University of Nevada, Reno

Cognitive Impairments in Undergraduates with a History of Mild Traumatic Brain Injury

A thesis submitted in partial fulfillment
of the requirements for the degree of

Bachelor of Science in Neuroscience and the Honors Program

by

Alexandrea Kilgore-Gomez

Dr. Marian Berryhill, Thesis Advisor

May, 2020

UNIVERSITY OF NEVADA RENO

THE HONORS PROGRAM

We recommend that the thesis
prepared under our supervision by

ALEXANDREA KILGORE-GOMEZ

entitled

Cognitive Impairments in Undergraduates with a History of Mild Traumatic Brain Injury

be accepted in partial fulfillment of the
requirements for the degree of

BACHELOR OF SCIENCE, NEUROSCIENCE

____
Marian E. Berryhill, Ph.D., Thesis Advisor

____
Matthew Means, P.S., Director, **Honors Program**

May, 2020

Abstract

Millions of traumatic brain injuries (TBI) occur in the United States each year with a majority of cases classified as mild traumatic brain injuries (mTBI, concussions). However, little data reflects whether symptoms resolve years after injury despite the common assumption that cognitive functioning returns to premorbid levels after 3 months post-injury. Previous findings have demonstrated variable visual working memory (WM) performance following a mTBI, but there is little known about the lasting implications of mTBI and whether cognitive deficits persist years after injury. This investigation employs a visual change detection task and a visual attention distractibility task to understand the deficits in undergraduates with a history of mTBI in WM and attention respectively. These paradigms allowed us to understand when deficits emerge in the mTBI population in WM and attention. In addition to performance on these cognitive tasks, we also collected academic measures from participants such as study attitude and habit questionnaires, self-reported GPA, and change in major. This study found that cognitive performance was heterogeneous for the mTBI group and that academic measures are not a predictor of cognitive performance or mTBI outcome. The results indicate that mTBI participants have mixed outcomes in cognitive performance, with some deficits persisting years after injury.

Acknowledgements

I would like to thank a few individuals for their contributions to my thesis projects. I would firstly like to thank my mentor Dr. Marian Berryhill. She has supported me over the entire course of my undergraduate career and has been integral in shaping my future. I am so grateful to have worked with her and learned from her over the years. I would also like to thank Hector Arciniega for guiding me throughout this project. Jorja Shires and Carlos Carrasco helped tremendously in the coding aspect of this project and I thank them for their help. I would like to thank the National Science Foundation and the Honors Program for providing my funding: The National Science Foundation EPSCoR UROP Summer Award and the Honors Undergraduate Research Award. Lastly, I am grateful to my friends and classmates for running in my experiments for the sake of this project. In addition, my parents have supported me throughout my lifetime and I thank them sincerely.

This thesis would not have been possible without these individuals.

Table of Contents

List of Tables

List of Figures

Introduction

Traumatic brain injury (TBI), or disruption of brain activity caused by events such as accidents or sports, is becoming better known given increased media attention. Recent reports illustrate that multiple concussions and repeated head injuries can cause chronic traumatic encephalopathy (CTE), typically associated with repeated injuries in high-impact sports such as boxing or football (McKee et al., 2009). Yet, little is known about the lasting implications of mild traumatic brain injury (mTBI), commonly known as *concussion*. mTBI is described by the American Congress of Rehabilitation Medicine as a mild insult to the head that results in a brief period of unconsciousness followed by impaired cognitive function. It is well established that even a single mTBI leads to pathophysiological changes in the brain. mTBI causes an array of symptoms, including headaches, fogginess, depression, anxiety, noise and light sensitivity, and irritability (Mild Traumatic Brain Injury Committee, 1993). Concussion is the most prevalent type of TBI. Millions of mTBIs occurring in the U.S. every year and many mTBI cases go unreported because individuals are not formally diagnosed by physicians (Taylor et al., 2017). Patients with uncomplicated cases of mTBI are believed to fully recover within several months after symptoms resolve and patients generally resume daily activities with lasting cognitive consequences. However, because of the varied ways in which people are injured, the mTBI population is highly heterogeneous. Emerging findings clarify that that subsets of mTBI survivors exhibit long-term cognitive impairments. There is insufficient data tracking mTBI patients over lengthy time periods (>1 year) to allow an examination of the trends in cognitive changes; this is because medical intervention ends after a several-week period or the resolution of lingering symptoms. There is a lack of research on the consequences of mTBI on working memory (WM) and attention, two cognitive domains that are essential to our everyday functioning. These functions allow us to select and maintain important information to accomplish immediate and pending goals.

Because there is a high prevalence of reported mTBIs, it is important to understand its associated lasting cognitive impairments. In other words, it is important to identify the likelihood and extent of lasting cognitive deficits to begin to address them. As such, the aim of this thesis is geared towards understanding the consequences of mTBI on WM and attention.

Background: Definition of mTBI

Mild traumatic brain injury (mTBI), which includes concussion, is the most common type of traumatic brain injury and is colloquially defined to as a head injury that temporarily affects brain functioning. The symptoms of mTBI generally fall into categories of physical symptoms, cognitive deficits, and behavioral changes (Mild Traumatic Brain Injury Committee, 1993). Physical symptoms of mTBI include but are not limited to headaches, nausea, vomiting, dizziness, blurred vision, noise and light sensitivity, and sleep changes. In some instances, mTBI is also associated with a loss of consciousness that does not exceed 30-minutes. Immediate cognitive deficits are common and can include changes in attention, memory, or other executive functions (e.g., planning ahead, motivation, following through on a task). mTBI is also defined by behavioral changes that can include alterations in irritability, anxiety, or emotional lability. Symptoms of brain injury may or may not persist, for varying lengths of time following an injury (Mild Traumatic Brain

Injury Committee, 1993). Some people may not become fully aware of, or acknowledge, the extent of their symptoms until they fail to return to normal functioning. mTBI poses unique challenges for medical practitioners to diagnose (Mayer, Quinn, & Master, 2017). As is the case with many neurological disorders, there are currently no biomarkers in the form of a laboratory test or an advanced neuroimaging technique that can be used to reliably detect an mTBI.

Recent research has shown atypical neural network activity in individuals with a history of mTBI using resting state electroencephalogram data (Arciniega et al. 2020). As this is an emerging field, clinicians rely on more subjective diagnostic criteria to evaluate patients. However, the medical field is fragmented in terms of diagnostic and agreement regarding which prognostic factors which impacts patient care (Mayer et al. 2017). It is the generally accepted view across physicians that mTBI is not a significant health event, perhaps because nothing can be done in terms of treatment, and because symptoms typically resolve on their own and are *believed* to lead to full recovery. Persistent symptoms last in some patients, a condition called Persistent Concussion Syndrome (PCS; Ryan & Warden, 2009) that is not the focus of the current research. However, the perspective that mTBI leads to no lasting consequences is now clearly in question. The extent and prevalence of effects remains unclear.

The absence of consensus in defining mTBI diagnostic criteria also poses nosological challenges for neuroscience researchers and clinicians alike. It is currently hotly debated on whether it is appropriate to use the terms *mTBI* and *concussion* interchangeably, or if the two terms refer to two discrete clinical entities or not, such that concussion is a milder form of mTBI (Mayer et al., 2017). Others argue that using vague terminology such as concussion leads to misunderstandings and subjectivisms in the diagnostic process that results in unreliable science, unreliable clinical guidelines, and muddled public policy as the term concussion has no clear definition or pathological meaning (Sharp & Jenkins, 2015). Without a clear consensus on the diagnostic criteria, it becomes very difficult to study the associated cognitive impairments in a systematic way.

Epidemiology

The global and national burden of mTBI is significant. mTBI is an important public health problem in the United States resulting in disabling conditions and long-term societal costs. In 2013, it was reported that a total of approximately 2.8 million TBI-related emergency department visits, hospitalizations, and deaths occurred in the United States (Taylor et al., 2017). A meta-analysis (Cassidy et al., 2004) showed that 70-80% of all treated brain injuries are rated as mild. This statistic is significant because many individuals who sustain a head injury do not present to an emergency department for evaluations. Researchers know that the national burden of mTBI is underreported for this very reason (Bazarian et al., 2005). Older teenagers (ages 15 to 19 years) and older adults (ages 65 and older) are the most likely age demographics to sustain a mTBI. (Cassidy et al., 2004; Faul, et al., 2010).

A gender difference exists for individuals who sustain a mTBI. The male to female ratio for this injury is observed to be 2:1 (Georges & Booker, 2020). However, female sex is associated with significantly higher odds of poorer outcome after mTBI (Bazarian et al., 2020). Regardless of incidence, males and females recover from mTBI at the same approximate rate (Bazarian et al., 2010).

The individual hardship of mTBI extend beyond the yearly statistics. More broadly, moderate to severe TBI is a primary cause for injury-induced death and disability. In the United States alone, these outcomes have an annual incidence of approximately 500 to 100,000 (Georges & Booker, 2020). Approximately 5.3 million U.S. citizens are currently living with TBI-related disabilities (Smith, Johnson, & Stewart, 2013). Cognitive deficits caused by mTBI can interfere with school, work, relationships, and activities of daily life (Rabinowitz & Levin, 2014). Thusly, there are societal and humanistic impacts of mTBI that cannot be objectively measured.

mTBI Etiology

Mild TBI is the result of closed head injuries. There are several mechanisms that cause the resulting mTBI. This list includes events such as direct head trauma, falling, whiplash, rotational forces, and other forces elsewhere on the body that are transmitted to the head. Common causes of mTBI range from commonplace events such as falls, bicycle accidents, and sports-related impacts, to more serious incidents like motor vehicle accidents and assaults (Cassidy et al., 2004, Taylor et al., 2017). These injuries degrade the structural integrity of neurons, there is an initial fast metabolic crisis induced by shearing forces damaging the axons that is followed by several days of atypical metabolism (Johnson et al., 2013). The prolonged damage is believed to result in disconnection in neural connectivity due to incomplete restoration of white matter tracts.

