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## Cumulative Effects of Concussions on Auditory Processing

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**NORTHERN ILLINOIS UNIVERSITY**

**Cumulative Effects of Concussions on Auditory Processing**

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**University Honors Program**

**In Partial Fulfillment of the**

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**By**

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**DeKalb, Illinois**

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subtest within the *Color-word interference test*, whereas performance for the participant with concussion (P1) stayed the same or had marginal improvements. P1's number of correct responses remained the same across trials, while the non-concussion group's performance decreased or showed insignificant improvement on the *Verbal fluency test*. All participants were able to attain perfect scores on the auditory task by the third trial, but P1 exhibited worse initial performance. The healthy controls showed repeated practice effects on a subset of the tasks, but the participant with a history of concussion did not show these effects. This suggests there are subtle performance differences between individuals with and without a history of concussion that may be identifiable with specific, repeated behavioral tasks.

Cumulative Effects of Concussions on Auditory Processing

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## Abstract

The current study aimed to investigate the cumulative effects of concussions on auditory processing and other higher-level cognitive processes in a preliminary trial hoping to inform future research in which a larger sample can be obtained. A quasi-experimental design was used; participants were divided based on whether they had a history of concussion. Participants were measured on one auditory task and two verbal tests over the course of three trials during a semester. The non-concussion group showed performance improvements for each subtest within the *Color-word interference test*, whereas performance for the participant with concussion (P1) stayed the same or had marginal improvements. P1's number of correct responses remained the same across trials, while the non-concussion group's performance decreased or showed insignificant improvement on the *Verbal fluency test*. All participants were able to attain perfect scores on the auditory task by the third trial, but P1 exhibited worse initial performance. The healthy controls showed repeated practice effects on a subset of the tasks, but the participant with a history of concussion did not show these effects. This suggests there are subtle performance differences between individuals with and without a history of concussion that may be identifiable with specific, repeated behavioral tasks.

### Cumulative Effects of Concussions on Auditory Processing

On average, 19% of the American population aged 15 years and older is participating in a sport or exercising on any given weekday; this figure equates to roughly 12 million people (U.S. Department of Labor, 2013). During recent years, the dangers of sports-related concussions has become a public issue, in part due to several retired professional athletes coming forward to openly discuss the debilitating cognitive effects they are experiencing after sustaining concussions. In the United States alone, it is estimated that between 1.6 million and 3.8 million sports-related traumatic brain injuries (TBI), including concussions, occur each year (Graham, Rivara, Ford, & Spicer, 2014). The number of sports-related traumatic brain injuries suffered every year is certainly higher than the above statistic, as many concussions are not reported. Similarly, the percentage of Americans who participate in sports is also certainly higher, given that there are a large number of youth athletes who are under the age of fifteen and were not accounted for in these data.

Some people may be surprised to learn that a mild concussion is classified as a mild TBI (Musiek & Chermak, 2009). Many individuals are not aware of the lasting impact concussions can have on daily life, or that problems may continue long after initial symptoms disappear. The existing knowledge of the effects of traumatic brain injury combined with the alarming prevalence of concussions demonstrated by the above figures and the substantial number of people at higher risk for concussions because they participate in sports, has prompted scientific inquiry about the impact of concussions on cognitive processes.

During a concussion, the head makes contact with something that is either stationary or moving, which causes a very rapid change in the forces of acceleration, deceleration, and rotation that usually keep the brain balanced in a cushion of cerebrospinal fluid (Graham et al.,

2014; Iverson, Gaetz, Lovell, & Collins, 2004). This rapid change in forces causes the brain to make contact with the skull, which may result in bruising or bleeding (Graham et al., 2014). Often times, this damage occurs in the frontal lobe. This part of the brain is responsible for executive functioning; this can be thought of as the lobe that makes you behave like and reason like an adult. The frontal lobe contains the expressive language area and it controls emotion, behavioral inhibition, awareness of one's abilities, and plays a role in concentration and judgment (Kolb & Whishaw, 2014). Damage due to a concussion can occur in more than one part of the brain and may not necessarily occur in the frontal lobe. Although damage to executive functioning abilities produce some of the most noticeable symptoms of a concussion, damage to the temporal lobe can cause cognitive impairments related to memory as well as to hearing, understanding language, and making sense of sounds in one's environment, which is collectively referred to as processing auditory information (Kolb & Whishaw, 2014).

