Performance in Sustained Auditory Attention Task by Concussed and Non-Concussed Athletes

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Abstract

Concussions may pose a great danger to the brain, specifically to brains of athletes who are repeatedly exposing themselves to mild traumatic brain injury (mTBI). Covassin, Stearne, and Elbin (2008) found that a history of concussions can affect neurocognitive functioning. De Beaumont et al. (2009) looked at former athletes who sustained their last concussion more than 30 years ago: electroencephalography (EEG) recordings showed athletes with a history of concussion demonstrated decreased attentional control during a standard auditory oddball target detection task. The behavioral results showed decreased performance on a variety of tasks. This may indicate issues in episodic memory and frontal lobe functions. These areas are sensitive to early-onset Alzheimer’s disease. The current study uses an auditory oddball target detection task to detect attention in concussed and non-concussed collegiate athletes. It was hypothesized that concussed athletes would have a lower accuracy and slower reaction time than non-concussed athletes. Results indicated that males performed better, regardless of group. However, because of the small sample of males, females alone were also analyzed. Concussed females had a lower accuracy but were notably faster than non-concussed women. Concussed females also had a notably higher false alarm rate than non-concussed females. The sample size was too small to show significance, but running more participants may reveal more significant results.
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When football players take to the field each fall, about 10% can expect to sustain at least one concussion that season (Moser, 2007). Currently approximately 300,000 sport-related concussions are reported in the United States each year (Covassin, Stearne, & Elbin, 2008). The study of sports concussions is less than 30 years old; they were first studied in the 1980’s at the University of Virginia. The concussions experienced by athletes during the 70’s and 80’s were not reported because the concussions were not viewed as a serious problem. However, today we are learning about some of the negative cognitive effects the athletes of the 70’s and 80’s are experiencing due to these concussions. It’s been found that concussions are a form of mild traumatic brain injury (mTBI) and can be much more serious than previously believed (DeBeaumont et al., 2009). Concussions pose a great danger to the brain, specifically to brains of athletes who are repeatedly exposing themselves to mTBI.

Despite the seriousness of concussions, they are often unreported. Many individuals do not know the causes or symptoms of concussions. Concussions are not limited to impact; they can occur from whiplash or rotational injuries. Anything that would cause the brain to greatly move around the skull can damage the axon, a portion of a neuron that helps fire messages, meaning helmets may not always prevent concussions. In order to prevent concussions, we must understand what specifically causes them and all of the effects they may have on the brain. It is difficult to measure the inner workings of the brain, especially when the effects may not be seen for years. The current literature
highlighting measures currently used to examine the effects of concussions on athletes, specifically the cognitive changes that occur due to concussion, will be discussed.

**Detecting Effects of Concussions**

The first step in understanding a concussion is to know the symptoms. It can be associated with immediate symptoms of disorientation, amnesia, nausea, confusion, visual disturbance, blank stare, slurred speech, vertigo, headache, loss of consciousness, or any alteration in consciousness (Moser, 2007). These symptoms can also last less than 15 minutes and still be a sign of a mild concussion. Once an athlete has experienced a concussion, he or she is four to six times more likely to sustain another concussion because of the prior damage (Moser, 2007). How can we measure the effects of these concussions on the brain? Neurological exams are not sensitive enough to detect subtle changes in attention, memory, speed of processing, and reaction time. The best way to examine these changes is through neurocognitive testing. Moser (2007) discusses computerized tools that examine verbal memory, visual memory, reaction time, processing speed, impulse control, and more shortly following the concussion. However, these work best when the athlete has taken the same test during the pre-season, in order to compare pre-season abilities to post-concussion abilities. Also, it is possible that effects will not be noticeable until months after the concussion, when the athlete is done playing in the off-season.

Other methods of assessment detect the effects of concussion on cognition, balance, and symptoms in athlete. In a meta-analysis looking at studies between 1970 and 2006, McLeod (2009) found that sport related concussions had a large negative effect on
cognitive function during the initial assessment and a small negative effect during the first 14 days post-injury. The largest neurocognitive effects were found with the Standardized Assessment of Concussion during the immediate assessment and with pencil/paper neurocognitive tests at the follow up assessment. There were large negative effects noted at both assessment points for postural control measures (maintaining balance). Overall, it is important to include neurocognitive measures, postural control tests, and symptom reports into a multifaceted concussion battery to best assess concussions. Surveys show athletic trainers are not currently using multifaceted assessments (McLeod, 2009). Once an athlete passes an assessment, there is no long-term follow-up afterwards.