Previous work in the lab has examined the etiology of mTBI by grouping injuries by non-sport, individual sport, team sport, and high-impact sport. The results of this analysis indicated that in individuals with a history of mTBI, the etiology did not predict the observed degree of visual working memory deficit (Arciniega et al. 2020). There is growing concern that lasting behavioral and anatomical changes are associated with high impact sports (Pan et al. 2016). An area of growing research interest is the relationship between repeated head injuries and cognitive outcomes.

Pathophysiology

At the cellular level the pathophysiology of mTBI predominately involves axonal injury (Laskowski et al., 2015). mTBI is also associated with a reduction of midbrain white matter integrity (Hirad et al., 2019). Axons in the white matter appear to be vulnerable to injury due to the mechanical loading nature of the impacts sustained (Johnson et al., 2013). One explanation for lasting cognitive deficits is that mTBI causes heterogeneous diffuse axonal injuries due to shearing forces (Arciniega et al. 2019). Few studies have investigated the long-term outcomes in the mTBI population despite its high prevalence and despite evidence that suggests there are some significant changes (Kenzie et al., 2017).

Media Attention and Public Awareness

Media attention in recent years has furthered the national conversation regarding mTBI and its everyday occurrence in our society. This conversation has been framed in the context of the high incidence of mTBI in high impact sports such as football, hockey, and boxing as well as in military personal.

In particular, considerable media attention has been paid to the discovery (Hay et al., 2016) and research associated with chronic traumatic encephalopathy (CTE) in professional athletes. CTE is characterized by the atrophy of myriad brain regions and enlargement of ventricles which is associated with memory disturbances, personality changes, Parkinsonism, and speech and gait abnormalities (McKee et al., 2009). Whereas CTE is characterized by significant, severe cognitive deficits, mood disorders, physical symptoms and clearly visible abnormal pathology than mTBI, there is a lesson that can be learned in that what was once considered inconsequential may not be so harmless. Recent studies, predominately based on autopsy and late-life data collected in professional athletes, suggests that the effects of mTBI may be more severe than originally believed (Mayer et al., 2017, Taylor et al., 2018).

The effects of a history of mTBI on visual working memory (WM)

The cognitive effects of mTBI can be long-lasting. In individuals with a history of mTBI, behavioral deficits are reported in a majority of patients and are accompanied by neural differences that are detectible *years* after an mTBI (Bajaj et al., 2018). One reason to carefully explore WM is that it is a key cognitive domain. WM is the representation of information that a person can temporarily access and manipulate while completing a task (Wheeler & Triesman, 2002). WM is limited in volume (Cowan et al., 2005) and is separated into 3 distinct stages: encoding, maintenance, and retrieval. WM is essential for reasoning and guiding decision-making behavior. WM is important because it allows us to sustain representations of items that are no longer present and is considered a 'mental workspace'. WM is essential for higher-order cognitive tasks such as manipulating information, planning ahead, resisting distraction, and completing goals. Examples of daily uses of WM include remembering a phone number, carrying out mental arithmetic problems, and remembering the position of other cars when switching lanes. If information cannot be retained in WM and integrated successfully, cognitive difficulties arise. For example, many people have the experience of losing their train of thought, immediately forgetting a new acquaintance's name, or not recalling what they needed from the refrigerator.

WM capacity is limited to about three or four items, and is both correlated with many important real-world abilities along with predicting performance on higher-order cognitive tasks. WM is sensitive to mTBI because it involves frontoparietal connections that rely on long white matter tracts across multiple brain regions. Additionally, it is well-established that WM is positively correlated with fluid intelligence (Engle et al., 1999).

Data from our lab has demonstrated that there is great heterogeneity in mTBI performance and recovery. Four different samples of undergraduates with a history of mTBI (mean >4 years post-mTBI) had visual working memory (WM) impairments (Arciniega et al., 2019). These participants were otherwise healthy and reported no residual symptoms of mTBI, despite having a history of injury. The nature of WM deficits emerged across the three stages of WM. Making the task easier at each stage did not benefit the mTBI group, which means that no single WM stage accounts for the deficits (Arciniega et al. 2019). This work leaves mTBI deficits without a clear attribution to a particular stage of WM and therefore suggests a mechanism that implicates each stage of WM in the deficit.

Impact of mTBI on Attention

Attention describes the process of integration of important stimuli in the environment while ignoring irrelevant distractors (Anderson, 2005). To encode an item, a participant must first attend to the item. By this logic, if attention fails, then working memory fails. Therefore, attention and WM are inextricably linked. Attention involves selectively concentrating on one item while ignoring distractors. Maintaining attention for more than a few seconds is essential for mastering tasks in everyday life.

Selective attention in particular is defined as the capacity of reacting to certain stimuli selectively when other information is presented simultaneously. Selective attention incorporates focused and divided attention, where the process of filtering out relevant sensory information from irrelevant distractors is important (Ziino & Ponsford, 2006). Previous behavioral work has indicated that impairments in selective attention may be the most common and enduring cognitive deficit in mTBI (Mayer et al., 2012). This top-down cognitive control is essential for daily functioning, as humans are constantly bombarded by similar and dissimilar information.

After observing deficits in the visual WM domain in mTBI participants (Arciniega et al., 2019), we suspected this same primarily non-complicated mTBI patient population may also have deficits with attention. This would be important to know because it would likely impose additional adverse effects on these students' academic outcomes. Thus, we hypothesize that mTBI participants fail to ignore distractors at the same rate as their neurotypical controls.

Approach and Aims

This thesis investigated the WM and attentional deficits after mTBI. Both WM and attention are cognitive domains essential for accomplishing immediate goals: from identifying important elements of the environment (e.g., cars, someone speaking to you, what you need from the fridge) to remembering what you are trying to do (e.g., remembering what you needed to grab from the counter). Individuals who self-report a history of mTBI may present asymptomatically, but they may or may not be free from cognitive changes as a result of their head injury. Individuals who present with even modest persistent effects of symptoms could have permanently attenuated cognitive function. It is imperative that the behavioral mechanisms underlying WM and attention in mTBI populations are better understood as they can have life-altering impacts on daily functioning.

Unfortunately, some unknown percentage (across several class surveys some 15-30%) of undergraduate students at the University of Nevada, Reno (UNR) report a history of mTBI. The majority of these individuals report sustaining their injury during their late-teen years. Testing in this otherwise healthy, motivated, intelligent population is noteworthy because undergraduates are arguably the best-case scenario of mTBI survivors. This population allows for the study of *whether* individuals with a history of mTBI differ in behavioral performance when compared to their unaffected classmates. Follow-up questions include addressing what kinds of deficits, whether it impacts their academic performance, and how to remediate performance.

Overall, the goal if the current research is to understand the WM and attentional deficits in undergraduates with a history of mTBI. When studying a special population, it is important not only to identify the behavioral deficits, but also which domains are spared so that the cognitive strengths of the population can be used to their advantage when developing coping strategies. Previous research studies, as shown above, identify a lack of research in understanding the long-term sequela associated with a history of mTBI. This thesis, however, further investigates how WM and attention contribute to behavioral deficits observed in select mTBI cohorts. The two research aims to advance the understanding of cognitive impairments in undergraduates with a history of mTBI.

Experiment 1 investigated the initial *encoding* period of WM. This experiment marked the final installment in a series of lab experiments wherein the stages of WM were systematically manipulated to understand when the deficits associated with mTBI emerged. Participants completed a visual WM change detection task for Experiment 1. Experiment 2 ventured outside of the WM domain and into the cognitive domain of attention, a closely related but precursor stage to WM. The line of WM research had been exhausted by investigated encoding, maintenance, and retrieval time points by concluding that WM is globally impaired. Investigating attention allowed for the exploration of cognitive impairments more broadly by looking at associated deficits, including those that contribute to effective WM. In Experiment 2, participants completed a visual attention task requiring them to ignore distractors. By understanding which mTBI participants have WM and attentional deficits and when they emerge, it may be possible to develop a training program or study strategies to overcome poor outcomes and improve cognitive performance.

Methods

Recruitment

Participants for Experiments 1 and 2 were recruited from undergraduate courses at UNR to ensure well-matched participant populations using convenience sampling. Additionally, participants were also recruited from the UNR SONA Psychology system.

Referrals were also solicited form the UNR Disability Resource for mTBI participants specifically.

Experiment 1

Participants

Thirty undergraduate students with a self-reported history of mTBI (22 females, 20.51 mean years old) participated in this study (see Table 1 for demographics). This cohort of mTBI individuals had a mean number of 2.76 mTBIs and 3.44 years since their most recent injury. mTBI participants reported whether their injuries were diagnosed by a physician. A total of 20 out of the 30 participants had their head injury formally diagnosed. They also provided information regarding the etiology of their most recent mTBI. By category, 10 sports-related, 7 car accident-related, and 13 other-related mTBIs were reported; see Table 2 for details. Twenty-five age- and education-matched neurotypical control participants (17 females, 20.4 mean years old) with no history of mTBI also completed Experiment 1; see Table 1 demographics.

Participants completed a demographics sheet approved by the Internal Review Board. The following include the questions asked: participant's age, sex, handedness, years of education, ethnicity, number of mTBI, date of most recent mTBI, duration of loss of consciousness, if any, formal medical diagnosis, etiology, and symptoms at the time of injury. The control participants did not have a history of neurological disorders. All participants were in good health. The Institutional Review Board at the University of Nevada, Reno approved all experimental protocols. Each participant gave written, informed consent prior to participating in the experiment in accordance with the guidelines of the University of Nevada, Reno Internal Review Board and were reimbursed $10/hour or course bonus credit.