There has been some research about auditory and visual information processing, including a study done by Madigan, DeLuca, Diamond, Tramontano, and Averill (2000) in which the authors examined the speed and accuracy of individuals with a traumatic brain injury. Most of these individuals had experienced a TBI as a result of a motor vehicle accident. Speed and accuracy were assessed on a "computerized serial addition task" in which participants were presented with a number from 1 to 9 using either auditory or visual stimuli and asked to add it to the number they had previously seen or heard before saying the sum out loud (Madigan et al. 2000). Prior studies have established that individuals who have suffered a TBI perform less accurately on perception of stimuli compared to a control group without a history of concussion, but these studies did not take the speed at which the individuals responded to the task into account. Information processing speed was found to be impaired for individuals who have



suffered a traumatic brain injury in the moderate-to-severe range, in comparison to individuals without any history of TBI (Madigan et al., 2000). Additionally, the TBI group presented a significantly slower rate of information processing on auditory tasks than the rate presented on visual tasks (Madigan et al., 2000). This study's findings confirmed that cognitive functions were impaired and also showed evidence of auditory processing impairments in the TBI group. Madigan et al. (2000) suggested that these auditory processing deficits were seen as a result of damage to the temporal lobes, which are very likely to be injured during any closed head injury. While this study focused on individuals who had sustained a moderate-to-severe TBI, there was evidence that mild TBI could result in greater auditory difficulties, given the likelihood of damage to the temporal regions of the brain when a TBI is experienced.

A seminal study by Bergemalm and Lyxell (2005) showed perceptive deficits for auditory information and cognitive impairments in more than half of participants with head injuries seven to eleven years after the last head injury was sustained. The authors also measured Auditory Brainstem Response (ABR) and found damage in more than half of individuals with a history of concussion; eighty-eight percent of the participants with ABR issues also received failing scores on one or more of the cognitive tasks that were administered. This study was a major contribution to the finding that the damage sustained during a concussion results in long-lasting deficits and has an effect on the auditory pathway.

A study intending to verify the disruption of auditory processes after sport-related concussions showed that concussions do not damage hearing/auditory detection, but do lead to impaired auditory processing (Turgeon, Champoux, Lepore, Leclerc, & Elleberg, 2011). The most significant deficits were present when the group of athletes with a history of concussion were presented with a test involving simultaneously presented bilateral auditory stimuli; half of

the experimental group exhibited significant deficits greater than 2 *SD* less than the control non-concussed group (Turgeon et al., 2011). This shows that athletes with a history of concussion are likely to have difficulties processing auditory information, such as speech, in environments in which there is background noise or more than one person attempting to speak to them. A limitation of this study was the small sample size, with only eight individuals in the experimental group and eight individuals in the control group (Turgeon et al., 2011).

Electrophysiological abnormalities in individuals with a history of concussion have been measured using evoked-response potentials (ERP) and ABR. These measures have been used to determine differences that are important for information processing at a neuronal level (Thériault, De Beaumont, Gosselin, Filipinni, & Lassonde, 2009). The ERP are generated in part by the primary auditory cortex, which is located in the temporal lobe (Musiek & Chermak, 2009). Decreased amplitudes of evoked-response potentials are correlated with decreased memory and attention abilities, and auditory brainstem responses have been useful for diagnosing lesions located in the eighth cranial nerve and in the brainstem (Thériault et al., 2009). Research examining retired athletes with a history of concussion showed significantly slower responses and ERP results in comparison to the control group of similarly aged non-concussed athletes (De Beaumont et al., 2009). This study replicated and extended the ideas presented by Bergemalm and Lyxell (2005) regarding the long-lasting damage of concussions to a group with the last concussion having been sustained more than thirty years prior to testing. Through the use of behavioral testing and electrophysiological testing, the study by De Beaumont et al. (2005) was able to give evidence that damage resulting from concussions is chronic.

Much of the current research focuses on the effects mild traumatic brain injury has on cognitive processes such as attention, memory, and concentration. These processes, along with emotion regulation and several functions, all occur in the frontal lobe of the brain; this is an area highly susceptible to injury (Kolb & Whishaw, 2014). Another area of the brain that is quite vulnerable during brain impact is the temporal lobe (Madigan et al., 2000). Some functions of the temporal lobe include hearing, language comprehension, memory, and interpretation of one's environment (Kolb & Whishaw, 2014). These functions are crucial to activities of daily life and are necessary components of an individual's ability to effectively interact with their environment. A myriad of studies have been aimed at assessing the cognitive impact of TBI on the frontal lobe and its associated processes. Although many of these studies have resulted in invaluable information, they have lacked examination of other parts of the brain that are damaged by mTBI. The impact of concussions on auditory processing and other temporal lobe functions has been largely overlooked, but undoubtedly must still be investigated. There is substantial evidence to support the proposal that both the frontal and temporal lobes can be affected by concussions. In sum, the current body of published research does not adequately examine the cumulative effects of concussions on auditory processing and the cognitive functions associated with the temporal lobe, therefore, it is the general purpose of this study to examine these effects.

