Published in final edited form as:

Brain Inj. 2018 ; 32(9): 1110–1114. doi:10.1080/02699052.2018.1483031.

Convergent thinking and traumatic brain injury: an investigation of performance on the remote associate test

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Abstract

Objective: While deficits in several cognitive domains following moderate-to-severe traumatic brain injury (TBI) have been well documented, little is known about the impact of TBI on creativity. In the current study, our goal is to determine whether convergent problem solving, which contributes to creative thinking, is impaired following TBI.

Methods: We administered a test of convergent problem solving, the Remote Associate Task (RAT), as well as a battery of neuropsychological tests, to 29 individuals with TBI and 20 healthy comparisons.

Results: A mixed-effect regression analysis revealed that individuals with TBI were significantly less likely to produce a correct response, although on average they attempted to respond to the same number of items. Moreover, we found that the TBI (but not the comparison) group's performance on the RAT was significantly and positively associated with verbal learning and memory, providing further evidence supporting the association between declarative memory and creative convergent thinking.

Conclusion: In summary, our findings reveal that convergent thinking can be compromised by moderate-to-severe TBI, furthering our understanding of the higher-level cognitive sequelae of TBI.

Keywords

Creativity; convergent thinking; memory; Remote Associate Test; creative thinking

Introduction

In the USA alone, every year there are over 1.7 million new cases of traumatic brain injury (TBI), often leading to long-term cognitive sequelae across cognitive domains (1). While

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Disclosure statement

No potential conflict of interest was reported by the authors.

deficits in traditional neuropsychological domains such as memory, language, and attention have been well documented, less is known about the impact of TBI on multi-domain cognitive phenomena like creativity.

Creativity is the capacity to generate adaptive and original ideas, and it is a universal human attribute that plays a crucial role in everyday life (2). Creativity requires the orchestration of different types of cognition, which range from the ability to produce varied and original ideas (divergent thinking/problem solving) to the ability to find a specific solution to a problem (convergent thinking/problem solving) (3–5). Divergent thinking has been measured with tasks such as the Alternative Uses Task, which requires participants to generate original uses for everyday objects (e.g. using a shoe as a flowerpot) or with subtests of the Torrance Tests of Creative Thinking, which assess the ability to imagine and describe unusual situations or draw imaginative figures (6). Convergent thinking, on the other hand, is often measured using the Remote Associate Task (RAT) (7). When completing the RAT, participants are shown compounds made up of three cue words related with each other (e.g. guy, rain, down), and are asked to identify a fourth word (solution) that is associated with all three cues (e.g. fall). The solution can be related with each of the three words by forming a compound word (e.g. rainfall, downfall) or common phrase (e.g. fall guy, fall down) when combined with it, or because it has a close semantic association with it. While the RAT has been used as a general measure of creativity, several studies have suggested that it is a specific measure of convergent thinking processes in creativity (5), as it requires the individual to hone in on a specific solution to a problem (8). Convergent thinking measured by the RAT is in turn associated with, although distinguishable from, other higher-order cognitive processes such as working memory, associational fluency, intelligence (5), as well as declarative (episodic) memory (9). The RAT is a valid and reliable test of convergent problem solving (10,11). To date, no research has examined how creativity, either in the form of convergent or divergent thinking, is affected by TBI.

The goal of the current study was to examine convergent problem-solving abilities in individuals with a history of TBI. Although impairment in several domains that contribute to convergent problem solving (e.g. working memory (12), executive functioning (13) and declarative memory (14)) has been demonstrated, to date no study has examined the performance of individuals with TBI on a task that specifically measures convergent thinking processes in creativity. Here, we administered the RAT to a sample of individuals with moderate-to-severe TBI and to a healthy comparison group to compare their performance. We hypothesised that individuals with TBI would perform worse than comparison participants, revealing deficits in convergent problem solving. Our secondary aim was to examine the relationship between convergent problem solving in individuals with TBI and other cognitive domains. In particular, we focused on the association between convergent thinking and verbal learning and memory, executive functioning, processing speed, and psychosocial distress.

Methods

Participants

Twenty-nine individuals with moderate-to-severe TBI and 20 healthy comparison (HC) participants took part in the study. The two groups were matched for age ($t(47) = 1.22, p > .05$), sex ($\chi^2(1, N = 49) = .41, p > .05$) and years of education ($t(47) = 1.5, p > .05$). Individuals with TBI were recruited through the University of Iowa Brain Injury Registry, while healthy participants were recruited from the Iowa City community (Table 1).

