Recognition and Recall in hmTBI

Mild traumatic brain injury (mTBI), or concussion, is an increasing public health concern with an estimated two million seeking treatment per year in the U.S. (Roy et al., 2022). However, many who sustain an mTBI do not seek treatment (Demakis & Rimland, 2010), suggesting its prevalence is likely underestimated. It is expected that mTBI symptoms (e.g., issues with attention, processing speed, and memory) fully resolve within three months of injury (McInnes et al., 2017). Nonetheless, a subset of individuals continues to report symptoms after this time (Prince & Bruhns, 2017), suggesting mTBI may have persistent cognitive consequences.

The full extent of the remote effects of mTBI on cognitive function remain unclear. Working memory (WM) is the ability to hold onto and manipulate information over brief durations. In a decade of past research, we found that undergraduates with a history of mTBI (hmTBI, more than four years post-injury) exhibited worse visual WM (VWM) than those without hmTBI when probed by old/new recognition (Arciniega et al., 2021). We note that we did not observe worse VWM in 2022-2023 participants. Previous research also suggests impulsivity is linked to differences in executive function, and that impulsive individuals are more likely to sustain head injuries (Arciniega & Kilgore-Gomez, 2020; Romer, 2010). However, it is unclear whether there is a relationship between hmTBI, impulsivity, and VWM performance.

Because of the heterogeneity of mTBI, it is important to clarify who is likely to have lasting cognitive changes, and why. One way to test mTBI's effect on VWM in finer detail is by assessing recall. Unlike with recognition, probing WM with recall requires individuals to reproduce remembered stimuli, utilizing frontal networks (Berryhill et al., 2011). Examining recall provides insight into the precision of retained representations, which is not possible with old/new recognition paradigms. In contrast to WM *recall*, WM *recognition* instead relies on parietal structures. This is visible when recall and recognition trials are presented in separate blocks, allowing one strategy to dominate, rather than being interleaved (Berryhill et al., 2010, 2011). By examining the relationship between potentially different areas of damage and cognitive outcomes, the current experiment will allow us to try to predict what kind of mTBI profile causes VWM deficits.

Our question was whether hmTBI impairs VWM *recall* and *recognition* equally. Further, we asked whether impulsivity varies in undergraduates with hmTBI and whether it relates to VWM performance differences. We hypothesized that hmTBI students would have lower performance *and* precision than students without hmTBI. Moreover, we predicted that hmTBI students would perform disproportionately worse when probed with recall than when probed with recognition, relative to controls. We also predicted that VWM deficits in the hmTBI group, if they existed, would relate to greater impulsivity levels. Uncovering any interactions between VWM recall, recognition, and impulsivity in the hmTBI group would aid our understanding of the fine-grain impacts of mTBI.

Materials and Methods

Participants

We recruited undergraduates from the University of Nevada, Reno. Inclusion criteria consisted of being at least 14 years old, having no neurological history (e.g., no history of coma, stroke, autism, etc.), and having normal or corrected-to-normal vision (including no color blindness) tested by the short version of the Ishihara's color test (Ishihara, 1992). Final analyses included 37 participants (14 females, 22 males, 1 other), aged 18 to 25 years (M = 19.8 years, SD = 1.66 years). Of these, 12 had hmTBI (9 females, 3 males), aged 18 to 25 years (M = 20.0 years, SD = 2.00 years), and 25 were healthy controls (13 females, 11 males, 1 other), aged 18 to 23 years (M = 19.7 years, SD = 1.51 years). We excluded 15 participants for the following reasons: failure to pass the practice after three attempts, <50% accuracy in any task, reporting exclusionary conditions in the demographics questionnaire, failing the Ishihara's color test, or computer malfunction. All participants provided verbal assent. Participants received experimental credit that can be contributed toward class credit or a $10 Amazon gift card. All procedures followed the guidelines and regulations approved by the University of Nevada, Reno Institutional Review Board.

Apparatus

We coded the tasks in MATLAB (R2023b version, The MathWorks, Natick, MA) using the Psychophysics Toolbox 3.0.19 extension (Kleiner et al., 2007; Pelli, 1997) and presented them on a 27" WQHD (2560 x 1440) widescreen IPS monitor using a Mac mini (M1, 2020) computer. We conducted statistical analyses using IBM SPSS Statistics (Version 29).

