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Examination of Neurocorrelates of Mild Traumatic Brain Injury in Young Adults

Rachel J. Raucci
Ursinus College, raraucci@ursinus.edu

Adviser: Joel Bish

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Abstract

In recent years, there has been an upswing in the number of concussion diagnoses per year in the United States, particularly in young athletes with still-developing brains. Accompanying this recent trend is an increased amount of research on concussions and their long-term impacts. This ongoing research project collects and compares data from concussed and non-concussed individuals using various neuropsychological batteries, self-report surveys and participants' EEG readings. Data analysis of the results from 51 participants indicates that previously concussed individuals differ from their non-concussed counterparts. Specifically, individuals who have suffered a concussion exhibit specific and occasionally idiosyncratic deficits in executive control and impulse control tasks. These behavioral and neurological patterns are remarkably similar to those exhibited by individuals with ADD/ADHD. While most symptoms tend to diminish over time, many of the aforementioned executive control deficits and markers last well beyond the self-reported symptoms of the injury.

Keywords: concussion; TBI; D-KEFS; RBANS; EEG; executive control

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Concussions are a mild form of traumatic brain injury (TBI) that arise from a direct or indirect blow to the head, face, or neck (Broglio et al., 2017; Daneshvar et al., 2011). Most commonly, injury occurs from the brain hitting the skull due to biomechanical forces, which causes damage to the cortical tissue (DeKosky, Ikonomovic, & Gandy, 2010; McCrory et al., 2012). While maximum injury is seen at the point of impact, the frontal and temporal regions of the brain have been shown to be consistently susceptible to contusions (Duff, 2004). Research suggest that immediately following injury, there is a cascade involving abrupt neuronal depolarization, release of excitatory neurotransmitters, ionic shifts, altered glucose metabolism and cerebral blood flow, and impaired axonal function, and these changes can result in several neurological impairments (Daneshvar et al., 2011).

An estimated 1.6 million to 3.8 million concussions occur in the United States yearly, and the pediatric and adolescent populations sustain about 65% of these concussions (Center for Disease Control and Prevention, 2017). Half of the concussions in these populations occur because of sports (Children’s Hospital of Philadelphia, n.d.). About 2 in 10 high school athletes who play contact sports suffer a concussion each year (University of Pittsburgh Medical Center, n.d.).

While no two concussions have the exact same presentation or outcomes, there are several common symptoms that are often associated with concussions. These include loss of consciousness, amnesia, irritability, anxiety, inattention, slowed reaction times, confusion, drowsiness, headaches, nausea/vomiting, increased sensitivity to light and sound, vertigo, and/or emotional lability (Daneshvar et al., 2011; Rao, Syeda, Roy, Peters, & Vaishnavi, 2017). Depending on the individual and the circumstances of the injury, some of these symptoms will resolve spontaneously, while others may linger for indefinite periods. Factors shown to result in prolonged symptom duration include being female, previous history of concussion(s), previously diagnosed attention-deficit/hyperactivity disorder (ADHD), and participation in a non-helmet sport (McKinlay, Grace, Horwood, Fergusson, & MacFarlane, 2009; Miller et al., 2016). For example, Beaumont, Lassonde, Leclerc, and Théoret (2007) demonstrated that contact-sport athletes with prior concussive history were three times more likely to sustain another concussion than athletes with no prior concussive history, and that the athletes who sustained three or more concussions recovered significantly slower than those who had only sustained one. It has also been shown that the types of symptoms exhibited by a concussed individual can indicate, to some degree, how long their recovery will take. A study done on 101 concussed athletes from varying sports showed that a headache lasting more than 3 hours, difficulty concentrating for more than three hours, retrograde amnesia, or loss of consciousness were all indicators that there would be prolonged recovery (Chad, McKeag, & Olsen, 2004).

While most individuals recover from concussive symptoms within days or weeks of the initial injury, others may continue to suffer from neuropsychiatric symptoms for months to years afterwards. This persistence of symptoms is known as postconcussive syndrome (PCS) (Rao et al., 2017). Reported symptoms include attention deficits, fatigue, impulsivity, irritability, changes in affect, learning and memory problems, inflexibility, lack of initiative, socially inappropriate behaviors, headaches, and personality changes (Duff, 2004). PCS is considered to be fully recoverable with proper treatment, but its effects can still wreak havoc on one's quality of life by preventing the afflicted individual from returning to school, work, and/or sports, or by exacerbating a pre-existing neuropsychiatric condition like depression (Daneshvar et al., 2011). Sustaining multiple concussions makes developing PCS more likely, and also increases one's chance of developing degenerative diseases like Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis, or chronic traumatic encephalopathy (Broglio et al., 2017; Daneshvar et al., 2011). There is also the risk of inducing second-impact syndrome, where sustaining a second TBI before the symptoms of the first TBI have resolved can lead to cerebral edema and brain herniation only minutes after injury (Rao et al., 2017).

These negative impacts of concussions have recently become a main research focus as the number of concussions sustained yearly continues to rise. This rise is mostly due to an increase in the number of students participating in school sports, which is where a large number of concussions occur (Miyashita et al., 2014). This is problematic considering that people under the age of 25 still have developing neural pathways. Executive functions involve developing and implementing an approach to tasks not habitually performed, which generates higher levels of creative and abstract thought (Swanson, 2014; Wodka et al., 2008). These functions occur in the frontal lobes of the brain, which continue maturing until late adolescence and are the last areas to develop (Arain et al., 2013; Daneshvar et al., 2011; Wodka et al., 2008). Studies have found that developing brains are more vulnerable to injury, and a TBI has the potential to significantly harm executive functioning by inducing hyperactivity and/or sustained cognitive impairments (Daneshvar et al., 2011; Duff, 2004). An evaluation of NFL athletes and high school football players by Pellman, Lovell, Viano, and Casson (2006) compared ImPACT test scores between the two groups to determine differences in their recovery from concussion. They determined that high school athletes were suffering from significantly larger cognitive declines than the NFL players at both an initial testing 1-3 days post-injury, and at a second follow-up testing within seven days of injury. The researchers attributed these results to differing rates depending on the athlete's age, as well as a different tolerance for concussions in high school and professional athletes.

As previously mentioned, ADHD has been implicated as a risk factor for concussions, most likely due to its known risk for increasing accidents due to increased levels of impulsivity and risk-taking behavior (Biederman, 2016). However, studies are now also focusing on how concussions affect the development of ADHD (McKinlay et al., 2009; Miller et al., 2016). This is a complex area of research because the executive dysfunction symptoms of PCS are extremely similar to those of ADHD. Several studies have found that more severe instances of mild TBIs significantly increase the probability of symptoms associated with ADHD, oppositional defiant disorder, and obsessive-compulsive disorder (Duff, 2004; McKinlay et al., 2009). A study conducted by Elbin et al. (2013) evaluated 2,377 high school and collegiate athletes using a computerized neurocognitive test for concussions. They determined that athletes who self-reported a diagnosis of ADHD, a learning disability, or both scored significantly lower on the test than their non-afflicted counterparts. They also displayed a significantly greater number of baseline concussion symptoms than control students. Therefore, not only can ADHD increase the chances of sustaining a concussion, it may also be induced by the injury itself. This complicates situations where a researcher or medical professional is testing for ADHD or mild TBI, as one may appear to present as the other.

One method of assessing concussions invovles using electroencephalogram (EEG) data. Previous research by Jasper, Kershman, and Elvidge (1940) demonstrated that TBIs produce both reversible and irreversible changes in brain activity. The EEG data of 64 people who had suffered a TBI was analyzed for differences in various brain waves. While the amount and type of delta wave activity were the best measures of the severity of brain damage, most patients assessed in the study had slower delta waves than normal, and they were often irregular. Some patients also demonstrated prominent alpha rhythms, but they were disorganized and irregular. Other research involving analysis of EEG data after cognitive rehabilitation supports this notion of increased alpha waves following cerebral trauma, as injured patients who underwent the rehabilitation showed a decrease in alpha waves over time (Stathopoulou and Lubar, 2004). Jasper et al. also concluded that while some patients demonstrated minimal clinical evidence of cerebral injury, the EEG was able to detect even mild abnormalities in brain wave activity. However, EEGs are not a definite measure of whether someone has sustained a concussion; the data often only provides positive indication of brain trauma in cases of mild TBIs.