There have been a variety of cognitive effects found from concussions. One of the major effects is on memory, both short-term and long-term. In a one month long longitudinal study examining semantic clustering strategies and its relation to delayed memory deficits in concussed and non-concussed athletes, researchers used the Hopkins Verbal Learning Test and the Stroop Test to observe differences between concussed participants and a control group (Bruce & Echemendia, 2003). Two hours post concussion, there were no differences between strategies used in the concussed and control groups but 48 hours post concussion the concussed group performed significantly poorer while the control group’s performance improved due to the strategies used to cluster semantics (Bruce & Echemendia, 2003). One week later, there were no differences between strategies used in the control group and the concussed group. The findings are consistent with the literature that most athletes eventually return to baseline
levels of functioning within one week. This study only examines the short-term effects of concussions. All of these studies looked at athletes days and weeks post-concussion. Immediate effects of concussions seem mild but other research has shown that the long-term effects of concussion are more serious.

**Long-Term Effects of Concussions**

It has been found that there can be neurocognitive deficits in athletes who report a history of concussion (Covassin et al., 2008). Using a computer program to assess neurocognitive functions and concussion symptoms, researchers compared control athletes (N=36) and athletes with a history of two or more concussions (N=21). Five days post-concussion, athletes with a history of concussions demonstrated lower verbal memory score and slower reaction time than control athletes. It was found that a history of concussions can affect neurocognitive functioning (Covassin et al., 2008). If a history of concussion affects athletes post-concussion, athletes could also be affected years later by the history of concussions. There appears to be a long-term effect of multiple concussions on cognitive performance over time. Initial assessments the weeks after a sustained concussion are not detecting these effects.

Looking further down the road, former athletes who sustained their last concussion more than 30 years ago showed decreased performance in episodic memory and frontal lobe functions (DeBeaumont et al., 2009). These areas are sensitive to early-onset Alzheimer’s disease. Using transcranial magnetic stimulation (TMS) during a motor execution task and electroencephalography (EEG) recordings during a standard auditory oddball target detection task, this study demonstrated that former athletes with a
history of concussion had lower performance on neuropsychological, behavioral, and electrophysiological tests of episodic memory, target detection, and response inhibition (DeBeaumont et al., 2009). This study demonstrates that the effects of concussion are long-term and can have serious side effects, such as the possibility of memory issues leading to Alzheimer’s disease. Furthermore, Guskiewics, K., Marshall, S., and Bailes, J. (2005) found that dementia-related symptoms may be a result of repetitive concussions in professional football players.

Interim/ Transitional Effects of Concussions

Although research has looked at the immediate effects of concussion, such as days later, and the long-term effects of concussions, such as 20 years later, there is not much research on the effects of concussions one to ten years post-concussion. Is it possible to detect smaller changes before long-term memory issues begin to set in? The current study examines how a concussion within the last ten years may or may not affect how athletes perform an auditory attention task. The current study is using a demanding sustained auditory attention task similar to the one used by DeBeaumont et al. (2009). The literature shows that this will be a good way to analyze concussions, because it is an involved cognitive task (Simon-Dack & Teder- Sälejärvi, 2008). The current study hypothesized that athletes who had obtained a concussion or concussions during their athletic career would have lower accuracy and longer reaction times when detecting an auditory target than athletes who had never experienced a concussion (non-concussed athletes).

Method
Participants

Participants were 18 students who attended Ball State University and identified as athletes who were either currently involved in a sport or were involved in a sport during high school. Participants were recruited through an introductory psychology course and through fliers posted on campus. Students in the introductory psychology course received one and a half hours of research participation credit for participating. Students recruited through fliers and campus wide emails were paid $10 per hour. Participants’ data were analyzed if they met certain exclusion criteria and adhered to the instructions of the study. Out of 40 students who volunteered to participate in the study, 28 participants cleared all of the exclusion criteria and their data were analyzed. Of those 28, data from 10 participants were not included because the task was not completed properly. Of the 18 participants remaining, 66.67% were female and 33.33% were male. Ages ranged from 18-27 years old. Of the 18 participants, 33.33% had experienced a concussion within the last 10 years and 66.67% had never experienced a concussion.

Materials

In order to evaluate the research hypotheses, participants completed two questionnaires: a Health Survey and the Edinburgh Handedness Inventory.

