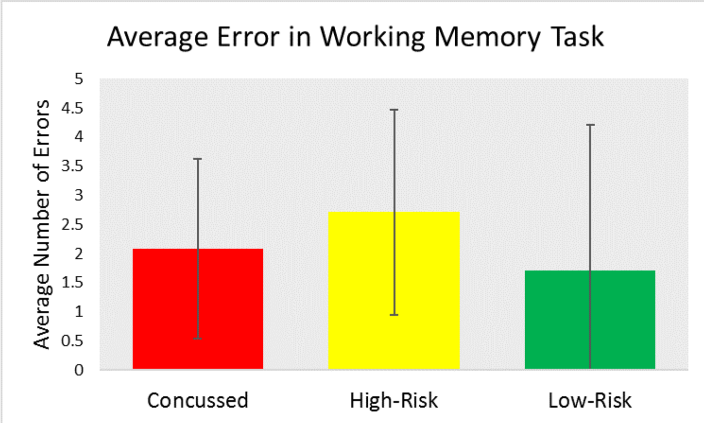

Figure 3. Average total error of basket counts during auditory oddball task for each group (n=38). Low-risk group had the best accuracy in the working memory task.

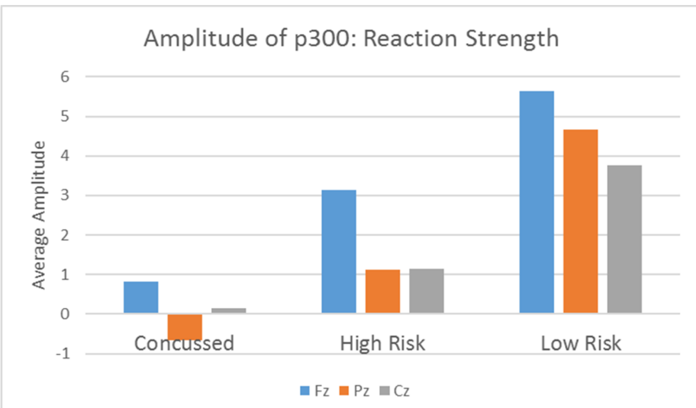

Figure 4. Average amplitude between groups at central locations of the brain of the event-related potential wave. The data shows that group three – non-concussed with low risk sports had the best amplitude for the change in stimuli. This is inversely correlated with rare tone errors. The less errors for rare tones in the auditory oddball task correlates to better attendance to the change in stimuli and better amplitude of the P3 wave.

obvious concussive injury is experienced. A correlation between participation in high risk-sports and cognitive impairments has not been well established and warrants much greater study. Future studies of the effects of sports-related head injuries and participation in high-risk sports will continue to inform athletes and the public and facilitate improvements in regulations and equipment to make sports safer.

Acknowledgements

Initial funding for this study was received through a Magellan Guarantee grant awarded to Tyisha Henderson. This research was supported by the University of South Carolina Aiken Department of Psychology and Department of Biology and Geology. Special thanks to the Psychology Department, University of South Carolina, Aiken, for allowing use of their laboratory facilities, and to Dr. Laura Swain and Dr. Alexandra Roach for technical assistance. Thank you to Tyisha Henderson for introducing the research question in collaboration with the C-NERVE program at the University of Wisconsin-Stout. Also, special thanks to James Conley Waters, Lily Anzouni, and Yasmin Bedenbaugh for additional help with data collection and analysis. Additionally, the author is grateful to Dr. Virginia Shervette, Department of Biology and Geology, University of South Carolina, Aiken, for her mentorship.

Notes and References

**Corresponding author email: MichelleV@usca.edu*

1. Broglio, SP, Moore, RD, & Hillman, CH. 2011. A history of sport-related concussion on event-related brain potential correlates of cognition. International Journal of Psychophysiology, 82(1): 16-23.
2. Marar, M, McIlvain, NM, Fields, SK, & Comstock, RD. 2012. Epidemiology of concussions among United States high school athletes in 20 sports. The American Journal of Sports Medicine, 40(4): 747-755.
3. Slobounov, S, Sebastianelli, W, & Hallett, M. 2012. Residual brain dysfunction observed one year post-mild traumatic brain injury: combined EEG and balance study. Clinical Neurophysiology, 123(9): 1755-1761.
4. Broglio, SP, Eckner, JT, Paulson, HL, & Kutcher, JS. 2012. Cognitive decline and aging: The roles of concussive and subconcussive impacts. Exercise and Sports Science Reviews, 40(3): 138-144.
5. Wilson, MJ. 2012. The effects of repetitive, subconcussive impacts on electrophysiological measures of attention and information processing speed (Doctoral dissertation). The University of Tennessee
6. Daneshvar DH, Riley DO, Nowinski CJ, McKee AC, Stern RA, & Cantu RC. 2011. Long term consequences: effects on normal development profile after concussion. Phys Med Rehabilitation Clin N Am, 22(4): 683-700.
7. Broglio, SP, Pontifex, MB, O'Connor, P, & Hillman, CH. 2009. The persistent effects of concussion on neuroelectric indices of attention. Journal of Neurotrauma, 26(9): 1463-1470.
8. Luck, SJ, & Kappenman, ES. 2012. The Oxford Handbook of event-related potential components. New York (NY): Oxford University Press, Inc. p. 4, 564-567.
9 Polich, J. 2007. Updating P3: an integrative theory of P3a and P3b. Clinical Neurophysiological, 118(10): 2128-2148.
10. Rechel JA, Yard EE & Comstock RD. 2008. An Epidemiologic Comparison of High School Sports Injuries Sustained in Practice and Competition. Journal of Athletic Training, 43(2):197-204.
11. Bell, DR, Guskiewicz, KM, Clark, MA, & Padua, DA. 2011. Systematic review of the balance error scoring system. Sports Health: A Multidisciplinary Approach, 3(3): 287-295.