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**Research Article**

# Cognitive performance in older people after mild traumatic brain injury: Trauma effects and other risk factors

Camilla Hume[1], Biswadev Mitra[2,3,4], Bradley Wright[1] and Glynda Jane Kinsella[1]

[1]School of Psychology and Public Health, La Trobe University, Melbourne, Australia, [2]Emergency and Trauma Centre, The Alfred Hospital, Melbourne, Australia, [3]School of Public Health and Preventive Medicine, Monash University, Melbourne, Australia and [4]National Trauma Research Institute, The Alfred Hospital, Melbourne, Australia

## Abstract

**Objective:** Cognitive symptoms are common in the initial weeks after mTBI, but recovery is generally expected within three months. However, there is limited information about recovery specifically in older age cohorts. Therefore, this study investigated cognitive outcome three months after mTBI in older adults (≥ 65 years) compared to trauma and community age-matched controls and explored risk factors for outcome after traumatic injury. **Methods:** Older mTBI patients ($n = 40$) and older adults with mild traumatic injury but without head injury ($n = 66$) were compared to a noninjured community control group ($n = 47$). Cognitive assessment included neuropsychological and computerized tests. Group differences were compared on individual tasks and overall cognitive performances using composite scores. Regression analyses identified predictors of outcome for trauma patients and moderator analyses explored possible interactions of mTBI severity with age and cognition. **Results:** As well as lower performances in processing speed and memory, both trauma groups had significantly lower performance on composite neuropsychological ($d = .557$ and .670) and computerized tasks ($d = .783$ and .824) compared to noninjured controls. Age, education, and history of depression were direct predictors of cognitive performance after mild traumatic injury (with or without head injury). Further moderation analysis demonstrated that mTBI severity (Glasgow Coma Scale < 15) moderated the impact of older age on computerized assessment ($\beta = -.138$). **Conclusions:** Three months after mild trauma (regardless of head injury), older people demonstrate lower cognition compared to noninjured peers. However, severity of mTBI (Glasgow Coma Scale < 15) can interact with older age to predict poorer cognitive outcomes.

**Keywords:** brain Concussion (MeSH); mTBI; aged (MeSH); older age; cognition (MeSH); neuropsychological assessment

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Mild traumatic brain injury (mTBI) affects approximately 56 million people globally each year (Dewan et al., 2019). Commonly observed cognitive changes after injury include slowed processing speed, poor attention and executive functioning, and cognitive fatigue (Carroll et al., 2014; de Freitas Cardoso et al., 2019). These deficits are generally transient, and recovery is expected within three months of injury for adults without additional risk factors (Carroll et al., 2014; Karr et al., 2014). Importantly, older age has been suggested as a risk factor associated with slower mTBI recovery (Lingsma et al., 2015; Fraser et al., 2019). Research with older adult populations, however, often combines different TBI severity groups (de Guise et al., 2020) or focuses on mortality rates after injury rather than cognition, making it difficult to determine the specific impact of mTBI on cognitive outcome in older age. Additionally, younger adults are often used as comparison groups (Hume et al., 2021) which is problematic given potential differences in psychosocial factors (e.g., retirement, family roles) and biological factors (e.g., age-related cognitive changes, increased risk of comorbidities) that are unique to older adult cohorts (Papa et al., 2012) and may impact cognition (Bittencourt-Villalpando et al., 2021). Further investigation is needed to better understand the impact of mTBI on cognition in older age cohorts (i.e., ≥ 65 years and older).

Early research with an older adult cohort identified selective cognitive deficits in executive functioning two to three months after mild-moderate head injury (Goldstein et al., 1994). However, when cognitive function among patients with mTBI was directly compared to those with moderate TBI, findings were more modest (Goldstein & Levin, 2001) suggesting that combining TBI severity may have accounted for some cognitive deficits reported in early research. Additionally, cognitive deficits have been noted in older people with orthopedic injury (Aharon-Peretz et al., 1997) which raised the possibility that deficits were not unique to minor head injury and that trauma per se may influence cognitive performance in older age. Indeed, more recent research suggests that performance on complex multi-factorial behaviors such as prospective remembering can be reduced in mild trauma patients with or without brain injury (Gryffydd et al., 2021). However, the impact of mTBI on more standard neuropsychological tests assessing specific cognitive skills involving processing speed, memory, and executive function (de Freitas Cardoso et al., 2019) remains unclear in older

**Corresponding author:** Camilla Hume, email: c.hume@latrobe.edu.au

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**Table 1.** Criteria used to identify mild traumatic brain injury in older adults

| |
|---|
| a) one or more of the following symptoms either observed or self-reported: |
| (i) confusion or disorientation |
| (ii) loss of consciousness (LOC) ≤ 30 min |
| (iii) posttraumatic amnesia for ≤ 24 h |
| (iv) other transient neurological abnormalities, (e.g., focal signs, intracranial lesion not requiring surgery) |
| b) GCS score of 13–15 by 30 min postinjury or later upon presentation for health care |
| c) symptoms are not due to drugs, alcohol, medications, caused by other injuries or treatment for other injuries, caused by other problems (e.g., psychological trauma, language barrier, co-existing medication condition), or caused by penetrating craniocerebral injury |

age cohorts, especially when compared to trauma controls as well as noninjured peers.

Although it is often assumed that older people may find a computer interface difficult to use through a lack of familiarity, many older people are now more computer literate than previous cohorts (Wagner et al., 2010; Pike et al., 2018). This is relevant as computer-based tasks are increasingly used as part of assessment for cognitive symptoms after mTBI (Karlsen et al., 2021). The often-cited advantages include rapid and automated scoring, increased test-retest reliability, and the ability to more accurately measure reaction time (in milliseconds) on tasks of processing speed and executive function (Schatz & Browndyke, 2002). This may be particularly useful to detect small but meaningful cognitive change after mTBI, and exploration of their use with older age patients will be informative for future practice.