Computerized Tasks

Barratt Impulsiveness Scale-Brief (BIS-Brief). We used the Barratt Impulsiveness Scale-Brief (BIS-Brief) to obtain a unidimensional impulsivity score for each participant (Steinberg et al., 2013). It uses a 4-point Likert scale and consists of eight of the 30 items from the BIS-11 (Patton et al., 1995; Stanford et al., 2009). For forward-scored questions (items 2, 5, 14, and 19), response options range from 0 “Strongly Disagree” to 4 “Strongly Agree.” Items 1, 8, 9, and 12 are reverse-scored. BIS-Brief scores range from 8-32, with greater scores indicating higher impulsivity levels.

mTBI Symptom Inventory. To define hmTBI status, we asked participants to complete ten questions of demographic information and whether they have had any previous concussions/head injuries. If an individual reported hmTBI, we asked ten follow-up questions regarding details of their injury (e.g., time of injury, loss of consciousness, location of impact, etc.). Additionally, we asked individuals with hmTBI to rate the severity of 28 potential symptoms at the time of injury and currently.

Visual Working Memory (WM) Task (Recognition, Recall). We replicated the visual WM tasks from Zhang and Luck (2008) using modified code from Suchow et al. (2013) and Foster et al. (2017). In each trial, participants encoded a sample array of three colored squares presented for 100 ms, followed by a 900 ms WM delay. In recognition trials, participants reported whether a single square matched the corresponding sample square (50% same, 50% different by 180 degrees in color space) in color via a mouse click (see Figure 1A). We instructed half of the participants to left-click if the colors were the same and right-click if they were different, and the other half of the participants to do the opposite (pseudorandomized). In recall trials, participants reported the color of a square from the original sample (indicated by the square in lighter gray) by clicking on the color wheel (see Figure 1B). We centered the wheel in color space at (L = 70, a = 20, b = 38) with a radius of 60, which comprised 360 evenly distributed colors (Zhang & Luck, 2008). To reduce the influence of spatial memory, we rotated the wheel between trials. The distance between the color of each square shown in a trial, including the recognition probe, was at least 30 degrees to ensure discriminability.

Each participant completed eight sets of 25 trials (50% recognition, 50% recall) for both ‘intermix’ and ‘block’ conditions. For the intermix condition, we randomized the presentation order of recognition and recall trials, allowing us to examine dual performance. For the block condition, each trial set contained trials of the same type (e.g., all recognition *or* all recall), allowing us to investigate performance when one strategy dominates. We counterbalanced the order of the intermix and block conditions across participants. Before each set, we informed participants whether it would contain all recognition trials (“matching”), all recall trials (“color wheel”), or a mixture (“matching and color wheel”). Self-paced breaks followed each set.

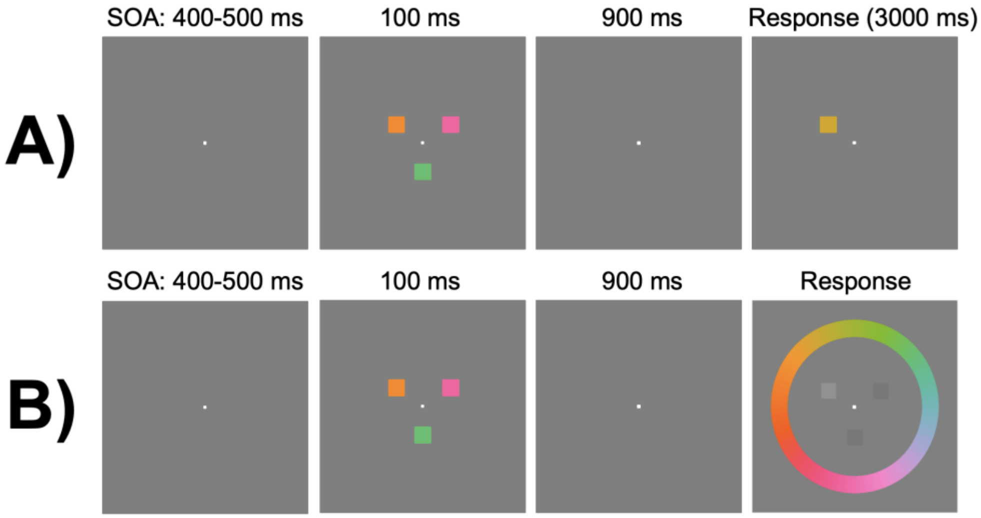

Figure 1. *Working memory task design. Example of a recognition trial **(A)** and a recall trial **(B)**. Following a stimulus onset asynchrony (SOA), three differently colored squares appeared. **(A)** At the end of a recognition trial, one probe appeared, and participants indicated via mouse click whether it matched the original square in the same position. **(B)** At the end of a recall trial, participants reported the color of the original square in the same position as the light gray square by clicking on the color wheel.*