Existing research shows that cognitive processes involved with processing of auditory stimuli are negatively impacted after sustaining a concussion. It is not known how the auditory processing skills of individuals who have sustained multiple concussions differ from those of individuals who have experienced fewer or no concussions. This study will seek to gather participants who have sustained or are likely to sustain multiple concussions, such as student

athletes, and compare the data to students with no history of concussion. The current study predicts that the ability to process auditory information and the ability to perform on higher-level cognitive tasks will suffer in those who have sustained concussions in comparison to those without history of concussion. We will expect to see that individuals who have sustained concussions will have a decreased performance throughout the study or performance will remain the same. Conversely, we will expect to see healthy participants who have not sustained concussions will either have performance that remains the same or performance improvements due to repeated practice.

## **Method**

### **Participants**

Participants included in the study were three university students between the ages of 18 and 25 years ( $M= 20.80$ ,  $SD= 0.84$ ) and consisted of one female and two males. One participant, a University student athlete hereafter referred to as P1, had a history of sustaining one diagnosed concussion; the other two participants had no prior history of diagnosed concussion and served as healthy controls. Participants were recruited using flyers approved by Northern Illinois University's Institutional Review Board (IRB) and did not receive compensation for their participation in the study. Criteria for participation included all of the following: no history of alcohol and/or substance abuse; no history of neurological disorders, psychiatric disorders, or learning disabilities; no medical condition requiring daily medications or radiation therapy; not currently pregnant; and between the ages of 18 and 25. Participants were all native English speakers. These criteria were verified in an initial health history questionnaire. The experimenter determined all eligible participants based on answers to questionnaires. One potential participant was excluded from the study due to failure to meet at least one of the aforementioned

requirements. An additional participant did not complete the three required trials and therefore, her Data were excluded.

### Measures

The independent variable within this study was the presence of having sustained a concussion. The dependent variables measured were the participant's percentage of correct responses on an auditory task and performance on verbal fluency task. Measures used included the *Delis-Kaplan Executive Function System (D-KEFS)*, which is a neuropsychological test battery used to measure executive functioning in adolescents and adults aged 8 years, 0 months to 89 years, 11 months (Delis, Kaplan, & Kramer, 2006). The *Verbal fluency* subtest in this measure was used to assess the participants' fluency in spoken language. This subtest was segmented into three conditions: letter fluency, category fluency, and category switching abilities. The *Color-word interference* subtest in this measure was used to assess the participants' abilities to inhibit a dominant, automatic verbal response. This subtest is segmented into four conditions: color naming, word reading, inhibition, and inhibition/switching. The latter two conditions are versions of a Stroop task. Prior studies have shown that individuals who have sustained a mild TBI tend to have lower scores on Stroop tasks in comparison to both normative age-matched scores and to individuals with moderate-to-severe TBI (Jamora, Young, & Ruff, 2012).

Additional measures used include the *Dichotic Digits* test from Auditec, Inc., which was used to assess binaural integration. This measure is an audio recording that measures the ability to process different stimuli arriving at the ears simultaneously. This task requires relatively rapid auditory processing, as well as attentional capabilities, which have been shown to be impaired in individuals who have sustained a mild TBI (Jamora et al., 2012). The above three behavioral

tests are able to evaluate cognitive functions that are known to be susceptible to damage from a concussion and are sensitive to common deficits exhibited by individuals after concussion, including attention, processing speed, and verbal memory (Porter, Constantinidou, & Marron, 2014).

### **Equipment**

The equipment included a portable CD player and a set of intra-aural headphones.

### **Procedure**

Participants were asked to fill out a self-report health history questionnaire. The experimenter then determined all eligible participants based on answers to the questionnaires. All eligible participants then continued onto the testing portion of the study, which lasted approximately 40 minutes per session. Three sessions were completed and there was a minimum of one week in between each session.

For the initial task, the subjects were fitted with insert-earphones for the *Dichotic digits: Single pairs* auditory processing assessment. In an audio recording, two different numbers were played simultaneously, one in each ear, and subjects were asked to repeat the numbers they heard immediately after hearing them. This continued until all 50 pairs of numbers had been presented.

