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Evidence of cognitive decline in older adults after remote traumatic brain injury: an exploratory study

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Separate bodies of literature indicate that a history of a traumatic brain injury (TBI) and natural aging may result in overlapping cognitive profiles, yet little is known about their combined effect. We predicted that a remote TBI would compound normal age-related cognitive decline, particularly affecting executive function. Neuropsychological task performance was compared between a group of older adults who sustained a TBI in their distant past ($N = 9$) and a group of older adults with no history of head injury ($N = 15$). While all participants scored in the normal range on the Mini-Mental State Examination, the TBI group scored lower than the non-TBI group. Also, in line with predictions, the TBI group made more errors on measures of executive functioning compared to the non-TBI group (the Trail Making B test and the incongruent condition of the Stroop Test), but performed similarly on all tasks with little executive requirements. Findings from this exploratory study indicate that a past TBI may put older adults at a higher risk for exacerbated age-related cognitive decline compared to older adults with no history of TBI.

Keywords: concussion; attention; Stroop Test; Trail Making Test; aging

Each year, approximately 10 million individuals worldwide sustain a traumatic brain injury (TBI; Hyder, Wunderlich, Puvanachandra, Gururaj, & Kobusingye, 2007). Residual cognitive complaints are common after TBI and while they may linger for years (Alves, Macciocchi, & Barth, 1993; Arcia & Gualtieri, 1993; Meares et al., 2011; Vanderploeg, Curtiss, Luis, & Salazar, 2007), longer-term outcomes are poorly documented. Older adults may be especially vulnerable to residual effects of a past TBI as they are also undergoing normal age-related changes in brain and cognitive function. For example, older adults with no history of head injury (Bopp & Verhaeghen, 2007; Park et al., 2002; Salthouse & Babcock, 1991) and younger adults with TBI (Bublak, Schubert, Matthes-von Cramon, & von Cramon, 2000; Christodoulou et al., 2001; McDowell, Whyte, & D'Esposito, 1997) both show impairments on cognitive tasks that require executive processing, but not on tasks with minimal executive demand (*TBI*: Haut, Petros, Frank, & Lamberty, 1990; Potter, Jory, Bassett, Barrett, & Mychalkiw, 2002; Seignourel et al., 2005; Solbakk, Reinvang, Nielsen, & Sundet, 1999; *older adults*: Brink & McDowd, 1999; Hartley, 1993; Spieler, Balota, & Faust, 1996; Verhaeghen & De Meersman, 1998). Accordingly, in the current study, we conducted an exploratory study to examine if the long-term effects of TBI are exacerbated by normal age-related changes in function, and specifically whether executive function is impacted.

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Executive processes have been linked to the frontal lobes and are susceptible to disruption when prefrontal cortical regions are damaged (Duncan, Johnson, Swales, & Freer, 1997). The vulnerability of the frontal lobes to both aging (Prull, Gabrieli, & Bunge, 2000; Raz et al., 1997; West, 1996) and TBI (Adams, 1975; McDonald, Flashman, & Saykin, 2002) may explain the similar cognitive profile observed in these populations; a compromised ability to carry out executive processes (Ozen, Skinner, & Fernandes, 2010; Tweedy & Vakil, 1988; Vakil & Tweedy, 1994). Executive processing is implicated in a range of cognitive tasks when there is a need to plan, organize inputs and outputs, learn novel information, inhibit distracters (Norman & Shallice, 1986), or to focus, divide, and switch attention (Baddeley, 1996). The classic Stroop Test, for example, provides a measure of one's ability to inhibit a pre-potent response (such as reading) when it does not conform to task demands. For instance, identification of the ink color in which a word is printed (e.g., red) is slower when the word's meaning is incongruent (e.g., green) than when it is congruent (e.g., red) with that ink color. Reports indicate that non-head-injured older adults (Brink & McDowd, 1999; Hartley, 1993; Spieler et al., 1996; Verhaeghen & De Meersman, 1998) and younger adults with a past TBI (Potter et al., 2002; Seignourel et al., 2005; Solbakk et al., 1999) react significantly slower than healthy younger adults when presented with incongruent stimuli, but not with congruent stimuli. These separate bodies of literature indicate that normal aging and TBI may similarly affect executive processes.

As suggested by Moretti and colleagues (2012), such deficits may be especially pronounced for older adults who have experienced a TBI earlier in life, as their brains are susceptible to both age- and TBI-related changes. In particular, the effects of aging may lead to exacerbated cognitive decline in an individual with a history of TBI as less age-related neuronal loss would be required to exceed a threshold adequate for a deficit. Research shows that multiple concussions (mild TBIs) may lead to mild cognitive impairment (MCI; Guskiewicz et al., 2005) and may result in similar patterns of neural degeneration and cognitive sequela found in individuals who suffered from Alzheimer's disease (McKee et al., 2009). In fact, several studies report head injury as a risk factor for Alzheimer's disease (Guo et al., 2000; Johnson, Stewart, & Smith, 2010; Mortimer et al., 1991; O'Meara et al., 1997; Rasmusson, Brandt, Martin, & Folstein, 1995; Roberts et al., 1994). However, the potential effects of a remote TBI on normal age-related cognitive decline are still unclear.