Procedure

Participants who met inclusion criteria completed two practice block sets of the WM task. One set contained 20 recall trials and the other 20 recognition trials. Participants repeated the practice until they exceeded 50% accuracy on the recognition trials and fell below 90 degrees of error on the recall trials (chance performance), and we dismissed those who did not pass after three attempts. After completing the practice, participants completed the visual WM task, which lasted about 30 minutes. At the end of the study, they completed a demographics questionnaire that included the BIS-Brief and the mTBI symptom inventory.

Results

mTBI Symptom Inventory

Of the twelve hmTBI participants, only three were able to report the location of their head injury (e.g., back of head versus front of head). Thus, we did not look at differences in location of head injury across more frontal (recall) or parietal (recognition) demanding conditions.

Barratt Impulsiveness Scale-Brief (BIS-Brief)

To calculate total BIS-Brief scores (M = 16.2, SD = 3.54), we followed published procedures and summed scores across all eight items (Patton et al., 1995; Steinberg et al., 2013). The hmTBI group (M = 16.0, SD = 4.33) and control group (M = 16.3, SD = 3.22) exhibited the same level of impulsivity, $t(35)$ = .22, p = .41 (see Figure 2).

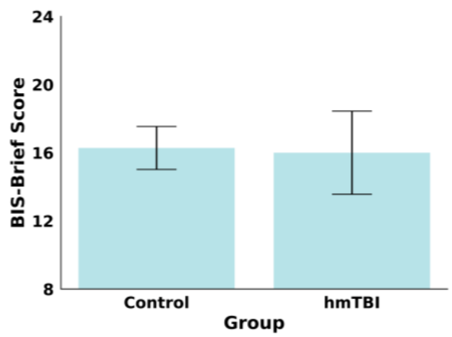

Figure 2. *Comparison of total Barratt Impulsiveness Scale-Brief (BIS-Brief) scores between the history of mild traumatic brain injury (hmTBI) group and the control group. Error bars represent 95% confidence intervals.*

Recognition VWM

We assessed the effects of hmTBI status and condition ('block,' 'intermix') on recognition VWM accuracy and reaction time using a two-way mixed MANOVA. There were no group-level differences. In the intermix condition, the hmTBI group (*M* = 0.78, *SD* = 0.079) performed similarly to controls (*M* = 0.81, *SD* = 0.055). For the block condition, the hmTBI participants (*M* = 0.80, *SD* = 0.057) performed almost identically to controls (*M* = 0.79, *SD* = 0.062; see Figure 3A).

Additionally, the hmTBI group (*M* = .80 s, *SD* = .062) had a similar reaction time to the control group (*M* = .80 s, *SD* = .058) in the block condition. This was also the case for the intermix condition, where hmTBI participants (*M* = .78 s, *SD* = .076) showed no deficits compared to controls (*M* = .81 s, *SD* = .055; see Figure 3B).

Overall, the MANOVA found no main effect of hmTBI status, $F(1, 34) = 1.77$, $p = .19$. However, there was a main effect of condition, $F(1, 34) = 7.15$, $p < .05$. A univariate ANOVA revealed participants responded slower in the intermix condition (*M* = .89 s, *SD* = .206) than in the block condition (*M* = .77 s, *SD* = .161), $F(1, 34) = 12.89$, $p < .01$.

