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Associations between Cumulative Concussion and Academic Success in University Students

Michael Broggi
University of Massachusetts Amherst

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A Thesis Presented

by

MICHAEL J. BROGGI JR.

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Approved as to style and content by:

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Rebecca E. Ready, Chair

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Elizabeth Harvey, Member

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Amanda Marcotte, Member

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Caren Rotello, Department Head
Psychological and Brain Sciences

ABSTRACT

ASSOCIATIONS BETWEEN CUMULATIVE CONCUSSION AND ACADEMIC SUCCESS IN UNIVERSITY STUDENTS

MICHAEL J. BROGGI JR., B.A., UNIVERSITY OF RHODE ISLAND

M.A. SOUTHERN CONNECTICUT STATE UNIVERSITY

M.S., UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Rebecca E. Ready

Individuals with a history of multiple concussions may be at risk for relative weaknesses in executive functioning and processing speed. These weaknesses could adversely influence academic skills and academic success. This study determined if the relative weaknesses in executive functions and processing speed mediate associations between multiple concussions and academic outcomes in university students. To achieve this aim, university students with a history of three or more concussions (n = 58) were compared to two control groups (ns = 57) on measures of executive functions, processing speed, academic skills, and academic success. Results indicated no significant differences between the groups on measures of executive functioning or processing speed. The multiple concussion group endorsed significantly more psychological symptoms, had a slower reading rate, and had a lower grade point average (GPA) than controls with no history of concussion. Executive functioning and processing speed did not mediate the associations between concussion status and academic skills or academic success. Future research should investigate other potential mediators, such as psychological symptoms, that may account for differences in academic skills and performance amongst students with multiple concussions.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

One out of every 75 college students is expected to experience a concussion each academic year and of those students 41% of have had a previous concussion (Breck et al., 2019). Persons with multiple concussions also exhibit relative weaknesses in executive functioning and processing speed (e.g., Gardner et al., 2010; Shuttleworth-Edwards & Radloff, 2008). It is important to understand how multiple concussions are associated with academic functioning because these students may be at an increased risk of academic difficulties.

Higher education is cognitively demanding. Thus, there is reason to suspect that a history of multiple concussions might have an adverse impact on college-level academics. Academic skills (e.g., reading, organization, planning) depend on processes such as executive functioning and processing speed. Weaknesses in academic skills could have negative associations with academic performance for students with multiple concussions.

The goal of this study was to determine the association between a history of multiple concussions – at least 12 months after the last injury – and academic skills and academic success in university students. Academic outcomes were assessed in a comprehensive and multidimensional manner. Additionally, we determined if executive dysfunction and slowed processing speed mediated the associations between concussion status (i.e., multiple versus zero or one previous concussion) and academic outcomes.

1.1 Definition and Acute Effects of Single Concussion

The American Association of Neurological Surgeons (2017) defines a concussion as an injury to the brain that is characterized by immediate and transient alteration in brain function.

Acute symptoms of concussion include reduced or slowed fine motor skills, poor balance, blurred vision, sensitivity to light and noise, sleep disturbance, headache, dizziness, and in some cases seizures (Dahl & Emanuelson, 2013). Impaired attention, processing speed, and working memory are common (e.g., Felmingham et al, 2004; Halterman et al., 2006; Keightley et al., 2012; McAllister et al., 2006). Psychological changes such as increased anxiety, apathy, depression, irritability, and lability are frequently reported (e.g., Chaput et al., 2009; Kontos et al, 2012).

The acute recovery period following concussion lasts less than 1 week for the majority (85-87%) of adults and collegiate athletes (e.g., Guskiewicz et al., 2003; McCrea et al., 2009). A review of 120 studies found the majority of studies reported full recovery 3 – 12 months after a concussion (Carroll et al., 2004). Similarly, a review of 39 studies found no deficits or impairments on neuropsychological testing by 3 months post injury (Belanger et al., 2005). Thus, the effects of a single concussion - while disruptive and variable - are time-limited.

1.2 Physiological Mechanisms of Concussion

Following a concussive injury, pathophysiological changes occur in the brain such as an ionic flux, unregulated glutamate release, and an increase in glucose metabolic rates (Giza & Hovda, 2014). The brain's increased need for glucose is then impeded by a drop in cerebral blood flow (Wilberger et al., 2006). This lack of glucose supply and increased demand sets up an energy crisis in the brain following concussion (Giza & Hovda, 2014).

Diffuse axonal injury (DAI) is the disruption of white matter tracts due axons that stretch, swell, or shear (Smits et al., 2011). Axonal injury can occur after a concussion due to the forces of rapid acceleration or rotational movement (Blennow et al., 2012). Frontal white matter areas of the brain have demonstrated particular vulnerability to the axonal shearing in concussion (e.g., Mayer et al., 2014; Sorg et al., 2014).

Neuropsychological testing coupled with neuroimaging have identified the frontal white matter areas, specifically the dorsolateral prefrontal cortex (dlPFC), as having a primary role in executive functioning, specifically working memory, attentional control, and inhibition (e.g., Curtis & D'Esposito, 2003; Mars & Grol, 2007). Individuals with continued symptoms after a single concussion (i.e., >3 months) have demonstrated reduced functional connectivity during working memory tasks in the dlPFC relative to healthy controls (Hocke et al., 2018). Thus, brain regions associated with executive functioning may be vulnerable to injury following a single concussion.

1.3 Relative Cognitive Weaknesses Associated with Multiple Concussion

Many studies use groups with participants who have two or more concussions as multiple concussion sample (e.g., Collins et al., 1999; Wall et al., 2006). However, research is mixed as to whether those with a history of two concussions have cognitive weaknesses compared to controls (e.g., Bruce & Echemendia, 2009; Iverson et al., 2006). Thus, for this project, "multiple concussion" was be defined as three or more previous concussions.

A great deal of research has focused on the cognitive changes following concussion. A common screening of cognitive functioning in concussion research is the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT). The ImPACT's visual memory and verbal memory composite scores are composed of tasks that probe attention, learning, memory, and working memory within each respective (i.e., visual and verbal) domain (ImPACT Applications Inc., 2011). Covassin et al. (2010) studied collegiate athletes who had experienced multiple concussions and were on average over 3 years since their last injury; the multiple concussion group scored significantly lower on the ImPACT visual and verbal memory composites than individuals with no history of concussion. In a more recent study, college athletes with a history of multiple concussions scored significantly lower at baseline on the verbal memory section of the ImPACT than athletes with no previous concussion (Iverson et al., 2012). Whereas these studies demonstrate relative weaknesses following multiple concussions, it is difficult to draw conclusions about the precise nature of the group differences because the composite scores are multifactorial.