In younger adults, several individual predictors have been identified as important risk factors for poorer mTBI outcome, including age (Fraser et al., 2019; Bittencourt-Villalpando et al., 2021), gender (Yue et al., 2019), cognitive reserve (Fraser et al., 2019), and preinjury physical and mental health (Booker et al., 2019; Varner et al., 2021). Additionally, recent mTBI research has highlighted the importance of investigating the possible interaction between certain risk factors and cognitive outcome after mTBI (Stenberg et al., 2020; Levin et al., 2021).

In relation to injury variables and cognitive outcome, the evidence in younger age cohorts is mixed (Silverberg et al., 2015; Booker et al., 2019; Varner et al., 2021). Presence of intracranial injury on neuroimaging has been associated with poorer early postinjury outcome (Voormolen et al., 2019; Karr et al., 2020), including cognitive outcome two weeks postinjury (Iverson, 2006; Frenette et al., 2019). Conversely, other studies have found no relationship between intracranial injury findings and 12-month cognitive outcome (Nelson et al., 2019). Initial presenting Glasgow Coma Scale (GCS) has also been identified as a common predictor of global recovery after mTBI, but with only reasonable discriminability (Mikolić et al., 2021). Whether these same risk factors, including markers of injury severity, are important predictors and/or moderators of cognitive outcome in older mTBI patients is still not clear.

The aim of the current study was to build on previous mTBI literature and focus specifically on cognitive performance (processing speed, attention and executive function, and memory) in an older age cohort. We examined cognition in older people after mTBI, using standard neuropsychological tests and computerized tasks, and compared performances to older patients who sustained mild traumatic injury without head injury and to noninjured older people. It was hypothesized that three months following mTBI, older people would show lower cognitive performance compared to those with mild traumatic injury without head injury. It was also expected that performances by both trauma groups (i.e., mTBI and trauma controls) would be lower on cognitive tasks compared to noninjured older adults.

We also investigated possible predictors of cognitive outcome after mild traumatic injury (with or without head injury) in this older adult cohort. We included possible markers of mTBI injury severity (presence of intracranial lesions and GCS) to determine whether mTBI factors significantly contributed to cognitive deficits. We also explored whether injury severity measured as the presence of abnormal intracranial neuroimaging or GCS < 15 would potentially interact with age to negatively impact cognitive outcome.

## Methods

### *Participants*

We used a cohort design to investigate cognitive status of older adults following mild trauma (mTBI, trauma control group), compared to independent community-dwelling older adults. This study was part of a larger investigation of older adults following traumatic injury, some of which has been reported elsewhere (Gryffydd et al., 2021) and was approved by the Alfred Health Ethics Committee and La Trobe University Ethics Committee (project ID 382/15). All data included were obtained in compliance with institutional/national research standards for human research and the Helsinki Declaration.

### *Eligibility criteria*

Inclusion criteria for all participants were based on previous research (Kinsella et al., 2014) and included: 1) age ≥ 65 years, 2) English fluency, 3) functional independence prior to injury, (i.e., independence at home), and 4) residence within three hours of The Alfred Hospital, Melbourne Australia. Exclusion criteria were: 1) diagnosed life-threatening medical illness, 2) conditions known to affect cognition (e.g., Alzheimer's dementia), 3) current serious psychiatric illness, and 4) hospitalization for a previous significant head injury. Participants either presented to the emergency department after injury (with or without head injury) or were noninjured community-based older adult volunteers.

### *Injury definitions*

Presence of mTBI was identified based on consensus criteria (Kristman et al., 2014; Lefevre-Dognin et al., 2021) outlined in Table 1.

Other physical symptoms of mTBI such as headache, vomiting, nausea, dizziness, blurred vision, and fatigue were used as supporting evidence of injury but were not used as criteria to identify mTBI (Lefevre-Dognin et al., 2021). Individuals with abnormal CT brain imaging (i.e., complicated mTBI) were included, as this falls within the spectrum of mild injury (Lefevre-Dognin et al., 2021; Silverberg et al., 2021). Patients were excluded based on severity of TBI (GCS scores < 13 at 30 min or later after injury, loss of consciousness (LOC) > 30 min, and posttraumatic amnesia > 24 h).

Mild traumatic injury was categorized as any extra-cranial traumatic injury resulting in an abbreviated injury scale (AIS; Gennarelli & Wodzin, 2008) score of ≤ 3 in any domain, no reported confusion surrounding the accident, and a GCS of 15. For the trauma control group, any patients who sustained a