Because of the increased incidence of concussions, it is critical that testing procedures exist which can accurately assess whether an individual has suffered a concussion. Furthermore, there needs to be more research on how concussions affect executive functioning in the long term since most studies involving concussions focus on newly-sustained concussions. The main aim of this research was to learn more about the long-term effects of concussions on executive functioning in the brain, specifically in young adults. Both concussed and non-concussed students were assessed using neuropsychological batteries, surveys about ADHD/executive functioning and attitudes towards concussions, and electroencephalogram (EEG) readings. It was expected that those with concussions would have significantly different results on these assessments than non-concussed individuals; specifically, they were expected to show lower performance than their non-concussed counterparts on the executive functioning tasks and have differences in brain wave activity shown by the EEGs.

Method

Participants

Participants were recruited between June 2016 and March 2017. During June and July 2016, a mass email was sent to all students living on the Ursinus College campus. Participants scheduled a session with one of our researchers, which consisted of roughly 1.5 hours of testing, and were then compensated for their time with a gift card. Between September 2016 and March 2017, participants signed up for a 1.5-hour time slot using the SONA online research scheduling system. Participants were compensated with academic credit for a PSYC100 course at Ursinus College. There were 51 total participants, with 31 female participants and 20 male participants. These participants were separated into two groups: 28 controls (non-concussed), and 23 individuals who had previously sustained a concussion. Each participant signed an informed consent document and was assigned a participant ID to ensure confidentiality. The mean age of the control group was 19.59 years, and the mean age of the concussed group was 19.22 years. For concussed individuals, the amount of time elapsed since the last sustained concussion ranged from 1 month to 34 months, with a mean time of 10.4 months. These differences between the two groups are summarized in Table 1.

Testing

Participants were tested within a prearranged 1.5-hour time slot at Ursinus College. Testing was conducted one-on-one with a student researcher. In order to avoid affecting the participants' attention capabilities and results, the tests were conducted with as few distractions as possible. This was accomplished by conducting testing in a quiet, secluded classroom with only the participant and the student researcher present.

Demographic/Concussion Attitudes Survey: The first section of the concussion attitudes survey asked participants questions regarding gender, age, sports involvement over their lifetime, and concussive history. Questions on concussion history included the number of concussions sustained within their lifetime, the duration of symptoms, whether or not the concussion was sustained from athletics, and if they were confirmed by a physician or trainer. The second section asked participants yes or no questions to assess their knowledge on concussions, and included questions such as identifying concussive symptoms, their long term effects, and what sports held the highest risk for concussions. It also asked if the participant or someone they knew had ever hidden a concussion or cheated on baseline concussion tests. The final section of the survey asked participants to rate different medical diagnoses on a 7-point scale based on their importance to the participant personally, to a general student athlete, and to all of society. Diagnoses listed included drug addiction, ADD/ADHD, Parkinson's disease, TBI, ACL teal, Alzheimer's disease, chronic depression, concussion, broken bone, torn Achilles, autism, and chronic anxiety. A copy of this survey is included in Appendix A.

Delis-Kaplan Executive Functioning System (D-KEFS): The D-KEFS is a set of nationally standardized tests that evaluate higher level cognitive functions in both children and adults aged 8 to 89. Each test evaluates a different executive functioning ability in a game-like format. The researcher administering the test read a script provided in the D-KEFS stimulus booklet in order to maintain consistency across participants. The full D-KEFS consists of nine tests that total 90 minutes; however, our research team chose to omit three of these tests (Design Fluency, Sorting, and Word Context) due to time constraints when testing participants. This did not affect scoring of the other tests, as each was designed to be a flexible stand-alone testing measure that can be administered individually if needed. Our shortened version of the D-KEFS took between 35-50 minutes to complete. The six tests that were administered are described below:

(1) *Trail Making Test* assesses attention, cognitive flexibility, visual scanning, number and letter sequencing, and motor speed. There are 5 separate conditions for the Trail Making test. The first condition presents a page filled with different numbers and asks the participant to identify all the 3's. The second condition presents a page with the numbers 1 to 16, and asks the participant to connect the numbers sequentially without making mistakes. The third condition presents a page with the letters A to P and instructs the participant to connect the letters sequentially without making mistakes. The fourth condition presents a page with both the numbers 1 to 16 and the letters A to P, and the participant must switch between connecting the numbers and letters sequentially without making mistakes (e.g., 1 to A, A to 2, 2 to B, B to 3). The fifth condition presents a page with dots connected by a dotted line, and asks the participant to connect all the dots by tracing over the dotted line. All 5 conditions are timed, and participants are instructed to complete each test in as little time as possible.

(2) *Verbal Fluency Test* assesses efficient lexical organization and cognitive flexibility. There are three different conditions for this test. In the first condition, the participant is given 1 minute to list as many words as they can for a letter. This is repeated three times with a different letter each time. In the second condition, the participant is given 1 minute to list as many animals as they can, and then another minute to list as many boys' names as possible. In the last condition, the participant is given one minute to list as many fruits and pieces of furniture as they can, and they are instructed to switch between answering with a fruit and a piece of furniture.

(3) *Color-Word Interference Test* evaluates selective attention, inappropriate response inhibition, and cognitive flexibility. This test consists of four conditions. In the

first condition, the participant is presented with a page that has different colored blocks (red, green, or blue) and is asked to read all the colors in order without making mistakes. For the second condition, the participant is shown a page with the names of colors printed in black ink. They are then asked to read all the words in order without making mistakes. For the third condition, the participant is presented with a Stroop test (a page consisting of the names of colors printed in a different color ink). The participant is instructed to read the color the word is printed in and not the word itself for all items on the page without making mistakes. For the fourth condition, the participant is presented with a page that has more color names printed in different colored inks. However, on this page, some of the words are enclosed in boxes. The participant is instructed to, without making mistakes, read the color of the ink if the word is not in a box, and to read the actual word if it is in a box. All four conditions are timed.

(4) *Twenty Questions Test* measures strategic thinking, the ability to formulate abstract questions, visual attention, object recognition, categorization, and the ability to incorporate feedback into decision-making. The participant is presented with a page displaying 20 pictures of common objects, is told the researcher has selected one of the items on the page, and that they must ask the researcher yes/no questions in order to guess the correct item. This is run four times, and each time they are guessing at a pre-determined new object.

(5) *Tower Test*, which assesses forward planning of a sequence of steps, spatial planning, visual learning, inhibition, and rule learning. Over the course of 9 trials, the participant is given a certain amount of pre-arranged blocks, and they must arrange the blocks to create a correct "tower" shown to them in a picture. They are only allowed to use one hand, can

only move one piece at a time, and cannot put big pieces on top of little pieces. Each trial is timed and must be completed in the fewest number of moves possible.

(6) *Proverb Test* measures verbal abstraction. In the first section, participants are read a total of 8 proverbs and asked to explain their meaning. In the second section, participants are shown the same 8 proverbs in multiple choice format, and are instructed to select the best meaning for each proverb from a list of 4 choices (Delis, Kaplan, & Kramer, 2001a; Delis, Kaplan, & Kramer, 2001b; Latzman & Markon, 2009; Shunk, Davis, & Dean, 2010; Swanson, 2014).

Repeatable Battery for the Assessment of Neuropsychological Status (RBANS): The RBANS is a neuropsychological battery composed of twelve subtests (List Learning, Story Memory, Figure Copy, Line Orientation, Picture Naming, Semantic Fluency, Digit Span, Coding, List Recall, List Recognition, Story Recall, Figure Recall) that evaluate executive function abilities. It gives scores for five important components of executive functioning: immediate memory (List Learning, Story Memory), visuospatial/constructional (Figure Copy, Line Orientation), language (Picture Naming, Semantic Fluency), attention (Digit Span, Coding), and delayed memory (List Recall, List Recognition, Story Recall, Figure Recall). As with the D-KEFS, the test administrator read a script provided in the RBANS test booklet in order to maintain consistency across participants. The RBANS was designed specifically to be a shorter neuropsychological evaluation, and took only between 20 and 30 minutes to complete. Each of the 12 tests is described below:

(1) *List Learning* evaluates immediate memory. The participant is read a list of 10 words, and asked to repeat back as many of the words as they can remember. This same list

is read 4 times, and after each reading the examiner records how many words the participant correctly recalls.