Processing speed indicates how efficiently an individual processes simple information (Cepeda et al., 2013). Individuals with two or more concussions demonstrate relative weaknesses in processing speed when compared to individuals with no history of concussion (Gardner et al., 2010). That is, individuals with a history of multiple concussions scored significantly lower than healthy controls on the ImPACT visual motor speed composite index and significantly lower on the Wechsler Adult Intelligence Scale – Third Edition (WAIS-III) processing speed index, even after post-concussive symptoms have resolved (Gardner et al., 2010). Rugby players with a history of two or more concussions were significantly slower than athletes from non-contact sports in completing a task of visuomotor speed (Trail Making Task A) and complex processing speed (Digit Symbol Substitution; Shuttleworth-Edwards & Radloff, 2008). Thus, those with at least two concussions demonstrate slowed processing speed compared to those with fewer injuries.

Executive functions include a range of cognitive processes, including mental flexibility, planning, initiation, inhibition, attention regulation, set switching, and working memory (Castellanos et al., 2006). Part B of the Trail Making Task (TMT-B) and Color-Trails Part 2 are measures of executive functioning that assess task switching, working memory (Sanchez-Cubillo et al., 2009), and executive control (Arbuthnott & Frank, 2000). Athletes with two or more concussions completed TMT-B and Color-Trails Part 2 significantly slower than those with fewer injuries (Collins et al., 1999; Shuttleworth-Edwards & Radloff, 2008; Wall et al., 2006). Similarly, those with multiple concussions performed worse than those with a single concussion on a task of inhibition and interference (i.e., Stroop Color and Word Test; Wall et al., 2006). These slower performances on tasks of executive functioning indicate those with two or more concussions have weaknesses in executive functioning domains compared to those with fewer injuries.

1.4 Executive Function, Processing Speed, and Academic Skills

Processing speed and several components of executive functioning – specifically inhibition, planning, and working memory – are regulatory processes that are vital to academic skills and are associated with reading, writing, and behaviors that promote academic success. In regard to reading, executive functions and processing speed contribute to reading comprehension and reading rate abilities. For example, differences in working memory and planning predict reading comprehension abilities between groups of children with reading disabilities and controls (Sesma et al., 2009). Working memory is the best predictor of word reading and reading comprehension abilities in children and adolescents (Christopher et al., 2012). Similarly, adults with reading disabilities demonstrate significantly lower scores on measures of working memory than controls (Beidas et al., 2013; Georgiou & Das, 2015) and demonstrate deficits in processing speed compared to controls (Stoodley & Stein, 2006; Trainin & Swanson, 2005). Thus, weaknesses in executive functions and processing speed are associated with reading difficulties.

Writing skills are also related executive function abilities. In a review of the literature in young children, attention, inhibition, and working memory are a main component of neuropsychological models of writing (Hooper et al., 2011). Further, children with writing difficulties score significantly lower than children without writing difficulties on tasks of initiation and sustained attention (Hooper et al., 2002). However, it is unclear to what extent executive functioning or other cognitive processes are associated with academic writing in higher education populations as little research has focused on the writing skills of adults. It can be concluded, at least in younger groups, writing difficulties are related to lower executive functioning abilities.

Weaknesses in executive functioning can interfere with behaviors and productivity that are conducive to academic success. Time-management, motivation, and inhibition skills predict ratings of work performance, work quality, and even behavioral and interpersonal problems at work (Barkley & Murphy, 2010). Former athletes with a history of multiple concussions reported more problems in everyday activities, the ability to control their behavior, problem solve, plan, stay organized, and sustain effort when compared to normative data (Seichepine et al., 2013). Therefore, individuals with a history of multiple concussions are likely to have more difficulties in their everyday activities, in part due to weaknesses in executive functioning.

In relation to academics, regulatory behaviors that promote student success are linked to executive functions. Impulsivity, self-control, distractibility, motivation, and organization were strong predictors of procrastination (Steel, 2007). Lower self-reported inhibition, self-monitoring, and task monitoring predict academic procrastination in college students (Rabin et al., 2010). In turn, academic procrastination is associated with lower academic achievement (Moon & Illingworth, 2005). Thus, lower abilities to inhibit and monitor could negatively impact academic success.

In summary, lower executive function and processing speed abilities are associated with decreased reading and writing skills. Weaknesses in executive functioning are related to increased behaviors that are in contrast to academic success. As previously discussed, persons with multiple concussions have weaknesses in these regulatory processes. Thus, difficulties in academic skills and lower academic performance could be expected in university students with multiple concussions.

1.5 Concussions and Academic Performance

The majority of the literature regarding concussion and academic performance focuses on younger children and high-school athletes and indicates that concussion has – at least in the short term – a negative impact on academics (Ransom et al., 2015). Indeed, high school athletes with a history of multiple concussions demonstrated significantly lower GPAs than athletes with no history of concussion (Moser et al., 2005).

GPA is the most common academic outcome used in academic research, and is useful, but it has limitations such as not reflecting qualities or skills that help students succeed after their college career (York et al., 2015). To more fully capture academic success, this study measured components of York et al.'s (2015) model of academic success (e.g., academic achievement, attaining course and major learning objectives, acquiring necessary skills and competencies, a student's satisfaction with their institution and environment, persistence, and post college performance), as well as some foundational academic skills (e.g., reading, writing, and typing abilities), was used to determine if, and how, a history of multiple concussions influences academic performance and skills in college students.

York et al.'s (2015) theoretical model of academic success is a relatively new inception and there are no instruments available to measure the model. A self-report inventory to measure academic success was developed for the present study following this model. Students responded to a learning difficulty assessment questionnaire to examine other skills important to academics, such as concentration, organization, time management, and self-inhibition.