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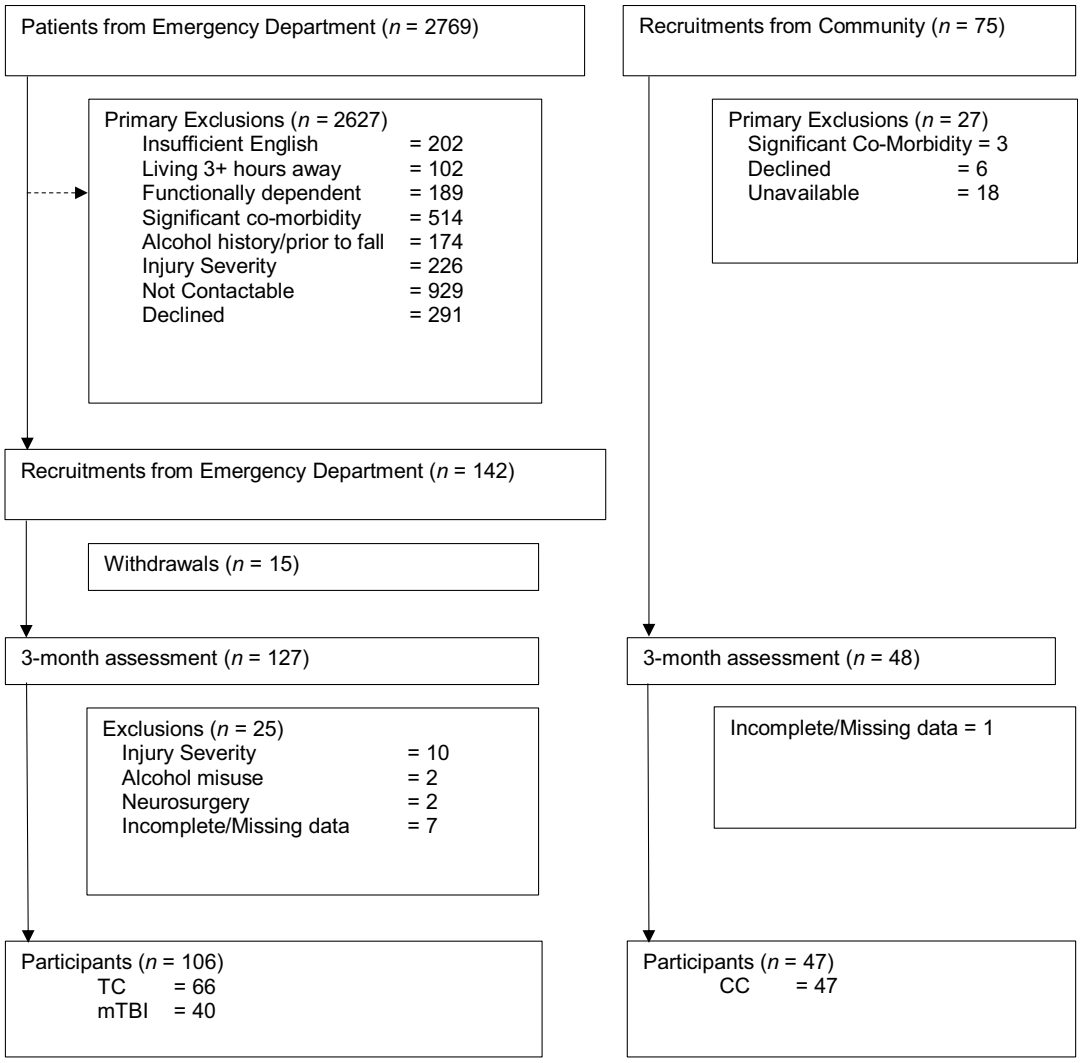


**Figure 1.** Flow of participants throughout the study. Note. CC = Community Control group; TC = Trauma Control group; mTBI = mild Traumatic Brain Injury group. Withdrawals = participants who either were no longer able to participate (moved interstate, ill health), no longer wished to participate or incomplete data set.

traumatic injury to the head region (AIS score 1+) were excluded. AIS scores were used to calculate a total injury severity score (ISS) and a peripheral injury score (excluding the head region) (ISS; Baker et al., 1974; Copes et al., 1988).

### *Recruitment*

Trauma patients who consecutively visited The Alfred Hospital emergency department following acute injury (with or without head injury) were recruited between January 2016 and March 2019 (see Figure 1). Patient medical records were screened for suitability. Older adults who met eligibility criteria were contacted and underwent a telephone interview, including a cognitive screening questionnaire (TELE, using a cut-score of < 17; Gatz et al., 1995). Follow-up assessments were scheduled for three months post-injury at either the participants' home, or at The Alfred Hospital Melbourne site or La Trobe University Melbourne campus.

A community control group of healthy older adults without traumatic injury, living independently in the community was also recruited. Volunteers were recruited through researchers' networks, and local sporting and social communities. Participants completed the same telephone interview as trauma patients described above. Any community volunteers who had sustained an orthopedic injury within the previous six months were excluded, to control for the possibility of ongoing difficulties related to previous traumatic injury.

### *Outcome measures*

#### *Cognitive tasks*

Cognitive assessment measured performances in several cognitive domains commonly impacted after mTBI in younger age cohorts (Carroll et al., 2014) including processing speed, attention and executive functioning, and learning and memory. The selected cognitive tasks were administered in the same order for all participants.

Standard neuropsychological tasks included; i) Coding (WAIS-IV; Weschler, 2008) to measure psychomotor speed and information processing speed; Trail Making Test (TMT; Reitan & Wolfson, 1995) to measure visual scanning, visual-motor skills and attentional set-shifting (Miyake et al., 2000) iii) Color-Word Interference Task (CWT; Delis et al., 2001) as an executive functioning task to assess inhibition and attentional set-shifting abilities; and iv) Hopkins Verbal Learning Test-Revised (HVLT-R; (Benedict et al., 1998) to measure learning and memory. These

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tasks are all shown to have adequate psychometric properties (see Lezak et al. 2012 for further administration information).

CogState computerized cognitive tasks (see www.cogstate.com) that have adequate psychometric properties and are sensitive to changes in processing speed, attention and executive functioning after mTBI (Maruff et al., 2009) were selected for assessment and administered using a standard laptop. Three tasks were administered, always in the same order: i) Detection task (DET) was used to measured simple reaction time and processing speed and required participants to focus on a playing card that was face-down in the center of the screen and press the "yes" key as quickly as possible once they perceived that the card had turned over; ii) Identification task (IDN), which measured complex attention and processing speed, required participants to focus on a playing card that was face-down in the center of the screen and to determine the color of the card as soon as it turned over. If the card was red, they pressed the "yes" key and if the card was not red (i.e., black) they pressed the "no" key; iii) Two-back task (TBK) uses a well-known paradigm to measure working memory and executive function (Mackworth, 1959; Moore & Ross, 1963). Participants focused on a playing card in the center of the screen, and as soon as the card turned over, they pressed the "yes" key if they believed the card was the same as the one shown two cards ago (i.e., "two back"), or "no" if the card was not.

#### *Predictors of outcome*

Potential predictors were grouped into "preinjury," "peri-injury," and "postinjury" variables for ease of interpretation (see Silverberg et al., 2015). Preinjury variables included age, education level, gender, number of comorbidities, and self-reported previous history of depression. Peri-injury characteristics consisted of GCS, LOC, abnormal neuroimaging findings, and peripheral ISS. We used peripheral ISS, which excluded injury to the head region, to account for severity of traumatic injury. Postinjury variables were current levels of psychological distress (Depression Anxiety Stress Scale-21 distress score; Crawford & Henry, 2003) and pain *("to what extent do you feel that physical pain prevents you from doing what you need to do?"*).