(2) *Story Memory* evaluates immediate memory. The participant listens to a short story read by the examiner and is then asked to recall as much of the story as they can. Scoring is based on whether the participant can recall pre-determined key words from the story; however, the participant is not informed which words are the key words. The story is read twice, and after each reading the examiner records how many key words are recalled.

(3) *Figure Copy* evaluates visuospatial/constructional abilities. The participant is shown a multipart geometric drawing and asked to draw an exact copy on a sheet of paper. The participant is allowed to view the image through the entirety of this subtest. Points are awarded based on correctness and completeness of the drawing, as well as on proper placement of all parts of the drawing.

(4) *Line Orientation* evaluates visuospatial/constructional abilities. The participant is shown an image consisting of 13 connected lines that are labeled 1-13 and that form different angles. Below this image are two of these same lines forming an angle, but with no labels. The participant is asked to match the two lines at the bottom with two of the lines at the top. This is repeated for 10 trials.

(5) *Picture Naming* assesses language abilities. The participant is shown a picture of a common object (ex: chair) and is asked to name the picture. If the participant does not know the name of the object, they are prompted with a hint and allowed to guess again. This is repeated for 10 trials.

(6) *Semantic Fluency* assesses language abilities. The participant is asked to name as many fruits and vegetables as they can in 1 minute.

(7) *Digit Span* evaluates attention. The examiner reads off a string of numbers, and the participant is asked to repeat back the numbers in the same order. The length of the strings increases with each trial. There are 8 total trials, and the test may be discontinued before all trials are completed if the participant gets a certain amount of answers wrong in a row.

(8) *Coding* evaluates attention. The participant is given a sheet with various different symbols that have empty boxes. At the top of the sheet, there is a key where each symbol to the numbers 1 to 9. The participant is asked to match each symbol, in order, with its corresponding number. The test lasts 90 seconds and is completed only once.

(9) *List Recall* delayed memory. The participant is asked to recall the list of words from the first subtest (List Learning).

(10) *List Recognition* evaluates delayed memory. The examiner reads 20 words (10 targets, 10 distractors) to the participant and asks them to identify whether or not each word was on the original list from the first subtest.

(11) *Story Recall* evaluates delayed memory. The participant is asked to recall as many details from the second subtest (Story Memory) as possible.

(12) *Figure Recall* evaluates delayed memory. The participant is giving a sheet of paper and asked to recreate the geometric figure from the third subtest (Figure Copy). The participant is not allowed to see the image again before drawing (Randolph, 1999).

Barkley Deficits in Executive Functioning Scale Long Form (BDEFS-LF): The BDEFS-LF is a theoretically and empirically based self-report survey used to assess executive function deficits. It is commonly used in conjunction with diagnostic tests to diagnose ADHD. The survey asked the participant to rate their abilities in things like problem solving, impulse control, and organization on a 4-point scale for 89 different items. These items evaluate the five major areas of executive function problems: self-management, self-organization and problem solving, inhibition/self-restraint, self-motivation, and self-regulation of emotion (Barkley, 2011). Scores include a total summary score (total sum of the scores for all five sections), an extreme index score (the number of items rated a 3 or 4), and an ADHD Index score. The ADHD Index score was calculated by summing the scores on 11 specific questions from the test. The BDEFS-LF took about 10-15 minutes to complete (Allee-Smith, Winters, Drake, & Joslin, 2012; Barkley, 2011). A copy of the BDEFS-LF is included in Appendix B.

BioPac: Each participant underwent an EEG using BioPac. A ground electrode was placed behind the participant's left ear, and this functioned as the common reference point. Two other electrodes were placed using the internationally recognized 10/20 positioning system. The 10 and 20 refer to the distances between adjacent electrodes, which are either 10% or 20% of the total front-back or right-left distance of the skull (Trans Cranial Technologies, 2012). These two electrodes were placed on each side of the forehead near the hairline at sites frontopolar (FP) 1 and FP2. The first test had the subject close their eyes and sit still for 20 seconds, then open their eyes and sit still for 20 seconds, and re-close their eyes and sit still for the remaining 20 seconds. This test measured alpha and beta waves under those three conditions. The second test had the subject close their eyes and sit still for 10 seconds, then attempt to solve the following mental math problem read out loud by the researcher for the remaining 20 seconds: 2 minus 4, times 3, plus 9, double that, double again, divide by 4, add 12, divide by 5. Participants were ensured that they did not need to correctly solve the problem or provide an answer at the end, just that they should follow along and attempt to solve the problem in their head. This test provided measurements for overall EEG and alpha waves under these two conditions.

Data Analysis

Independent samples *t*-tests were run using Statistical Package for the Social Sciences (SPSS) software to find differences between the control and concussed groups for performance on the various subtests of the D-KEFS, RBANS, and BDEFS-LF. An independent samples *t*-test was also used to assess differences on variables from the EEG. For the first EEG test, these variables included amplitude measurements from standard deviation measurements for alpha, beta, delta, and theta waves for each condition (eyes closed, eyes open, and eyes re-closed). For the second EEG test, the variables included amplitude measurements from standard deviation measurements for total EEG and alpha waves, as well as the difference for the Alpha-RMS mean for each condition (eyes closed and mental arithmetic).

Discriminant function analyses was also used with SPSS software to assess how accurately certain combinations of tests could predict whether an individual had previously sustained a concussion. This was done in two separate analysis procedures. The first used an enter method in which all predictors were included, and the second used a stepwise method that selected for only those predictors that significantly added to the model. Predictor variables used to determine concussive history included all the neuropsychological assessments. Entire sets of data were not present for every individual, and so some of these analyses did not include all 51 participants.

Results

Independent samples *t*-tests were conducted on several variables to determine how much previously concussed participants (N=23) differed from non-concussed participants (N=28). Table 2 summarizes the results for which tests concussed individuals performed better or worse than non-concussed individuals. There was a significant difference between concussed and non-concussed individuals on the Barkley Extreme Index, with concussed individuals reporting higher levels of executive dysfunction (Fig. 1; t (47) = -5.761, p = .000). Concussed participants scored significantly lower on both the RBANS Attention Index (Fig. 2; t (49) = 4.540, p = .000) and the RBANS Delayed Memory Index (Fig. 3; t (49) = 2.271, p = .028). There was a significant difference in scores between the two groups for the D-KEFS Trails 2 Test (Fig. 4; t (40) = -2.407, p = .021) and the D-KEFS Trails Tests Combined (Fig. 5; t (40) = -2.221, p = .032), with concussed individuals scoring better than non-concussed individuals.

There were also significant differences between concussed and non-concussed participants for the D-KEFS Verbal Fluency Test in category switching (Fig. 6; t (40) = -2.330, p = .025) and category fluency (Fig. 7; t (40) = -2.391, p = .022). Concussed individuals performed better than their non-concussed counterparts on both the aforementioned tests. Lastly, concussed participants scored significantly lower than non-concussed participants on the D-KEFS Tower Test (Fig. 8; t (40) = 2.134, p = .039). Discriminant function analysis revealed that using just these 9 tests can predict with 92.9% accuracy whether or not a participant has suffered from a concussion (Table 3). It also showed that even using just Barkley Extreme Index, RBANS Attention Index, and D-KEFS Trails 2 Test can predict whether or not an individual has suffered a concussion with 83.3% accuracy (Table 4).

Discussion

Our results indicate that individuals who have previously sustained at least one concussion have significant deficits in various executive function abilities, even after their initial concussive symptoms have resolved. Previously concussed participants scored higher on the Barkley Extreme Index and lower on the RBANS Attention Index than control participants. The Barkley Extreme Index is a measure of the severity of executive dysfunction symptoms experienced in everyday life, while the RBANS Attention Index evaluates attention, one of the major components of higher-level functioning. This is likely due to the increase in executive dysfunction that many people experience after a concussive episode. When adolescents and young adults suffer a concussion, they are more likely to have frontal lobe damage since their brains are still developing (Daneshvar et al., 2011). The effects of this are likely to manifest as ADD/ADHD symptoms and directly affect one's ability to make decisions, control impulsivity, and pay attention (McKinlay et al., 2009). The effects of this are also seen in how control participants scored lower on the RBANS Delayed Memory Index, but not on the RBANS Immediate Memory Index. A possible explanation for this is that previously concussed individuals still have sufficient working memory that is not significantly worse than that of non-concussed participants; however, although they are able to hold information in their working memory, it is more difficult for them to store it for longer periods of time.