1.6 Concussion and Psychopathology

Concussions increase psychological symptoms immediately after injury (Yang et al., 2015) and potentially – in the context of multiple concussion – after acute recovery. At a 9 year follow up, athletes were more likely to be diagnosed with depression if they sustained a concussion and the rate of depression amongst players increased with each additional concussion (Kerr et al., 2012). Less is known about other psychological symptoms – such as irritability and anxiety – following multiple concussions.

1.7 The Present Study

This study examined associations between multiple concussions and academic skills and success in college students. Academic skills, success, and cognitive abilities were measured in three groups, namely university students who reported a history of three or more concussions, students who reported a history of a single concussion, and a control group who reported no history of concussion. Students with one previous injury served as a clinical control group because the effects of a single concussion on cognition are more acute than chronic (Williams et al., 2015).

It was hypothesized that, students with a history of multiple concussion would score significantly lower on measures of executive function, processing speed, academic skills, and academic success than students with a single, or no previous, concussion. If significant differences in academic outcomes were found, we determined if group differences in academic outcomes were mediated by cognition. It was hypothesized multiple concussion status would be associated with lower academic outcomes and this relationship would be, at least partially, mediated by differences in executive functioning and processing speed.

This study fills a gap in knowledge about the association between multiple concussions, cognitive abilities, and academic outcomes in university students. We measured a broad range of academic outcomes. By determining the academic skills and performance areas that are weaknesses in university students with multiple concussion, interventions could be created to assist these students achieve academic success. For example, if students with multiple concussions exhibited significantly slower reading and/or writing rates, accommodations such as extended time on assignments could be recommended for these students to increase their likelihood of success. This study may assist university academic support staff and clinicians identify students who may be at an increased risk for academic difficulties (e.g., students with three or more concussions). Results could also be used to develop psycho-education materials to teach educators, students, and their parents about associations between multiple concussions and academic performance.

CHAPTER 2

METHOD

2.1 Power Analysis

A power analysis using G*Power and pilot data from 13 university students who had a history of three or more concussions was conducted. This multiple concussion group was compared to students with one or no previous concussion (n = 64) on a processing speed task. There was a medium effect size difference in processing speed between the multiple concussion and control group.

G*Power revealed that three groups of 56 participants would be needed to reach a power of .80 ($\alpha = .05$, medium effect sizes) for the analysis of variance (ANOVA) to assess for group differences on executive functioning, processing speed, and academic outcomes.

For powering the mediation models, G*Power revealed a total of 550 participants would be needed to reach a power of .80 ($\alpha = .05$, small effect sizes). Bias-corrected bootstrapping calculations were conducted to adequately power the model. In these calculations, bootstrapping creates a resampled group from a generated population. To test the mediation models, bias corrected means, standard errors, and confidence intervals were generated using 10,000 bootstrapped samples for adequate power.

2.2 Participants

Three groups [i.e., three or more previously diagnosed concussions (MC; $n = 58$), history of a single concussion (SC; $n = 57$), and no history of concussion ($n = 57$)] of students from the University of Massachusetts Amherst (UMass) participated in this study (Table 1). Participants in the concussion groups must not have experienced a concussion within the past 12 months. All participants were 18 years or older and native English speakers. Exclusion criteria were a history of Learning Disabilities (LDs), Attention Deficit Hyperactivity Disorder (ADHD), Asperger's or Autism Spectrum Disorder.

2.3 Procedure

Undergraduate students in psychology courses completed pre-screen questions that indicated if they were eligible for the study. Eligible participants were invited to participate and signed up for study slots using the SONA system. Participants provided informed consent prior to beginning the study.

Next, participants completed a Demographic Questionnaire (Appendix A), and questionnaires about academic performance (Academic Success Questionnaire, Appendix B), psychological functioning (i.e., Beck Depression Inventory - II, Affective Reactivity Index, State-Trait Anxiety Inventory, Barkley Current and Childhood Inattention and Hyperactivity Scales), a learning difficulty questionnaire (Kane Learning Difficulty Assessment), and present concussion symptoms (Post-Concussion Scale). Participants in the concussion groups were interviewed about their previous concussions using the Concussion History Questionnaire (Appendix C). To control for potential group differences in intelligence, all participants completed a brief measure (North American Adult Reading Test) to estimate premorbid IQ.

Next, participants completed a cognitive assessment with focus on executive functioning and processing speed abilities. The tasks (Table 2) focused on cognitive abilities that may be compromised after concussion and are vital for academic performance (i.e., attention processes, inhibition, processing speed, and working memory). Lastly, participants completed measures of academic skills (i.e., reading speed and reading comprehension, writing and dictation speed, typing speed; Table 3). Study sessions lasted about 90 minutes. Participants received one SONA credit for every half-hour of participation, rounded up to the closest half-hour. Study procedures were approved by the UMass Institutional Review Board (IRB).

2.4 Measures

2.4.1 Demographic Questionnaire

Participants reported their age, gender, race/ethnicity, handedness, socioeconomic status, and their current academic status (e.g., number of semesters completed, current grade point average, major; Appendix A). .

2.4.2 Concussion History Questionnaire

On the Concussion History Questionnaire (Appendix C), participants indicated if previous concussions had been diagnosed by a medical professional, the date of each injury, mechanism of injury (e.g., sports, motor vehicle accident, fall), if the individual lost consciousness, and if they experienced amnesia before or after the injury.

2.4.3 Adverse Childhood Experiences Questionnaire (ACEs)

Adverse childhood experiences are potentially traumatic experiences that can affect long-term health (Center for Disease Control, 2019). This questionnaire includes 10 potentially traumatic events participants could have experienced (e.g., emotional, physical, or sexual abuse, emotional or physical neglect, household substance use and mental illness, parental separation, and parental incarceration). Positive associations between adverse childhood experiences and head injuries have been found (Ma et al., 2019).

2.4.4 Affective Reactivity Index – Self Report (ARI)

The ARI assesses irritability over the past 6 months and consists of six items that are rated on a 3-point likert scale (e.g., 0 = not true, 1 = somewhat true, 2 = certainly true). The ARI demonstrates high internal consistency (α = .88 - .92; Stringaris et al., 2012). Self-report and caregiver/parental reports demonstrate strong correlations (r = .58 – .73; Stringaris et al., 2012). Although it was originally designed for children and adolescents, the ARI has strong convergent validity with other measures that assess mood irritability in adults (r = .53 – .80; Mulraney et al., 2014).