### *Statistical methods*

First, data was checked for skewness to ensure variables were normally distributed. Any significantly skewed variables were transformed using square-root, log10, or inverse transformation, dependent on skewness severity. Missing variable analysis, conducted using Little MCAR test, identified no systematically missing data, $\chi^2 = 9770.867$, $df = 49695$, $p = 1.00$. Therefore, multiple imputation analysis was performed using five imputation datasets, and then using pooled values from these datasets to replace missing items (8% of the final dataset) for subsequent analysis.

Variable scores were transformed into standardized z-scores for ease of interpretation. For all tasks, negative z-scores indicated poorer performance and positive z-scores indicated better performance. The mean of the entire sample for each variable was 0 and the standard deviation was 1.0. We also used a recommended methodology to derive cognitive composite scores for standard neuropsychological performance and computerized assessment to increase the power of the statistical approach and reduce the number of analyses needed (Silverberg et al., 2017). Z-scores for each neuropsychological subtest were averaged to create an overall neuropsychological composite z-score (NPZ), and z-scores for each computerized test were averaged to create an overall computerized composite score (COGZ). Accuracy percentages were examined as a way of checking performance validity on computerized tasks. As recommended by Cogstate, the cut-off for valid performances was < 80% accuracy on tasks.

For statistical analysis, Multivariate Analysis of Variance (MANOVA) was conducted to determine differences between the three groups, using injury group allocation as the independent variable, and subtest variables as the dependent measures. Separate MANOVAs were conducted for each neuropsychological task. A MANOVA was also conducted to determine group differences across the three computerized tasks, where reaction time was the dependent variable for the detection and identification tasks, and reaction time as well as accuracy were dependent variables for the two-back task. For any significant MANOVAs, univariate analysis was conducted using adjusted significance values based on the Holm method (Holm, 1979) followed by post hoc analysis of contrasts using Student-Newman-Keuls. For categorical variables, chi-square analysis was conducted to determine differences between allocated groups.

To investigate predictors of cognitive performance after injury, two hierarchical regressions were conducted for the combined trauma group (i.e., mTBI and TC groups) using cognitive composite scores (NPZ and COGZ) as the outcome variables of interest. First, demographic data (i.e., age, education, and gender) were entered into the model as possible predictor variables. The next model also included potential preinjury predictors, including comorbidities and history of depression. Next, peri-injury characteristics were added, including GCS score (GCS 15 or GCS < 15), LOC (yes or no), presence of intracranial injury (i.e., uncomplicated or complicated mTBI), and peripheral ISS. Finally, postinjury variables (i.e., psychological distress and pain three months postinjury) were added to create the final model.

Using separate moderator regression analyses, we also explored whether the expected relationship between age and cognitive outcome for the combined trauma group (mTBI and TC) was moderated by two possible measures of injury severity: presence or absence of intracranial injury or GCS (i.e., 15 or < 15).

Analyses were performed using SPSS Version 27.0 (IBM Corp, 2020) and a regression PROCESS macro system (version 4.0; Hayes, 2018).

## Results

One-hundred and forty-two trauma patients agreed to participate. Fifteen participants withdrew prior to or following three month assessment, and 21 participants were excluded from analysis, leaving a total of 106 participants (see Figure 1). Patients were allocated into two sub-groups; (i) mild traumatic brain injury (mTBI; $n = 40$), and (ii) trauma control group (TC; $n = 66$). Forty-seven community control participants also agreed to participate (CC).

### *Demographics*

Demographic characteristics were examined to determine differences between the final sample compared to those who withdrew or were excluded. Mean age was significantly lower in the final sample, ($M = 74.34$ years, $SD = 6.13$) compared to those not included ($M = 79.33$ years, $SD = 7.80$), $F(1,190) = 18.337$, $p < .001$, *partial* $\eta^2 = .088$. In contrast, education and gender did not differ significantly between groups. Additionally, all participants included in the final sample passed two embedded performance validity tests on standard neuropsychological tasks (see

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**Table 2.** Demographic and injury information for mild traumatic brain injury (mTBI), Trauma control (TC), and community control (CC) groups

| | mTBI ($n = 40$) | TC ($n = 66$) | CC ($n = 47$) | $p$ |
|---|---|---|---|---|
| Age (years) – M (SD) | 74.70 (6.20) | 74.68 (6.74) | 73.60 (5.09) | .597 |
| Gender: Female – *n* (%) | 19 (46.3) | 38 (57.6) | 27 (57.4) | .549 |
| Years of education – M (SD) | 13.42 (2.60) | 13.27 (2.63) | 13.36 (2.67) | .957 |
| No. of Comorbidities – M (SD) | 3.58 (2.32) | 3.58 (1.97) | 3.77 (2.56) | .894 |
| History of depression – *Yes (%)* | 4 (10.0) | 17 (25.8) | 7 (14.9) | .133 |
| Current pain – M (SD) | 1.42 (0.20) | 1.48 (0.20) | 1.53 (0.20) | .044 |
| Current distress – M (SD) | 2.59 (1.11) | 2.31 (1.20) | 1.99 (1.47) | .095 |
| Days since injury – range | 108 (87–135) | 105 (71–139) | | .142 |
| Peripheral ISS – Median (IQR) | 4 (1–8) | 4 (1–8) | | .582 |
| Mechanism of Injury: *n* (%) | | | | |
| Fall | 29 (72.5) | 51 (77.3) | | |
| Bicycle Accident | 5 (12.5) | 6 (9.1) | | |
| Motor Vehicle Accident | 3 (7.5) | 6 (9.1) | | |
| Assault | 3 (7.5) | 1 (1.5) | | |
| Walking Injury | – | 2 (3.0) | | |
| Length of Stay – M days (SD)[b] | 3.62 (3.32) | 0.94 (1.58) | | < .001[a] |
| GCS < 15: yes – *n* (%) | 15 (37.5) | 0 (0.0) | | |
| LOC: *yes* – *n* (%) | 19 (47.5) | – | | |
| PTA: *yes* – *n* (%) | 16 (40.0) | – | | |
| Neuroimaging findings: yes – *n* (%) | 20 (50.0) | – | | |

*Note.* [a]Indicates significant p value after alpha adjustments; [b]Reduced sample size for groups due to missing data; ISS = injury severity score; GCS = Glasgow coma scale; LOC = loss of consciousness; PTA = posttraumatic amnesia.