Health Survey. This health survey was modified by the researcher from initial survey questions used in previous research by Simon-Dack & Teder-Sälejärvi (2008). It contained eight questions to screen for factors known to affect sensory information processing (see Appendix A). Participants were asked if they had ever had a sports-related concussion and to describe the incident. Participants were also asked about any
medical problems, tobacco use, hearing problems, medications, neurological disorders, attention disorders, or learning disorders. Participants who met these exclusion criteria or were taking psychopharmaceuticals (e.g. antidepressants, anti-anxiety medication, anti-psychotics, etc.) may have participated but were excluded from data analysis due to the recorded effects of these drugs on thought processes. Data from individuals diagnosed with mental health, neurological, or learning disorders were also excluded from data analysis. Individuals who are left-handed were not included in data analysis due to an increased probability of cerebral lateralization differences (how the two hemispheres of the brain specialize in specific functions) in spatial and language processing (Stephan et al., 2007). Since this is an auditory experiment, data from individuals with pre-diagnosed hearing loss were also excluded from data analysis.

**Edinburgh Handedness Inventory.** The Edinburgh Handedness Inventory contained ten questions and was created by R.C. Oldfield (1971: see Appendix B). It is a measurement scale used to assess the dominance of a person's right or left hand in everyday activities. Participants indicate the use of hands in a list of activities by putting a check in the appropriate column. When the preference is so strong that participants would never try to use the other hand, unless absolutely forced to, participants are to put two checks. If in any case participants are indifferent, they put a check in both columns. A percentage of hand-use is then calculated to determine the participant's hand-preference.

**Procedure**
The IRB at Ball State University approved this study in October 2010. Students taking introduction to psychology (Psyc 100) were able to sign up to participate in the study as time slots were posted on the Psyc 100 experiment website. Other students were recruited via fliers posted on campus and campus wide emails. Participants then contacted the principal investigator to sign up for a time slot. Participants came into the lab individually at their scheduled time. They were asked to read through and sign an informed consent document then if they agreed to participate. Participants then read survey instructions and filled out the Health Survey and the Edinburgh Handedness Inventory. The experimenter was present to answer any questions they might have. Participants then completed a simple hearing task to ensure their hearing was in the normal range: they listened to a series of sounds via headphones delivered at decreasing decibel levels in each ear and were asked to count the number present (Simon-Dack, 2008). Once normal hearing perception was established, participants completed an experimental practice block and then began the experiment.

**Task**

The task was an auditory oddball target detection task. Participants were told to attend to a specific speaker (right or left) while staring at a fixation point in front of them. Participants heard “standard” frequency pink-noise sound-bursts sequentially and randomly emanating from both speakers. Occasionally a rare, higher-pitched “deviant” sound would be played. When played from the attended speaker, this was the “target” sound. Participants were instructed to press a foot pedal, indicating that they detected the target (see Figure 1). This continued for 16 blocks of 500 sounds bursts each, 10% of
which were deviants and 5% of which were target sounds. The speaker to which the
participant was to attend alternated every block.

*Figure 1.* An example of a trial sequence during an attend left block condition.

Most studies have relied on classic neuropsychological tests to detect residual
cognitive anomalies and have been found to be inconclusive. In the current study, the
researchers aim to investigate how attentional and cognitive deficits potentially caused by
concussion may be revealed in a sustained attention task similar to the one used by De
Beaumont et al. (2009). De Beaumont et al. (2009) provide electrophysiological evidence
that there are sustained performance deficits acquired due to concussions and the current study aims to detect that damage through behavioral measurements taken during a simple yet demanding sustained attention task. If such a simple behavioral task could be used to detect potential subtle cognitive deterioration post-concussion, early interventions could be developed to aid athletes in academic settings.

The current study implemented auditory oddball target detection while recording participants' response times and accuracy. It was hypothesized that athletes who have obtained a concussion or concussions during their career would have lower accuracy and longer reaction times when detecting an auditory target than athletes who have never experienced a concussion (non-concussed athletes).