Before starting the visual WM task, all participants completed two metacognitive awareness forms— the Revised Two-Factor Study Process Questionnaire (R-SPQ-2F) and the Metacognitive Awareness Inventory (MAI). These questionnaires were administered to participants to assess their attitudes towards studying and their study habits. The R-SPQ-2F is a 20-item questionnaire (see Table 5 in the Appendix) used to identify participants' metacognitive strategies for learning (Biggs et al., 2001). Participants responded to questionnaire items using a 5-point Likert scale response, ranging from 'never or rarely true of me' to 'always or almost always true of me.' The R-SPQ-2F identifies if a participants' learning is occurring at a deep or surface level. The version of the R-SPQ-2F used here had two scales, Deep and Surface. Each subsection has a maximum score of 50. A high score on the Deep scale is desirable as it demonstrates that a participant engages in deep learning strategies such as studying for understanding rather than specific answers to questions. A low score on the Surface scale is desirable as it would imply that a participant holds less surface-oriented attitudes and study strategies, such as striving for the minimum passing grade in a course.

The MAI is an instrument designed to assess general self-regulated learning skills across disciplines in adults. The questionnaire is a 52-item inventory (see Table 6 in the appendix) in which the items are classified by type of cognitive knowledge or specific metacognitive process: declarative, procedural, conditional, planning, informational management strategies, monitoring, debugging strategies, and evaluation (Schraw &

Dennison, 1994). Participants were instructed to mark the items in the inventory either 'true' or 'false' based on their study habits and attitudes. True statements corresponded to a mark with the value 1. Items marked 'false' by participants received a mark of 0. Cumulative scores were calculated for the participants based on the sum of the 8 categories. The highest possible score on the MAI was 52.

Participants were also asked to self-report their GPA. This was done in a de-identified fashion. These two measures—questionnaires and GPA—were collected in order to assess academic differences as a function of mTBI status.

Table 1. Demographics for Experiment 1

	Age (SD)	# (# F)	Years of Education	Undergraduate GPA
mTBI	20.5 (2.5)	30 (22)	14.0 (1.5)	3.34 (0.52)
Control	20.4 (1.8)	25 (17)	14.7 (1.0)	3.46 (0.40)

The top row includes data for mTBI participants, and the second row reflects the control group in Experiment 1. The mean number of years of education and undergraduate GPA on a 4.0 scale are compiled. #, number; F, female; SD, standard deviation.

Table 2. mTBI Information for Experiment 1

# mTBI (SD)	Time (SD)	LOC Duration (# LOC Participants)	# Formal Medical Diagnoses	Etiology Category
2.8 (2.1)	3.4 y (3.3)	12.6 min (13)	20	10 sports-related 7 car-related 13 other-related

The mean number of mTBIs and the time (in years) since the last mTBI are compiled. #, number; F, female: LOC, loss of consciousness; min, minutes; SD, standard deviation, y, years.

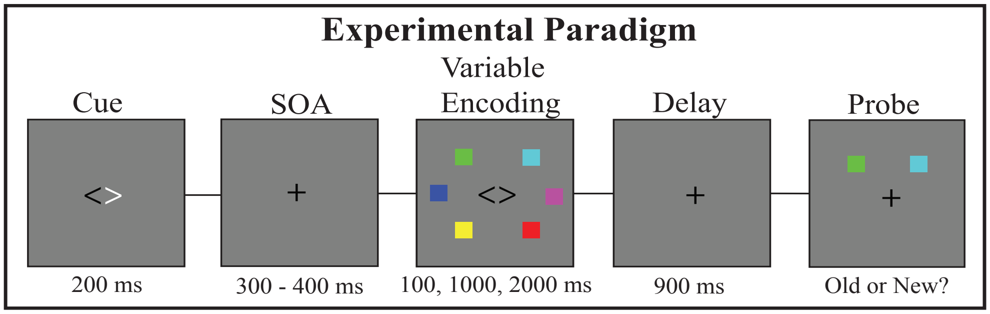
Stimulus Apparatus and Display

The task was presented on a 19-in. NEC MultiSync CRT Monitor (75 Hz, 1,024 x 768) in MATLAB (The MathWorks, Natick, MA) with the Psychophysics Toolbox 3.0 extension using a Mac mini 2.5-GHz dual-core Intel Core i5 processor. Participants sat at a distance of 57 cm from the screen.

Task Design and Procedure

In the change detection visual WM task, three colored squares (0.7° × 0.7°, degrees visual angle) were presented, chosen from a set of seven easily discriminable colors (cyan, white, red, blue, yellow, green, and magenta). Trials began with a fixation cross (0.4° × 0.4°, 300 ms), followed by a left or right arrowhead (2.1° × 0.4°, 200 ms), cueing to the side of the screen to covertly attend. After a delay (300-400 ms), the stimuli were presented (100, 1000, or 2000 ms) in two rectangular areas (7.1° × 12.2°) 4.6° from fixation. The stimuli presentation (encoding period) was pseudorandomized within the task. After a delay (900 ms), the probe appeared (3 s). Participants then indicated whether the stimulus and probe item matched ("o" key; 50%) or not ("n" key, 50%). These self-paced trials included three untimed breaks. The participants were asked if they had any questions after hearing the instructions. Before testing, participants completed 36 practice trials. There were 216 trials, or 72 trials per encoding duration. Participants were instructed to maintain fixation. This task took approximately 25 minutes to complete. The proportion correct and K values were recorded. Two controls were considered outliers because their performance accuracy was >2 standard deviations below the mean and were subsequently removed. See Figure 1 for a visual representation of the paradigm.

Figure 1. Visual WM Task Paradigm



A cue (200 ms) indicates which side of the display to covertly attend while fixating on the cross. After a delay (stimulus onset asynchrony: SOA: 300-400 ms) the stimuli appear (100, 1000, or 2000 ms, equal probability) and are followed by a delay (900 ms). During the probe image, stimuli are presented on both sides to balance the visual display. The participant reports via key press whether the probe stimulus matches/mismatches what was viewed during encoding ('old', shown above).

Behavioral Data Analysis

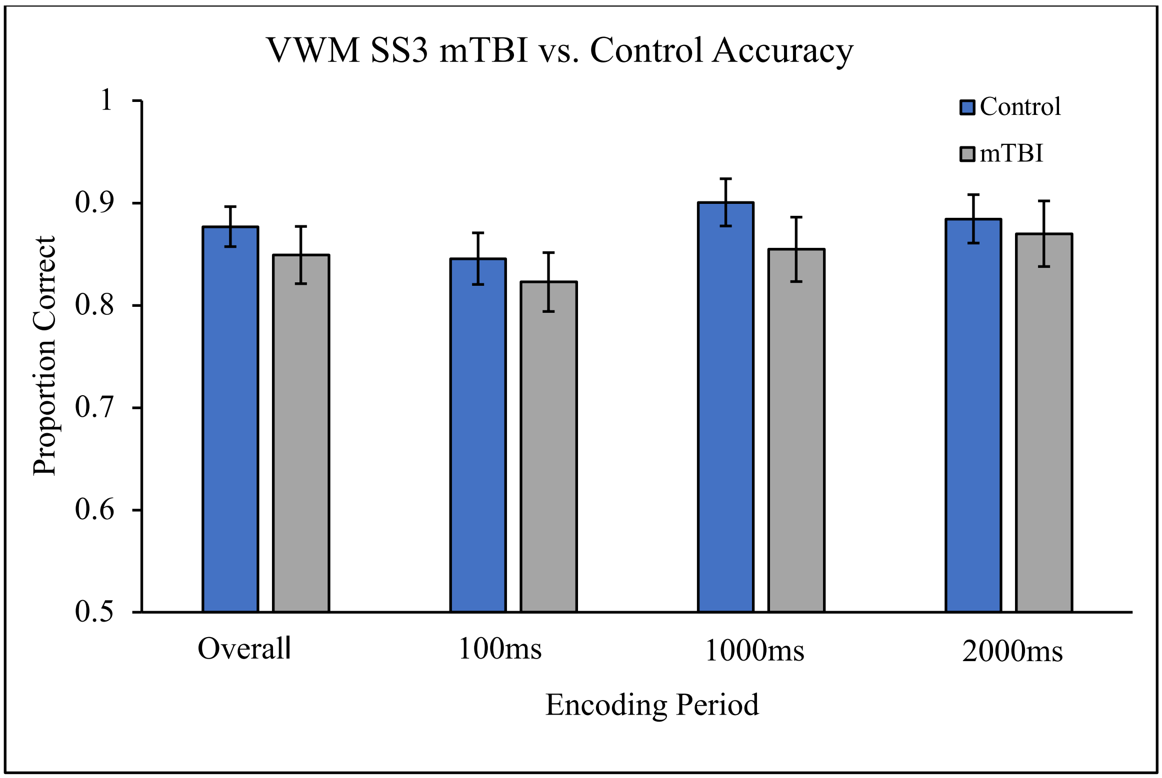
Accuracy and K values were calculated across participants and compared between groups using parametric statistical approaches. The primary performance measures were accuracy and visual WM capacity, calculated as: K = Set size*(Hit rate – False alarm rate).