2.4.5 Barley Adult ADHD Rating Scale- IV (BAARS-IV)

The BAARS-IV is a self-report measure of ADHD symptoms over the past 6 months. Participants indicate the frequency of ADHD symptoms in their daily activities (Barkley, 2011, p. 1). This study used the retrospective childhood report and current symptoms report. Each contains 18 items that are evenly broken down between attention and hyperactivity difficulties. Test-retest reliability over a 2-3 week period has been found to be adequate for childhood (r = .73 - .82) and current reporting (r = .66 - .72; Barkley, 2011, p. 54).

2.4.6 Beck Depression Inventory Second Edition (BDI-II)

The BDI-II is a 21-item self-report measure of depressive symptoms over the past two weeks (Wang & Gorenstein, 2013). A recent review by Wang and Gorenstein (2013) found 2-week test-retest reliability to range from .76 - .96 and found the BDI-II to have diagnostic accuracy for the classification of major depressive disorder (MDD) of approximately 75%.

2.4.7 State-Trait Anxiety Inventory (STAI)

The STAI contains self-report questions about anxiety symptoms (Julian, 2011). For this study, state anxiety was measured via 20 items. In a review by Barnes et al. (2002), the STAI state scale test-retest reliability ($r = .70$) and internal reliability ($\alpha = .91$) were adequate.

2.4.8 Post-Concussion Scale (PCS)

The PCS measures the presence and severity of post-concussion symptoms (e.g., headache, light sensitivity, feeling mentally "foggy") in the past 2 days. The PCS was developed to assess post-concussion symptoms as reported by athletes and has demonstrates high internal consistency in healthy controls ($r = .88 - .93$) and in individuals experiencing post-concussion symptoms ($r = .93$; Iverson et al., 2006).

2.4.9 North American Adult Reading Test (NAART)

The NAART is a list of 61 irregular and uncommon English words that is used to estimate verbal intelligence (Uttl, 2002). The NAART can be abbreviated to 35 words without losing psychometric properties and significantly correlates ($r = .75 - .77$) to Wechsler Adult Intelligence Scale - Revised Vocabulary score (Uttl, 2002). Performance on irregular word reading lists to estimate prior intellectual functioning is unaffected by closed head injuries and provides valid estimate of premorbid intellectual functioning (Watt & Carroll, 1999).

2.4.10 Wechsler Adult Intelligence Scale - Fourth Edition (WAIS-IV), Coding

The WAIS-IV Coding task measures processing speed (Roivainen, 2011).

Participants are presented with nine symbols, paired with a different number. The participant must draw the symbol that corresponds to the number in a box below each number. Participants are prompted to complete as many of the boxes as they can in 120 seconds. The WAIS-IV Digit Symbol-Coding task has high test-retest reliability (*r* = .86; Wechsler, 2008). In terms of validity, the digit symbol-coding task correlates (*r* = .56) to the Repeatable Battery for the Assessment of Neuropsychological Status' attentional index (Wechsler, 2008, p. 97).

2.4.11 WAIS-IV Digit Span

The WAIS-IV Digit Span task measured participant working memory. In this task, participants recall numbers that are read aloud by the administrator in a specified order (i.e., forward, backwards, sequentially). The digit span task correlates (*r* = .57; Wechsler, 2008, p. 49) to the working memory index of the Wechsler Memory Scale and exhibits high (*r* = .83) test-retest reliability (Wechsler, 2008, p. 67). The total score from the subtest was used in analyses.

2.4.12 Trail Making Test, Part A (TMT-A)

Part A of the TMT measures visual search and visual processing speed (Sanchez-Cubillo et al., 2009). In this task, participants are given a sheet of paper with numbers scattered around the page. They must draw a continuous line - not lifting the pen from the paper - around the page connecting the numbers in order as quickly as they can. Completion time and errors were recorded. The TMT-A demonstrates high test-retest reliability (*r* =.75; Giovagnoli et al., 1996).

2.4.13 Trails Making Test, Part B (TMT-B)

The TMT-B measures working memory, cognitive flexibility, and executive control (e.g., Korrtle et al., 2002; Sanchez-Cubillo et al., 2009). In Part B of the TMT, numbers and letters are scattered around the page and participants must match numbers to letters in the order the letter appears in the alphabet (e.g., 1 – A, 2 – B, 3 – C). Participants must connect the letters and numbers in a continuous line and are asked to complete the task as quickly as they can. The TMT-B demonstrates high test-retest reliability ($r = .85$; Giovagnoli et al., 1996) and TMT-B scores significantly correlate ($r = .33$) to other measures of executive functioning such as the Wisconsin Card Sorting Task (Sanchez-Cubillo et al., 2009). Completion time and errors were recorded.

2.4.14 Delis-Kaplan Executive Functioning System (D-KEFS), Color-Word Interference (CW)

The D-KEFS CW task assesses cognitive flexibility and attentional control by having participants either reading words or saying the color ink in which a word is printed (Delis et al., 2001, p. 21). The task begins by having participants identify a various colors on a grid (CW-Color Naming) as quickly as they can. In the second part of the task (CW – Reading), participants read aloud a set of words (e.g., red, blue, or green) as quickly as possible. The first two parts of the CW task are considered verbally mediated measures of processing speed.

The final two assess executive abilities. The third task involves inhibition because the words are printed in an opposing color (CW – Inhibition). In the final task (CW – Switching), different rules dictate the correct response. For each of the four subtests, time of completion and number of errors was recorded. Test-retest reliability for the DKEFS-CW task ranges from .62 - .76 (Homack et al., 2005).

2.4.15 Kane Learning Disability Assessment (KLDA)

The KLDA is a survey that assesses academic skills in university students (e.g., reading, spelling, concentration, memory, organization) (Kane et al., 2011). That is, the KLDA provides information about individual learning strengths and weaknesses (Kane et al., 2011). There are 9 subtest scores and a total score derived from participant responses. Thirty-day test-retest reliability for the total score is .87 (Kane et al., 2011).