Recent reports indicate that executive impairments may persist for decades after TBI. For instance, participants who experienced a TBI anywhere from 2 to 30 years in their past showed working memory deficits, but only when a heavy demand was placed on executive processes (i.e., during a divided attention task; Anderson & Knight, 2010). Moreover, retired athletes with a history of concussion, sustained anywhere from 27 to 41 years in their past, demonstrated selective attention deficits, but only when successful performance depended on inhibiting interfering stimuli (De Beaumont et al., 2009). While these studies provide evidence for long-lasting executive impairments, it is still unknown whether such problems persist into older adulthood (mean age = 41 years; Anderson & Knight, 2010; and age range = 50–65 years; De Beaumont et al., 2009). To our knowledge, an experiment has not been designed to compare cognitive performance in a sample of older adults who sustained a TBI decades earlier to those with no history of a TBI. Accordingly, the purpose of this exploratory study was to examine two groups of older adults to test whether a remote history of TBI exacerbates normal age-related impairment in cognition, specifically in executive functioning.

We compared performance of older adults with a history of TBI at least 20 years in their past to that of older adults with no history of head injury on a battery of

neuropsychological tasks that vary in the degree to which they require executive function: Digit Span Test (Wechsler, 1997), Trail Making Test (Reitan & Wolfson, 1985), California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987), and the Stroop Test. The Digit Span Forward (Digit Forward) and Trail Making A (Trails A) tests are traditionally considered to require little to no executive processing, whereas Digit Span Backward (Digit Backward) and Trail Making B (Trails B) tests measure executive/frontal lobe function (Digit Span Test: Aben, Stapert, & Blokland, 2012; Bopp & Verhaeghen, 2005; Stuss & Levine, 2002; Trail Making Test: Demakis, 2004; Ettlin et al., 2000; Stuss & Levine, 2002). For the Stroop Test, the neutral and congruent conditions are known to require little executive processing, relative to the incongruent condition (Ben-David, Nguyen, & van Lieshout, 2011; Bryan & Luszcz, 2000; Demakis, 2004; MacLeod, 1991). Lastly, though immediate verbal recall on the CVLT is not a typical measure of executive processing, such processes are thought to be involved in semantic clustering of recall output (i.e., grouping items according to semantic category; Gershberg & Shimamura, 1995; Hirst & Volpe, 1988).

Participants also completed self-report measures of everyday memory failures (The Memory Failures Scale; MFS) and attention errors (Attention-Related Cognitive Errors Scale; ARCES; Carriere, Cheyne, & Smilek, 2008), as well as depression (Beck Depression Inventory-II; BDI; Beck, Steer, & Brown, 1996) and anxiety (State-Trait Anxiety Inventory; STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1970). While we considered it important to obtain self-report measures of cognitive and affective functioning to supplement the neuropsychological assessments in this exploratory study, we did not necessarily expect the groups to vary as previous research has not found differences between older adults with and without a recent TBI on similar measures (Klein, Houx, & Jolles, 1996). The Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1998) was also administered as a screening tool for gross cognitive impairment. Both the older adults groups were predicted to score within the normal range on this task, as all participants in this study were healthy, independently functioning volunteers.

We predicted that if cognitive differences were observed between older adults with and without a past TBI, they would be limited to subtests known to measure executive function. Specifically, we expected that lower scores may be observed on Digit Backward, Trails B, the incongruent Stroop condition, and/or semantic clustering on the CVLT in older adults with TBI. We did not anticipate group differences on the subtests known to require little or no executive processing: Digit Forward, Trails A, congruent or neutral Stroop conditions. If lower semantic clustering scores were observed in the TBI group on the CVLT, we expected that this may result in lower immediate recall performance.

Method

Participants

Participants were recruited using the Waterloo Research in Aging Pool (WRAP) and received token monetary remuneration for their participation. WRAP is a database of healthy seniors in Waterloo, Ontario, Canada, who are recruited by various means (e.g., newspaper ads and flyers posted in community). During the initial WRAP recruitment procedure, potential participants are interviewed over the phone by the WRAP coordinator to gather demographic and health information for the database. The current study used the WRAP database to set specific criteria pertaining to head injury status, time since injury, visual and auditory health, handedness, and to screen for psychological and neurological disorders.

To be included in the study, all participants must have reported to have normal or corrected-to-normal vision and hearing, to be fluent in English, to be able to read and write unassisted, to be right handed, to be free from psychological or neurological disorders, and, for TBI older adults, to have experienced the head injury at least 20 years in their past. Based on our previous research (Ozen & Fernandes, 2011, 2012; Ozen et al., 2010), our goal was to recruit a total of 40 participants (20 in each group). The WRAP coordinator provided the researcher with the names and contact information of all eligible control and TBI participants who fit the inclusion criteria. All potential participants were telephoned and invited to take part in the study. A total of 30 participants agreed to participate in the study (13 TBI older adults and 17 non-TBI older adults).