For the second task, the subjects completed the *D-KEFS Verbal fluency* subtest. In the letter fluency condition, participants are presented with instructions to name as many words they can think of that start with a given letter in 60 seconds; this repeats until three different letters have been assessed. For the next condition in this subtest, category fluency, participants were given a category and asked to name as many items in this category as they could in 60 seconds. An example category is “animals”. This was given in two trials. In the final condition in this subtest, category switching, participants were given two categories and asked to switch back and

forth between the two, naming one item per category. For example, a participant would first have to name an item from the category “fruit” and next have to name an item from the category “furniture”. They were also given 60 seconds to complete this task.

In the final task, the *D-KEFS Color-word interference* subtest was given. Participants were timed for each condition within this subtest. In the first condition, color naming, participants were presented with a page which had patches of color on it and instructed to say the colors as quickly as they could without skipping any or making any errors. For the second condition, word reading, participants were presented with a page of either the words “red”, “blue”, or “green” printed on it in black ink and given the same instructions as the previous condition, except they were to read the words on the page aloud. In the third condition, inhibition, participants were presented with a page of color words in different color ink than the words themselves. For example, the word “blue” may be printed in red ink. They were given the same instructions as in previous conditions, except they were to name the color of the ink the words were printed in, rather than reading the words themselves aloud. For the final condition, inhibition/switching, the page looked much like the one in the third condition, with the addition of boxes drawn around some of the words. Participants were to name the color of the ink for the words not contained within a box. For the words with a box around them, participants were to read the word instead of the ink color.

Once all tasks were completed, the subject was thanked for their participation and asked to schedule a second and third testing date, with at least one week between each session. The procedures from the first session were repeated at the second and third sessions and the same assessment tools were used.

## Results

Participants from the non-concussion group and the participant with history of concussion were assessed with two neuropsychological tests and one auditory test. This study was a quasi-experimental time-series design. Performance on the *Verbal fluency test* was scored based on the mean number of correct responses for each of the three subtests (See Table 1) and compared to norm-referenced scores based on age. Participants' performance on the *Color-word interference test* was compared using the mean completion times for each of the four subtests (See Table 2) and compared to norm-referenced scores based on age. The hypothesis that individuals who have sustained concussions will have a decreased performance throughout the study or performance will remain the same was partially confirmed by the comparisons of the data gathered in this study. As seen in Table 3, for two of the *Color-word interference test* subtests, the participant with a history of concussion, P1, remained at the same completion time during the third trial as during the first trial. This prediction was confirmed in each of the subtests within the *Verbal fluency test* (See Table 4). An overall decrease in performance across trials was not observed.

The hypothesis that participants who have not sustained concussions will either have performance that remains the same or performance improvements due to repeated practice was confirmed in each of the four subtests within the *Color-word interference test* (See Table 3). This prediction was not confirmed in the results of the *Verbal fluency test* (See Table 4). Contrary to the hypothesis regarding performance of the participants with history concussion on the *Dichotic digits: Single pairs test*, both P1 and the non-concussed participants improved their initial scores to a perfect performance by the third trial (see Figure 3).



### Discussion

Often times a concussion occurs when a person's head collides with a moving or stationary object or person in their environment; this results in a quick change in the forces generally protecting the brain in a layer of cerebrospinal fluid (Graham et al., 2014; Iverson et al., 2004). Without enough time to compensate for the change, the brain makes contact with the skull; this can cause the brain to bruise or bleed (Graham et al., 2004). Prior research has shown that even after initial symptoms fade, concussions leave a lasting impact cognitive processes, including those involved with processing auditory stimuli (Bergemalm & Lyxell, 2005).

In the United States, there is a very high incidence rate of sport-related concussions each year (Graham et al., 2014). This, in combination with the large proportion of the population who participates in sports, necessitates further research into the effects of concussions on all cognitive processes, not just frontal lobe processes (U.S. Department of Labor, 2013). This study sought to investigate any differences in the performance of individuals who have sustained concussions on auditory processing and higher-level cognitive measures in comparison to individuals who have no history of concussion.