**Table 3.** Z-score means (M) and standard deviations (SD) and Cohen's d effect sizes for mild traumatic brain injury (mTBI), traumatic injury (TC), and noninjured older people (CC) on neuropsychological subtests

| Measure – M (SD) | $mTBI_1$ ($n = 40$) | $TC_2$ ($n = 66$) | $CC_3$ ($n = 47$) | $p$ | $d_{12}$ | $d_{23}$ | $d_{13}$ |
|---|---|---|---|---|---|---|---|
| CODE | −0.18 (0.99) | −0.13 (0.98) | 0.34 (0.97) | .020 | 0.051 | 0.482[a] | 0.531[a] |
| TMT-A | 0.05 (0.96) | −0.32 (1.06) | 0.40 (0.80) | < .001 | −0.361 | 0.749[a] | 0.399 |
| TMT-B-A | −0.05 (1.00) | −0.17 (0.95) | 0.27 (1.04) | .070 | −0.124 | 0.445 | 0.313 |
| CWT T1 | −0.02 (0.88) | −0.14 (0.98) | 0.21 (1.11) | .192 | −0.127 | 0.338 | 0.228 |
| CWT T2 | 0.02 (0.99) | −0.18 (0.91) | 0.24 (1.10) | .090 | −0.213 | 0.423 | 0.209 |
| CWT T3 | −0.18 (1.02) | −0.01 (0.93) | 0.29 (1.04) | .057 | 0.176 | 0.215 | 0.456 |
| CWT T4 | −0.01 (1.09) | −0.19 (0.95) | 0.27 (0.95) | .053 | −0.179 | 0.484 | 0.275 |
| HVLT T1 | −0.06 (1.25) | −0.13 (0.88) | 0.24 (0.89) | .130 | −0.068 | 0.418 | 0.280 |
| HVLT Total | −0.17 (1.08) | −0.09 (0.93) | 0.28 (0.98) | .070 | 0.081 | 0.389 | 0.438 |
| HVLT Delay | −0.09 (0.91) | −0.18 (0.99) | 0.34 (1.01) | .019 | −0.094 | 0.521[a] | 0.445[a] |
| HVLT Disc | −0.18 (0.94) | −0.22 (1.06) | 0.47 (0.81) | < .001 | −0.039 | 0.716[a] | 0.745[a] |
| NPZ | −0.09 (0.66) | −0.16 (0.65) | 0.29 (0.70) | .002 | −0.107 | 0.670[a] | 0.557[a] |

*Note.* [a]Significant *p* value; CODE = coding; TMT-A = trail making test part A; TMT-B-A = trail making test part B minus part A; CWT = DKEFS color-word interference task; T1 – 4 = Trial 1 through 4; HVLT T1 = Hopkins Verbal Learning Task Trial 1; HVLT Total = HVLT Total across three learning trials; HVLT delay = HVLT delayed recall; HVLT disc = HVLT Discrimination Index; NPZ = neuropsychological composite z-score.

Bailey et al. 2018 and Eglit et al. 2020 for details of method), and none were involved in compensation-seeking after injury.

Characteristics of the final sample are presented in Table 2. On average, trauma participants were seen for follow-up assessment 106 days after injury (range = 71–139 days). The three injury groups (i.e., mTBI, TC and CC) did not significantly differ on age, education level or gender. Additionally, after using alpha adjustments, self-reported history of depression $\chi^2$ (2, $n = 149$) = 4.028, $p = .133$, *phi* = .164, current pain, $F(2,150) = 3.193$, $p = .044$, *partial* $\eta^2 = .041$, and current distress $F(2,150) = 2.393$, $p = .095$, *partial* $\eta^2 = .031$, did not differ between groups.

Trauma groups did not differ on peripheral ISS, indicating that mTBI patients had similar severity of nonhead injury compared to the TC group. There were also no group differences for mechanism of injury, however, the mTBI on average had a longer hospital stay following injury compared to trauma controls, $F(2,87) = 25.69$, $p < .001$, *partial* $\eta^2 = .228$. This was expected, as older people are often monitored closely following head injury, particularly those with intracranial bleeding.

### *Group differences on cognitive tests*

One-way MANOVAs for each neuropsychological test revealed group differences for HVLT and TMT tasks, but not the DKEFS color-word interference task (CWT). Univariate Analysis of Variance (ANOVA) identified small to medium trauma effects for HVLT delay, $F(2,150) = 4.044$, $p = .019$, *partial* $\eta^2 = .051$, and HVLT discrimination index, $F(2,150) = 8.046$, $p < .001$, *partial* $\eta^2 = .097$, where the mTBI and TC groups performed worse than the community control group. A medium effect for TMT-A was observed, $F(2,150) = 7.771$ $p < .001$, *partial* $\eta^2 = .094$, where the TC group performed worse than the community control group, but the mTBI group did not differ from either control groups.

A one-way ANOVA was conducted for the Coding task (CODE) and identified a medium trauma effect, $F(2,150) = 4.022$, $p = .020$, *partial* $\eta^2 = .051$, where the mTBI and TC groups performed worse than the community control group.