At the start of the experiment, the researcher asked participants a subset of those phone interview questions in person to confirm responses to study-specific questions asked during the initial recruitment phone interview. If inconsistencies were found between a participant's phone interview and in-person responses, his/her data were excluded from data analyses. As a result, six participants were excluded from the analyses: two control participants (both reported, in person, to have experienced a past head injury) and four TBI participants (one reported to be left-handed, one had a history of stroke, one had epilepsy, and one did not lose consciousness; see Classification and Severity of TBI section). Therefore, the final sample included 24 older adults; nine who reported a past TBI (six female) and 15 who reported no history of head injury (nine female).

Classification and severity of TBI

A TBI was defined as a closed head injury that resulted from the head being hit, the head striking an object, or any acceleration/deceleration force (i.e., whiplash; Kay et al., 1993) that resulted in a loss of consciousness (LOC). Participants who reported brain damage for any other reason (e.g., stroke) were not included in the study. In total, our TBI group consisted of three participants who sustained two past TBIs each, and six participants who sustained one past TBI each (a total of 12 TBIs in a sample of nine participants). Severity of TBI was classified by participants' self-reported duration of LOC and posttraumatic amnesia (PTA).

The TBI was labeled as "mild" if LOC did not exceed 30 min and PTA was no longer than 24 hr (Kay et al., 1993); "moderate" if LOC was between 30 min and 6 hr or PTA between 1 and 7 days (Seignourel et al., 2005); and "severe" if LOC was more than 6 hr or PTA of more than 6 days (Seignourel et al., 2005). Using these criteria, of the 12 head injuries that our nine participants sustained, five were classified as mild, four as moderate, two as severe, and one undetermined (see Table 1). Time since injury ranged from 23 to 73 years ($M = 51.54$, $SD = 16.32$). With the exception of two head injuries, all participants reported that they sought medical attention immediately following the incident. Of these participants, three underwent a brain scan (i.e., Computed Tomography or Magnetic Resonance Imaging), all showing unremarkable results, four did not have brain scans, and two did not recall whether they did or not.

Neuropsychological tests and self-report scales

All participants completed the MMSE at the beginning of the experimental session to screen for gross cognitive impairment. Short-term memory and working memory were assessed using the Digit Forward and Digit Backward tasks, respectively. Trails A and Trails B (http://doa.alaska.gov/DMV/akol/pdfs/UIowa_trailMaking.pdf) were used to

Table 1. Demographic and head injury details for TBI participants.

Gender	Age	Education	TSI (years)	LOC	PTA	LOH	Severity	Cause of injury
M	80	16.0	73[1]	–	–	4 weeks	–	*Run over by car*
			5[2]	1 hr	–	Overnight	Moderate	*Fell down stairs*
F	84	17.0	46[1]	5–10 min	Incident	No	Mild	*Car accident: landed in ditch*
			37[2]	20 min	Incident	3–4 days	Mild	*Car accident: rear-ended*
F	74	13.0	58	5 days	Incident	2 weeks	Severe	*Car accident*
F	66	16.5	49	15 min	No	6 days	Mild	*Car accident: T-bone crash*
M	68	16.0	43[1]	1 hr	No	Few hours	Moderate	*Assault: direct hit to head*
			37[2]	1 hr	No	Few hours	Moderate	*Assault: direct hit to head*
M	72	12.0	60	Few minutes	~1 hr	Few hours	Mild	*Fell out of car and hit head*
F	76	12.0	–	45 min	No	Overnight	Moderate	*Fell down stairs head first*
F	82	12.0	67	5 min	No	No	Mild	*Riding bike and hit by truck*
F	61	12.0	23	Days	Week prior	Yes (unknown)	Severe	*Car accident: head went through windshield*
Mean	***73.67***	***14.17***	***51.54***					
SD	*7.71*	*2.24*	*16.32*					

Notes: TSI = Time since injury; LOC = length of unconsciousness; PTA = posttraumatic amnesia; Incident = PTA lasted the length of the incident; LOH = length of hospitalization; "–" = participant could not recall. Superscripts 1 and 2 in TSI column indicate the first and second TBI details. The first participant in the table experienced two TBIs, reporting that the second TBI was sustained less than 20 years in his/her past (5 years prior). Another participant could not remember the TSI. These two participants' data were included in the analyses, as their scores on all neuropsychological measures were within 2 *SD*s of the group mean.

examine processing speed and attentional switching, respectively. Contrary to standard procedures, participants were not informed when they committed an error. Instead, participants continued tracing in order, whether they self-corrected the error or not. If an error affected subsequent traces (e.g., the participant continued tracing in order, but from letter to number, instead of number to letter), only the initial error was counted unless a new error was committed. Errors were calculated after test completion.

To obtain measures of immediate verbal recall and semantic clustering, the first trial (of List One) from the CVLT was used (Trial One of the CVLT). Because we only administered one trial of the word list, we used the List-Based Clustering Index (LBC) from Stricker, Brown, Wixted, Baldo, and Delis (2002) to calculate semantic clustering for each participant. The LBC determines how many observed semantic clusters occurred in a participant's recall beyond what would be expected if recall was random (maximum of 9 and minimum of −3 on Trial One of CVLT). The expected value in the formula is based on the categories represented on the original list (4 on the CVLT) and is independent of words recalled.