The data partially support the hypothesis that individuals who have sustained concussions will have a decreased performance throughout the study or performance will remain the same, in that for two of the four *Color-word interference test* subtests, the completion time for the participant with a history of concussion remained the same for the third trial as it was during the first trial. The largest increase in performance was an improvement of 3 seconds between the first and third trials for P1, whereas there was as much as a 16 second improvement between the first and third trial was observed for one of the two participants in the non-concussion group. All participants' completion times fell within the average or slightly above average range when

compared with normative figures. This suggests that neither group had difficulty naming or reading high-frequency words with speed, nor difficulty with verbal inhibition of a more intuitive response to the task than the target response (Delis, Kaplan, & Kramer, 2001). This finding is consistent with existing literature which has shown that concussion does not always cause significantly impaired performance when compared to normative data (Porter et al., 2014). This is one reason why ideally, athletes should be tested pre-season to establish baselines. The athlete's post-concussion test results can later be compared with these baselines (Porter et al., 2014).

This prediction regarding the participant with history of concussion was confirmed in three of the four subtests within the *Verbal fluency test*, in that the number of correct responses remained the same or decreased across the three trials. An overall decrease in performance across trials was not observed in all subtests for the P1.

Congruent with the hypothesis that participants who have not sustained concussions will either have performance that remains the same or performance improvements due to repeated practice, performance times decreased in the non-concussion group for each of the four subtests within the *Color-word interference test*. This means that participants in this group were able to complete the task in less time over the course of the three trials, therefore exhibiting a better performance. This prediction of similar or increased performance levels for the group without a history of concussion was not confirmed in the results of the *Verbal fluency test*. Performance scores decreased over the course of the three trials in two of the four subtests of this measure and marginally increased in the other two subtests. This could be a result of one of the two participants from the non-concussion group demonstrating greater difficulty with the *Verbal fluency test* than with the *Color-word interference test*. The difficulty may possibly be attributed

to anxiety involved with being required to produce words for novel categories without delay and each condition having a 60 second time limit. According to Delis et al. (2001), for individuals with test-related anxiety, performance on the category switching subtest is often poorer; this was observed for the participant who demonstrated greater difficulty on the *Verbal fluency test*.

Contrary to the hypothesis regarding performance of P1, but consistent with the hypothesis for the non-concussion group, all participants improved their initial scores to a perfect performance by the third trial on the *Dichotic digits: Single pairs test*. This hypothesis may not have been supported due to the complexity of the task, as well as it being only one subtest from a battery of auditory assessments. When isolating one task from an assessment, a complete representation of participant's strengths and/or deficits cannot be formed. In future studies, a more complete audiological test battery should be used to measure participants' auditory processing abilities. Additionally, future research should include electrophysiological measures, such as measuring ABR or ERP of participants.

In summary, the current research was conducted as a preliminary study to inform future investigation of the relationship between concussions, auditory processing, and other higher-level cognitive processes. The healthy controls showed repeated practice effects on a subset of the tasks, but the participant with a history of concussion did not show these effects. This suggests there are subtle performance differences between individuals with and without a history of concussion that may be identifiable with specific, repeated behavioral tasks, but results from this preliminary study must be investigated further with a larger sample. The findings in this study did not align with previous research showing decreased processing speed for visual information for the concussion participant in comparison with the non-concussion group (See Figures 4 and 5). Although the behavioral tests used in this research have been shown to detect

cognitive differences in individuals when compared against themselves, it is more difficult to detect significant differences when comparing concussed individuals to normative data; electrophysiological measures are able to provide more substantial evidence of deficits. Findings from this study add to the current body of research by providing a preliminary trial that will inform the use of different measures in later research and by suggesting that slight differences may be detectable using repeated behavioral measures over time.

Table 1

*Mean Correct Responses on Verbal Fluency Test in Participants With and Without History of Concussion*

Verbal Fluency Test	Group Condition			
	Concussion		Non-Concussion	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Letter Fluency	45.66	4.72	47.00	8.36
Category Fluency	48.66	5.68	36.50	4.23
Category Switching	18.00	0	13.50	3.01
Category Switching Accuracy	8.33	1.15	6.50	1.37

Table 2

*Mean Completion Times in Seconds on Color-Word Interference Test in Participants With and Without History of Concussion*

Color-Word Interference Test	Group Condition			
	Concussion		Non-Concussion	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Color Naming	23.33	1.52	23.50	1.87
Word Reading	19.33	0.57	19.16	0.98
Inhibition	30.66	1.15	39.50	9.07
Inhibition/Switching	37.00	2.00	44.83	5.56

Table 3

*Mean Completion Times in Seconds on Color-Word Interference Test across Three Trials in Participants With and Without History of Concussion*