Brain injury severity was determined based on the Mayo Classification System (15). TBI injuries were considered moderate-to-severe when at least one of these criteria was met: (1) Glasgow Coma Scale (GCS) <13 (i.e. moderate (<13) or severe (<8) according to the GCS), (2) positive acute CT findings or lesions visible on a chronic MRI, (3) loss of consciousness (LOC) >30 min, or (4) post-traumatic amnesia (PTA) >24 h. Injury-related information was acquired through medical records and semi-structured interviews with the patient. Cause of injury were falls (17), motor vehicle accident (MVA; 9), assaults (2), and sports injuries (2). One participant had suffered two separate TBIs.

All participants were free of aphasia, confirmed by an aphasia quotient higher than 93.8 on the Western Aphasia Battery (WAB) (16) or by assessment by a speech language pathologist. All activities were approved by the Institutional Review Board.

Remote Associate Test

We selected 16 compound items ranging in difficulty from a pool created by Bowen and Jung-Beeman (17).¹ Participants saw an example item and solved it in the instruction phase, and were then given 8 min to solve as many items as they could. They were explicitly told that they could solve the items in whichever order they wanted (e.g. starting from the top or the bottom, skipping ahead, etc.).

Given that individuals with TBI have been repeatedly found to have lower processing speed than non-injured peers, we decided to allot 30 s for each item (even, for instance, an item that has been solved by 52% of healthy participants in 2 seconds, 84% of participants in 7 s and 96% of participants in 15 s, such as cottage/Swiss/cake (solution: cheese)). Of the 8 min available, participants could decide how long they wanted to dedicate to each item.

Neuropsychological tasks

To characterise the sample and to examine the relationship between RAT performance and other cognitive domains, participants were administered several neuropsychological tasks. Tasks included (1) a measure of verbal learning and memory: the California Verbal Learning Test (CVLT-Immediate), short-delay verbal recall (CVLT-Short Delay) and long-delay verbal recall (CVLT-Long Delay) (18); (2) a measure of processing speed: the processing

¹The compounds selected were: Cottage, Swiss, Cake (Cheese); Cream, Skate, Water (Ice); Dew, Comb, Bee (Honey); Night, Wrist, Stop (Watch); Duck, Fold, Dollar (Bill); Sleeping, Bean, Trash (Bag); Food, Forward, Break (Fast); Fish, Mine, Rush (Gold); Cadet, Capsule, Ship (Space); Way, Board, Sleep (Walk); Keg, Puff, Room (Powder); Dress, Dial, Flower (Sun); Hammer, Gear, Hunter (Head); Guy, Rain, Down (Fall); Hold, Print, Stool (Foot); Lift. Card, Mask (Face).

speed index of the Wechsler Adult Intelligence Scale (WAIS-PSI) (19), computed using the Symbol Search and Coding subtests; (3) a measure of executive functioning and task-switching: the Trail Making Test B (Trails B) (20); and (4) a measure of psychological distress and psychiatric disorders: the Brief Symptoms Inventory (BSI) (21). Data for the BSI were not collected for one participant in the HC group.

Statistical analyses

To analyse the RAT data we performed a mixed-effect logistic regression using the `glmer` function (22) in R (R Core Team, 2016). This analysis allowed us to probe whether individuals with TBI were more or less likely than HCs to produce correct answers to the RAT items. Responses to each item were marked as either correct or incorrect and then entered in the model. The model included group as the only predictor, and was dummy coded using healthy comparison participants as the reference group. The maximum random effect structure supported by the data was determined using a model simplification approach and a maximum likelihood estimation test, and included intercepts for subject and for item ($\chi^2(1) = 198.53$, $p < .001$). For clarity, results (log odds) are also reported in odds ratios (a measure of effect size) and in probability terms.

Group differences on neuropsychological tasks were determined using one-tailed *t*-tests, with the hypothesis that individuals with TBI would underperform HCs. Two participants with TBI were unable to complete Trails B, and to avoid outlier-driven spurious statistical results their scores were Winsorised. Multiple comparison correction was determined using the Benjamini–Hochberg (BH) false discovery rate (FDR) procedure. BH-corrected *P* values are reported, as well as effect sizes using Cohen's *d*. The associations between neuropsychological performance and RAT scores were examined using Pearson correlations. Again, the BH FDR procedure was used to correct for multiple comparisons.

Results

Remote Associate Test

A mixed-effect logistic regression revealed a significant group effect on RAT performance, ($Z = -2.16$, $p < .05$, 95% CI $[-1.7, -.08]$) with individuals with TBI being significantly less likely to produce a correct answer to the average compound item.