Participants also completed a 5-min version of the Stroop task administered with E-prime v.1.2 software (Psychology Software Tools Inc., http://www.pstnet.com/) to measure selective attention and response inhibition. They were informed that a string of letters ("xxxx", "red", or "green" presented in Courier New font, with 18 point size) would appear one at a time on the computer screen, and to press the "z" key if the font color was red and "m" if the font color was green (counterbalanced).The task consisted of 138 trials: 46 were neutral ("xxxx" shown in red or green), 46 congruent (the word "red" in red-color font and the word "green" in green-color font), and 46 incongruent (the word "red" in green-color font and the word "green" in red-color font). Participants' accuracy and response time in each condition were recorded.

All participants completed a demographic/health information form, the BDI for depression symptoms, the STAI to measure state and trait anxiety, the ARCES for everyday attention errors and the MFS for memory failures. Participants also completed two experimental computer-based tasks to obtain sensitive measures of attention and working memory, respectively (results not reported here): The Slip Induction Task (SIT; see Clark, Parakh, Smilek, & Roy, 2012 for original task details) and the Repetition Detection Task (see Ozen, Itier, Preston, & Fernandes, 2013 for original task details). For the purposes of this exploratory study, however, we excluded these assessments from our analyses as they are experimental in nature. Instead, we only included the results of the neuropsychological tests, as the cognitive functions measured by each test are well-established in the literature, and the tests are applicable and widely available to clinicians and researchers. The SIT and Repetition Detection Task results will be reported elsewhere.

Experiment procedure

After reading the Information Letter and signing the Consent Form, participants completed the demographic/health questionnaire. Next, participants completed the MMSE followed by Digit Forward and Backward and Trails A and Trails B. Participants then completed the Repetition Detection Task that was followed by Trial One of the CVLT. Next, the STAI and BDI were administered, followed by the Stroop task, the ARCES, and the MFS. Participants finished the experiment by completing the SIT. All procedures were performed in compliance with University of Waterloo's ethics guidelines for human research and were approved by the University's Office of Research Ethics.

Results

Independent samples *t*-tests were used to compare group means on demographics, the MMSE, the Trail Making test, the Digit Span test, and Trial One of the CVLT. Additional qualitative analyses were conducted where appropriate.

The mean age was 73.87 (*SD* = 7.61) for control participants and 73.67 (*SD* = 7.71) for TBI participants, which did not differ significantly, t (22) = 0.06, $p > .05$. The mean number of years of education was 14.80 (*SD* = 2.0) for control participants and 14.01 (*SD* = 2.24) for TBI participants, which also did not differ significantly, t (22) = 0.84, $p > .05$. On the MMSE, all control (*M* = 29.33, *SD* = 0.62) and TBI (*M* = 28.67, *SD* = 1.00) participants achieved a score of at least 27 out of a maximum 30, indicating that they were free of gross cognitive impairment (Folstein et al., 1998).

Even though all participants in each group scored within the normal range on the MMSE, the TBI group scored significantly lower than the non-TBI group, t (22) = 2.44, $p = .02$ (see Figure 1). Looking at the data, 78% of TBI older adults made at least one error on the MMSE (7/9), whereas only 40% of non-TBI older adults made an error on the MMSE (6/15).

No significant differences were observed between groups on mean completion time for Trails A or Trails B (see Table 2). Significant differences were found, however, between groups for the mean number of errors for Trails B, but not Trails A. That is, older adults with TBI committed significantly more errors on Trails B (*M* = 1.11, *SD* = 0.93) than non-TBI older adults (*M* = 0.27, *SD* = 0.70), t (22) = −2.53, $p = .02$ (see Figure 2). A chi-square test revealed that significantly more TBI older adults committed at least one error (count of six) compared to non-TBI older adults (count of two), $x^2(1) = 7.20$, $p < .01$.

A qualitative analysis of Trails B data showed that the majority of errors (60%) made by the TBI group were due to a failure to switch task sets either from number to letter or from letter to number (e.g., one participant traced K-L, instead of K-12-L; another traced 5-6 instead of 5-E-6). In other words, these errors were characterized by participants completely *missing* a switch from one task set to another. In contrast, only one error (25%) in the non-TBI group was due to a failure to switch from one task set to another. Instead, the majority of errors (75%) committed in the non-TBI group occurred *while* participants were switching from one task set to another (e.g., 6-G instead of 6-F). Only one of the errors (10%) made by the TBI group was of this type.

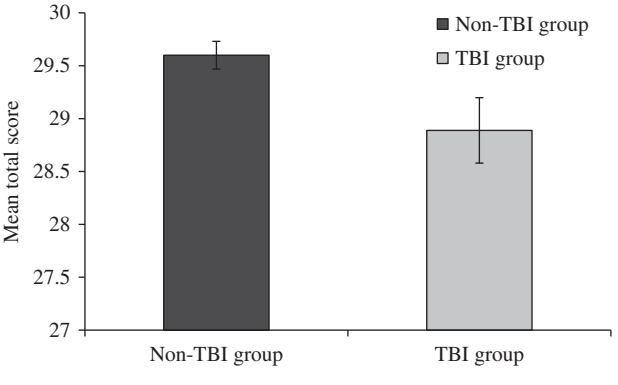


Figure 1. Mean number of correct responses for non-TBI and TBI groups on MMSE. Error bars represent standard errors of respective means.