Color-Word Interference Test	Group Condition					
	Concussion			Non-Concussion		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Color Naming	25	23	22	25.5	22.5	22.5
Word Reading	19	20	19	19.5	19	19
Inhibition	30	32	30	45	38	35.5
Inhibition/Switching	39	35	37	48	44.5	42

Table 4

*Mean Correct Responses on Verbal Fluency Test across Three Trials in Participants With and Without History of Concussion*

Verbal Fluency Test	Group Condition					
	Concussion			Non-Concussion		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Letter Fluency	42	51	44	45.5	52	43.5
Category Fluency	55	44	47	40	38	31.5
Category Switching	18	18	18	14.5	10.5	15.5
Category Switching Accuracy	9	7	9	7	5	7.5

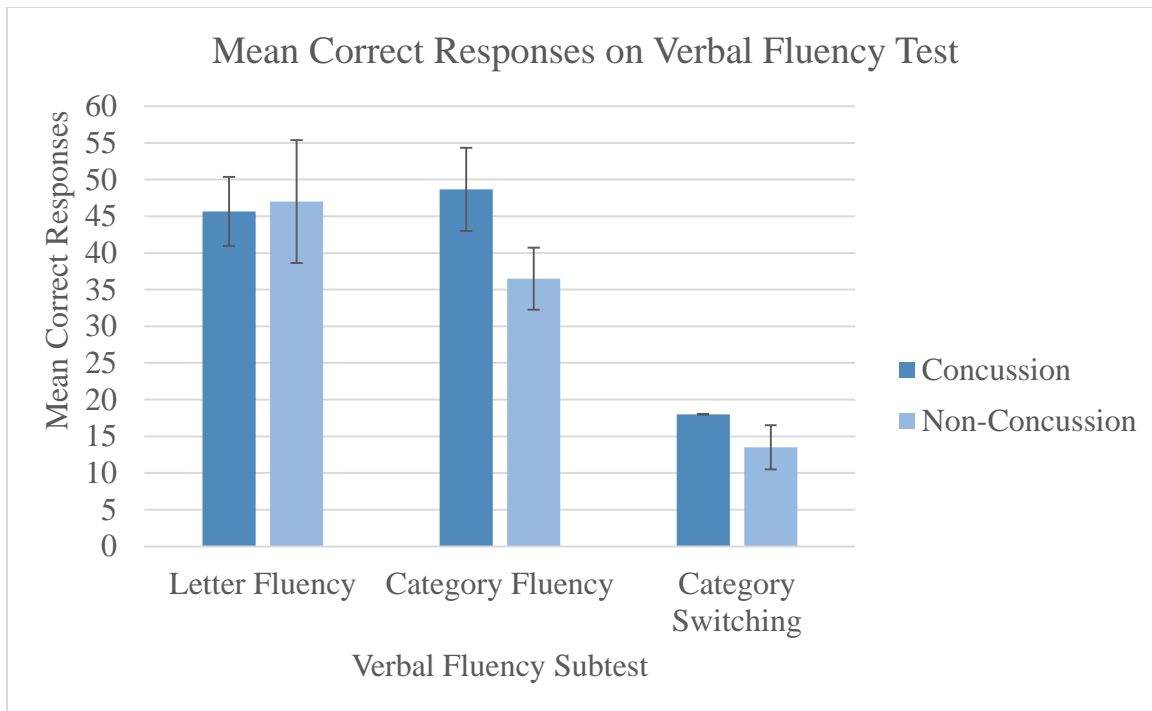


Figure 1. Mean number of correct responses for letter fluency, category fluency, and category switching subtests by participants during the *Verbal fluency test*.