On average, the log odds of producing the correct response for individuals with TBI was .105, while the log odds of producing the correct response for HCs were .99. In probability terms, individuals with TBI had a 52.62% probability of producing the correct answer, while HCs had a 72.9% probability of producing the correct answer to the average item. In odds ratio, individuals with TBI were 2.45 times less likely than comparison participants to produce a correct response (Figure 1; Table 2).

Neuropsychological tasks – group comparison

Individuals with TBI performed significantly worse than HCs on the following neuropsychological tests: the WAIS-PSI ($t(47) = 2.83$, BH $p = .006$, $d = .82$), the Trails B ($t(45.57) = 4.19$, BH $p = .006$, $d = 1.16$), the CVLT-immediate ($t(47) = 2.34$, BH $p = .02$, d

= .67), and the CVLT-short delay ($t(47) = 2.01$, BH $p = .04$, $d = .58$). Moreover, they had significantly higher scores on the BSI ($t(30.85) = -3.85$, BH $p < .001$, $d = 1.17$). There were no significant differences in performance on the CVLT-long delay ($t(47) = 1.58$, BH $p = .08$, $d = .46$) (Table 2).

Neuropsychological tasks - association with the RAT

Within the healthy comparison group, RAT performance did not significantly correlate with any of the neuropsychological measures (all $ps > .5$, all $rs < .12$). Within the TBI group, however, RAT performance was significantly correlated with CVLT-Immediate ($r = .54$, BH $p = .01$), WAIS-PSI ($r = .53$, BH $p = .01$), CVLT-short ($r = .47$, BH $p = .02$), and CVLT-long ($r = .43$, BH $p = .03$). RAT performance did not correlate with Trails B or with the BSI.

Given that participants with TBI tend to have lower processing speed than healthy individuals (which was also true in the current study), we performed a one tailed t -test to determine whether the number of attempted responses on the RAT was significantly different between the two groups (with the hypothesis that individuals with TBI would attempt significantly fewer compound items in their allotted 8 min). The purpose of this analysis was to investigate whether the group difference in RAT performance could be driven by underlying differences in processing speed. The one-tailed t -test showed that individuals with TBI did not attempt significantly fewer trials than healthy comparisons ($t(46.21) = 1.49$, $p > .05$). Individuals with TBI attempted on average 11.48 items ($SD = 3.57$) while HCs attempted on average 12.7 items ($SD = 2.2$).

Discussion

The aim of the current study was to examine how a form of creative thinking, convergent problem solving, is impacted by moderate-to-severe TBI. Our findings revealed that individuals with TBI are less likely than healthy individuals to perform accurately on the RAT. Moreover, we found that, within the TBI group, convergent problem solving skills correlated with test scores in several neuropsychological domains. We discuss each finding below.

Convergent thinking, a form of creativity, is crucial to decision-making in everyday life, as it allows people to apply logic to produce adaptive solutions to problems. The current study revealed that individuals with a history of moderate-to-severe TBI show impairment in their convergent thinking abilities. While the fact that brain damage and impairment of specific brain structures (e.g. hippocampus) can compromise creativity (both divergent and convergent thinking) has been reported before (9,23,24), here we show for the first time that TBI can also lead to deficits in convergent problem solving. That individuals with TBI display disruptions in convergent thinking expands our knowledge of the breadth of cognitive impairment in this population, especially in view of how the breakdown of individual cognitive skills (e.g. memory) can result in the disruption of higher-level, more complex multi-domain abilities (25). Future research is warranted to determine if performance on the RAT, a measure of an ability that is important in everyday life and that is associated with other higher-order cognitive abilities (or other measures of multi-domain abilities), may be a better predictor of long-term outcomes than performance in a single

cognitive domain (e.g. executive function). Given the importance of convergent thinking to adaptive behaviour and problem solving, the knowledge that individuals with TBI demonstrate deficits in this capacity should be taken into consideration by rehabilitators when deciding a treatment plan; moreover, caregivers should be informed about the potential day-to-day repercussions of such deficits in individuals with TBI.

While we found a significant correlation between processing speed and RAT performance, it appears unlikely that the time available for the task drove the group difference in task performance. Indeed, the time allocated for the RAT (30 s for each compound item, regardless of difficulty, and a total of 8 min for the whole task) was higher than estimated in Bowden and Jung-Beeman's study. Moreover, we found that, on average, individuals with TBI and healthy comparison participants attempted the same number of items. This indicates that while individuals with TBI were able to work through the same number of items as HCs, their responses tended to be incorrect more often, suggesting that the deficits in convergent thinking would likely remain were the time allotted for the task unlimited. However, future research should confirm this hypothesis.