Table 2. Neuropsychological task and self-report questionnaire results.

Task/questionnaire	Non-TBI group	TBI group	*t*-Value	*P*-value	Cohen's *d*
Mini-Mental State Examination	**29.33 (0.62)**	**28.67 (1.00)**	**2.44**	**0.02**	**0.85**
Digit Span Forward	8.27 (2.28)	7.78 (1.56)	0.57	0.58	0.24
Digit Span Backward	7.67 (2.16)	6.78 (1.92)	1.02	0.32	0.43
Trail Making A, RT	34.70 (12.10)	30.85 (7.90)	0.41	0.41	−0.36
Trail Making B, RT	75.79 (35.66)	81.19 (35.73)	−0.49	0.72	0.15
Trail Making A, errors	0.13 (0.35)	0.00 (0.00)	1.13	0.27	–
Trail Making B, errors	**0.20 (0.56)**	**1.44 (1.88)**	**−2.53**	**0.02**	**1.02**
CVLT Trial 1	7.20 (3.05)	6.56 (2.83)	0.51	0.61	0.22
CVLT semantic cluster	0.89 (1.55)	0.11 (0.99)	1.35	0.19	0.57
ARCES	30.47 (4.16)	31.67 (4.39)	−0.67	0.51	−0.28
MFS	29.13 (5.33)	29.44 (3.74)	−0.15	0.98	−0.06
STAI (state)	**34.53 (9.09)**	**27.44 (3.88)**	**2.21**	**0.04**	**0.93**
STAI (trait)	**34.87 (7.00)**	**28.89 (4.28)**	**2.30**	**0.03**	**0.97**
BDI	6.80 (4.86)	6.11 (6.19)	0.30	0.76	0.13

Notes: Values represented are mean group scores (standard deviations in parentheses). Items in bold indicate significant difference between groups. CVLT = California Verbal Learning Test; ARCES = Attention-Related Cognitive Error Scale; MFS = Memory Failures Scale; STAI = State Trait Anxiety Inventory; BDI = Beck Depression Inventory.

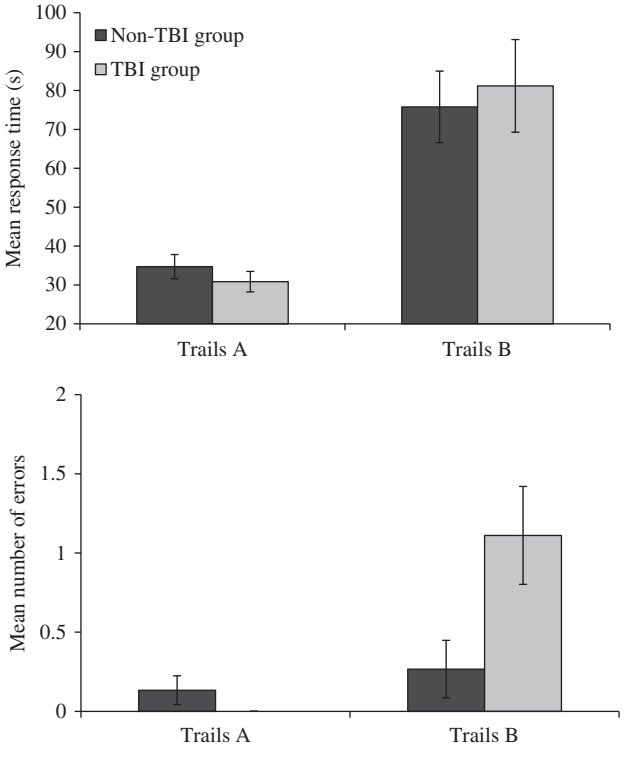


Figure 2. Top graph: mean completion time for the non-TBI and TBI group to complete Trails A and B. Bottom graph: mean number of errors made by the non-TBI and TBI groups when completing Trails A and B. Error bars represent standard errors of respective means.

No differences were found between groups on the Digit Forward and Backward tests nor on immediate recall and semantic clustering on Trial One of the CVLT (for group means and effect sizes on all measures, see Table 2).

Stroop accuracy and median response times were analyzed using two repeated-measure Analyses of Variance (ANOVAs), with Trial Type as the within-subject variable (congruent, incongruent, and neutral) and Group as the between-subject variable (TBI and non-TBI older adults). With respect to accuracy, there was a main effect of Trial Type, F (2, 44) = 9.30, $p < .01$, $\eta_p^2 = 0.30$, regardless of group membership, whereby participants had higher mean accuracy on congruent ($M = 0.99$, $SD = 0.02$) compared to incongruent trials ($M = 0.97$, $SD = 0.04$), t (23) = 3.31, $p < .01$ (see Figure 3). There was also a main effect of Group, F (1, 22) = 7.15, $p < .05$, $\eta_p^2 = 0.25$, such that the non-TBI group had significantly higher mean accuracy ($M = 0.99$, $SD = 0.02$) compared to the TBI group ($M = 0.97$, $SD = 0.04$). This main effect was clarified by a significant Group × Trial Type interaction, F (2, 44) = 4.72, $p < .05$, $\eta_p^2 = 0.18$. Follow-up independent t-tests (with Bonferroni correction applied) showed that the TBI group had lower accuracy ($M = 0.94$, $SD = 0.06$) than the non-TBI group ($M = 0.98$, $SD = 0.02$), $t = 2.88$, $p < .01$, $d = 1.10$, but only in the incongruent Trial Type.