Results

Accuracy and reaction time (RT) were analyzed using a 2 X 2 between-subjects multivariate analysis of variance (ANOVA) with the factors group (concussed, non-concussed) and sex (male, female). No main effects on accuracy for concussion \( [F(1, 14) = .742, p = .403] \), sex \( [F(1, 14) = 2.223, p = .158] \), or interactions \( [F(1, 14) = 2.37, p = .146] \) were found. No main effects on reaction time for concussion \( [F(1, 14) = 2.707, p = .122] \), sex \( [F(1, 14) = .688, p = .421] \) or interactions \( [F(1, 14) = .002, p = .129] \) were found. Means and reaction times for concussed and non-concussed participants are listed in Table 1.

Table 1. Mean Accuracy, Reaction Times, and False Alarm Rates for concussed and non-concussed participants.
<table>
<thead>
<tr>
<th>Group</th>
<th>Accuracy</th>
<th>False Alarm Rate</th>
<th>Reaction Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Concussed (n = 10)</td>
<td>84% (SD=6.1%)</td>
<td>.34%</td>
<td>819.98 ms (SD=61.02)</td>
</tr>
<tr>
<td>Concussed (n = 8)</td>
<td>87% (SD=8.7%)</td>
<td>.52%</td>
<td>754.13 ms (SD=64.01)</td>
</tr>
</tbody>
</table>

An examination of group means indicated that concussed male participants were outperforming all other groups. Furthermore, male participants overall were outperforming female participants in both accuracy (males $M = 90\%, SD = 7.6\%$; females $M = 83\%, SD = 6.4\%$) and reaction time measures (males $M = 759$ ms, $SD = 92.45$ ms; females $M = 806$ ms, $SD = 51.96$ ms), although these findings were not significant. However, lack of non-concussed male participants ($n = 2$) made the differences between concussed and non-concussed males difficult to quantify. Therefore, due to a low number of male participants, especially in the non-concussed group, differences between women only were analyzed.

In females, no main effects on accuracy for concussions [$F (1, 14) = .355; p = .564$] were found. No main effects on reaction time for concussion [$F (1, 14) = 4.419; p = .062, \eta_{p}^2 = .31$] were found. Means and reaction times for concussed and non-concussed female participants are listed in Table 2. Although none of these results are significant, it is interesting that non-concussed females are slightly more accurate than concussed
females but concussed females are much faster than non-concussed females. Also, the false alarm (FA) rate for concussed females (.94%) is notably higher than the FA rate for non-concussed females (.34%) [F (1, 14) = 2.748; p = .128]. The majority of the literature has focused on male athletes and there is not much research on only female athletes to compare this information.

Table 2. *Mean Accuracy, Reaction Times, and False Alarm Rates for concussed and non-concussed female participants.*

<table>
<thead>
<tr>
<th>Group</th>
<th>Accuracy</th>
<th>False Alarm Rate</th>
<th>Reaction Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Concussed (N=8)</td>
<td>84% (SD=.063)</td>
<td>.34%</td>
<td>826.03 ms (SD=48.83)</td>
</tr>
<tr>
<td>Concussed (N=4)</td>
<td>82% (SD=.073)</td>
<td>.94%</td>
<td>767.62 ms (SD=36.07)</td>
</tr>
</tbody>
</table>

**Discussion**

**Implications**

The hypothesis that concussed participants would have a lower accuracy rate and a slower reaction time than non-concussed participants was not supported. In fact, our results contradicted this finding by indicating concussed athletes had a higher accuracy rate and a faster reaction time than non-concussed athletes. However, this could be due to the small sample size and the ceiling performance of three of the four concussed males. In general, males outperformed females regardless of group. This is supported in the literature that men respond more accurately than women to targets in attended locations
during auditory processing (Simon-Dack et al, 2009). Looking at females alone, the concussed females are faster than non-concussed and the false alarm rate indicates that concussed females have almost twice as high a false alarm rate than non-concussed females.

**Inhibitory Mechanisms and Concussion**

In more sensitive tests of RT, RT is slowed after concussion. However, concussions have been shown to specifically affect inhibitory systems. De Beaumont (2009) used TMS to reveal that asymptomatic concussed athletes who sustained their last concussion on average 3 years prior to testing still exhibited a significantly prolonged cortical silent period (CSP) when compared with controls, an indication that inhibitory mechanisms in the motor cortex are not working properly. De Beaumont (2009) showed that the time elapsed since their last sports concussion did not influence the duration of the CSP, thus suggesting that abnormalities in these inhibitory mechanisms of the primary motor cortex were relatively stable over time. Perhaps, in the current study, instead of concussion revealing slowed reaction times, it affected the motoric system more subtly, and particularly the inhibitory system. Concussed athletes may have had issues with fine motor skills because of their lack of inhibition. Participants were not responding in a controlled fashion but apparently stomping down on the foot pedal very hard and very quickly, which may explain why concussed participants had faster RTs. This also correlates with the finding that concussed participants had higher FA rates than non-concussed participants. The lack of inhibition may cause concussed participants to inadvertently respond to non-targets before they can control themselves and stop.
Methodological Issues to Address