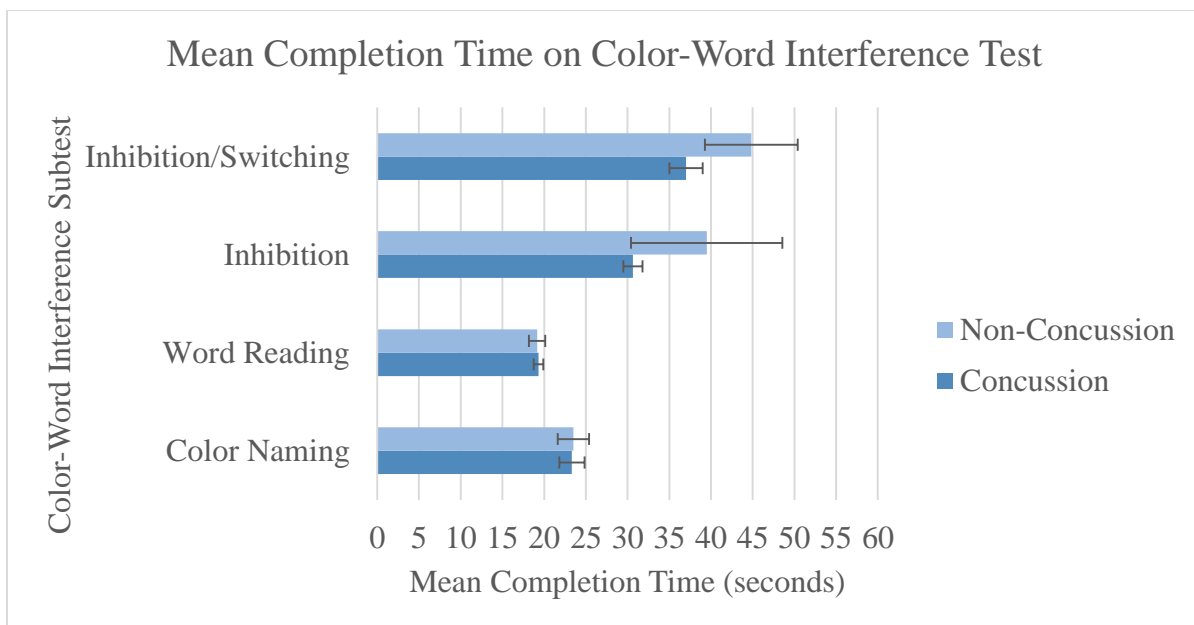


Figure 2. Mean completion time for inhibition/switching, inhibition, word reading, and color naming subtests by participants during the *Color-word interference test*.

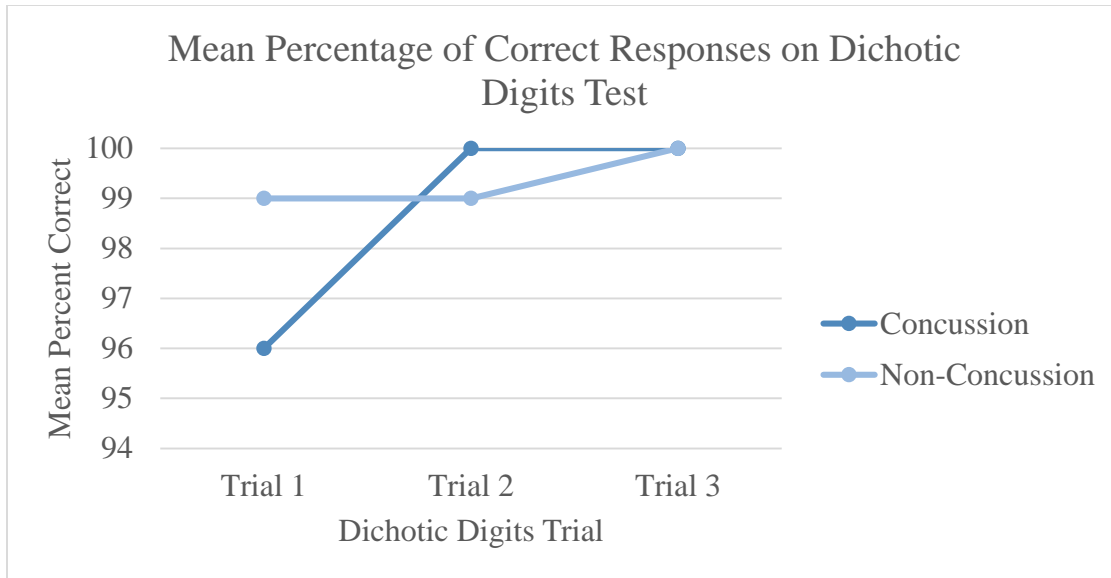


Figure 3. Mean percentage of correct responses given for each trial by participants during the *Dichotic digits: Single pairs test*.