2.4.16 Academic Success Questionnaire (ASQ)

The ASQ (Appendix B) was developed for this study and was inspired by York et al.'s (2015) model of academic success in higher education. The questionnaire asks participants about how well they are attaining course learning objectives, if they are acquiring necessary skills for future success, and their level of satisfaction with their courses and institution. Development and initial validation for this measure were completed concurrent with the present study. A factor analysis from two samples ($n1$ = 150, $n2$ =164) revealed 10 items loaded onto a single factor with a relatively strong loading (i.e., >.60) across the samples. The 10-items exhibited good to excellent internal reliability (sample 1 α = .76, sample 2 α = .89). These items demonstrated strong internal consistency in the present study sample (α = .90). The 10 items were averaged to create a total score to indicate perceived academic success.

2.4.17 Nelson Denny Reading Test (NDRT), Part II

Part II of the NDRT assesses reading speed and reading comprehension in teenagers and adults in the United States (Coleman et al., 2010). First, participants read aloud a passage as quickly as possible (i.e., the curriculum based method [CBM]) to measure their reading rate. Measurement of reading rate is more reliable when persons read aloud versus silent reading and validity data are stronger (Lewandowski, et al., 2003). In the next section of the NDRT, participants have 20 minutes to read 7 passages and answer multiple choice questions about each passage. There are 38 questions and the total score is the number of correct answers. NDRT Comprehension significantly correlates with other measures of reading ability such as Woodcock-Johnson Reading Fluency Subtest score (r = .48; Lewandowski et al., 2003).

2.4.18 Woodcock-Johnson Tests of Achievement Fourth Edition (WJ-IV), Sentence Writing Fluency

The sentence writing fluency task assesses writing speed; participants quickly write sentences from pictures of stimuli. For each item, three different pictures are presented and participants must create a sentence about the pictures without changing the form of the stimuli (making them plural if singular) or omitting any of the objects or actions depicted. Participants have 5 minutes to complete as many sentences as they can. The number of correctly completed sentences was recorded. The sentence writing fluency task demonstrates high (r = .88) test-retest reliability (Mather & Wendling, 2014, p. 56).

2.4.19 Typing Speed Test

An online typing test (https://www.speedtypingonline.com/typing-test) measured participants typing abilities. Participants were provided a passage to type. The number of words accurately typed in a minute was recorded.

2.5 Analytic Plan

This study investigated potential differences on academics, executive function, and processing speed measures in university students with history of multiple concussion, one previous concussion, and students with no previous head injury. If significant differences existed between the multiple concussion group and the control groups on measures of academics, a mediation model determined if executive functions or processing speed mediated the association between multiple concussions and academic skills and academic success. For all analyses, the Holm Adjustment (Holm, 1979) was used to determine statistical significance, correcting for multiple comparisons. The Holm method is based on the Bonferroni correction but is less conservative and calculates *p*-values based on a hypothesis ranking system (Chen et al., 2017).

Preliminary analyses were conducted to check for distribution and skew of cognitive and academic scores. In the case of skew, variables were transformed (i.e., Log transformations) to create normal distributions. ANOVAs with post-hoc comparisons were conducted to test for group differences on potential control variables (e.g., estimated verbal IQ, psychological symptoms). For example, given that psychological symptoms might be elevated in the multiple concussion group and associated with poorer academic outcomes (Hysenbegasi et al., 2005), they were an important variable to consider. If groups significantly differed on the potential control variables, the variables were controlled to test hypotheses.

Since there were several measures of academic skill, executive functioning, and processing speed, analyses were conducted to reduce these data. We conducted correlations and principle component analyses (PCA) for scores of the same construct; when high correlations and single factor loadings were found, composite scores were created (e.g., a total processing speed score from TMT-A, CW-Color Naming, CW-Word Reading, and digit-symbol coding). The composite scores were used in primary analyses to reduce the likelihood of type 1 error due to multiple comparisons.

To test the hypothesis that students with multiple concussions had weaknesses in academic and cognitive domains, the dependent variables were scores from academic and cognitive measures and the independent variable was concussion group. Data were analyzed using an ANOVA - or analysis of covariance (ANCOVA), if necessary - with post-hoc comparisons to examine if the groups differed significantly on dependent variables.

To test our mediation models, we determined if the associations between concussion group status and academic outcomes was mediated by executive functioning or processing speed. SPSS with Process-macro version 3.4 tested this aim because it allows for multiple independent variables and testing covariates within the mediation model. If no group differences are found between the two control groups on measures of cognition and academics, then these groups were collapsed into a single control group to test the mediation model. Hayes (2013) steps for a mediation model were used in which an ordinary least squares regression in SPSS with PROCESS-macro is conducted. If significant group differences existed, then the groups remained separate in the model.

CHAPTER 3

RESULTS

3.1 Preliminary Analyses

The distributions of psychological symptoms, cognitive, and academic scores were determined and test variables with skew +/- 1.0 (i.e., ARI, BDI, BAARS-IV Current Attention and Hyperactivity, PCS, CW-Color Naming, Reading, Switching, Inhibition, TMT-B, WJ-IV Sentence Writing Fluency) were transformed into log10 or log10 +1 to approximate a more normal distribution. ANOVA with post-hoc comparisons (Table 4) were conducted to test for group differences on psychological symptom, adverse childhood experience, and pre-morbid intelligence variables. The MC group endorsed significantly greater psychopathology than the SC and control groups. Thus, depression, irritability, post-concussion symptoms, current problems in attention and hyperactivity, and state anxiety scores were controlled in primary analyses. Additionally, the single concussion group scored significantly lower on estimated IQ and this variable was also controlled.

Correlations among measures of processing speed and executive functions were calculated to determine if they were sufficiently associated to support aggregation. All measures of executive functioning exhibited significant correlations (Table 5) with each other, as did all measures of processing speed (Table 6). A principle component analysis was conducted to ensure all executive functioning (Table 7) and processing speed (Table 8) measures loaded onto single factors to create processing speed and executive functioning composite scores. Composite scores for executive functioning and processing speed were created by aggregating and averaging the standardized scores for each construct, respectively.

3.2 Group Comparisons of Academic and Cognitive Performance

To test our hypothesis that the MC group would have poorer executive function and processing speed scores than the SC and control groups, ANCOVAs were conducted to test for differences between the groups, controlling for group differences in psychological symptoms and estimated IQ. No significant group differences were found for the processing speed, $F(2, 162) = 0.68$, $p = .506$, or executive functioning composite, $F(2,162) = 0.52$, $p = .597$.

