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The Effects of Multiple Mild Traumatic Brain Injuries and Task Difficulty on Cognitive Function

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The Effects of Multiple Mild Traumatic Brain Injuries and Task Difficulty on Cognitive Function

By
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Abstract

Previous research regarding mild traumatic brain injuries (mTBI) indicates that even one mTBI can result in long-term cognitive deficits in memory, speed of processing, and attention. This study further investigated this research with the hypothesis that, after controlling for other influences of cognitive functioning, individuals with 2 or more mTBI would perform more poorly on a battery of cognitive tests than individuals with 0-1 mTBI. It was further predicted that the effect of task difficulty on speed of processing would be influenced by the number of mTBI participants experienced, such that speed of processing would be more negatively affected by task difficulty for participants with two or more mTBI than for participants with 0-1 mTBI. One hundred participants (72 female; 28 male) completed memory, speed of processing, and attention tests. The results from the present study partially validated previous research, as deficits were found in speed of processing but not in memory or attention. This research is critical to understanding the potential negative outcomes of suffering multiple mTBI, especially in light of the large number of mTBI suffered by individuals each year.

Keywords: Cognitive Deficits, Mild Brain Injury, Speed of Processing

The authors declare that there is no conflict of interest.

1.1 The Effects of Mild Brain Injury and Task Difficulty on Cognitive Function

Traumatic brain injuries are prevalent; some research estimated that 1.7 million traumatic brain injuries, both major and mild, occur each year in the United States alone (American Psychiatric Association, 2013). Of these 1.7 million, approximately 90% are mild (Korley, Kelen, Jones, & Diaz-Arrastia, 2016; Sterr, Herron, Hayward, & Montaldi, 2006). As the DSM-V defines, mild traumatic brain injury (mTBI) includes at least one of the following: loss of consciousness, post-traumatic amnesia, confusion, or evidence of neurological damage (e.g., neuroimaging showing injury, anosmia, or hemiparesis; American Psychiatric Association, 2013). Traumatic brain injuries are only classified as mild if these symptoms occur directly following impact or immediately after regaining consciousness. Though mild, research has shown that multiple mTBI may result in long-term cognitive deficits (King & Kirwilliam, 2011; McGrath et al., 2013; Wammes, Good, & Fernandes, 2016). The purpose of this study was to illuminate the possible cognitive deficits that arise from multiple mTBI by assessing memory, speed of processing, and attention in individuals who have had 0-1 mTBI and those who have had 2 or more mTBI. A secondary purpose of the present study was to explore how the number of mTBI interacts with task difficulty to affect participants' speed of processing.

Despite the vast and increasing amount of research that has indicated that there are cognitive deficits associated with mTBI (Willer & Leddy, 2007), the longevity of these deficits is often a point of discrepancy. More specifically, some research has shown that deficits were resolved within 3-5 weeks (Hinton-Bayre, Geffen, Geffen, McFarland, & Friis, 1999), whereas other research has demonstrated that deficits were still evident after 5 years (Marsh, Ludbroook, & Gaffaney, 2016); however, the majority of research indicates that cognitive deficits may persist for more than six months following injury (King & Kirkwilliams, 2011; Marsh et al., 2016; Satish, Streufert & Eslinger, 2006; Sterr et al., 2006). For individuals who have suffered from mTBI, understanding the longevity of their symptoms can play an important role in their rehabilitation. If they do not rest long enough following the injury, they can prolong recovery time and potentially worsen the cognitive deficits of the mTBI (Kelly & Erdal, 2016).

Impairments in verbal and visual memory are commonly reported following mTBI. Researchers found that 45% of individuals who had experienced mTBI had impaired verbal memory, and 16% had borderline impaired verbal memory (Marsh et al., 2016). Additionally, Marsh et al. (2016) found that 41% of individuals who had experienced mTBI had impaired visual memory, and 15% had borderline impaired visual memory. Other research found that participants experienced deficits in both autobiographical and episodic memory deficits following mTBI (Wammes et al., 2016).