Concussed individuals had higher mean achievement scores on both D-KEFS Trails 2 Test and D-KEFS Trails Combined. Concussions are known to increase levels of impulsivity, and this can potentially allow afflicted individuals to move faster through tests than the non-concussed participants (Hehar, Yeates, Kolb, Esser, & Mychasiuk, 2015). However, it is important to note that mistakes made during the tests were not factored into the scoring. It is possible that if the data analysis included errors made by participants during the Trails Tests, there may be no significant difference between concussed and non-concussed groups. They also would potentially show faster times for concussed individuals, but a greater amount of errors, which would demonstrate impulsivity. One explanation for why the D-KEFS Trails 2 Test was the only Trails Test that was significant on its own is that it involves connecting numbers sequentially. It is possible that sequentially connecting numbers requires less mental effort than sequentially connecting letters. One reason for this might be that numbers are more closely related to each other, while letters each have a distinct sound associated with them and cannot be "added" together like numbers can; however, this will require further investigation.

Concussed individuals also scored significantly higher on the D-KEFS Verbal Fluency Test for both category switching and category fluency. A possible explanation for this relates back to the impulsivity and lack of inhibition commonly seen as a lingering effect of a concussive episode. These characteristics would allow an individual to potentially list more answers than a non-concussed individual. Because they are listing more answers, concussed individuals have more opportunities to switch back and forth when necessary, which explains increased scores in both category fluency and category switching.

Previously concussed individuals scored a significantly lower mean achievement score on the D-KEFS Tower Test than non-concussed individuals. Some of the executive function problems exhibited by concussed individuals involve complex problem solving, and several of the towers in this test required a significant minimum number of moves to be solved (Elbin et al., 2013). Therefore, it makes sense that participants who have potential executive dysfunction from a concussive episode would score lower on this test.

It is worth noting that there were no significant differences between concussed and non-concussed individuals in any of the EEG data. More research should be conducted to evaluate the validity of using EEG data to determine the positive indication of cerebral trauma. However, it is possible that other similar techniques may be able to differentiate between normal individuals and those who have suffered a mild TBI (Nuwer, Hovda, Schrader, & Vespa, 2005). A study by Lee and Huang (2014) demonstrated that magnetoencephalography (MEG), another type of neuronal activity imaging technique, can pick up on abnormal delta waves generated by TBI patients. Therefore, while research should continue to investigate whether EEG can pick up on differences between concussed and non-concussed individuals, but these other options including MEG should be explored as well.

Because only some tests measured significant differences in cognitive abilities between concussed and non-concussed individuals, a new concussion battery should be developed to include all the tests that correctly predict whether an individual has suffered a concussion. This new battery will cut down substantially on the amount of time needed to administer concussion testing. It will also be more accurate than any of the batteries/tests on their own since it will combine the best measures from a variety of sources. As research continues and any other significant predictive measures are identified, they should be added to the battery as well. Based on the results of this study, the new concussion battery should at least include the BDEFS-LF Extreme Index, RBANS Attention Index, and D-KEFS Trails 2 Test. These tests can then be supplemented with D-KEFS Verbal Fluency category fluency, D-KEFS category switching, D-KEFS Trails Combined, D-KEFS Tower Test, and/or RBANS Delayed Memory Index to increase the accuracy of predicting previous concussions.

In addition to long-term executive dysfunction correlating with a concussive episode, researchers also agree that as the number of concussions an individual sustains increases, the severity of symptoms and damage to the brain also increases (Guskiewicz, 2003; Sports Concussion Institute, n.d.). However, many athletes, coaches, trainers, and parents are unaware of these risks due to a lack of sufficient educational materials on concussions. With the possibility of developing ADHD, PCS, degenerative diseases, or second-impact syndrome, it is alarming that many athletes and/or their coaches are not aware of long term consequences that concussions can create (Miyashita et al., 2014). This ignorance towards the risks of concussions is evident in the underreporting of concussions by the athletes themselves. Athletes who do not fully understand the risks of concussions may not believe they need to take recovery time, and thus may hide a concussion or exaggerate their level of recovery in order to speed up their return to play (Broglio et al., 2017). Some athletes, and even trainers or coaches, may simply not even know how to properly identify a concussion. Eighty five percent of concussions are presumed to be unwitnessed or underreported (McCarthy 2017). When this happens, coaches or trainers may allow the athlete premature return to play, but this has been proven to increase the risk of PCS (Makdissi et al., 2010).

Because of this lack of knowledge, there needs to be greater efforts in educating the public, especially student-athletes, on concussions. This includes recognizing concussive symptoms, proper recovery measures, and precautionary behaviors to avoid getting a TBI (Cusimano et al., 2013). Providing educational resources to athletes and coaches has been proven to increase one’s knowledge on concussive symptoms, as well as make athletes more likely to report them (Glang et al., 2015; Miyashita et al., 2014). However, there is still much room for improvement, and a long ways to go before educational materials on concussions can be considered fully effective.

One of the major limitations of this study was the disregard of multiple testing measures from the D-KEFS. Design Fluency Test, Sorting Test, and Word Context Test were all not included in the neuropsychological battery due to time constraints. However, it is possible that one or more of these tests demonstrates significant differences between concussed and non-concussed individuals. In future testing, these tests should be included in the battery in order to determine if they improve the accuracy of detecting previous concussive episodes.

Another limitation of this study was not using all the collected data in the D-KEFS scoring. When inputting data into the D-KEFS scoring software, there are two options for scoring: primary measures and primary + optional measures. Our research used only the primary measures, which means that several potentially important scoring components were not analyzed. One important example of this is from the Color-Word Interference Test. The primary measures only required input of the time needed to complete the test. However, optional measures also included the number of uncorrected and self-corrected errors made during the test. If these measures were also factored into the scoring, then it is possible that the Color-Word Interference Test would become a significant testing measure. Future testing should use all primary + optional scoring measures and evaluate how the significance of the data is affected.

It is possible that several of the factors collected in the Concussion Attitudes Survey may affect the results. Previous studies have demonstrated that factors like sex, presence of ADHD and/or a learning disability, or at least three previously sustained concussion can affect both one’s risk of sustaining a concussive episode and symptom duration (Elbin et al., 2013; McKinlay et al., 2009; Miller et al., 2016). Our survey collects a large amount of data that can be analyzed along with the neuropsychological test results and presence/absence of a previous concussive episode to see if any of these factors increase chance of sustaining a concussion. It would also be beneficial to investigate how people's attitudes and knowledge about concussions, which are also evaluated in the Concussion Attitudes Survey, relate to how many concussions they have sustained. Finally, since athletes have a much higher chance of getting a concussion, the data should be analyzed in terms of athletes versus non-athletes. All of these improvements, along with continued testing to increase the number of participants, will continue to enhance the data and provide more information on the long term effects of concussions.

Conclusion

This research demonstrates that individuals who have previously sustained at least one concussion will show significant differences on several measures of the BDEFS-LF, D-KEFS, and RBANS tests. These results are especially pertinent to student athletes, who are more vulnerable to neural injuries due to a lack of complete frontal lobe development. By combining all the significant testing measures determined in this study, a new neuropsychological study can be created that will both take less time to administer, and will have high accuracy for predicting whether an individual has previously sustained a concussion. This data should also be used in conjunction with similar studies to create educational resources for athletes, coaches, athletic trainers, parents of student-athletes, and the general public on the prevention and identification of concussions, as well as proper recovery measures.

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	Number of participants	Mean age of participants	Mean Time Elapsed Since Last Concussion
Concussed	23	19.22	10 months
Non-Concussed	28	19.59	0 months

Table 1. Group averages for concussed and non-concussed participant pools. The data presented in this table was generated in Dr. Joel Bish’s lab at Ursinus College, Spring 2017.

Better Performance by Concussed Individuals	Worse Performance by Concussed Individuals
DKEFS Trails 2 Test DKEFS Trails Tests Combined DKEFS Verbal Fluency Test category switching DKEFS Verbal Fluency Test category fluency	Barkley Extreme Index RBANS Attention Index RBANS Delayed Memory Index DKEFS Tower Test

Table 2. Summary table for concussed participants' performance compared to control participants. The data presented in this table was generated in Dr. Joel Bish's lab at Ursinus College, Spring 2017.