Although group differences for other subtests were not statistically significant, there were several medium effects for the

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**Table 4.** Number and percentage of participants who failed the validity performance check for computerized tasks

| Measure – *n* (%) | mTBI (*n* = 40) | TC (*n* = 66) | CC (*n* = 47) | Total (*n* = 153) |
|---|---|---|---|---|
| DET invalid | 3 (7.5) | 9 (13.6) | 3 (6.4) | 15 (9.8) |
| IDN Invalid | 3 (0.0) | 4 (9.0) | 1 (2.1) | 8 (5.2) |
| TBK Invalid | 2 (5.0) | 5 (7.6) | 0 (0.0) | 7 (4.6) |

*Note.* DET = detection task; IDN = identification task; TBK = two-back task. Parentheses indicate percentages.

mTBI and/or trauma control groups, when compared to noninjury participants (see Table 3). In contrast, differences between the mTBI and TC group were consistently small.

For overall neuropsychological performance (NPZ), an ANOVA revealed a significant medium trauma effect for the mTBI and TC groups compared to the community control group, $F(2, 150) = 6.517$, $p = .002$, *partial* $\eta^2 = .080$.

The percentage of participants who failed the validity check for each Cogstate task was small (see Table 4) and did not differ between groups for the detection task, $\chi^2$ (2, $n = 153$) = 1.958, $p = .376$, *phi* = .113, identification task, $\chi^2$ (2, $n = 153$) = 1.421, $p = .491$, *phi* = .096, or two-back task, $\chi^2$ (2, $n = 153$) = 3.631, $p = .163$, *phi* = .154. Those who failed the validity checks were older (*Mfail* = 77.41 years, *SD* = 7.307 vs *Mpass* = 73.84 years, *SD* = 5.763), $F(1,151) = 6.663$, $p = .011$, *partial* $\eta^2 = .042$, but other demographic variables of gender, education, and number of comorbidities did not differ between the two groups.

Analysis showed a significant group effect for computerized tasks, $F(8,252) = 2.664$, $p = .008$, *partial* $\eta^2 = .080$. Post hoc analysis revealed medium to large trauma effects, where the mTBI and trauma control groups were significantly slower than the community control group on the detection task $F(2,128) = 8.449$, $p = < .001$, *partial* $\eta^2 = 0.117$, and identification task, $F(2,128) = 5.744$, $p = .004$, *partial* $\eta^2 = 0.082$. Although the group differences on the two-back task reaction time and accuracy were not statistically significant, they were approaching medium effect sizes for both trauma groups when compared to the community control group (see Table 5).

ANOVA also indicated differences between groups for overall computerized assessment (COGZ), $F(2,128) = 8.892$, $p < .001$, *partial* $\eta^2 = .123$. Post hoc testing revealed a significant large trauma effect, where the mTBI and TC groups performed more poorly than the community control group.

### *Predictors of cognitive outcome after mild traumatic injury (with and without head injury)*

In the combined trauma group (mTBI and TC), hierarchical regression analysis identified older age, lower education, and history of depression as significant independent predictors of poorer performance on standard neuropsychological assessment (see Table 6). The final model explained 31.1% of the variance, $R^2 = .311$, $F(1,99) = 4.295$, $p = .041$.

For computerized assessment, older age was the only significant predictor of poorer outcome ($\beta = -.273$), explaining 7.4% of the variance, $R^2 = .074$, $F(1,83) = 6.767$, $p = .012$. After controlling for age, no other predictors were brought into the model.

### *Moderation analysis of injury severity on age and cognitive outcome after mild traumatic injury (with and without head injury)*

In the combined trauma group (mTBI and TC) those with and without intracranial injury did not differ for age, $F(1,104) = 0.292$, $p = .590$, *partial* $\eta^2 = .003$, education, $F(1,104) = 0.061$, $p = .860$, *partial* $\eta^2 = .001$, and gender, $\chi^2$ (1, $n = 106$) = 1.333, $p = .248$, *phi* = .112. Moderator regression analysis demonstrated that presence of intracranial injury did not moderate the relationship between age and cognitive outcome on either standard neuropsychological ($b = .007$, $p = .260$) or computerized assessment, ($b = .003$, $p = .542$).

In the combined trauma group (mTBI and TC) those with a GCS of 15 and those with GCS below 15 did not differ for gender, $\chi^2$ (1, $n = 106$) = 0.015, $p = .903$, *phi* = .012, education, $F(1,104) = 0.061$, $p = .860$, *partial* $\eta^2 = .001$, or age, $F(1,104) = 4.890$, $p = .062$, *partial* $\eta^2 = .044$, after alpha adjustments. Moderation regression indicated that GCS (i.e., GCS 15 or GCS < 15) did not moderate the relationship between age and standard neuropsychological assessment, $b = .001$, $p = .780$. However, injury severity as identified by GCS moderated the relationship between age and cognitive performance on computerized assessment ($b = -.138$, $p = .001$). Specifically, the moderated regression analysis showed a strong negative relationship between age and outcome for those with greater injury severity (i.e., GCS < 15) whereby older lower GCS interacted with older age to negatively predict poorer cognitive performance (see Figure 2).

## Discussion

This study investigated cognitive outcome after mTBI in older people compared to trauma controls (TC) without head injury and noninjured age-matched peers. Three months postinjury older people who sustained a mTBI showed lower cognitive performances on tasks involving processing speed and memory compared to noninjured peers. However, trauma patients without brain injury demonstrated similar levels of cognitive deficit, suggesting that after accounting for general trauma effects mTBI *per se* may have less influence on cognitive outcome than originally suspected. Within the combined trauma group, preinjury factors, especially age, predicted three month cognitive performance. However, severity of brain injury (GCS < 15) moderated the relationship between age and cognitive performance, such that older age predicts lower cognitive performance on computerized assessment only for those with a GCS score < 15.