For response times on the Stroop Test, a significant main effect of Trial Type was found, F (2, 44) = 10.56, $p < .05$, $\eta_p^2 = 0.34$. Specifically, participants had significantly

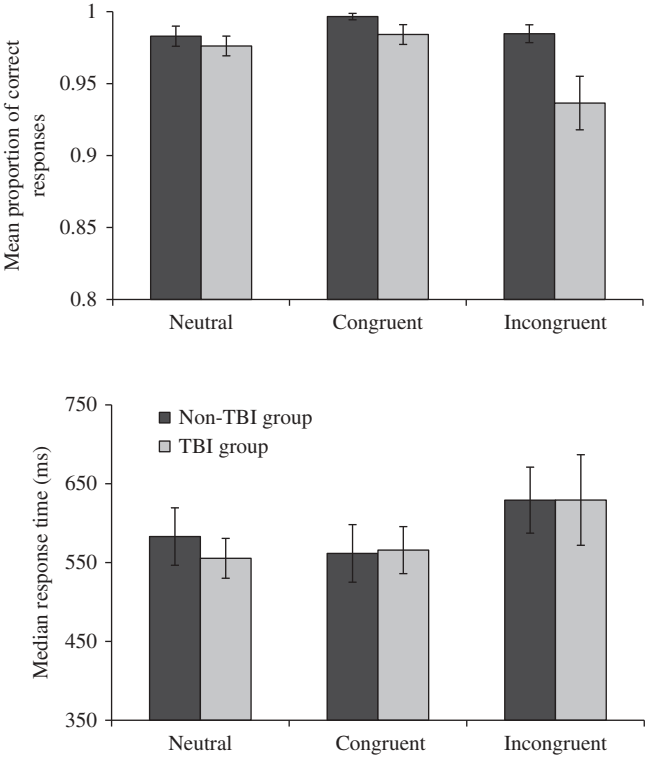


Figure 3. Top graph: mean proportion of correct responses made by the non-TBI and TBI groups in congruent, incongruent, and neutral conditions. Bottom graph: mean response times for the non-TBI and TBI groups in the congruent, incongruent, and neutral condition. Error bars represent standard error of respective means.

Table 3. Neuropsychological task and self-report questionnaire results separated by TBI severity.

Task/questionnaire	Mild TBI $N = 5$	Moderate/severe TBI $N = 4$	Non-TBI $N = 15$
Mini-Mental State Examination	29.00 (1.22)	28.75 (0.50)	29.60 (0.51)
Trail Making B, errors	1.00 (1.00)	1.25 (0.95)	0.20 (0.56)
Stroop Test (Incong Acc)	0.93 (0.07)	0.95 (0.05)	0.98 (0.02)
STAI (state)	26.80 (2.39)	28.25 (5.56)	34.53 (9.09)
STAI (trait)	29.40 (4.16)	28.25 (4.99)	34.87 (7.01)

Notes: Values represented are mean group scores (standard deviations in parentheses). A comparison of means across the mild TBI subgroup, the moderate/severe TBI subgroup and the control group (measures that demonstrated significant differences between the TBI and control groups). Statistical analyses were not performed on these data. Incong Acc = incongruent accuracy; STAI = State Trait Anxiety Inventory.

slower mean response times in the incongruent ($M = 629.30$, $SD = 162.29$) compared to the congruent ($M = 563.30$, $SD = 121.32$), $t\ (22) = 3.42$, $p < .01$, and neutral condition ($M = 572.24$, $SD = 118.45$), $t\ (22) = 3.15$, $p < .01$ (see Figure 3). No main effect of Group, $F\ (1, 22) = 0.02$, $p > .89$, $\eta_p^2 = 0.001$, or Group × Trial Type interaction, $F\ (2, 44) = 0.56$, $p > .50$, $\eta_p^2 = 0.03$, was found.

Independent samples *t*-tests were used to compare group means on all self-report scales (ARCES, MFS, STAI, and BDI). Significant group differences emerged on the STAI. Curiously, the non-TBI group reported higher mean scores on state anxiety ($M = 34.53$, $SD = 9.09$) compared to the TBI group ($M = 27.44$, $SD = 3.88$), $t\ (22) = 2.21$, $p < .05$ (see Table 2). The same pattern was evident for trait anxiety ($M = 34.87$, $SD = 7.01$) with the non-TBI group reporting higher mean anxiety scores compared to the TBI group ($M = 28.89$, $SD = 4.28$), $t\ (22) = 2.30$, $p < .03$. No differences between groups were found on the ARCES, MFS, or BDI (see Table 2).