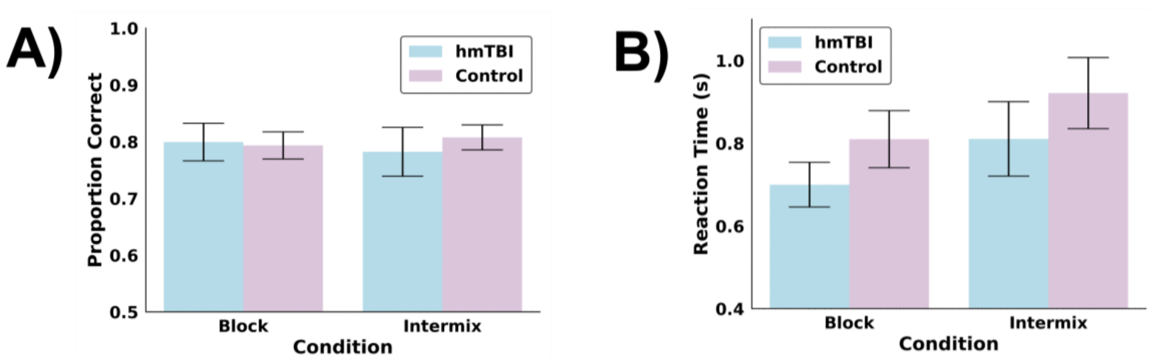

Figure 3. *Recognition VWM task results for the history of mild traumatic brain injury (hmTBI) group (blue) and control group (purple), across 'block' and 'intermix' conditions. Error bars represent 95% confidence intervals.* ***(A)*** *Results show no difference in accuracies between hmTBI participants and controls for either the block or intermix condition.* ***(B)*** *Results show participants respond faster in the block condition (p < .01), but no main effect of hmTBI status.*

Recall VWM

We also looked at the effects of hmTBI status and condition ('block,' 'intermix') on VWM recall error using a two-way mixed ANOVA (see Figure 4). In the block condition, the hmTBI group (M = 30.1, SD = 11.09) was just as precise as the controls (M = 26.6, SD = 7.41). This was paralleled in the intermix condition, where the hmTBI participants (M = 49.1, SD = 7.02) again performed similarly to controls (M = 44.2, SD = 7.31).

Altogether, there was no main effect of hmTBI status, $F(1, 34) = 2.74$, $p = .11$. Moreover, there was no main effect of condition on recall error, $F(1, 34) = 3.23$, $p = .079$: block condition (M = 27.7, SD = 8.77); intermix condition (M = 45.8, SD = 7.49).

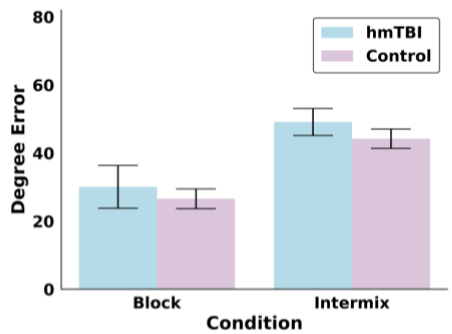

Figure 4. *Recall VWM task results for the history of mild traumatic brain injury (hmTBI) group (blue) and the control group (purple), across 'block' and 'intermix' conditions. Error bars represent 95% confidence intervals. Results show no difference in precision between hmTBI participants and controls for either the block or intermix condition, and no main effect of condition.*

Discussion

The prevalence of mTBI and its long-term consequences necessitate a deeper understanding of its impact on functions like VWM. Here, we aimed to investigate the potential cognitive effects of a hmTBI on VWM performance while also examining the role of impulsivity. By probing VWM with both recall and recognition, we aimed to discern the fine-grain effects of mTBI. Understanding these relationships is crucial for predicting which individuals might experience enduring cognitive changes following mTBI.

These findings revealed *no significant differences* in VWM recognition or recall performance between the hmTBI group and the control group. The hmTBI participants performed similarly to controls in both the recall and recognition VWM tasks, suggesting hmTBI does not result in persistent VWM deficits. This deviates from our lab's previous findings that individuals with hmTBI show cognitive deficits even more than four years post-injury, on average (Arciniega et al., 2019, 2021). Moreover, these findings found no difference in impulsivity level between those with hmTBI and those without hmTBI. This also contrasts with previous reports of increased impulsivity in hmTBI participants (Beidler et al., 2021; Liebel et al., 2021). However, a limitation of this study is a lack of power due to our small hmTBI sample. Time permitting, we could increase our power and gather more participants to achieve our goal of n = 25 for both the hmTBI group and the control group.

In the future, we plan to further investigate the effect of retrieval demands on VWM performance. Although insignificant, we found that when retrieval demands were intermingled and unpredictable, as observed in the intermix condition, participants tended to exhibit poorer recall performance compared to when they performed a recall block alone. This suggests participants could favor a less-demanding recognition strategy over a more-demanding recall strategy. In conclusion, we found no evidence of hmTBI deficits, but our findings highlight the need to understand the effect of different strategies on VWM.

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