Results

Behavioral Accuracy

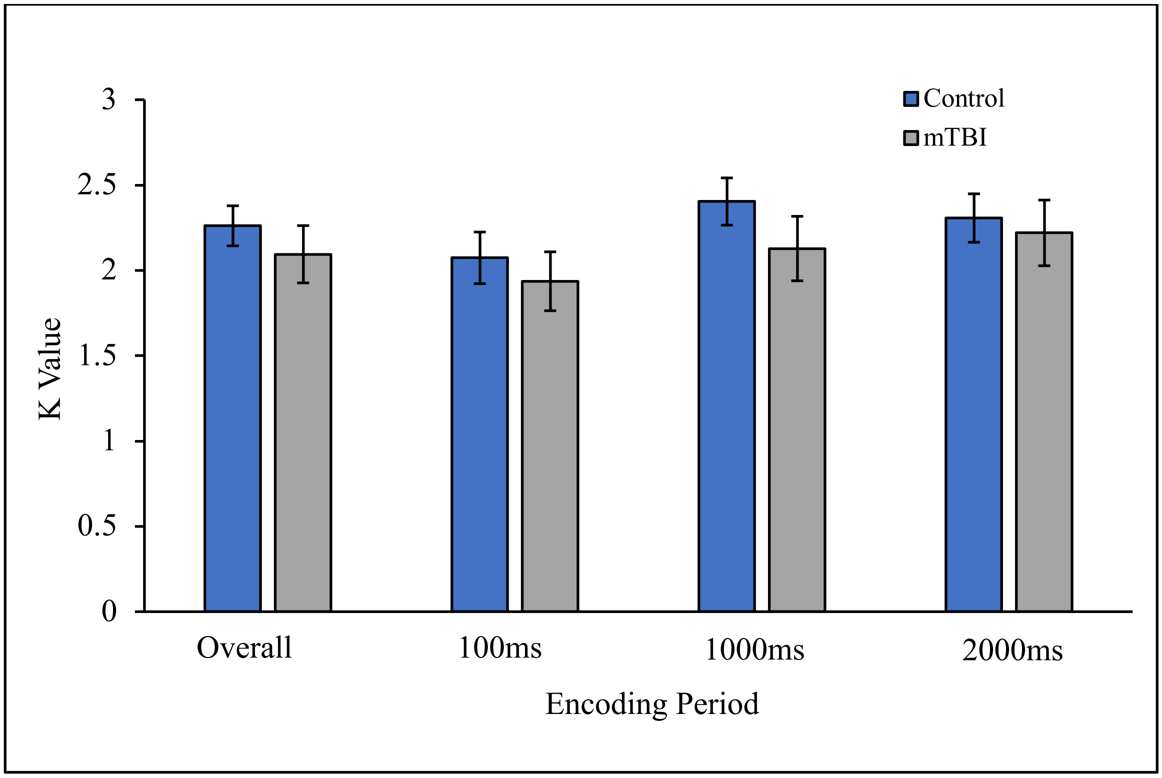
Accuracy and Cowan's K were subjected to separate mixed model ANOVAs with the within-subjects factor of encoding (100, 1000, and 1000 ms) and the between-subjects factor of group (control, mTBI). The accuracy data revealed main effects of encoding ($F_{1,53}$ = 28.963, p = 0.006, partial η^2 = 0.353), such that accuracy increased as encoding time increased; see Figure 2. No other main effects or interactions approached significance (all ps > 0.05). Pairwise comparisons t-tests for encoding periods across groups showed that a significant group difference emerged at an encoding period of 1000 ms ($p = 0.03$) but was not significant at other encoding durations of 100 ms ($p = 0.26$) or 2000 ms ($p = 0.49$); see Figure 2. The related Cowan's K results were showed the same pattern. The data revealed main effects of encoding, such that WM capacity measures increased as encoding time increased ($F_{1,53} = 28.963$, $p = 0.000002$, partial $\eta^2 = 0.353$). No other main effects of interactions approached significance (all ps > 0.05); see Figure 3.

Figure 2. Proportion Correct for Experiment 1



Behavioral performance (proportion correct) for the visual working memory change detection task with a set size of three. Plotted are the overall data (collapsing across encoding duration), and performance for each encoding duration (100 ms, 1000 ms, 2000 ms). Overall, there was a main effect of encoding duration, but no overall main effect of group membership. Error bars represent confidence intervals.

Figure 3. K Values for Experiment 1



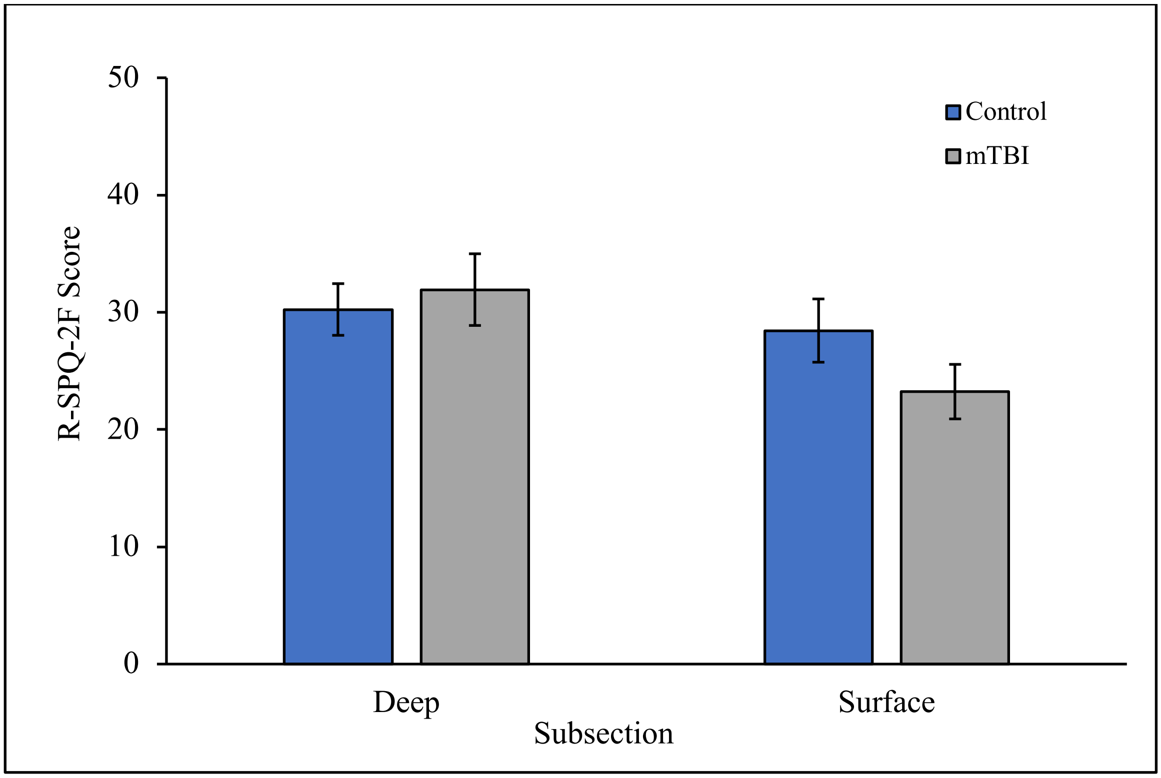
K values for the visual working memory change detection task with a set size of 3 were calculated. Plotted are the overall data (collapsing across encoding duration) and performance for each encoding duration (100 ms, 1000 ms, 2000 ms). As with the proportion correct, there was a main effect of encoding duration but no overall main effect of group membership. Error bars represent confidence intervals.

Academic Performance

Academic performance between the groups was examined next. To see if student reporting of academic attitudes and usual ways of studying differed between control and mTBI participants on academic questionnaires, we conducted a paired t-test. This t-test showed that R-SPQ-2F surface score significantly differed between groups ($p = 0.005$) and that the mTBI group had the lower score; see Figure 4. In the surface domain of the R-SPQ-2F questionnaire, a lower score is desirable as it suggests that students engage in less surface tendencies for their coursework such as doing the minimum amount of work to obtain a passing grade. The t-test revealed that group differences did not emerge for the R-SPQ-2F subsection ($p = 0.40$) or MAI ($p = 0.79$) questionnaire; see Figure 5 for plot of MAI scores.

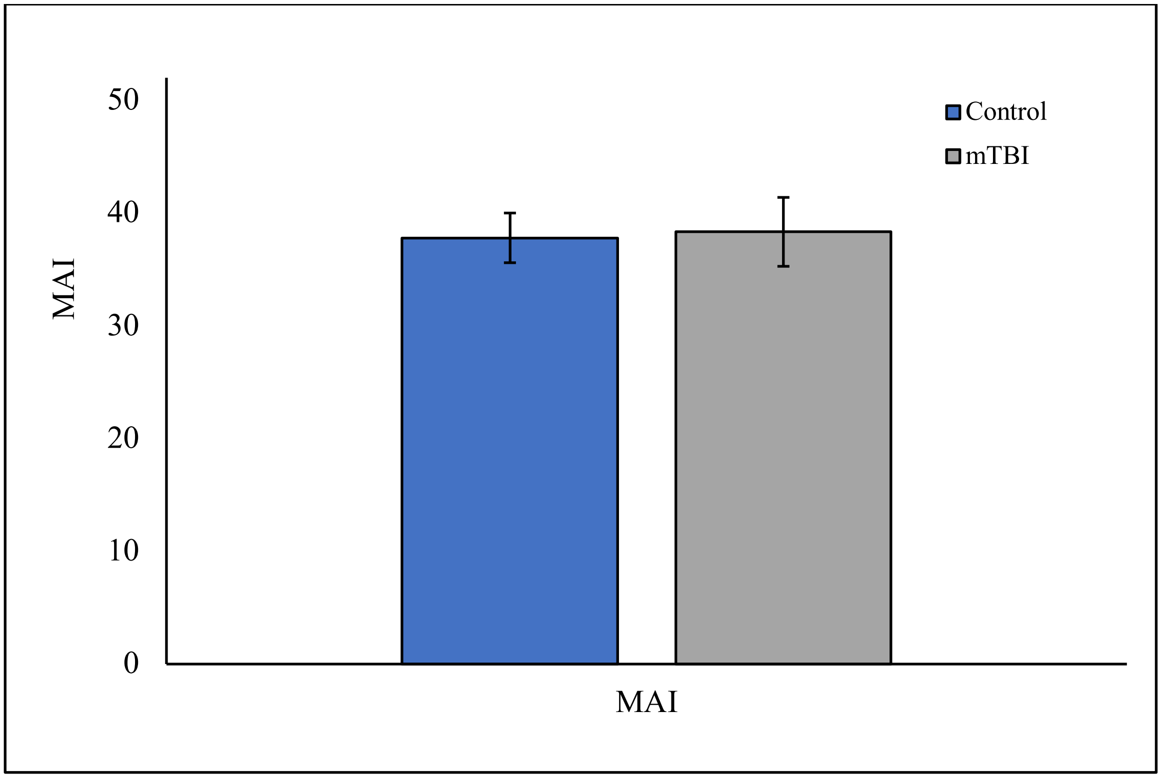
To determine if GPA differed between control and mTBI groups, we conducted a paired t-test. All GPAs reported by the control group represented undergraduate courses. However, 8 mTBI participants were first-semester college freshmen and thusly reported their unweighted GPA from high school. These mTBI participants were excluded from this analysis as the GPAs were clearly on a different scale from college GPAs. This t-test showed that GPA between control (M=3.46, SD=0.40) and mTBI (M=3.34, SD=0.52) were not significantly different; $t(45)=0.87$, $p=0.39$. GPA and performance on the visual WM task (100 ms encoding period proportion correct) were plotted for both groups in Figure 6. The R^2 values for the mTBI ($R^2 = 0.0053$) and control ($R^2 = 0.221$) did not suggest a correlation between performance on the visual WM task and GPA. The academic questionnaires and self-reported GPAs showed that academic performance on the whole is not a sufficient predictor of mTBI performance or outcomes.