Research has also indicated that mTBI can result in deficits in speed of processing, commonly operationalized as the amount of time a person requires to complete a mental task. Researchers found that 80% of individuals showed deficits in speed of processing after experiencing mTBI (Hinton-Bayre et al., 1999); however, participants had returned to their pre-mTBI level of cognitive functioning 3-5 weeks later. Thus, deficits in processing speeds were confined to the 1-2 week period following the mTBI (Hinton-Bayre et al., 1999). Other research shows that reductions in speed of processing can persist longer than two weeks. One particular study found that deficits were still evident one year following mTBI (Dymowski, Owens, Ponsford, & Willmott, 2015).

Another domain of cognitive functioning that is negatively impacted by mTBI is attention (Dymowski, et al., 2015; Sinclair, Ponsford, Rajaratnam, & Anderson, 2013). Evidence indicates that 62% of individuals had impaired attention after experiencing one or more mTBI (Marsh et al., 2016). Other research has found that many individuals experience deficits in attention capacity proportional to the severity of their mTBI (Dikmen et al., 2009; Draper & Ponsford, 2006). These individuals who are afflicted with deficits in attention have a lower quality of life with regards to autonomy and social acceptance (Everts et al., 2008).

Prior research has identified a variety of covariates that moderate the association between mTBI and cognitive deficits: multiple previous concussions, concussion severity, education level, and alcohol and drug use. Findings show that individuals with two or more mTBI show symptoms for a longer period of time following each consecutive mTBI (Graham, Rivara, & Ford, 2014; Mannix et al., 2013). Severity was also found to have an effect on cognitive functioning, such that deficits in cognitive functioning followed moderate and severe TBI but not mTBI (Roncadin, Guger, Archibald, Barnes, & Dennis, 2004). Among individuals who experienced mTBI, it was found that individuals with higher levels of education showed fewer deficits in cognitive functioning than those with lower levels of education (Rodrigues de Oliveria Thais et al., 2014), even when experiencing mTBI of equal severity and location. Research also found that that individuals with prior drug use, including alcohol, have been shown to have more severe cognitive deficits following mTBI than those with no prior drug use (Unsworth & Mathias, 2016).

Research has also investigated the effects of multiple repeated mTBI. This is commonly referred to as second impact syndrome, which may result in catastrophic or fatal outcomes (Cobb & Battin, 2004); however, other research has found less dramatic results and fewer residual effects in regards to physical and cognitive deficits (Moser & Schatz, 2017). Multiple mTBI have been highly understudied. Thus, one goal of the present study was to expand on these findings to provide further evidence for the consequences of multiple mTBI.

The focus of the present study was to provide confirmatory evidence for the associations between mTBI and memory, speed of processing, and attention. A secondary purpose was to experimentally manipulate task difficulty to evaluate its interaction with number of mTBI on speed of processing. Data was dichotomized such that participants with 0-1 mTBI were compared to those with 2 or more mTBI. This division was based on previous research, which indicated that multiple mTBI can result in more prominent deficits than a single mTBI (Graham et al., 2014). It was predicted that individuals with 0-1 mTBI would show fewer cognitive deficits in their memory, speed of processing, and attention than participants with 2 or more mTBI. Additionally, it was hypothesized that the effect of task difficulty on speed of processing would depend on the number of mTBI participants experienced, such that the speed of processing of participants who have had 2 or more mTBI would be more negatively affected by task difficulty than that of participants who have had 0-1 mTBI.

1.2 Method

1.2.1 Participants

One hundred undergraduate students from a regional college in the pacific northwest (72 female; 28 male) participated in this study. The average age of these participants was 23.48 years (*SD* = 9.14). The participants' average level of education was some college credit but no degree. Of the 100 participants, 16 indicated they had used non-prescription drugs and 11 indicated they have or currently engage in recreational drug use. Regarding alcohol use per week, 49 participants stated they consume 0 alcoholic drinks, 36 stated they consume 1-2 alcoholic drinks, 12 stated they consume 3-5 alcoholic drinks, and 2 stated they consume 5-10 alcoholic drinks. Forty-eight participants had experienced 1 or more mTBI. Of these 48 participants, 39 experienced the injury(ies) within the last month, 9 experienced the injury(ies) in the last 6 months, 1 experienced the injury(ies) in the last 6-12 months, 1 experienced the injury(ies) in last 3-5 years, and 1 chose not to answer. Participants were compensated for their participation by receiving course credit.