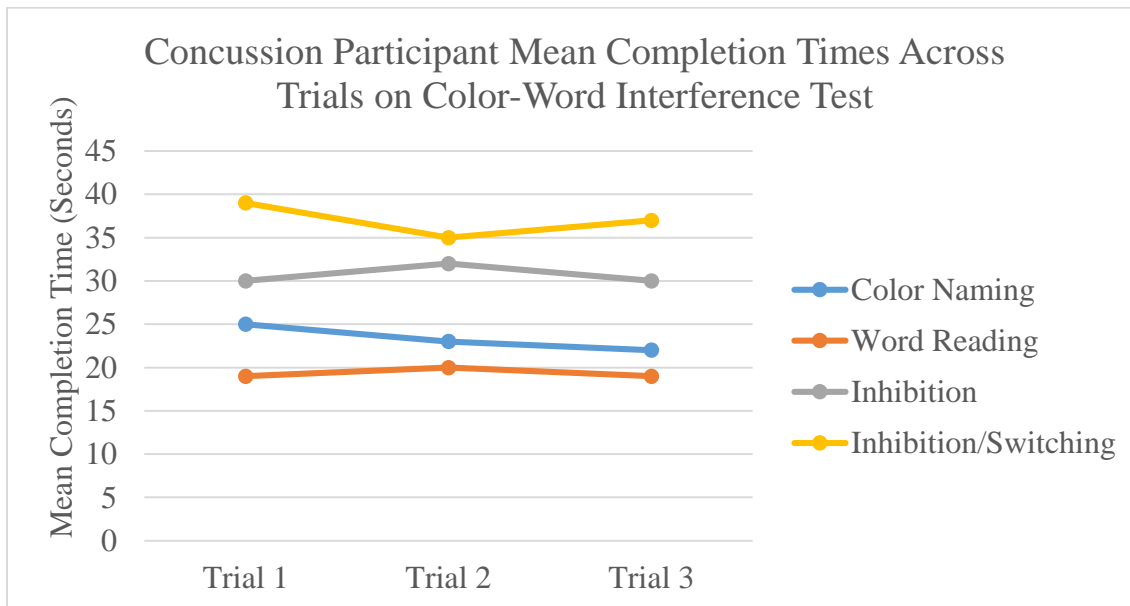


Figure 4. Mean completion times across three trials for inhibition/switching, inhibition, word reading, and color naming subtests by participant with history of concussion during the *Color-word interference test*.



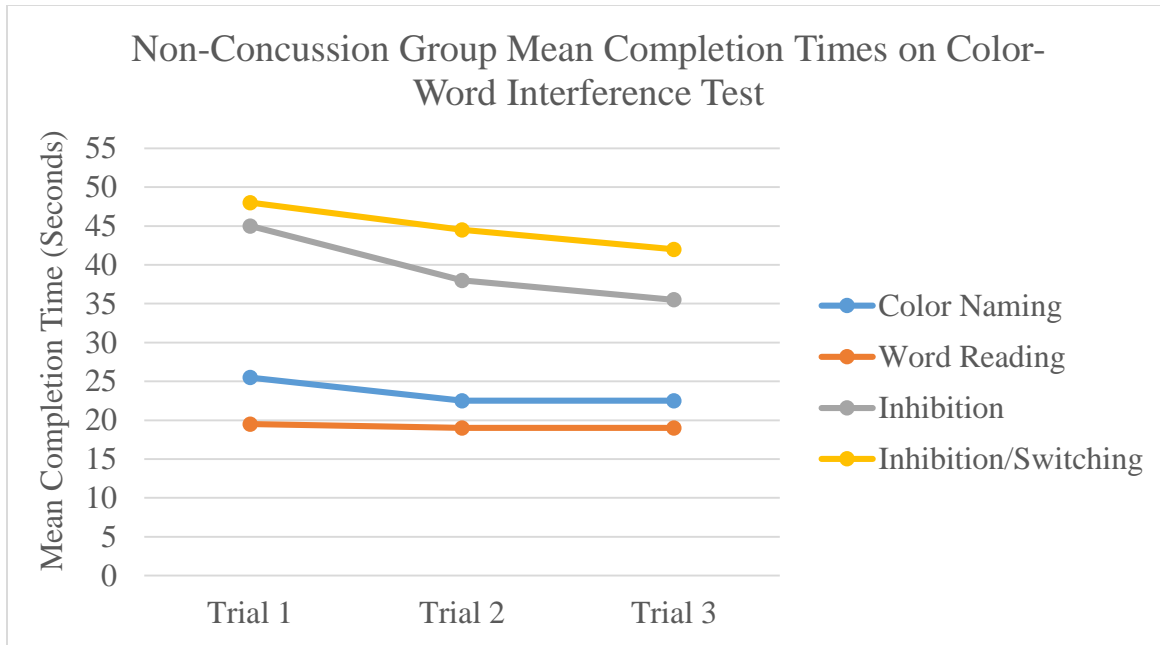


Figure 5. Mean completion times across three trials for inhibition/switching, inhibition, word reading, and color naming subtests by group without history of concussion during the *Color-word interference test*.

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