Due to the small sample size in this study, we did not have the power to examine if differences between control and TBI group scores were affected by TBI severity (mild vs. moderate/severe). While the data were not statistically analyzed, no mean differences were apparent between the mild and moderate/severe subgroups on any of the measures (see Table 3 for means).

Discussion

To our knowledge, this exploratory study is the first to document lowered cognition in older adults who sustained a TBI at least 20 years in their past. While all the participants scored in the normal range on the MMSE, older adults with a remote TBI showed evidence of decreased cognitive ability compared to the older adults with no history of head injury. Neuropsychological test results confirmed predictions that lower performance would be identified in the TBI group only on measures that rely heavily on executive function. Namely, older adults with TBI committed significantly more errors on Trails B and had lower accuracy rates on the incongruent condition of the Stroop Test compared to non-TBI older adults. Group differences were not detected, however, on the other two measures of executive functioning: Digit Span Backward and the semantic clustering on CVLT Trial 1. As expected, the older adult groups did not differ on subtests that made relatively fewer demands on executive function: Trails A, congruent and neutral Stroop conditions, Digit Forward, and immediate recall of Trial One on the CVLT.

The increased number of errors on Trails B, but not Trails A, in the TBI group is suggestive of a decreased ability in the executive process of attentional switching (Demakis, 2004; Ettlin et al., 2000; Stuss & Levine, 2002). These results are in line with reports of attentional switching deficits in non-TBI older adults (Ozen et al., 2010; Verhaeghen & Cerella, 2002; Wecker, Kramer, Hallam, & Delis, 2005) and provide evidence for the compounding effects of a remote TBI on normal age-related cognitive decline. Qualitative analyses in the current study revealed that the quality of the errors also differed between groups, reflecting a reduced ability to switch between cognitive sets.

Response time measures did not differ between groups on Trails A or Trails B in the current study. While standard timing measures on Trails B are sensitive to frontal pathology, Stuss et al. (2001) found they were eliminated when scores were corrected for speed on Trails A. They reported that frontal and nonfrontal patients were distinguished from each other when errors were measured on Trails B. Uncomplicated by timing confounds, Stuss and Levine (2002) concluded that Trails B errors are a valid measure of executive dysfunction. In the present study, the nonstandard administration of the Trail Making test may explain the lack of group differences on Trail Making timing measures as time to correct errors was not captured in completion time (Methods section: Neuropsychological Tests and Self-Report Scales). Yet, in light of the aforementioned studies (Stuss et al., 2001; Stuss & Levine, 2002), error rate may actually be a more valid measure of executive dysfunction overall.

The Stroop Test results also distinguished older adult groups in the current study. In particular, decreased ability in selective attention was observed in older adults with a remote TBI only when executive processes were required, as was the case on the incongruent Stroop condition, but not on the congruent and neutral conditions. These results are indicative of an executive functioning problem, but only when inhibition of automatic responses is required (Ben-David et al., 2011; Bryan & Luszcz, 2000; Demakis, 2004; MacLeod, 1991). This finding is in line with the literature, which documents response inhibition deficits several years post-TBI in young to middle-aged adults (Anderson & Knight, 2010; Potter et al., 2002; Seignourel et al., 2005; Solbakk et al., 1999). The results also suggest that long-lasting TBI-related cognitive decline may compound similar decline observed in non-head-injured older adults (Brink & McDowd, 1999; Hartley, 1993; MacLeod, 1991; Spieler et al., 1996; Verhaeghen & De Meersman, 1998). Together, the Trails B and incongruent Stroop condition results indicate that tasks that make heavy attention-related executive demands may be sensitive to the lasting effects of a TBI on older adults.

While the lack of group differences on Digit Forward was expected, the similar performance between groups on Digit Backward was somewhat surprising. Compared to non-head-injured young adults, working memory impairments have frequently been reported in young adults long after TBI (Leclercq et al., 2000; McDowell et al., 1997; Park, Moscovitch, & Robertson, 1999) and in non-head-injured older adults (Glass et al., 2000; Kramer, Hahn, & Gopher, 1999; Madden, Pierce, & Allen, 1996; Mayr, 2001; Plude & Hoyer, 1986). Therefore, we expected that lower performance on working memory tasks may emerge in older adults with a remote TBI. One possible explanation is that memory-related executive processes (e.g., simultaneously storing and manipulating information for correct recall) are less susceptible to the long-term effects of TBI in older adulthood compared to attention-related executive processes (i.e., switching attention between task sets and inhibiting automatic response during selective attention tasks).

Another possibility is that the Digit Span Test may not be sensitive to TBI-related executive decline above and beyond age-related impairment. For example, recent research

suggests that while performance on Digit Backward requires executive processes for successful completion, it also relies heavily on short-term memory processes (as in Digit Forward; Richardson, 2007). Aben and colleagues (2012) also put forth that short-term memory and working memory tasks are not process pure and there is much overlap between the constructs. Future research could help disentangle whether this study's Digit Span Test null findings are because working memory is indeed intact in older adults after a remote TBI or because tests are insensitive to detect a potential working memory deficit. For example, in order to detect long-term, and potentially subtle, cognitive effects of mild TBI in young adults, some research studies have demonstrated the importance of using nontraditional measures on neuropsychological tasks (e.g., discontinuation rates; Vanderploeg, Curtiss, & Belanger, 2005), as well as sensitive computer-based assessments of working memory (Anderson & Knight, 2010; De Beaumont et al., 2009; Ozen & Fernandes, 2012; Ozen et al., 2013).