1.2.2 Materials

1.2.2.1 Demographic Survey

The 18-item demographic survey included a variety of questions. For the purpose of this study, the relevant variables include highest level of education achieved, number of alcoholic drinks consumed per week, history of prescription and recreational drug use, severity of mTBI, and number of mTBI. Past and current prescription and recreational drug use was measured on a yes or no basis. To measure mTBI severity, an adapted Sport Concussion Assessment Tool (SCAT) was used to aid participants in recalling the symptoms of their mTBI.

1.2.2.2 Trail Making Task

The trail making task was used to assess participants' attention. This task involved connecting a series of dots that contain numbers and letters, alternating chronologically and in alphabetical order between numbers and letters, for example: 1-A-2-B-3-C. Participants first completed a short trail making task (Part A) to acquaint them with the structure of the task so that the longer, timed trail (Part B) would be reflective of their true ability. Participants then completed the longer trail making task (see Appendix A). The time participants took to complete the trail was recorded as the participants' score.

1.2.2.3 Rey Auditory Verbal Learning Task (RAVLT)

The RAVLT is a test used to assess a variety of cognitive functions. In this case, it was used to assess memory. The participants were read a list of 15 unrelated words (List A) and then repeated them back to the researcher. This process was repeated four additional times with the same set of words. Subsequently, participants were read a second list of unrelated words (List B), and then they repeated the second list back to the researcher. The participants' recall of List B was the sixth trial. Finally, participants recalled as many words from List A as they could without the researchers first reading them the list of words. This was the seventh and final time researchers asked participants to recall words. This procedure took approximately 7-10 minutes. The number of words remembered via free recall in the seventh trial was recorded as each participant's score.

1.2.2.4 Card Matching Task

A card matching task was used to assess participants' speed of processing. In addition, this task was chosen to test the interaction between mTBI and task difficulty as the difficulty of this task could be easily modified. Participants were assigned to complete either the difficult version of the task or the easy version of the task, such that participants were only exposed to one condition or the other. Task difficulty was assigned to participants in an alternating fashion and was operationalized as the number of playing cards faced downward – 16 (easy condition) or 24 (difficult condition). The participant was instructed to turn two cards over at a time to see if they matched. Once they found a match, the matched pair was set aside. The same eight pairs of cards were used for both difficulty levels; however, the difficult condition also included eight unmatched distractor cards. The time it took participants to locate the eight pairs of cards was recorded as the participants' score.

1.2.3 Procedure

Upon arrival, participants were presented with an informed consent document. After they read and signed this document, they were presented with the demographic survey, including an adapted SCAT for each mTBI the participant had experienced. After these surveys, the researcher administered a battery of cognitive tests. These tests were always administered in the same order: the Trail Making Task, the RAVLT, and the card matching task.

Once the participants had finished these tasks, a debriefing form was presented and the hypothesis of the study was revealed. Experimentation lasted approximately 20 minutes. There was no further contact with the participants other than the awarding of course credit.

1.3 Results

To explore whether attention deficits follow mTBI, an independent samples *t*-test was used to determine if there was a statistically significant difference in scores on the Trail Making Task between participants with 0-1 mTBI and those with 2 or more mTBI. There was no significant difference in attention scores in participants with 0-1 mTBI and those with 2 or more mTBI, $t(93) = -0.81$, $p = .42$. An independent samples *t*-test was also used to evaluate if there was a statistically significant difference in memory scores, assessed using the RAVLT, of participants with 0-1 mTBI and those with 2 or more mTBI. There was no significant difference in memory scores between participants with 0-1 mTBI and 2 or more mTBI, $t(93) = -0.71$, $p = .48$.