Figure 4. Revised Two-Factor Study Process Questionnaire Scores (R-SPQ-2F)



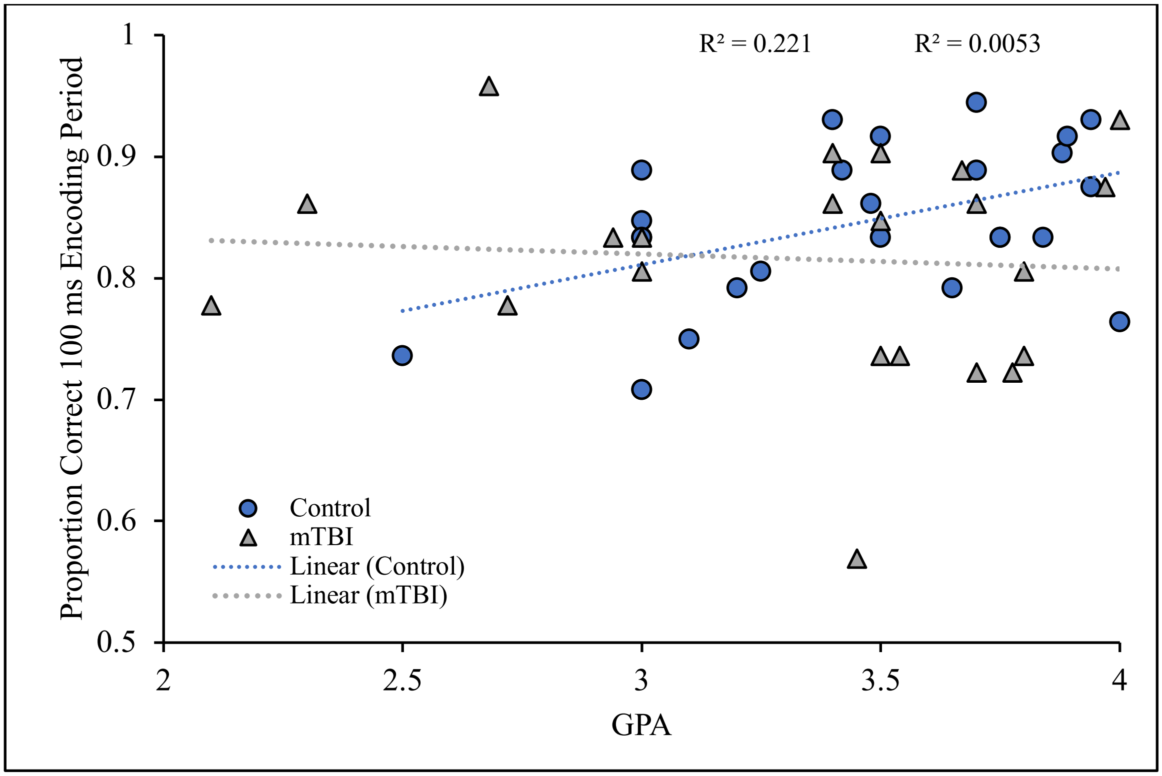
Plotted above are R-SPQ-2F scores for control and mTBI participants separated by deep and surface subsection. The maximum score for each subsection is 50. A high score on the deep subsection is desirable and a low score on the surface subsection is desirable. In other words, the mTBI group outperformed the control group numerically on both measures. Errors bars represent confidence intervals.

Figure 5. Metacognitive Awareness Inventory Scores (MAI)



Plotted above are MAI scores assessing study habits for control and mTBI groups showing no group-level differences. A higher score is more desirable; the MAI has a maximum score of 52. Errors bars represent confidence intervals.

Figure 6. Visual WM Performance by GPA



The scatter plot above displayed proportion correct of the 100 ms encoding period of the WM task by GPA for both control and mTBI groups. mTBI participants who reported a GPA from high school were excluded.

Experiment 2

After completing a series of experiments investigating the different stages of WM, we identified attention as the next cognitive domain of interest. Bearing in mind that WM and attention are inextricably linked domains, this new line of research allowed for the exploration of cognitive domains more broadly. Importantly, attending to salient, task relevant information instead of distractors from the environment is essential for successful WM.

A 2015 study investigated the way in which task-irrelevant stimuli disrupt WM when presented either at encoding or during the maintenance period in both older and younger adults (McNabb et al., 2015). Almost 30,000 datasets were collected through the use of a mobile phone game where participants were instructed to select the cells where circles had been presented, while ignoring distractor circles of a different color presented with as an encoding distractor or as a maintenance distractor. The study found that encoding period distractibility was correlated with WM capacity (McNabb et al., 2015). The purpose of Experiment 2 is to replicate the findings of McNabb et al. (2015) in the control group and to extend the study's paradigm into the mTBI population. Based on global deficits observed in the WM domain in previous experiments in the lab, we hypothesize that mTBI participants fail to ignore distractors at the same rate as their neurotypical controls. We predict that the mTBI group will perform worse than the control group of undergraduates with no history of mTBI on a visual attention task. We suspect that mTBI participants face cognitive challenges when attempting to attend to an item while suppressing the intrusion of distractor items.

Participants

Due to the circumstances of COVID-19, data collection was suspended, which prevented the planned collection of N=25 for both control and mTBI groups. Four undergraduates with a history of mTBI (2 female, 19 means years old) participated in this study; see Table 3. This cohort of mTBI individuals had a mean number of 1 mTBIs and 4.3 years since injury. mTBI participants self-reported their injuries—we did not require a formal diagnosis by a physician. One individual reported their injury as sport-related and the other participants reported other-related injuries; see Table 4 for Experiment 2 mTBI participant injury information. Seventeen age- and education-matched neurotypical control participants (16 females, 20.3 means years old) participated in Experiment 2; see Table 3. The control participants did not have a history of neurological disorders. All participants were in good health.

Participants completed a demographics sheet approved by the Internal Review Board. This sheet included all questions asked in Experiment 1 but additionally inquired about participants' major and if they have ever changed their major to further assess academic differences between groups. mTBI participants were also asked if they received support from the Disability Resource Center on campus. Each participant gave written, informed consent prior to participating in the experiment in accordance with the guidelines of University of Nevada, Reno Internal Review Board. All participants were reimbursed $10/hour or course bonus credit.

Table 3. Demographics for Experiment 2

	Age (SD)	# (# F)	Years of Education	Undergraduate GPA	# Reported Change in Major
mTBI	19.0 (1.7)	4 (1)	12.3 (1.41)	3.69 (0.09)	2
Control	20.3 (1.9)	17 (16)	13.8 (1.3)	3.71 (0.28)	5

The top row includes data for mTBI participants, and the second row reflects the control group in Experiment 2. The mean number of years of education and undergraduate GPA on a 4.0 scale are compiled. #, number; F, female; SD, standard deviation.

Table 4. mTBI Information for Experiment 2

# mTBI (SD)	Time (SD)	LOC Duration (# LOC Participants)	# Formal Medical Diagnoses	Etiology Category
1 (0)	4.3 y (2.7)	5.07 min (3)	0	1 sport-related 3 other-related

The mean number of mTBIs and the time (in years) since the last mTBI are compiled. #, number; F, female: LOC, loss of consciousness; min, minutes; SD, standard deviation, y, years.