To test for group differences in academic outcomes (i.e., reading rate, reading comprehension, typing speed, sentence writing fluency, GPA, ASQ), ANCOVAs (Table 9) were conducted, controlling for psychological symptoms and estimated IQ. Consistent with expectations, significant differences between the groups existed on reading speed, reading comprehension, GPA, and academic risk. Pairwise comparisons revealed the MC group read significantly fewer words per minute than the SC ($p = .001$) and control group ($p = .024$). On reading comprehension, pairwise comparisons showed the MC group ($p = .006$) scored significantly lower than the SC group but not control group. Unexpectedly, the control group scored significantly lower ($p = .016$) than the SC group on reading comprehension. The SC group also scored significantly higher on the KLDA Academic Risk scale than the control group ($p = .035$) but not the MC group ($p = .155$). The MC group reported significantly lower GPA ($p = .018$) than the control group but not the SC group.

For purposes of the mediation model, academic skill scores were standardized and aggregated into a composite due to significant correlations (Table 10) and loading on a single factor in the PCA (Table 11). ANCOVA revealed a significant difference between groups $F(2, 161) = 4.03$, $p = .02$. Pairwise comparisons indicated the MC group ($M = -0.79$, $SE = 0.38$) scored significantly lower on this composite ($p = .005$) than the SC group ($M = 0.72$, $SE = 0.37$).

3.3 Executive Functioning and Processing Speed as Mediators of Academic Outcomes

Models were run to test the hypotheses that executive functions and processing speed mediated the associations between concussion group and academic outcomes. Executive functioning or processing speed served as mediators, with psychological symptoms and estimated IQ as covariates. The executive functioning and processing speed composite scores were significantly correlated ($r = .56$), so parallel mediation models were used. The SC and control groups were collapsed into a single control group for because they did not significantly differ (i.e., GPA, Academic Skills). Psychological symptoms and estimated IQ were controlled in each model.

3.3.1 GPA

The first parallel mediation model tested if executive function or processing speed composite scores mediated the association between concussion status (i.e., zero or one concussion = 0, MC = 1) and GPA. There was a significant direct effect of concussion status on GPA but the indirect effect of concussion status on GPA through executive functioning -or processing speed - was not significant (Table 12).

3.3.2 Academic Skills

Concussion status (i.e., MC = 1, SC and control = 0) was the predictor variable with academic skill composite as the outcome. There was a significant total and direct effect of concussion status on academic skills but no indirect effects through executive functioning or processing speed (Table 13).

CHAPTER 4

DISCUSSION

The current study determined academic, cognitive, and psychological differences between university students with three or more previous concussions, those with a single concussion, and students with no history of head injury. Results indicated poorer academic functioning among university students with a history of multiple concussions compared to those with one or no prior concussions. For example, university students with multiple concussions read fewer words per minute and reported a lower GPA than their peers with no previous concussion. Those with multiple concussions also endorsed higher levels of psychopathology.

4.1 Psychopathology

The most substantial differences between groups were with regard to psychopathology. Students with multiple concussions reported significantly higher levels of depressive symptoms, anxiety, irritability, post-concussion symptoms, hyperactivity, and attention difficulties than their peers with fewer or no concussions. To our knowledge, there is no previous research on psychological symptoms in university students who were recovered from multiple concussions. The multiple concussion sample in our study was, on average, over 32 months since their last concussion. Thus, the multiple concussion group is well beyond the typical window of recovery (i.e., <12 months).

Causal associations between multiple concussions and psychological symptoms cannot be determined from this cross-sectional study; we do not know the prevalence of psychological symptoms prior to injury. One hypothesis is that elevations in psychopathology might be due to difficulties in emotion regulation in those with multiple concussions. Emotion regulation processes have been found to be inefficient for up to 20 months following a single concussion (Mäki-Marttunen et al., 2015). A second hypothesis is these elevations in psychological symptoms were premorbid. For example, elevations in ADHD symptoms, specifically impulsivity, are associated with higher rates of concussion (Kerr, 2014). What is clear from our study is students with multiple concussions have a higher level of distress than those with fewer head injuries. This distress appears to manifest in a wide range of psychological symptoms.

4.2 Academic Skills and Performance

Consistent with our expectations, university students with multiple concussions reported lower GPAs compared to their peers. In other work, high-school students with a history of multiple concussions also were more likely to have lower GPAs than those with no previous injury (LaRoche, et al., 2016). Our findings add support to the literature regarding multiple concussion and lower academic performance. Lower academic performance could have negative consequences for future graduate or professional school plans for students with multiple concussions (Merolla & Serpe, 2013).

Participants with multiple concussions exhibited lower academic skills relative to the control group. In our broader conceptualization of academic skills, we found the multiple concussion group had a significantly slower reading rate than the single concussion and control groups. As far as we are aware, this is the first study to examine associations between concussions and academic skills in university students.

Unexpectedly, the multiple concussion group did not endorse greater levels of learning difficulty relative to the control groups. This finding is somewhat surprising because – as discussed above – the multiple concussion group demonstrated poorer academic skills and lower GPAs than the control groups. The fact that our concussion groups differed in expected directions on some – but not all – academic measures, indicate the specific skill difficulties students with multiple concussions experience.

4.3 Executive Functions and Processing Speed

Contrary to expectations and previous findings (e.g., Collins et al., 1999; Gardner et al., 2010; Shuttleworth-Edwards & Radloff, 2008; Wall et al., 2006), university students with multiple concussions did not exhibit relative weaknesses in executive functioning and processing speed when compared to their peers with one or no previous concussions. One possible reason for not replicating these findings is that our study only recruited participants who were beyond the window of recovery following concussion. Participants might have still been recovering from their last concussion when relatively lower executive functioning and processing speed scores were found relative to controls (Gardner et al., 2010; Wall et al., 2006).

A strength of this study and possible explanation for why group differences were not found in executive function was the exclusion of students with ADHD. For example, university students with ADHD can have weaknesses in executive functioning (Gapin et al., 2015; Schweitzer et al., 2006). One study that found weaknesses in executive functioning in persons with multiple concussions did not exclude those with ADHD (Shuttleworth-Edwards & Radloff, 2008). Further, ADHD is associated with higher rates of multiple concussions (Nelson et al., 2016). Thus, previously reported differences in executive functioning amongst athletes with multiple concussions might be due – in part – to the multiple concussion groups containing more persons with ADHD.