To examine whether the effect of task difficulty on speed of processing depended on number of mTBI, a 2 (difficulty level: easy, hard) X 2 (number of mTBI: 0-1, 2 or more) Analysis of Covariance was conducted. Preliminary interaction of the individual covariates with the independent variables indicated a significant interaction with education level; as a result education level was not used as a covariate. After significant adjustment (see Table 1) by the covariates of severity of concussions, alcohol use, non-prescription drug use, and recreational drug use, there was a main effect for task difficulty, such that participants took longer in the difficult condition ($M = 269.01$ s, $SE = 17.83$ s) than the easy condition ($M = 74.10$ s, $SE = 13.52$ s), $F(1, 88) = 86.02$, $p < .001$, $\eta^2 = .49$. There was no main effect for concussion level, $F(1, 88) = 0.96$, $p = .33$. The main effect of task difficulty was qualified by an interaction between task difficulty and number of mTBI, such that participants with 2 or more mTBI took significantly longer in the difficult condition ($M = 307.70$ s, $SE = 36.71$ s) than the easy condition ($M = 67.03$ s, $SE = 25.73$ s). Participants with 0-1 mTBI also took longer in the difficult condition ($M = 202.33$ s, $SE = 14.57$ s) than the easy condition ($M = 81.17$ s, $SE = 16.23$ s), but this pattern of effect was less strong among these participants, $F(1, 90) = 4.85$, $p = .03$, $\eta^2 = .05$.

1.4 Discussion

The purpose of the present study was to investigate cognitive deficits in attention, memory, and speed of processing following mTBI. Additionally, the researchers investigated the effect of task difficulty on speed of processing as a function of the number of mTBI. Results did not support the prediction that individuals with 0-1 mTBI would show fewer cognitive deficits in memory and attention than participants with 2 or more mTBI. The obtained null findings regarding memory and attention are incongruent with previous research, which does suggest that there are deficits in these domains following mTBI (e.g., Kim et al., 2012). Deficits were found in speed of processing, such that the effect of task difficulty on speed of processing depended on the number of mTBI, such that participants with 2 or more mTBI were more negatively affected by task difficulty than participants with 0-1 mTBI even after accounting for covariates. This finding is supported by previous research (Dymowski et al., 2015; Hinton-Bayre et al., 1999; Willmott, Ponsford, Hocking, & Schönberger, 2009).

To ensure that the resulting interaction was not the result of a third variable, the following covariates identified from previous research were included in the model: multiple previous concussions, concussion severity, education level, and alcohol and drug use. Of these co-variates, only education level was shown to moderate the relationship between number of mTBI and cognitive deficits. In the current study, the relationship between mTBI and deficits in speed in processing persisted after accounting for level of education.

Previous longitudinal research found that individuals regain some cognitive functioning in the year following the mTBI; however, progress toward recovery or full recovery after this is rare (Yeates et al., 2002). This research is congruent with the findings of the present study, as they both demonstrate that long-term cognitive deficits may result from mTBI; however, other research indicates that participants will return to baseline cognitive functioning within 3-5 weeks following the mTBI (Hinton-Bayre et al., 1999). These results may be due to measures that are insensitive to subtle differences in the functioning of participants before and after mTBI. If cognitive deficits are resolved within 3-5 weeks of mTBI (Hinton-Bayre et al., 1999), this may be an explanation for the non-significant results found in the present study regarding deficits in memory and attention as the majority of participants (96%) indicated that more than 5 weeks had passed since their last mTBI.

The present study was modeled after the study by Clarke et al. (2012), such that several variables were operationalized in the same manner across both studies. The pattern of significant and null results from Clarke et al. (2012) paralleled those found in the present study. Given that other research demonstrates there are deficits in both memory and attention following mTBI (e.g., Kim et al., 2012), the RAVLT and the Trail Making Task may not be sensitive enough to detect the difference between the cognitive functioning of individuals with 0-1 mTBI and those with 2 or more mTBI. If these tasks were manipulated by task difficulty as was done for the speed of processing measure, perhaps deficits would have been more apparent.

Participants' demographics and the design of the card matching task limited the present study. There was little variability in participants' age and ethnicity, such that 82% of the participants were between the ages 18 and 25, and 64% of the participants were Caucasian. Consequently, this sample may be limited in its ability to generalize to other populations. The other limitation relates to the card matching task. This task was created specifically for this study and has not been used in previous research to the knowledge of the researchers. Thus, this task has not been evaluated for its ability to assess participants' speed of processing. Researchers who wish to use this task in the future should first assess its convergent validity with another task that has been previously validated to measure speed of processing.

In addition to correcting the limitations of the present study, future research could experimentally manipulate task difficulty for measures of attention and memory. To vary difficulty on the RAVLT, the words could be related in the easy condition and unrelated in the difficult condition. The more related the words are, the more easily participants should be able to remember the words (Tullis, Benjamin, & Ross, 2014). Difficulty in the attention task could be varied by presenting two different trails after the practice trail; which would be varied in difficulty through length. By experimentally manipulating the difficulty of these tasks, deficits in memory and attention following mTBI may be more easily detected.