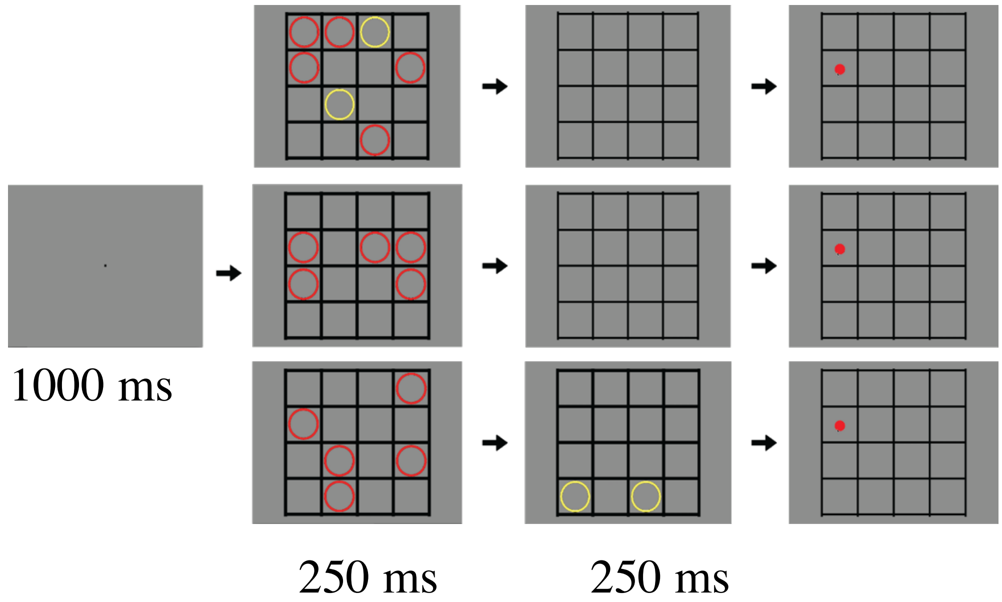
Stimulus Apparatus and Display

The task was presented on a 17-in. NEC MultiSync CRT Monitor (75 Hz, 1,024 x 768) in MATLAB (The MathWorks, Natick, MA) with the Psychophysics Toolbox 3.0 extension using a Mac mini 2.5-GHz dual-core Intel Core i5 processor. Participants sat at a distance of 57 cm from the screen. Search arrays consisted of a black 16 cell (4x4) grid that would be populated by 5 red annuli (1° visual angle). Distractors were yellow annuli (1° visual angle) that would be either presented at encoding (simultaneously with the red annuli) or during the maintenance period (directly after the red annuli presentation). All annuli were of equal luminance.

Task Design and Procedure

In the visual attention distractibility task participants first viewed a fixation dot (1000 ms) followed by the presentation of a blank 16 cell (4x4) grid without any stimuli presented (750). Next, red annuli were presented for 250 ms randomly located within the 16 cells. Immediately following this, all five red annuli disappeared and the grid remained empty (250 ms). During the encoding distractor condition, two yellow distractor annuli were presented with the stimuli during encoding. During the maintenance distractor condition, 250 ms after the stimuli disappeared, two yellow distractor items appeared for 250 ms before disappearing. During the no distractor condition, red annuli were presented for 500 followed by the probe screen. For all conditions, participants had unlimited time to use the mouse click to report the location of the five cells in which red annuli were presented. During the encoding and maintenance distractor conditions, participants were instructed to click only the cells where the original encoding stimuli were presented. These self-paced trials included one untimed break. I asked the participants if they had any questions after giving them instructions. Before testing, participants completed 12 practice trials. Participants anonymously self-reported their GPA at this time and knew that their data and GPA information was not linked to their identity. There were 210 trials; 70 trials per condition (encoding distractors, maintenance distractors, and no distractors). The proportion correct and median correction reaction time were recorded. Three controls performed >2 standard deviations below the mean and were removed as outliers. See Figure 7 for a visual representation of the paradigm.

Figure 7. Visual Attention Task Paradigm



Visual recall task with yellow distractor annuli. The maintenance distractor condition is depicted here. Participants viewed a fixation dot (1000 ms) followed by presentation of a 4x4 grid including 5 red annuli (250 ms). Once the annuli disappeared, the lines of the grid changed thickness, indicating to the participants to respond via mouse clicks where they had seen the red annuli. Feedback on clicks were given in the form of a red dot indicating were the participant had placed a click. Distractors were yellow annuli. They were presented either at the same time (top left panel) or immediately after the red annuli (bottom left panel) (250 ms). In the no distractor condition, middle panel, no yellow annuli appeared. Modified from McNab et al., (2015).

Data Analysis

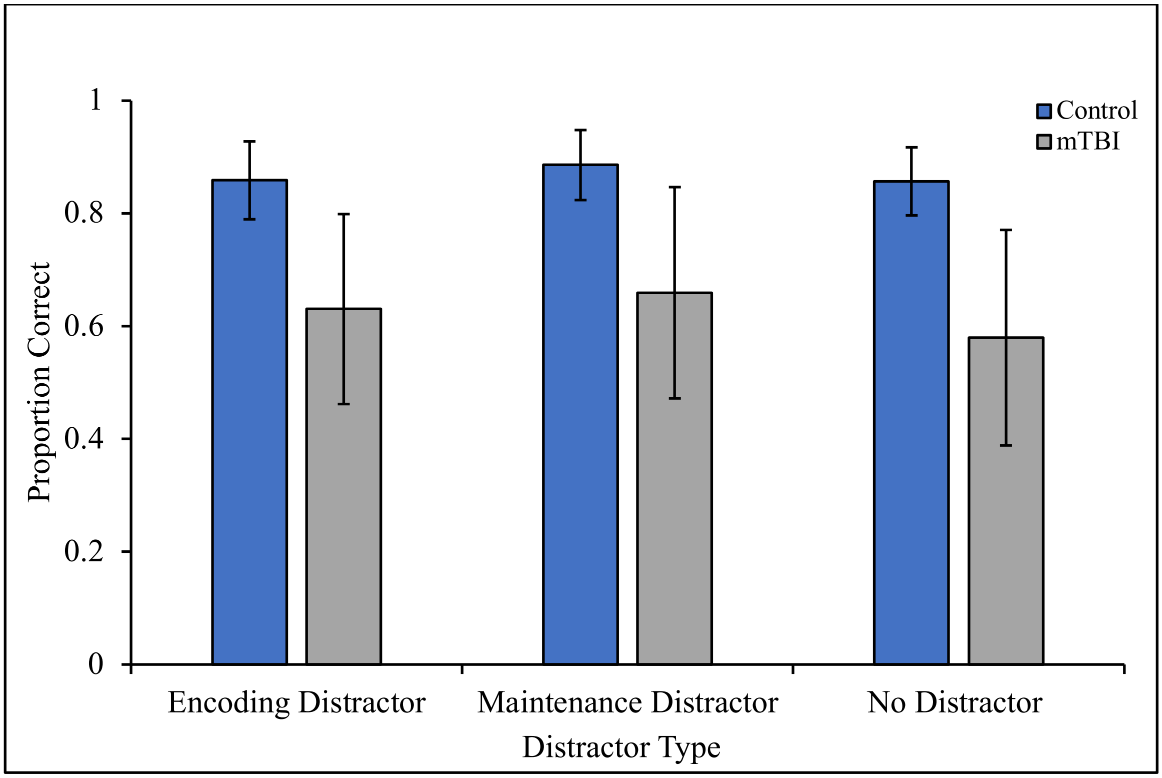
Performance accuracy per condition was calculated across participants and compared between groups using parametric statistical approaches.

Results

Behavioral Accuracy

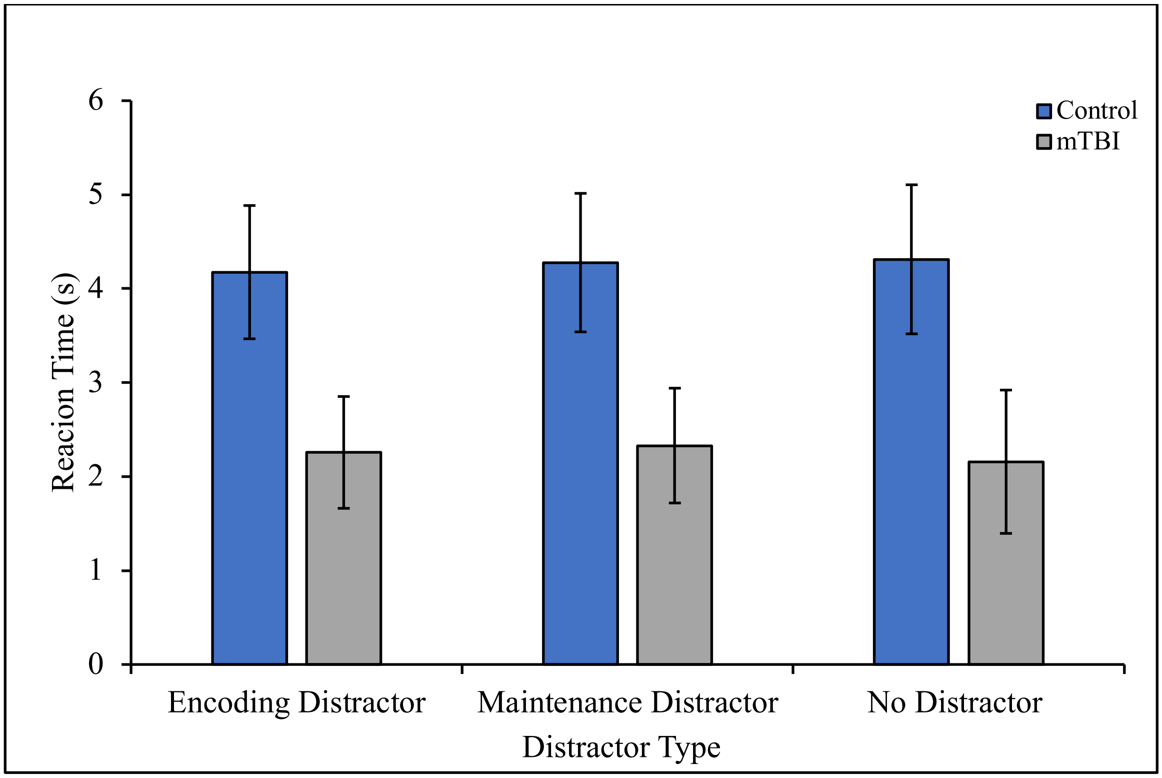
To identify differences between the control and mTBI groups, behavioral accuracies (proportion correct) and median correct reaction times were subjected to a mixed model ANOVA with the within-subjects factor of distractor condition (encoding distractor, maintenance distractor, no distractor) and the between-subjects factor of group (control, mTBI). These preliminary data did not reveal a main effect of distractor ($F_{1,19}$ = 0.023, p = 0.881, partial η^2 = 0.001) nor the main effect of group ($F_{1,19}$ = 0.179, p = 0.677, partial η^2 = 0.009); see Figure 8. Median correct reaction times did not have a main effect of distractor ($F_{1,19}$ = 2.821, p = 0.109, partial η^2 = 0.129) or of group ($F_{1,19}$ = 0.785, p = 0.387, partial η^2 = 0.040); see Figure 9. The figures show the numeric differences between the groups, though and indicate that although there is no statistical significance, there is a trend toward greater impact of distractors on the mTBI group. Additionally, numeric differences reveal that the control group had higher median correction reaction times compared to the mTBI group. The failure to reach significance in any interaction can be at least partially attributed to the uneven number of participants in each group and the shortcoming of data collection secondary to the COVID-19 outbreak.