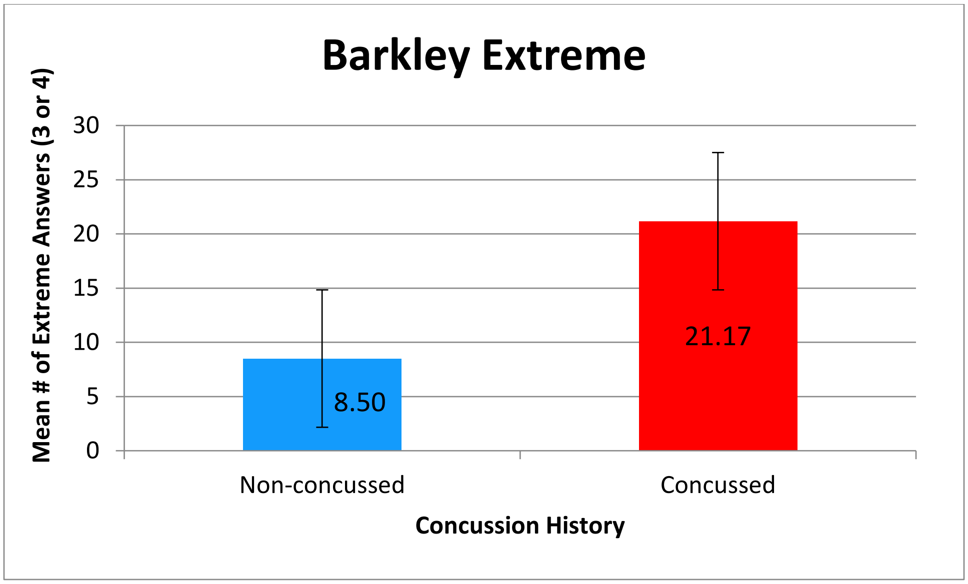


Figure 1. Average number of extreme answers on BDEFS-LF for previously concussed and non-concussed participants. The data presented in this figure was generated in Dr. Joel Bish's lab at Ursinus College, Spring 2017.

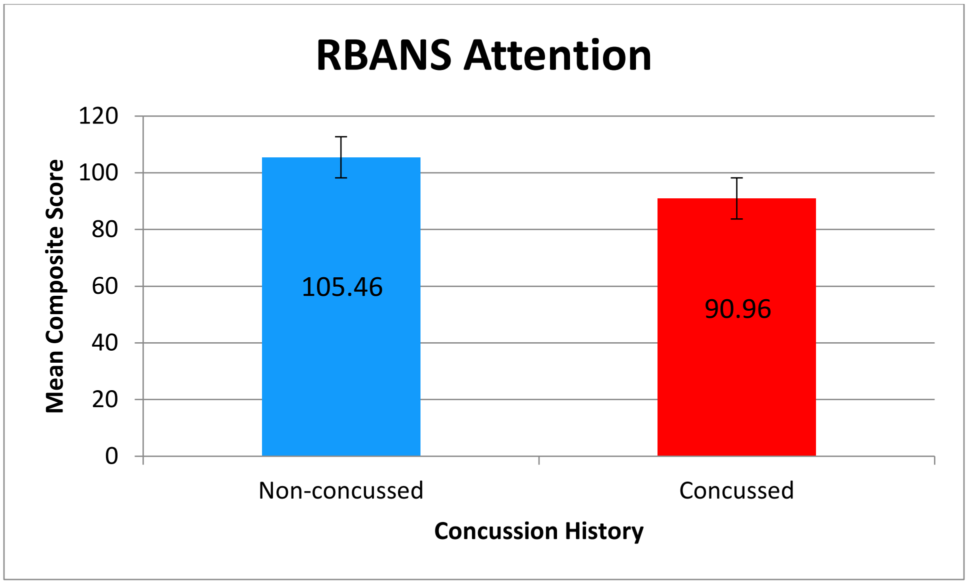


Figure 2. Mean scores for previously concussed and non-concussed individuals on RBANS Attention Index. The data presented in this figure was generated in Dr. Joel Bish’s lab at Ursinus College, Spring 2017.

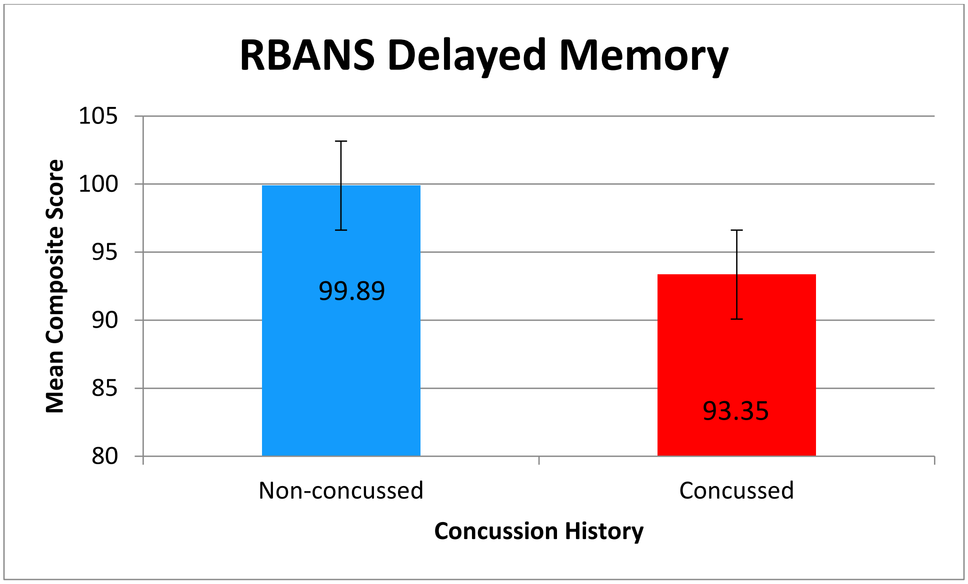


Figure 3. Mean scores for previously concussed and non-concussed individuals on RBANS Delayed Memory Index. The data presented in this figure was generated in Dr. Joel Bish's lab at Ursinus College, Spring 2017.

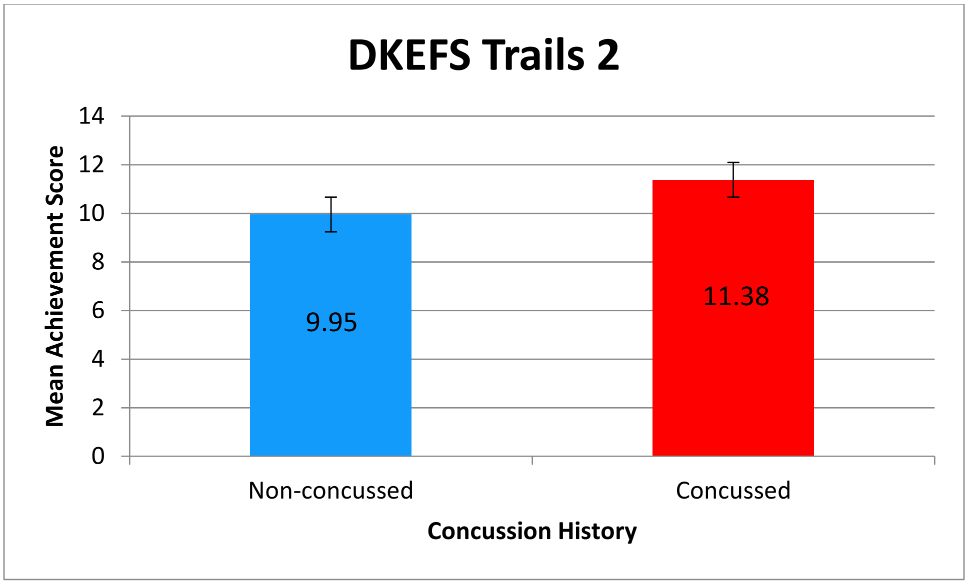


Figure 4. Mean achievement scores for previously concussed and non-concussed participants on D-KEFS Trails 2 Test. The data presented in this figure was generated in Dr. Joel Bish's lab at Ursinus College, Spring 2017.