4.4 Limitations and Future Research

The samples in the current study were primarily female and had little ethnic or racial diversity and thus may not generalize to more diverse samples. Concussion-status was self-reported and was not confirmed by record review. Documented history of concussion would be useful to verify concussion status in future research. Our study was cross-sectional and thus we do not know if psychological symptoms and/or academic difficulties were present prior to head injury and conclusions about causality cannot be made.

Future studies should focus on possible mediators of the association between academic performance and concussion status. Our data suggest that concussion group differences in academic difficulties may not be due in large part to group differences in executive functions or processing speed. Research on other constructs such as psychological symptoms could be useful in explaining the differences in lower academic skills and performance. By uncovering these mechanisms, more targeted interventions to improve academic outcomes in students with a concussion history could be created. Interventions could include referrals to psychological service centers for psycho-education about difficulties following multiple concussions.

Research should determine if cognitive behavioral therapy (CBT) or other forms of psychotherapy are effective for students with multiple previous concussions with anxiety, depressive symptoms, attention difficulties, and elevated post-concussion symptoms. Persons with chronic anxiety, depression, and attention complaints benefit from individual CBT (Tiersky et al., 2005). CBT is also useful in providing information, education, and reassurance for those with prolonged post-concussion symptoms (Al

Sayegh et al., 2010). Academic difficulties should be monitored to investigate if CBT can assist students with multiple concussions to improve their academic performance.

For persons with attention and academic difficulties following multiple concussions, cognitive rehabilitation may be useful. Cognitive rehabilitation (e.g., direct attention training, metacognitive strategy instruction, and implementing technology) techniques can assist students in attaining their academic goals (Sohlberg & Ledbetter, 2016). Future research should focus on implementing these modalities in students with multiple concussions while monitoring academic progress.

4.5 Implications and Conclusion

The current study investigated the academic outcomes and cognitive abilities of university students with a history of zero, one, or multiple concussions. Results indicated that university students with a history of multiple concussions demonstrated increased psychological symptoms - including anxiety, depressive symptoms, attention difficulties, and hyperactivity – as well as lower GPA and lower reading rates than their peers with a history of one or zero concussions. Whether the psychological symptoms and weaknesses in academic skills and performance are a consequence of multiple concussions or were present prior to the injuries remains unclear.

Given the high rate of concussion amongst college students (e.g., 1:75 each academic year; Breck et al., 2019), clinicians and academic support staff should be alert for elevations in psychological symptoms and academic problems in students with a history of multiple concussions. Students with multiple concussions should be assessed for psychopathology and possibly referred to mental health and academic support services to assist them in reaching their academic potential.

Table 1. Demographic Frequencies and Descriptive Statistics by Group

	Control *n* = 57	Single Concussion *n* = 57	Multiple Concussion *n* = 58
Age	20.18 (1.30)	19.67 (1.23)	19.72 (1.46)
Biological Sex			
Female	74%	79%	72%
Race			
White	72%	84%	85%
Asian	7%	7%	10%
Latinx	4%	4%	4%
Currently Employed	47%	44%	41%
Hours Worked per Week	7.55 (10.03)	7.55 (10.03)	5.18 (7.07)
Socioeconomic Status			
Lower	4%	4%	4%
Lower-middle	21%	14%	7%
Middle	42%	46%	33%
Upper-middle	32%	32%	53%
Years of Education	14.21 (1.42)	13.76 (1.50)	14.12 (1.17)
Semesters Completed	3.74 (2.01)	3.05 (2.10)	3.41 (2.15)
Number of Diagnosed Concussions	0.00 (0.00)	1.00 (0.00)	3.59 (1.42)
Months Since Last Concussion	-	51.82 (39.10)	32.85 (17.57)

Table 2 Measures of Executive Functioning and Processing Speed

Executive Functioning	Processing Speed
Trails B	Trails A
CW - Inhibition	CW- Color Naming
CW- Switching	CW- Reading
WAIS-IV Digit Span	WAIS-IV Coding

Table 3. Measures of Academic Skills and Academic Success

Academic Skills	Academic Success (AS)
Kane Learning Disability Assessment	Grade Point Average (GPA)
Reading Rate	ASQ Score
Reading Comprehension	
Sentence Writing Fluency	
Typing Speed	

Table 4. Psychological Symptom and Estimated IQ Control Variables

	Control	Single Concussion (SC)	Multiple Concussion (MC)	*F*	*p*	Partial η^2
Estimated IQ	118.73 (4.00)	116.67 (4.00)	117.31 (4.40)	3.72	.026	.04
ACEs	1.26 (1.60)	1.11 (1.52)	1.39 (1.96)	0.38	.682	.01
BDI	7.34 (6.79)	7.76 (5.67)	13.44 (9.54)	12.31	<.001	.13
BAARS-IV Current Inattention	0.83 (1.66)	1.04 (1.46)	2.13 (2.26)	8.36	<.001	.09
BAARS-IV Current Hyperactivity	0.82 (1.07)	1.32 (1.53)	1.71 (1.40)	6.25	.002	.07
BAARS-IV Childhood Inattention	1.02 (1.94)	1.00 (1.64)	1.74 (2.15)	2.83	.062	.03
BAARS-IV Childhood Hyperactivity	1.46 (2.13)	1.53 (1.73)	1.68 (1.95)	0.20	.816	.00
ARI	1.21 (1.39)	1.41 (1.94)	2.29 (2.19)	5.37	.005	.06
Post-Concussive Symptoms	11.63 (11.28)	16.12 (12.56)	25.78 (17.66)	15.07	<.001	.15
STAI-State	34.74 (11.02)	31.66 (7.99)	38.31 (11.10)	6.18	.003	.07

Table 5. Correlations between Executive Functioning Measures

	Digit Span	Trails B	DKEFS Inhibition	DKEFS Switching
Digit Span	-	.33**	.27**	.15
Trails B	.17*	-	.72**	.48**
DKEFS Inhibition	.29**	.41**	-	.67**
DKEFS Switching	.17*	.28**	.52**	-

Note. Subtest correlations for the MC group are above the diagonal, the SC and control groups are below.
**p* < .05, ***p* < .01

Table 6. Correlations between Processing Speed Measures

	Coding	Trails A	DKEFS Color Naming	DKEFS Word Reading
Coding	-	.32*	.55**	.37**
Trails A	.33**	-	.36*	.33**
DKEFS Color Naming	.35**	.25**	-	.71**
DKEFS Word Reading	.33**	.29**	.68**	-

Note. Subtest correlations for the MC group are above the diagonal, the SC and control groups are below.
$*p < .05$, $**p < .01$.