As expected, older people who sustained a mTBI performed worse on neuropsychological tests (standard and computerized) compared to noninjured aged peers. However, unexpectedly, both trauma groups (mTBI and TC) demonstrated a similar level of cognitive deficit when compared to the noninjured control group. This trauma effect was found on overall composite measures of cognition and within the cognitive domains of processing speed, attention, and memory. This suggests that three months after injury, older people may expect ongoing cognitive difficulties. Given that z-scores on all cognitive tasks remained within normal limits (i.e., within 1.5 SDs of the mean) the deficits reported here can be considered "mild". However, even subtle cognitive difficulties may impact global outcome or functional status after injury and may interact with already expected age-related changes in processing speed, attention and executive functioning (Murman, 2015). The current findings extend previous research in older people which focused on more specific everyday cognitive behaviors involving prospective memory (Kinsella et al., 2014).

Reasons for these identified generalized trauma effects on cognition remain speculative, but potentially include *i)* inflammatory responses to trauma (Lord et al., 2014) and lifestyle factors, including disrupted sleep or reduced exercise (Markovic et al., 2021), or

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**Table 5.** Standardized z-score means (M) and standard deviations (SD) for mild traumatic brain injury (mTBI), traumatic injury (TC), and noninjured older people (CC) on computerized tasks

| Measure – M (SD) | $mTBI_1$ ($n = 34$) | $TC_2$ ($n = 54$) | $CC_3$ ($n = 43$) | *P* | $d_{12}$ | $d_{23}$ | $d_{13}$ |
|---|---|---|---|---|---|---|---|
| DET | −0.17 (0.98) | −0.28 (0.97) | 0.48 (0.88) | < .001 | −0.113 | 0.816[a] | 0.702[a] |
| IDN | −0.28 (0.75) | −0.14 (1.00) | 0.40 (1.07) | .004 | 0.153 | 0.523[a] | 0.721[a] |
| TBK | −0.07 (1.13) | −0.17 (0.91) | 0.27 (0.97) | .086 | −0.100 | 0.470 | 0.326 |
| TBKACC | −0.15 (1.01) | −0.12 (0.96) | 0.27 (0.93) | .101 | 0.031 | 0.412 | 0.435 |
| COGZ | −0.17 (0.71) | −0.18 (0.66) | 0.36 (0.65) | < .001 | −0.015 | 0.824[a] | 0.783[a] |

*Note.* [a]$p < .05$; DET = detection task; IDN = identification task; TBK = two-back task; TBKACC = two-back task accuracy; COGZ = Cogstate Composite z-score.

**Table 6.** Hierarchical regression models for predictor variables for overall Neuropsychological test performance (NPZ) for the combined Trauma group (mTBI and TC)

| | *β* | *p* | *F* | *df* | *p* | $R^2$ Δ |
|---|---|---|---|---|---|---|
| Model 1 | | | 31.669 | 1, 101 | < .001 | .239 |
| Age | −.489 | < .001 | | | | |
| Model 2 | | | 19.574 | 2,100 | < .001 | .043 |
| Age | −.431 | < .001 | | | | |
| Education | .214 | .017 | | | | |
| Model 3 | | | 14.911 | 3,99 | < .001 | .030 |
| Age | −.435 | < .001 | | | | |
| Education | .200 | .023 | | | | |
| Depression history | −.173 | .041 | | | | |

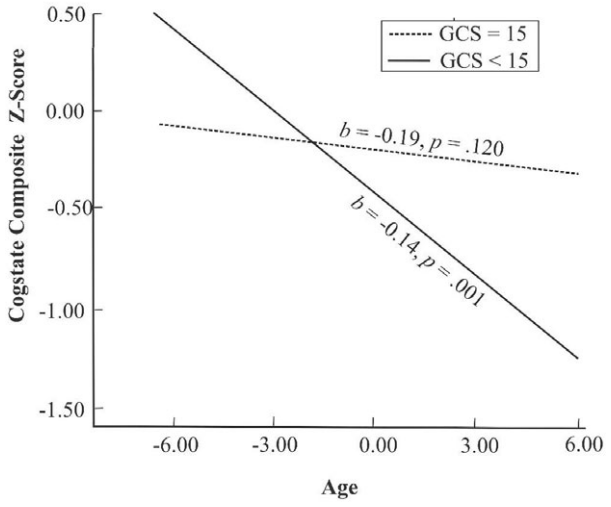


**Figure 2.** Moderated regression analysis of Glasgow Coma Scale (GCS) and the association between age and overall computerized assessment performance (COGZ) for the combined trauma group (mTBI and TC).

*ii)* preinjury psychological resources and coping styles (Meares et al., 2011). Biological explanations may relate to persisting inflammatory responses after traumatic injury. Both adult mTBI and trauma control patients were shown to have similar altered white-matter diffusion characteristics on neuroimaging three months after injury, compared to noninjured peers (Wilde et al., 2019). For older adults, other aging factors such as comorbidities (Karr et al., 2021) and frailty (Abdulle et al., 2018) may interact with injury to adversely impact cognitive outcome or slow recovery. Additionally, a recent review highlights the possible impact of lifestyle factors such as exercise, diet, and sleep on neurocognitive mTBI recovery in older adults (Markovic et al., 2021), and these factors may also be important for recovery from mild traumatic injury without brain injury.

Alternatively, trauma effects on cognition may mirror a similar pathway as suggested for postconcussive symptoms (Meares et al., 2011; Ponsford et al., 2012) and relate primarily to premorbid characteristics like resilience, coping styles and perceived recovery from injury. In the current study, history of depression was a significant predictor of standard neuropsychological performance three months after mild traumatic injury, and previous research in older adults also suggests that psychosocial factors may be associated with poor global recovery after mTBI, including poor expectations of recovery, depression, and fatigue (Kristman et al., 2016). Research in younger cohorts has also examined postconcussive symptoms after different types of injury (i.e., mTBI or orthopedic injury) and found certain personality traits were useful to explain postconcussive symptoms, regardless of injury type (Parker et al., 2021). Whether any or all these explanations can be demonstrated to directly impact cognitive performance three months postinjury in older people is yet to be determined.