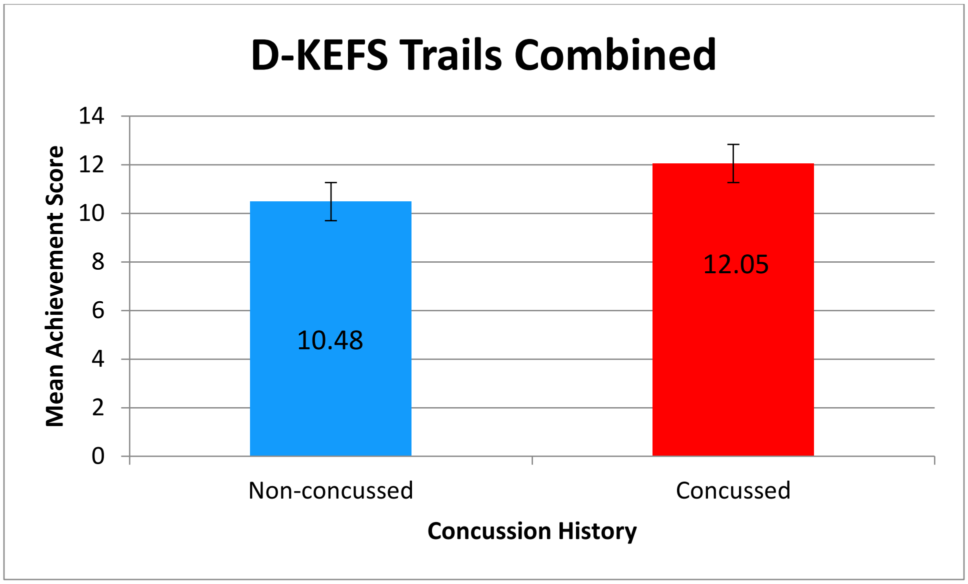


Figure 5. Mean achievement scores for previously concussed and non-concussed individuals on DKEFES Trails Tests Combined. The data presented in this figure was generated in Dr. Joel Bish's lab at Ursinus College, Spring 2017.

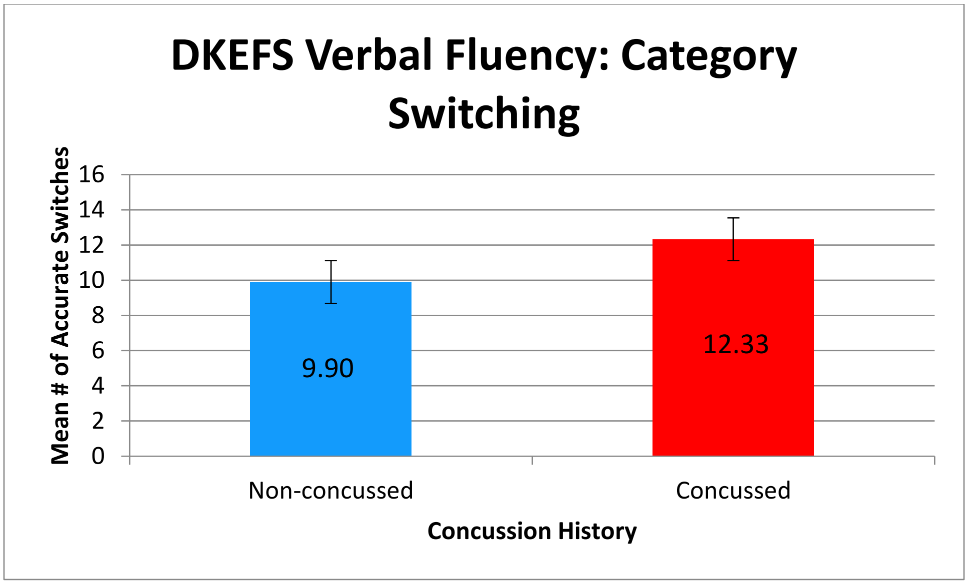


Figure 6. Mean number of accurate switches for previously concussed and non-concussed individuals on D-KEFS Verbal Fluency Test with category switching. The data presented in this figure was generated in Dr. Joel Bish's lab at Ursinus College, Spring 2017.

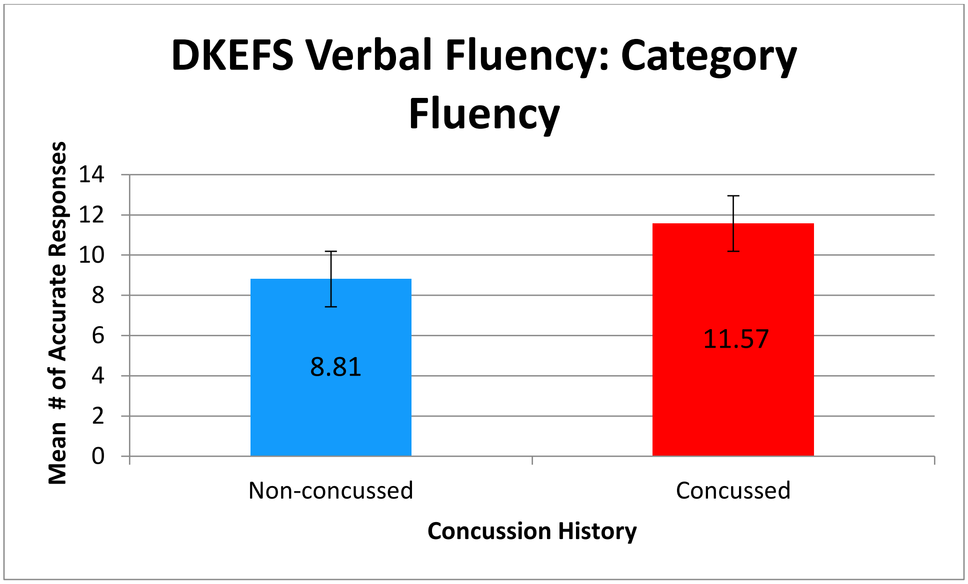


Figure 7. Mean number of accurate responses for previously concussed versus non-concussed participants on D-KEFS Verbal Fluency Test for category fluency. The data presented in this figure was generated in Dr. Joel Bish's lab at Ursinus College, Spring 2017.

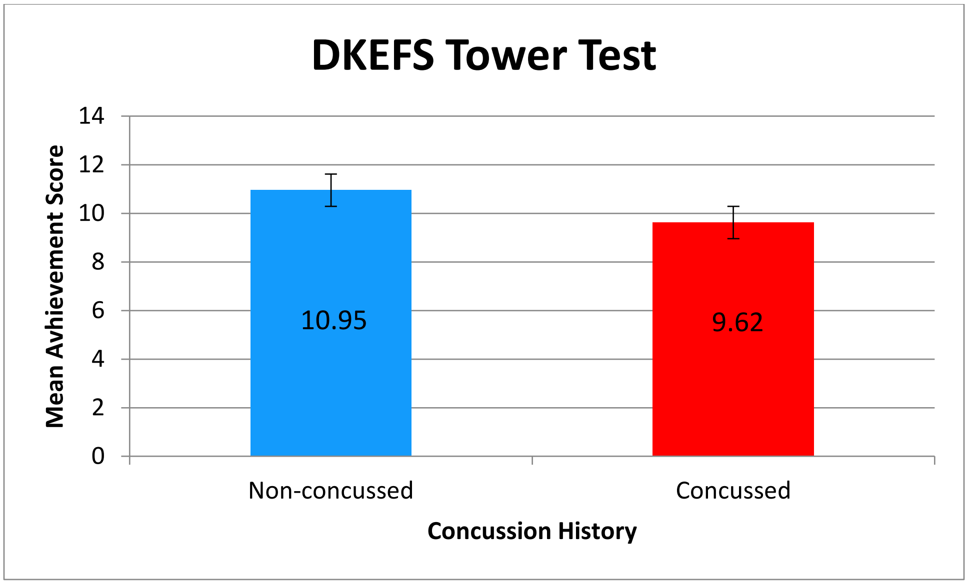


Figure 8. Mean achievement score on D-KEFS Tower Test for previously concussed and non-concussed individuals. The data presented in this figure was generated in Dr. Joel Bish’s lab at Ursinus College, Spring 2017.

			Predicted Group Membership		
		Conc	.00	1.00	Total
Original	Count	.00	18	3	21
		1.00	0	21	21
	%	.00	85.7	14.3	100.0
		1.00	.0	100.0	100.0

Table 3. Discriminant classification results for Barkley Extreme Index, RBANS Attention Index, RBANS Delayed Memory Index, D-KEFS Trails 2 Test, D-KEFS Trails 3 Test, D-KEFS Trails Tests Combined, D-KEFS Verbal Fluency Test category switching, D-KEFS Verbal Fluency Test category fluency, and D-KEFS Tower Test. Using just these 9 tests allows for 92.9% of original grouped cases to be correctly classified. The data presented in this table was generated in Dr. Joel Bish’s lab at Ursinus College, Spring 2017.