Table 7. PCA Loadings of Executive Function Measures

	Component 1
Digit Span	.48
Trails B	.70
DKEFS Inhibition	.87
DKEFS Switching	.75

Table 8. PCA Loadings of Processing Speed Measures

	Component 1
Coding	.65
Trails A	.54
DKEFS Color Naming	.83
DKEFS Word Reading	.83

Table 9. Cognitive and Academic Dependent Variable Scores

	Control	Single Concussion (SC)	Multiple Concussion (MC)	*F*	*p*	Partial η^2
Processing Speed Composite	0.05 (0.65)	0.09 (0.55)	-0.13 (0.85)	0.68	.506	.01
Executive Functioning Composite	0.04 (0.61)	0.11 (0.70)	-0.14 (0.84)	0.52	.597	.01
Reading-words per minute	169.69 (26.50)	170.83 (26.85)	156.19 (23.50)	5.47	.005	.06
Reading Comprehension	25.03 (6.64)	27.57 (5.08)	24.82 (5.96)	4.77	.010	.06
Typing Speed	48.08 (14.02)	46.49 (11.28)	42.85 (14.08)	0.83	.440	.01
Sentence Writing	31.09 (4.38)	31.36 (4.50)	29.80 (5.96)	1.80	.169	.02
Overall Academic Risk	2.12 (0.67)	2.45 (0.70)	2.74 (0.68)	2.32	.102	.03
GPA	3.57 (0.34)	3.50 (0.33)	3.36 (0.47)	3.00	.053	.04
ASQ	4.01 (0.52)	3.97 (0.44)	3.85 (0.52)	1.38	.255	.02

Table 10. Correlations among Academic Skill Measures

	Reading Speed	Reading Comprehension	Sentence Writing	Typing Speed
Reading Speed	-	.48***	.36***	.32**
Reading Comprehension	.36***	-	.12	.15
Sentence Writing	.29***	.30**	-	.33**
Typing Speed	.41***	.24**	.18*	-

Note. Subtest correlations for the MC group are above the diagonal, the SC and control groups are below.
* $p = .05$, ** $p < .05$, ***$p < .01$

Table 11. PCA Loading among Academic Skill Measures

	Component 1
Reading Speed	.80
Reading Comprehension	.63
Sentence Writing	.67
Typing Speed	.67

Table 12. Total, Direct, and Indirect Effects for Concussion Status on GPA through Executive Functioning or Processing Speed

	B	SE	*t*	*p*	95% CI
Total Effects	-0.16	0.07	-2.22	.028	-0.31 - -0.02
Direct Effects	-0.14	0.07	-2.00	.048	-0.28 – 0.01
Indirect Effects Total	-0.02	0.03	-	-	-0.09 – 0.02
Executive Functioning	-0.02	0.02	-	-	-0.08 – 0.01
Processing Speed	-0.01	0.01	-	-	-0.02 – 0.01

Table 13. Total, Direct, and Indirect Effects for Concussion Status on Academic Skills through Executive Functioning or Processing Speed

	B	SE	*t*	*P*	95% CI
Total Effects	-1.29	0.48	-2.68	.008	-2.23 - -0.34
Direct Effects	-1.06	0.44	-2.43	.016	-1.92 - -0.20
Indirect Effects Total	-0.23	0.24	-	-	-0.72 – 0.22
Executive Functioning	-0.08	0.09	-	-	-0.30 – 0.06
Processing Speed	-0.16	0.19	-	-	-0.57 – 0.21

APPENDIX A

DEMOGRAPHIC QUESTIONNAIRE

Age: ____________

Biological Sex: ____________

Race: White Black/African-American Latinx Asian

Other

Handedness: Left Right Mixed

How many years of education have you completed? ______________

How many semesters of university have you completed? ______________

What is your GPA? ______________

What is/are your major(s)? ____

Are you currently employed? Yes No

How many hours per week do you work? ______________

How would you define your family's socio-economic status?

Lower Lower-Middle Middle Upper-Middle Upper

APENDIX B

ACADEMIC SUCCESS QUESTIONNAIRE

I enjoy my classes.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I enjoy being a student.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I'm happy I chose to attend this college/university.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am acquiring the necessary skills to help me in my future career.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I will be successful after I graduate college.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I understand major points from courses.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am acquiring knowledge that will help my future studies.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I complete all my assignments.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I do the best I can in my courses.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I work hard in my courses.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

APPENDIX C

CONCUSSION HISTORY QUESTIONNAIRE

Please select one of the following:

☐ I have <u>definitely</u> had a concussion. It was doctor diagnosed.

☐ I have had a concussion but it was <u>not</u> doctor diagnosed.

☐ I do not know if I have had a concussion.

☐ I have <u>definitely</u> not had a concussion.

Please complete your concussion history below about <u>doctor-diagnosed</u> concussions

Most recent concussion
Date (month/year)__________ Age ________
☐ Lost consciousness
☐ Experienced amnesia

Second most recent concussion
Date (month/year)__________ Age ________
☐ Lost consciousness
☐ Experienced amnesia

Third most recent concussion
Date (month/year)__________ Age ________
☐ Lost consciousness
☐ Experienced amnesia

Fourth most recent concussion
Date (month/year)__________ Age ________
☐ Lost consciousness
☐ Experienced amnesia

Fifth most recent concussion
Date (month/year)__________ Age ________
☐ Lost consciousness
☐ Experienced amnesia

Sixth most recent concussion
Date (month/year)__________ Age ________
☐ Lost consciousness
☐ Experienced amnesia

Seventh most recent concussion
Date (month/year)__________ Age ________
☐ Lost consciousness
☐ Experienced amnesia

Eighth most recent concussion
Date (month/year)__________ Age ________
☐ Lost consciousness
☐ Experienced amnesia

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