Figure 8. Proportion Correct for Experiment 2



Plotted above is behavioral performance (proportion correct) for the visual attention task. Errors bars represent confidence intervals.

Figure 9. Visual Attention Task Reaction Time



Plotted above is the median correct reaction time in seconds for the visual attention task. Errors bars represent confidence intervals.

Academic Performance

To determine if GPA differed between control and mTBI groups, we conducted a paired t-test. All GPAs represented undergraduate coursework. This t-test showed that GPA between control (M=3.71, SD=0.28) and mTBI (M=3.69, SD=0.09) was not significant; t(19)=0.18, p=0.86. In terms of changing majors, 5 out of 17 controls and 1 out 4 mTBI participants reported changing their major at some point during their undergraduate career.

Discussion

Current Investigation and Goals

In this current investigation, we investigated the WM and attentional deficits in chronic undergraduates with a history of mTBI. In Experiment 1, we completed the final installment in a series of lab experiments wherein the stages of WM were systematically manipulated to understand when the deficits associated with mTBI emerged. In the visual WM task, we manipulated the encoding period (100 ms, 1000 ms, 2000 ms). Overall, it showed that there was a main effect of encoding period, such that longer encoding produced better WM performance. But, there was not a main effect of group. This finding was unexpected because we predicted the mTBI group would be impaired on this task, and indeed there was a numerical difference such that the control group performed better across conditions, but it was not statistically significant. Additionally, this marked a failure to replicate the 100 ms encoding period deficit in the mTBI population, a condition we have tested 5 times in different cohorts of mTBI participants and controls. Because of the pattern we previously detected in >100 mTBI participants, we thought about what might make this group different from early samples. One difference was that this population was particularly motivated and they had high GPAs. This population was recruited from summer session students; we theorized that this cohort of students is particularly motivated given their participation in summer classes. This might mean that our recruitment and our selection of an mTBI group produced one that was unusual.

In particular, the data on the WM behavioral task was even more heterogeneous than in previous mTBI cohorts in the lab, and on the whole, performed better than previous cohorts. Of particular note, 8 out of 30 mTBI participants were first-semester freshmen.

The majority of these mTBI participants received their injury during their early- to mid-teen years (pediatric mTBI), a critical period of their development we suspect helped them to recover from their injury faster and completely return to premorbid levels of cognitive functioning. Despite the fact that we did not see a main effect of group, it remains important to recognize that the mTBI cohort performed numerically lower than did the control group.

In terms of academic performance overall, we observed no difference in academic questionnaires (R-SPQ-2F and MAI) and self-reported GPAs between mTBI and Controls. However, the mTBI group scored lower on the R-SPQ-2F surface subsection which suggests that they hold few surface study attitudes and engage in less surface behaviors such as doing the minimum amount required to pass their courses. This finding was significant because we predicted that mTBI participants were compensating to perform alongside their unaffected peers by adopting more successful study attitudes and habits. In terms of GPA, there was not a significant difference between groups. Academic metrics (questionnaires and self-reported GPA) also did not correlated with performance on the WM task. From this, we learned that academic performance is not a sufficient predictor of WM performance or mTBI outcomes years after injury.

Experiment 2 ventured outside of the WM domain and into attention, allowing us to explore cognitive impairments more broadly by investigating deficits associated with WM by asking participants to complete a visual attention distractibility task. However, due to circumstances posed by the COVID-19 outbreak, data collection was suspended before we could collect our anticipated N=25 for both control and mTBI groups. A total of 17 Control and 4 mTBI participants completed the task which severely impacted the analyses of main effect of distractor type and group. The low and uneven number of participants between groups also rendered investigating group differences of GPA and change in major difficult. As the data currently stands, we did not observe a statistically significant main effect of distractor type or group on the visual attention distractibility task. There is a numerical difference showing a pattern of impairment in the mTBI group that may hold when a complete sample is tested. At this point, the data are too preliminary to draw strong conclusions based on the pattern of results.

Implications

mTBI has a high global and national incidence. Additionally, many undergraduate students may have unaddressed cognitive deficits secondary to a chronic history of mTBI that, unbeknownst to them, affect their performance in relation to their unaffected peers in undergraduate classes. Previous findings have demonstrated variable WM performance following a mTBI. However, little was known about the lasting implications of mTBI and whether cognitive deficits persist years after injury. The experiments presented in this thesis suggest that mTBI cognitive (WM and attention) performance at the group level is not globally impaired; this is a reassuring finding. To further explore the role that attention in mTBI deficits, future experiments could include specific tasks or neuropsychological testing to individually evaluate specific attention domains such as selective attention, sustained attention, attentional switching, and auditory selective attention. The group performance of mTBI participants in these domains would be an indicator in deficits emerge in these specific areas of attention.

Overall, through the systematic manipulation of the WM domain, it can be inferred that WM in mTBI participants is globally impaired at the group level. Attention is closely linked to WM and permits the entry of items. If attention fails during the encoding or maintenance periods of WM, items will not be permitted into the mental workspace. As such, it is likely that WM and attention will be studied in conjunction in future studies assessing the cognitive consequences of mTBI.

References

Arciniega, H., Kilgore-Gomez, A., Harris, A., Peterson, D.J., McBride, J., Fox, E., & Berryhill, M. E. (2019). Visual working memory deficits in undergraduates with a history of mild traumatic brain injury. *Attention, Perception, & Psychophysics. 81*(8), 2597-2603. https://doi-org.unr.idm.oclc.org/10.3758/s13414-019-01774-9

Arciniega, H., Kilgore-Gomez, A., McNerney, M. W., Lane, S., & Berryhill, M. E. (2020). Loss of consciousness, but not etiology, predicts better working memory performance years after concussion. *Journal of Clinical and Translational Research, 5*(S4). https://dx.doi.org/10.18053/jctres.05.2020S4.003

Anderson, J. R. (2005). Cognitive psychology and its implications. Macmillan.

Bajaj, S., Dailey, N. S., Rosso, I. M., Rauch, S. L., & Killgore, W. D. S. (2018). Time-dependent differences in cortical measures and their associations with behavioral measures following mild traumatic brain injury. *Human Brain Mapping, 39*(5), 1886-1897. https://doi.org/10.1002/hbm.23951

Bazarian, J. J., McClung, J., Shah, M. N., Cheng, Y. T., Flesher, W., & Kraus, J. (2005). Mild traumatic Brain injury in the United States: 1988-2000. *Brain Injury. 19*(2), 85-91. https://doi.org/10.1080/02699050410001720158

Bazarian, J. J., Blyth, B., Mookerjee, S., He, H., & McDermott, M. P. (2010). Sex differences in outcome after mild traumatic brain injury. *Journal of Neurotrauma. 27*(3), 527-539. https://doi-org.unr.idm.oclc.org/10.1089/neu.2009.1068

Biggs, J.B., Kember, D., & Leung, D.Y.P. (2001) The Revised Two Factor Study Process Questionnaire: R-SPQ-2F. *British Journal of Educational Psychology. 71,* 133-149. https://doi.org/10.1348/000709901158433

Cassidy, J. D., Carroll, L. J., Peloso, P. M., Borg, J., von Holst, H., Holm, L., Kraus, J., & Coronado, V. G. (2004). Incidence, risk factors and prevention of mild traumatic brain injury: Results of the WHO collaborating centre task force on mild traumatic brain injury. *Journal of Rehabilitation Medicine, 36*(43S), 28-60, https://doi.org/10.1080/16501960410023732

Cowan, N., Elliot, E. M., Saults, S., Morey, C. C., Mattox, S., Hismjatullina, A., Conway, A. R. A. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology, 51*(1), 42-100. https://doi.org/10.1016/j.cogpsych.2004.12.001

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General. 128*(3). 309-331. https://doi.org/10.1037/0096-3445.128.3.309

Faul, M., Xu, L., Wald, M. M., & Coronado, V. G. (2010). Traumatic brain injury in the United States: Emergency department visits, hospitalizations and death 2002-2006. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. https://permament.access.gpo.gov/gpo41911/blue-book.pdf

Georges A., Booker J.G. Traumatic Brain Injury. [Updated 2020 Mar 25]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2020 Jan. https://www.ncbi.nlm.nih.gov/books/NBK459300/

Hay, J., Johnson, V. E., Smith, D. H., & Stewart, W. (2016). Chronic traumatic encephalopathy: The neuropathological legacy of traumatic brain injury. *Annual Review of Pathology: Mechanisms of Disease. 11*(1)*,* 21-45. https://doi.org/10.1146/annurev-pathol-012615-044116