			Predicted Group Membership		
		Conc	.00	1.00	Total
Original	Count	.00	17	4	21
		1.00	3	18	21
	%	.00	81.0	19.0	100.0
		1.00	14.3	85.7	100.0

Table 4. Discriminant classification results for Barkley Extreme Index, RBANS Attention Index, and D-KEFS Trails 2 Test. Using just these 3 tests allows for 83.3% of original grouped cases to be correctly identified. The data presented in this table was generated in Dr. Joel Bish's lab at Ursinus College, Spring 2017.

Appendix A. Copy of the Demographics/Concussion Attitudes Survey.

What is your age? ____________

Gender M F Other

Major? ________________________________

Are you a collegiate student/athlete? Y N

Which sport/s? ________________________________

Did you participate in sports in high school? Y N

List sports and the number of years you participated in each **for your entire life.**

________________ __________

________________ __________

________________ __________

________________ __________

Have you ever suffered from a concussion resulting from athletics? Y N

If yes, how many and in which sports and at approximately what age?

Were they confirmed by a physician or trainer? Y N

Have you ever suffered from a concussion from a reason other than athletics Y N

How many, from what cause, and at what age?

For approximately how long did your symptoms last? Please list for each concussion.

Have you ever suffered from a concussion that wasn't reported to a health provider? Y N

Have you ever suffered from a concussion that wasn't reported to a coach/trainer? Y N

Have you ever suffered from a concussion that wasn't reported to a parent or guardian? Y N

Do you have friends or teammates that haven't reported a concussion to a health provider? Y N

Do you have friends or teammates that haven't reported a concussion to a coach/trainer? Y N

Do you have friends or teammates that haven't reported a concussion to a parent or guardian? Y N

Have you ever had to complete baseline, pre-season concussion testing (i.e. ImPact)? Y N

Have you ever performed poorly on baseline testing on purpose so that a concussion wouldn't be as easily determined later? Y N

Do you know of any friends or teammates that has performed poorly on baseline testing on purpose so that a concussion wouldn't be as easily determined later? Y N

Have you ever given up a sport because of your fear of concussions? Y N

Have you ever been told by a medical professional to stop playing a sport because of fear of concussions? Y N

Do you believe there are long-term effects (i.e. 6 months or longer) the result from concussions? Y N

Do you believe that an individual's learning/education could be affected by a concussion? Y N

Do you believe that the importance of a specific game should affect return-to-play decisions? Y N

Do you believe that the most common symptom of a concussion is loss of consciousness? Y N

Do you believe that the most common symptom of a concussion is dizziness? Y N

Do you believe that baseline testing is important for student athletes? Y N

Do you believe that baseline testing is reliable? Y N

Do you believe that concussions should be considered traumatic brain injuries? Y N

Have you ever been diagnosed with ADD/ADHD? Y N

Are you currently on medication for ADD/ADHD? Y N

If so, which medication? ______________________________

Rate the following on a on a scale of 1 to 7 regarding its impact on **you personally**:

1 2 3 4 5 6 7

Not impactful **moderately** **extremely impactful**

Drug addiction ____________

ADD/ADHD ____________

Parkinson's Disease ____________

Traumatic Brain Injury ____________

ACL tear ____________

Alzheimer's Disease ____________

Chronic Depression ____________

Concussions ____________

Broken Bone ____________

Torn Achilles ____________

Autism ____________

Chronic Anxiety ____________

Rate the following on a on a scale of 1 to 7 regarding its impact on a **general student athlete**:

1	2	3	4	5	6	7
Not impactful			**moderately**		**extremely impactful**	

Drug addiction ______________

ADD/ADHD ______________

Parkinson's Disease ______________

Traumatic Brain Injury ______________

ACL tear ______________

Alzheimer's Disease ______________

Chronic Depression ______________

Concussions ______________

Broken Bone ______________

Torn Achilles ______________

Autism ______________

Chronic Anxiety ______________

Rate the following on a on a scale of 1 to 7 regarding its impact on **all of society**:

1	2	3	4	5	6	7
Not impactful			**moderately**		**extremely impactful**	

Drug addiction ______________

ADD/ADHD ______________

Parkinson's Disease ______________

Traumatic Brain Injury ______________

ACL tear ______________

Alzheimer's Disease ______________

Chronic Depression ______________

Concussions ______________

Broken Bone ______________

Torn Achilles ______________

Autism ______________

Chronic Anxiety ______________

List the top 5 sports that you believe athletes suffer the most concussions while participating in them.

1. ______________________
2. ______________________
3. ______________________
4. ______________________
5. ______________________

Appendix B. Copy of the BDEFS-LF Self-Evaluation Form.

BDEFS-LF: Self-Report

Name: ______________________ Date: ______________

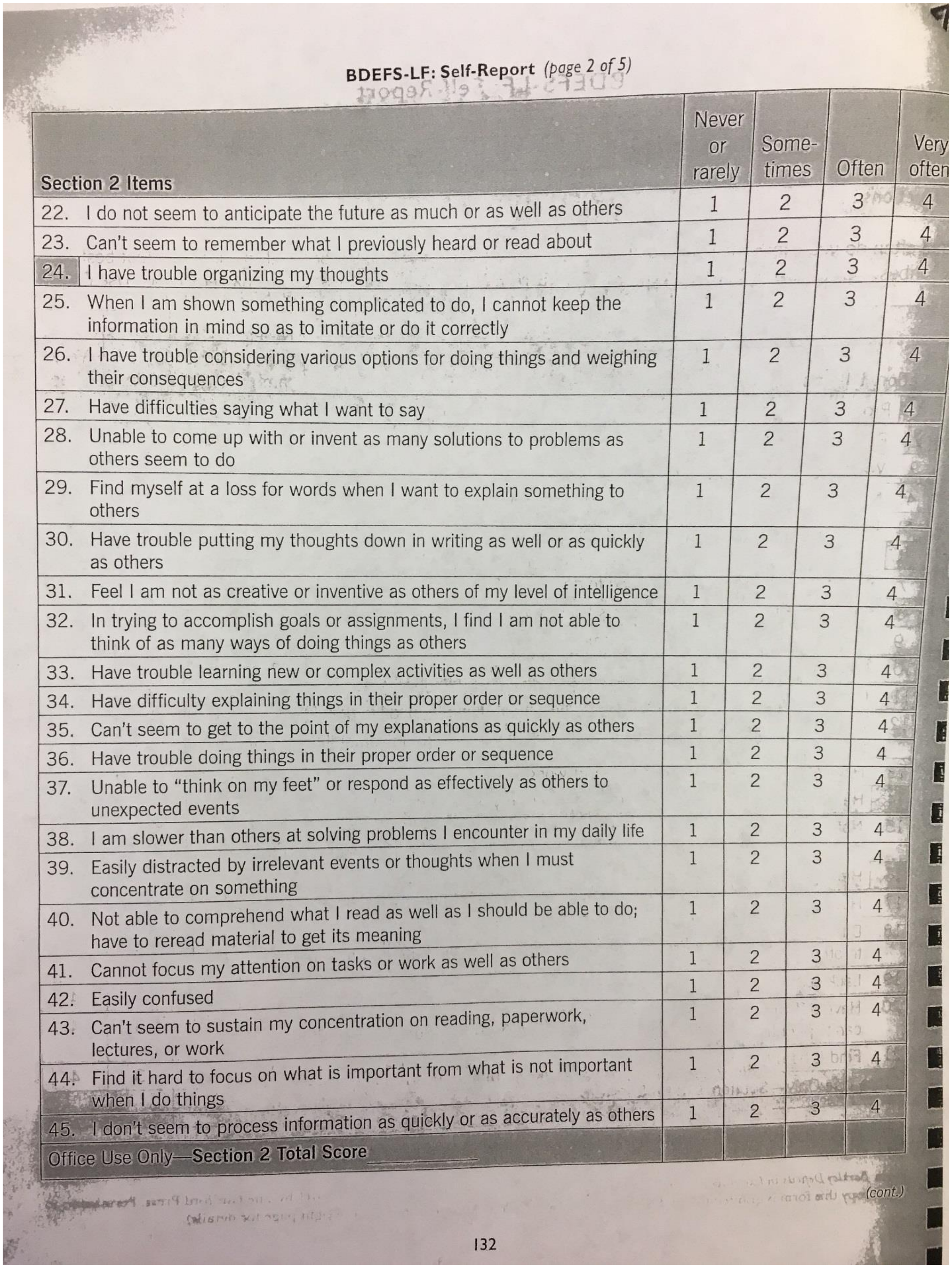
Sex: (Circle one) Male Female Age: ______________

Instructions

How often do you experience each of these problems? Please circle the number next to each item that best describes your behavior **DURING THE PAST 6 MONTHS**. Please ignore the sections marked "Office Use Only."