RAT performance was not significantly associated with our measure of executive functioning, the Trails B. It is possible that executive functions play a non-significant role in convergent thinking following TBI. However, this is unlikely, and it should be noted that the Trails B is prevalently a measure of set-shifting, and might be too specific to capture a large spectrum of executive functioning. Interestingly, we also found a strong correlation between the CVLT-immediate and the RAT performance. As the CVLT-Immediate is a measure of verbal working memory (which falls under the executive functions umbrella) (26), this appears to indicate that the ability to keep in mind and manipulate the three cue words may strongly influence one's ability to successfully respond to the RAT's items. Moreover, we also found significant correlations with memory (CVLT-short and long delay), which provides further evidence for a link between creative thinking and declarative (episodic) memory (9,23). It should also be noted that none of the participants had language impairments (as measured by the WAB), and that difficulties understanding the words that made up the compound items are not likely to have played a role in the TBI group's poorer performance. However, it is possible that group differences in language-related abilities do influence performance on the RAT. For instance, difficulties in semantic processing (i.e. the ability to encode meaning) might be affecting participants with TBI's abilities to form associations between the different words. Although in the current study we did not collect a measure of semantic processing, future work should attempt to further elucidate the relationship between semantic processing and convergent problem solving, and to examine convergent thinking using tasks that do not rely on semantic encoding.

Within the healthy comparison group, we did not find correlations between any of the neuropsychological measures and RAT performance. While this might be due to the relatively small sample size, which represents a limitation of the study, it might also indicate that broad cognitive domains such as working memory, executive functioning, and processing speed play a role in convergent thinking only when they are impaired, and that when they are intact other factors influence inter-individual differences in tasks such as the RAT.

In conclusion, the current study showed that individuals with moderate-to-severe TBI have deficits in convergent problem solving. Future work should investigate the relationship between convergent thinking and indices of quality of life and overall adjustment and outcome, as well as with more fine-grained neuropsychological measures. Moreover, while this study focused on one aspect of creativity, convergent thinking, future work should also examine the way TBI affects divergent thinking, using tasks that assess individuals' abilities to generate multiple solutions to problems without focusing on one specific answer.

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Figure 1. Percent of correct responses and attempted response on the RAT – Group comparison. Average percent attempted answers (HC: MEAN = 75.31, SD = 13.06; TBI: MEAN = 69.61, SD = 20.78), and of correct answers (HC: MEAN = 60.63, SD = 17.69; TBI: MEAN = 50, SD = 20.86) for the HC and TBI groups. Although the number of responses attempted by individuals with TBI did not significantly differ from healthy comparison, on average individuals with TBI were significantly less likely to produce a correct answer.

Table 1.

Participant demographics.

	N	AGE (<i>Mean±SD</i>)	SEX (<i>Females</i>)	EDUCATION (<i>Mean±SD</i>)	CHRONICITY (<i>Months, Mean±SD</i>)
HC	20	55.63 ± 16.1	8	15.1 ± 1.9	N/A
TBI	29	49.88 ± 16.2	12	14.17 ± 2.1	91.7 ± 133.1
Group Differences(<i>p</i>)	N/A	.23	.42	.14	N/A

Note: HC = Healthy comparison participants, TBI = Traumatic brain injury, *p* = *p*-value, SD = Standard Deviation, N/A = Not Applicable

Table 2.

Mean scores and group comparison for the RAT and the neuropsychological assessments.

	HC (Mean±SD)	TBI (Mean±SD)	Group Comparison(<i>p</i>)	Effect size
RAT (% correct)	60.63 ± 17.69	50 ± 20.86	<.05*	OR = 2.45
WAIS-PSI	111.1 ± 15.17	98.97 ± 14.44	<.01*	<i>d</i> = .82
Trails B (Z score)	.79 ± 1.02	-.9 ± 1.8	<.01*	<i>d</i> = 1.16
CVLT-immediate (t score)	57.6 ± 10.36	49.86 ± 12.7	<.02*	<i>d</i> = .67
CVLT-short delay (Z score)	.55 ± 1.02	-.08 ± 1.17	<.05*	<i>d</i> = .58
CVLT-long delay (Z score)	.35 ± 1.03	-.16 ± 1.2	>.05	<i>d</i> = .46
BSI	43.83 ± 8.9	52.52 ± 6.71	<.001*	<i>d</i> = 1.17

Note: HC = Healthy comparison participants, TBI = Traumatic brain injury, *p* = *p*-value, SD = Standard Deviation, OR: Odd Ratio, *d* = Cohen's *d*, RAT = Remote Associate Test, WAIS-PSI = Processing Speed Index, CVLT = California Verbal Learning Test, BSI = Brief Symptom Inventory. *p* Values for the WAIS-PSI, CVLT and BSI are determined using the Benjamini–Hochberg false discovery rate procedure.