Similar to the Digit Span Test results, our prediction that the TBI group may have lower scores in semantic clustering on Trial One of the CLVT was not supported. Studies on frontal lobe patients report deficits on free recall tasks, and these deficits are suggested to be due, in part, to the inability to use executive processes, such as strategies and cues (Gershberg & Shimamura, 1995; Hirst & Volpe, 1988). The lack of group difference in the current study suggests that a remote TBI did not affect older adults' ability to use the executive function of semantic clustering, at least during immediate word recall. However, this finding may be due to a floor effect in that both groups' semantic clustering score was close to zero (non-TBI = 0.89; TBI = 0.11), indicating that neither older adult group utilized this organizational strategy (Stricker et al., 2002). Notably, a recent report suggests that executive functioning capacities actually accounted for little variance in semantic clustering scores (Hill, Alosco, Bauer, & Tremont, 2012). Therefore, similar to the current Digit Span findings, perhaps traditional memory-related tests of executive functioning are not as process pure as once thought and, thus, are not the most sensitive tests for identifying cognitive decline in older adulthood after a remote TBI.

Overall, the current study demonstrated that decreases in cognitive functioning can be detected in otherwise healthy older adults with a remote TBI using traditional neuropsychological assessments. However, the self-report data show that the same participants do not report any differences in everyday memory and attention failures in daily life compared to non-head-injured controls. This lack of perceived problems in daily life may be due to the development of coping strategies developed earlier in life following the TBI event (Klein et al., 1996). On the other hand, it may be more likely that the observed cognitive decline in the TBI group is not of a magnitude that it affects daily function.

Unexpectedly, the non-TBI group reported significantly higher levels of self-reported anxiety compared to the TBI group, while no differences in depression symptoms were reported. Typically, increased levels of anxiety are reported long after TBI (Dischinger, Ryb, Kufera, & Auman, 2009; Westcott & Alfano, 2005). We suggest that a possible explanation for the lower levels of anxiety in our TBI group may be because participants were explicitly informed of the study's purpose – to examine cognitive functioning long after TBI. In this respect, the TBI group was fully aware that it was expected they may have decreased cognitive abilities due to a past head injury, likely accounting for their lowered anxiety levels (Ozen & Fernandes, 2011). On the other hand, non-TBI older adults may have reported heightened levels of anxiety as they may have been more worried about the expectation of having intact cognitive abilities compared to those with a past TBI.

When interpreting the findings of this study, there are several limitations that must be taken into consideration. First, both the history and severity of head injury were self-

reported, which impacts the reliability of the results. Also, in order to avoid unrelated variance in our sample and to answer our specific research question, our inclusion criteria was strict and, thus, sample size was very small. As a result, the representativeness and the statistical power to detect real differences between groups were reduced in this exploratory study. Our small sample size also increases the risk of extreme findings. We suggest future research continues to use strict inclusion criteria in order to exclusively examine the long-term effects of a remote TBI on age-related cognitive decline, but do so with a larger, more representative sample. In addition we were unable to determine the effect of TBI severity on cognitive functioning in the TBI group because of the small sample size. While not included in the analyses, the subgroup means (mild TBI vs. moderate/severe TBI) did not appear to differ. Nonetheless, the reliability of results would be improved if future research increased the sample size and determined if moderate/severe TBIs compound age-related cognitive decline to a greater extent than mild TBIs.

Another limitation of the current study is that we did not consider various health and lifestyle differences that may have accounted for group differences in cognition (e.g., independent vs. dependent living, physical health problems, physical activity, smoking). To decrease the likelihood that the groups would differ on such factors, all the participants were drawn from a database of healthy older adult volunteers living in the community (WRAP database), and only head injury status was used to distinguish the groups. Nonetheless, future research should control for such factors, as they may have a major influence on cognition and help to explain the subtle effects in this study. Lastly, it is important to remember that not all of the neuropsychological tasks were administered in a standard fashion (i.e., we used a version of the Trial Making Test available online with slightly altered administration procedures and a computerized version of the Stroop Test). However, considering that group differences were detected using these tests, future research may benefit from using nonstandard and sensitive cognitive tests to detect subtle effects of TBI on age-related cognitive decline.

In conclusion, the findings from this exploratory study suggest that attention-related tasks, reliant on executive functions such as response inhibition and attentional switching, may be sensitive in detecting decreased cognitive ability in otherwise healthy older adults who sustained a TBI at least 20 years in their past. Future research is necessary to determine why lower performance was identified on attention-related, but not memory-related, executive tasks. These neuropsychological results emphasize the importance of investigating longer-term effects of TBI in older adults, as they may compound normal age-related cognitive decline.

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