Hirad, A. A., Bazarian, J. J., Merchant-Borna, K., Garcea, F. E., Heilbronner, S., Paul, D., … Mahon, B. Z. (2019). A common neural signature of brain injury in concussion and subconcussion. *Science Advances*, *5*(8). https://doi.org/10.1126/sciadv.aau3460

Johnson, V. E., Stewart, W., & Smith, D. H. (2013). Axonal pathology in traumatic brain Injury. *Experimental Neurology. 246*, 35-43. https://doi.org/10.1016/j.expneurol.2012.01.103

Kenzie, E. S., Parks, E. L., Bigler, E. D., Lim, M. M., Chesnutt, J. C., & Wakeland, W. (2017). Concussion as a multi-scale complex system: An Interdisciplinary synthesis of present knowledge. *Frontiers in Neurology, 8.* https://doi.org/10.3389/fneur.2017.00513

Laskowski, R. A., Creed, J. A., Raghupathi, R. (2015). Pathophysiology of Mild TBI: Implications for Altered Signaling Pathways. *Brain Neurotrauma: Molecular, Neuropsychological, and Rehabilitation Aspects*. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/26269903

Mayer, A. R., Yang, Z., Yeo, R. A., Pena, A., Ling, J. M., Mannell, M. V., Stippler, M., & Mojtahed, K. (2012). A functional MRI study of multimodal selective attention following mild traumatic brain injury. *Brain Imaging and Behavior. 6*(2). 343-354. https://doi.org/10.1007/s11682-012-9178-z

Mayer, A. R., Quinn, D. K., & Master, C. L. (2017). The spectrum of mild traumatic injury: A review. *Neurology, 89*(6). 623-632. https://doi.org/10.1212/WNL.0000000000004214

McKee, A. C., Cantu, R. C., Nowinski, C. J., Hedley-Whyte, E. T., Gavett, B. E., Budson, A. E., Santini, V. E., Lee, H. S., Kubilus, C. A., & Stern, R. A. (2009). Chronic Traumatic Encephalopathy in Athletes: Progressive Tauopathy following Repetitive Head Injury. *Journal of Neuropathology and Experimental Neurology*, *68*(7), 709–735. https://doi.org/10.1097/NEN.0b013e3181a9d503

McNabb, F., Zeidman, P., Rutledge, R. B., Smittenaar, P., Brown, H. R., Adams. R. A., & Dolan, R. J. (2015). Age-related changes in working memory and the ability to ignore distractors. *Proceedings of the National Academy of Sciences, 112*(20), 6515-6518. https://doi.org/10.1037/pnas.1504162112

Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine. Definition of mild traumatic brain injury. (1993). *Journal of Head Trauma Rehabilitation. 8*(3), 86-87.

Pan, J., Connolly, I. D., Dangelmajer, S., Kintzing, J., Hol, A. L., & Grant. G. (2016). Sports-related brain injuries: connecting pathology to diagnosis. *Journal of Neurosurgery. 40*(4). https://doi.org/10.3171/2016.1.FOCUS15607

Rabinowitz, A. R., & Levin, H. S. (2014). Cognitive Sequelea of Traumatic Brain Injury. *Psychiatric Clinics of North America. 37*(1), 1-11. https://doi.org/10.1016/j.psc.2013.11.004

Ryan, L. M. & Warden, D. L. (2009). Post-concussive syndrome. *Internal Review of Psychiatry, 15*(4), 310-316. https://doi.org/10.1080/09540260310001606692

Schraw, G. & Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology, 19*(4)*,* 460-475. https://doi.org/10.1006/ceps.1994.1033

Sharp, D. J. & Jenkins, P. O. (2015). Concussion is confusing us all. *Practical Neurology. 15*(3). 172-186. https://doi.org/10.1136/practneurol-2015-001087

Smith, D. H., Johnson, V. E., & Stewart, W. (2013). Chronic neuropathologies of single and repetitive TBI: Substrates of dementia? *Nature Reviews. Neurology*, *9*(4) 211–221. https://doi.org/10.1038/nrneurol.2013.29

Taylor, C. A., Bell, J. M., Breiding, M. J., & Xu, L. (2017). Traumatic Brain Injury-Related Emergency Department Visits, Hospitalizations, and Deaths—United States, 2007 and 2013. *Morbidity and Mortality Weekly Report. Surveillance Summaries (Washington, D.C.: 2002)*, *66*(9), 1–16. https://doi.org/10.15585/mmwr.ss6609a1

Taylor, K. M., Kioumourtzoglou, M., Clover, J., Coull, B. A., Dennerlein, J. T., Bellinger, D. C., & Weisskopf, M. G. (2018). Concussion history and cognitive function in a large cohort of adolescent athletes. *The American Journal of Sports Medicine. 46*(13), 3262-3270. https://doi.org/10.1177/0363546518798801

Wheeler, M., & Treisman, A. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology-General*. *131*(1), 48-64. https://doi.org/10.1037/0096-3445.131.1.48

Ziino, C. & Ponsford, J. (2006). Selective attention deficits and subjective fatigue following traumatic brain injury. *Neuropsychology. 20*(3). 383-390. https://doi.org/10.1037/0894-4105.20.3.3

Appendix

Table 5. Revised Two-Factor Study Process Questionnaire

This table shows the statements from the Revised Two-Factor Study Process Questionnaire (R-SPQ-2F). Participants selected one of the following responses for each statement to best represent their attitudes towards studies and their usual ways of studying: A—this item is never or only rarely true of me, B – the item is sometimes true of me, C – this time is true of me about half the time, D – this time is frequently true of me, or E – this item is always or almost always true of me. Scorings for the questionnaire following a cyclical order: 1 – Deep, 2 – Deep, 3 – Surface, 4 – Surface.

Statements
1. I find that at times studying gives me a feeling of deep personal satisfaction.
2. I find that I have to do enough work on a topic so that I can form my own conclusions before I am satisfied.
3. My aim is to pass the course while doing as little work as possible.
4. I only study seriously what's given out in class or in the course outlines.
5. I feel that virtually any topic can be highly interesting once I get into it.
6. I find most new topics interesting and often spend extra time trying to obtain more information about them.
7. I do not find my course very interesting so I keep my work to the minimum.
8. I learn some things by rote, going over and over them until I know them by heart even if I do not understand them.
9. I find that studying academic topics can at times be as exciting as a good novel or movie.
10. I test myself on important topics until I understand them completely.
11. I find I can get by in most assessments by memorizing key sections rather than trying to understand them.
12. I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.
13. I work hard at my studies because I find the material interesting.
14. I spend a lot of my free time finding out more about interesting topics which have been discussed in different classes.
15. I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics.
16. I believe that lectures shouldn't expect students to spend significant amounts of time studying material everyone knows won't be examined.
17. I come to most classes with questions in mind that I want answering.
18. I make a point of looking at most of the suggested readings that go with the lectures.

19.	I see no point in learning material which is not likely to be in the examination.
20.	I find the best way to pass examinations is to try to remember answers to likely questions.

Table 6. Metacognitive Awareness Inventory Questionnaire

This table displays the statements from the Metacognitive Awareness Inventory (MAI). Participants marked the following 'True' or 'False.' Based on their responses, participants were given a score for the following categories: declarative knowledge, procedural knowledge, conditional knowledge, planning, informational management strategies, comprehension monitoring, debugging strategies, and self-evaluation. Each participant was then given a total score by summing the eight categories.

Statements
1. I ask myself periodically if I am meeting my goals.
2. I consider several alternatives to a problem before I answer.
3. I try to use strategies that have worked in the past.
4. I pace myself while learning in order to have enough time.
5. I understand my intellectual strengths and weaknesses.
6. I think about what I really need to learn before I begin a task.
7. I know how well I did once I finish a test.
8. I set specific goals before I begin a task.
9. I slow down when I encounter important information.
10. I know what kind of information is most important to learn.
11. I ask myself if I have considered all options when solving a problem.
12. I am good at organizing information.
13. I consciously focus my attention on important information.
14. I have a specific purpose for each strategy I use.
15. I learn best when I know something about the topic.
16. I know what the teacher expects me to learn.
17. I am good at remembering information.
18. I use different learning strategies depending on the situation.
19. I ask myself if there was an easier way to do things after I finish a task.
20. I have control over how well I learn.
21. I periodically review to help me understand important relationships.
22. I ask myself questions about the material before I begin.
23. I think of several ways to solve a problem and choose the best one.
24. I summarize what I've learned after I finish.
25. I ask others for help when I don't understand something.
26. I can motivate myself to learn when I need to.
27. I am aware of what strategies I use when I study.
28. I find myself analyzing the usefulness of strategies when I study.
29. I use my intellectual strengths to compensate for my weaknesses.
30. I focus on the meaning and significance of new information.
31. I create my own examples to make information more meaningful.
32. I am a good judge of how well I understand something.
33. I find myself using helpful learning strategies automatically.

34. I find myself pausing regularly to check my comprehension.
35. I know when each strategy I use will be most effective.
36. I ask myself how well I accomplish my goals once I'm finished.
37. I draw pictures or diagrams to help me understand what I am learning.
38. I ask myself if I have considered all options after I solve a problem.
39. I try to translate new information into my own words.
40. I change strategies when I fail to understand.
41. I use the organizational structure of text to help me learn.
42. I read instructions carefully before I begin a task.
43. I ask myself if what I'm is related to what I already know.
44. I reevaluate my assumptions when I get confused.
45. I organize my time to best accomplish my goals.
46. I learn more when I am interested in the topic.
47. I try to break studying down into smaller steps.
48. I focus on overall meaning rather than specifics.
49. I ask myself questions about how well I am doing while I am learning about something new.
50. I ask myself if I learned as much as I could have once I finish a task.
51. I stop and go back over new information that is not clear.
52. I stop and reread when I get confused.