Section 1 Items	Never or rarely	Some-times	Often	Very often
1. Procrastinate or put off doing things until the last minute	1	2	3	4
2. Poor sense of time	1	2	3	4
3. Waste or mismanage my time	1	2	3	4
4. Not prepared on time for work or assigned tasks	1	2	3	4
5. Fail to meet deadlines for assignments	1	2	3	4
6. Have trouble planning ahead or preparing for upcoming events	1	2	3	4
7. Forget to do things I am supposed to do	1	2	3	4
8. Can't seem to accomplish the goals I set for myself	1	2	3	4
9. Late for work or scheduled appointments	1	2	3	4
10. Can't seem to hold in mind things I need to remember to do	1	2	3	4
11. Can't seem to get things done unless there is an immediate deadline	1	2	3	4
12. Have difficulty judging how much time it will take to do something or get somewhere	1	2	3	4
13. Have trouble motivating myself to start work	1	2	3	4
14. Have difficulty motivating myself to stick with my work and get it done	1	2	3	4
15. Not motivated to prepare in advance for things I know I am supposed to do	1	2	3	4
16. Have trouble completing one activity before starting into a new one	1	2	3	4
17. Have trouble doing what I tell myself to do	1	2	3	4
18. Difficulties following through on promises or commitments I may make to others	1	2	3	4
19. Lack self-discipline	1	2	3	4
20. Have difficulty arranging or doing my work by its priority or importance; can't "prioritize" well	1	2	3	4
21. Find it hard to get started or get going on things I need to get done	1	2	3	4
Office Use Only—**Section 1 Total Score** ________				

(cont.)



BDEFS-LF: Self-Report *(page 2 of 5)*

Section 2 Items	Never or rarely	Some-times	Often	Very often
22. I do not seem to anticipate the future as much or as well as others	1	2	3	4
23. Can't seem to remember what I previously heard or read about	1	2	3	4
24. I have trouble organizing my thoughts	1	2	3	4
25. When I am shown something complicated to do, I cannot keep the information in mind so as to imitate or do it correctly	1	2	3	4
26. I have trouble considering various options for doing things and weighing their consequences	1	2	3	4
27. Have difficulties saying what I want to say	1	2	3	4
28. Unable to come up with or invent as many solutions to problems as others seem to do	1	2	3	4
29. Find myself at a loss for words when I want to explain something to others	1	2	3	4
30. Have trouble putting my thoughts down in writing as well or as quickly as others	1	2	3	4
31. Feel I am not as creative or inventive as others of my level of intelligence	1	2	3	4
32. In trying to accomplish goals or assignments, I find I am not able to think of as many ways of doing things as others	1	2	3	4
33. Have trouble learning new or complex activities as well as others	1	2	3	4
34. Have difficulty explaining things in their proper order or sequence	1	2	3	4
35. Can't seem to get to the point of my explanations as quickly as others	1	2	3	4
36. Have trouble doing things in their proper order or sequence	1	2	3	4
37. Unable to "think on my feet" or respond as effectively as others to unexpected events	1	2	3	4
38. I am slower than others at solving problems I encounter in my daily life	1	2	3	4
39. Easily distracted by irrelevant events or thoughts when I must concentrate on something	1	2	3	4
40. Not able to comprehend what I read as well as I should be able to do; have to reread material to get its meaning	1	2	3	4
41. Cannot focus my attention on tasks or work as well as others	1	2	3	4
42. Easily confused	1	2	3	4
43. Can't seem to sustain my concentration on reading, paperwork, lectures, or work	1	2	3	4
44. Find it hard to focus on what is important from what is not important when I do things	1	2	3	4
45. I don't seem to process information as quickly or as accurately as others	1	2	3	4
Office Use Only—**Section 2 Total Score** ______				

(cont.)

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BDEFS-LF: Self-Report *(page 3 of 5)*

Section 3 Items	Never or rarely	Some-times	Often	Very often
46. Find it difficult to tolerate waiting; impatient	1	2	3	4
47. Make decisions impulsively	1	2	3	4
48. Unable to inhibit my reactions or responses to events or others	1	2	3	4
49. Have difficulty stopping my activities or behavior when I should do so	1	2	3	4
50. Have difficulty changing my behavior when I am given feedback about my mistakes	1	2	3	4
51. Make impulsive comments to others	1	2	3	4
52. Likely to do things without considering the consequences for doing them	1	2	3	4
53. Change my plans at the last minute on a whim or last minute impulse	1	2	3	4
54. Fail to consider past relevant events or past personal experiences before responding to situations (I act without thinking)	1	2	3	4
55. Not aware of things I say or do	1	2	3	4
56. Have difficulty being objective about things that affect me	1	2	3	4
57. Find it hard to take other people's perspectives about a problem or situation	1	2	3	4
58. Don't think about or talk things over with myself before doing something	1	2	3	4
59. Trouble following the rules in a situation	1	2	3	4
60. More likely to drive a motor vehicle much faster than others (Excessive speeding)	1	2	3	4
61. Have a low tolerance for frustrating situations	1	2	3	4
62. Cannot inhibit my emotions as well as others	1	2	3	4
63. I don't look ahead and think about what the future outcomes will be before I do something (I don't use my foresight)	1	2	3	4
64. I engage in risk taking activities more than others are likely to do	1	2	3	4
Office Use Only—**Section 3 Total Score** ________				

Section 4 Items	Never or rarely	Some-times	Often	Very often
65. Likely to take short cuts in my work and not do all that I am supposed to do	1	2	3	4
66. Likely to skip out on work early if my work is boring to do	1	2	3	4
67. Do not put as much effort into my work as I should or than others are able to do	1	2	3	4
68. Others tell me I am lazy or unmotivated	1	2	3	4
69. Have to depend on others to help me get my work done	1	2	3	4

(cont.)

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70. Things must have an immediate payoff for me or I do not seem to get them done	1	2	3	4
71. Have difficulty resisting the urge to do something fun or more interesting when I am supposed to be working	1	2	3	4
72. Inconsistent in the quality or quantity of my work performance	1	2	3	4
73. Unable to work as well as others without supervision or frequent instruction	1	2	3	4
74. I do not have the willpower or determination that others seem to have	1	2	3	4
75. I am not able to work toward longer term or delayed rewards as well as others	1	2	3	4
76. I cannot resist doing things that produce immediate rewards even if they are not good for me in the long run	1	2	3	4
Office Use Only—**Section 4 Total Score** ______				
Section 5 Items	Never or rarely	Some-times	Often	Very often
77. Quick to get angry or become upset	1	2	3	4
78. Overreact emotionally	1	2	3	4
79. Easily excitable	1	2	3	4
80. Unable to inhibit showing strong negative or positive emotions	1	2	3	4
81. Have trouble calming myself down once I am emotionally upset	1	2	3	4
82. Cannot seem to regain emotional control and become more reasonable once I am emotional	1	2	3	4
83. Cannot seem to distract myself away from whatever is upsetting me emotionally to help calm me down. I can't refocus my mind to a more positive framework.	1	2	3	4
84. Unable to manage my emotions in order to accomplish my goals successfully or get along well with others	1	2	3	4
85. I remain emotional or upset longer than others	1	2	3	4
86. I find it difficult to walk away from emotionally upsetting encounters with others or leave situations in which I have become very emotional	1	2	3	4
87. I cannot rechannel or redirect my emotions into more positive ways or outlets when I get upset	1	2	3	4
88. I am not able to evaluate an emotionally upsetting event more objectively	1	2	3	4
89. I cannot redefine negative events into more positive viewpoints when I feel strong emotions	1	2	3	4
Office Use Only—**Section 5 Total Score** ______				

(cont.)