One weakness of the study is the lack of male participants. Males are typically more accurate and faster in this task than females, and the concussed male participants performed optimally. More male participants, especially more non-concussed males, are needed to see if this is a representative sample or if our concussed male performance levels were due to sampling error.

Due to the small sample size in general, it is impossible to know if the results are representative of concussed and non-concussed groups, as well as males and females. More subjects in all groups are needed to validate whether or not findings are a result of sample bias. Simon-Dack et al (2009) looked at 20 individuals, with ten females and ten males. A sample size closer to this study, with ten participants in each group, or an even larger sample size would be more appropriate.

The RTs found in the task are slightly longer than expected most likely due to the foot pedal used. The foot pedal used required more pressure to depress and had more resistance than expected. Participants who couldn’t respond hard enough to depress the foot pedal were excluded, which created an unexpected imbalance in excluding several non-concussed participants who weren’t always pressing hard enough as compared to concussed participants who seemed to be pressing very hard and thus rapidly depressing the pedal.

Future Research

More research looking at athletes with concussion and particularly comparing differential effects of concussion on men and women is necessary to clarify the results of
this study. Examining athletes based on number of concussions as opposed to concussed and non-concussed may help results to be clearer. Although a strength of this study was that it examined the effects of concussions on athletes from a variety of sports and of both sexes, it may also have introduced a large amount of variability into a small sample. Thus, examining athletes in terms of specific sports may reveal clearer results in terms of reaction time and accuracy since different types of athletics may require different response speeds. Perhaps the number of concussions and the duration since the last concussion is also relevant. Another area of development would be changing the way responses are recorded. The foot pedal used had a high resistance and may have increased recorded reaction times. A different foot pedal or a different way of recording data will be explored for future data collection.

The current study revealed that concussed females had a notably higher false alarm rate than non-concussed females. Although accuracy was not an issue, the differences in the FA rate and the considerably faster RTs may be an indication that concussions are affecting performance by subtly damaging neural inhibitory mechanisms in concussed athletes.
References


Appendix A

Health Survey

Participant Code: ______________________

The following set of questions is to screen for factors known to affect sensory information processing. Please be as honest as possible. Put a check next to all the following that apply to you.

1. What is your date of birth?

2. Have you ever hit your head and experienced a concussion? Yes No
   If yes, please explain and include the date and number of concussions experienced.
   1) Date   How
   2) Date   How
   3) Date   How
   4) Date   How

3. Since birth have you ever had any other medical problems? Yes No
   If yes, please explain.

4. Since birth have you ever been hospitalized? Yes No
   If yes, please explain.

5. Do you use tobacco (smoke and/or chew)? Yes No
   If yes, please explain.

6. Have you had any hearing problems? Yes No
   If yes, please explain.

7. Are you on any medications? Yes No
   If yes, please list them all including birth control.

8. Do you have now or have you ever had any of the following? Check yes or no.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neurological disorder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brain disorder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vascular disorder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning deficiency or disorder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading deficiency or disorder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention-deficit disorder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperactivity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you checked yes for any of the items in question 8, please describe your diagnosis briefly.
Appendix B

Edinburgh Handedness Inventory

Please indicate your preferences in the use of hands in the following activities by putting a check in the appropriate column. Where the preference is so strong that you would never try to use the other hand, unless absolutely forced to, put 2 checks. If in any case you are really indifferent put a check in both columns.

Some of the activities listed below require the use of both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try and answer all of the questions, and only leave a blank if you have no experience at all with the object or task.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Writing</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>2. Drawing</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>3. Throwing</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>4. Scissors</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>5. Toothbrush</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>6. Knife (without fork)</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>7. Spoon</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>8. Broom (upper hand)</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>9. Striking Match (match)</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>10. Opening box (lid)</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>TOTAL (count X's in both columns)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scoring:
Add up the checks in both left and right columns.
Whichever number is greater, would be considered your handedness.
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Signatures and Certifications:

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