It should be noted that on a single neuropsychological subtest involving speed of visual scanning and attention (TMT-A), the trauma control group performed worse than the community control group; however, groups did not differ on the more complex set-shifting trial after visual scanning and motor speed were taken into account (TMT-B-A). Reasons for this specific orthopedic trauma effect are unclear, as potential explanatory factors such as demographic characteristics, self-reported pain, or peripheral injury severity did not differ between the TC and other groups. Nevertheless, it may be that other unmeasured physical injury variables (e.g., residual joint stiffness) impacted motor performance, suggesting the need for closer profiling of physical health status in future research.

Given the mixed evidence of cognitive compromise in both older patients with mTBI and/or orthopedic injury, it was important to examine which factors contributed to ongoing cognitive difficulties three months postinjury. Results demonstrated that only premorbid factors (i.e., increasing age, lower education, and a history of depression) predicted lower neuropsychological performance, and age was the only direct predictor of outcome on computerized assessment. Other injury variables related to mTBI severity and self-reported pain and psychological distress three months after injury had little direct influence on cognitive outcome. Previous research in younger age samples has identified premorbid factors as particularly important for predicting global recovery from mTBI (Lingsma et al., 2015). In addition to the not unexpected role of demographic variables, our findings suggest the importance of preinjury psychological resources, even in older age, in postinjury cognitive status. A lifetime history of depression may signal a vulnerability in the older person to the stresses associated with traumatic injury, even when injury is mild. Further

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exploration of preinjury psychological health will extend our understanding of response to trauma in older people (see Parker et al. (2021) for discussion of this issue in younger age cohorts).

Although brain injury severity, measured as initial GCS score did not directly influence cognitive performance, it did moderate the influence of age on cognitive performance. That is, for patients with a GCS below 15, older age predicted lower cognitive performance, whereas there was no relationship between age and cognitive outcome for patients with a GCS of 15. For health professionals, a GCS below 15 may be a useful marker to identify older people at risk of poorer cognitive outcome after injury. This can be used to support early management plans, including links to community health resources if needed.

Unlike GCS score, the presence of intracranial injury did not moderate the relationship between increasing age and cognition. In adult cohorts there is mixed evidence about whether intracranial injury impacts cognitive outcome (Iverson, 2006; Lange et al., 2009; Karr et al., 2020). In older cohorts, there is an increased risk of intracranial bleeding following trauma in older people compared to younger people (McCulloch et al., 2020) possibly due to age-associated changes in brain structure (Flanagan et al., 2005; Thompson et al., 2012; Karibe et al., 2017) and increased prescription of anticoagulant medications (Peck et al., 2014). Therefore, intracranial injury may be more likely (despite milder injury) potentially making it a less reliable indicator of brain injury severity than other measures of injury.

Test performances on standard neuropsychological and computerized tasks in the current sample suggest that, with some caveats, both formats might be incorporated into cognitive assessment of the older person posttrauma. Almost all participants demonstrated valid performances on computerized tasks, with pass rates similar to previously published rates for healthy older people, of 93–95% (Stricker et al., 2019). Importantly, there were no differences between those who passed or failed the validity checks in terms of injury type, gender, education, or occupation. However, people who failed the validity checks were on average significantly older, suggesting that the "very old" may continue to have some difficulty completing computerized tasks if incorporated into clinical assessment.

### *Limitations and future directions*

Participants who withdrew or were excluded were significantly older which is an ongoing challenge within mTBI research involving older cohorts (Gardner et al., 2018) and suggests, given the influence of increasing age on cognitive performance, that some findings may be an underestimation of the cognitive difficulties experienced in unselected cohorts of older people presenting to emergency departments. Common comorbidities associated with older age (e.g., dementia diagnosis, current cancer treatment) were not included in this sample, focusing only on older people who were functionally independent and healthy prior to injury to reduce the confounding variables in this sample. However, older people who present to emergency departments from aged-care facilities or have a dementia diagnosis will be important to include in future large cohort studies to inform patient management and may add complexity to the moderating effects of injury severity on age and cognitive outcome.

Further design issues include measurement at a single timepoint which necessarily limits the ability to exclude possible premorbid cognitive deficits. However, all participants completed a comprehensive cognitive screen, making group differences more likely a reflection of postinjury status. This study examined group differences using matched comparison groups, however, it would also be beneficial to understand whether the identified cognitive difficulties translate to impaired day-to-day functioning. This is especially important as cognitive impairment in older people is a noted risk factor for falls (Pluijm et al., 2006; Williams et al., 2015). It would also be useful to investigate mechanism of injury (e.g., assault vs. fall from standing) to determine the impact of post-traumatic stress or fall-specific consequences such as fear-of-falling. Further longitudinal data is needed, for example six or twelve months postinjury, to determine whether the noted cognitive impairments are time-limited or persist over time. This is important as persisting trauma-related deficits incurred in middle-older age may lead to increased susceptibility to future cognitive decline (Livingston et al., 2020).

## Conclusion

The current study demonstrated that older patients have mild cognitive difficulties three months after mTBI, compared to noninjured peers. Importantly, this was also demonstrated for older patients who experienced a mild orthopedic traumatic injury but without additional head injury, highlighting the potential for cognitive difficulties to emerge following trauma per se rather than representing TBI-specific consequences. Age continued to be an important predictor of cognitive outcome after mild traumatic injury (with or without brain injury) in adults $\geq 65$ years. However, greater mTBI injury severity, measured as GCS score, also moderated the relationship between age and cognitive performance on computerized assessment, indicating that greater mTBI severity can interact with older age to impact cognition. Findings suggest that a GCS below 15 may be a useful way for clinicians to identify older age patients at risk of poorer cognitive outcome after mTBI. Further investigation is needed to confirm if cognitive recovery can be achieved within a broader timeframe (i.e., by 6 or 12 months review) and whether cognitive difficulties impact functional status. The present findings support the availability and access to neuropsychological review and intervention for older age patients within the first three months following mild trauma, regardless of head injury.

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