Previous research shows that individuals with 2 or more mTBI have more cognitive deficits than those with 0-1 mTBI (Alun, Provvidenza, & Tator, 2009; Brooks et al., 2013; Covassin, Elbin, Kontos, & Larson, 2010). The results of the present study support past research regarding long-term cognitive deficits in speed of processing; however, no cognitive deficits were found in memory or attention. These results add to a large body of research showing that mTBI results in cognitive deficits, and that mTBI should be responded to with concern.

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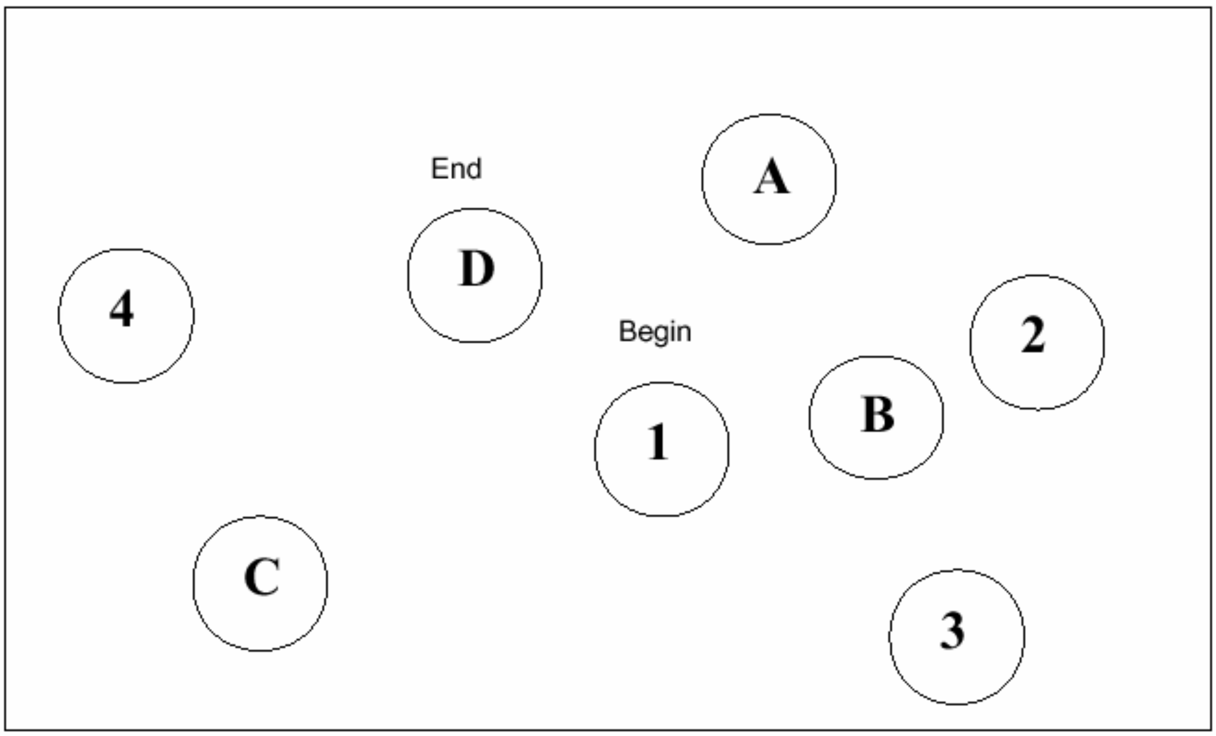
Table 1.
Adjusted and Unadjusted Group Means for Matching Time

	Adjusted M	Unadjusted M
Easy	74.10	78.33
Difficult	269.01	244.28
0-1 Concussions	155.75	165.31
0-2 + Concussions	187.37	156.27

Appendix A

Part A - Short Trail Making Task

You will complete this task by drawing a line between the letter digits in alphabetic/numeric order. For example: 1-A-2-B-3-C… Please try the following example, and then wait for the researcher to give you further instructions.



Part B - Long (Timed) Trail Making Task