CSIRO PUBLISHING

ORIGINAL ARTICLE
https://doi.org/10.1071/IB23080

Brain Impairment ASSBI

Online screening assessment of lifetime exposure to traumatic brain injury: a pilot study of associations between exposure and health status

Karen A Sullivan[A,*] and Elysia Caltabiano[A]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
Karen A Sullivan
School of Psychology and Counselling, Queensland University of Technology, O Block B Wing, Kelvin Grove Campus, Victoria Park Road, Kelvin Grove, Brisbane, 4059, Australia
Email: karen.sullivan@qut.edu.au

Handling Editor:
Jenny Fleming

Received: 23 February 2023
Accepted: 28 March 2023
Published: 23 January 2024

Cite this:
Sullivan KA and Caltabiano E (2024) *Brain Impairment* **25**, IB23080. doi:10.1071/IB23080

ABSTRACT

Background. This study aimed to conduct a pilot test of the feasibility and validity of administering an online screening measure of lifetime traumatic brain injury (TBI) exposure in Australia. **Methods.** One hundred and fifty six adults (aged 18–65 years) were recruited from the community via snowball sampling (convenience sample). A cross-sectional online survey was deployed that included the Ohio State University Traumatic Brain Injury Identification Method (OSU TBI-ID) short form. Secondary measures assessed post-concussion symptoms (the Rivermead Post-Concussion Symptoms Questionnaire), negative affective states (depression, anxiety, and stress scales), and behavioural health risks (items from the 2014 Ohio Behavioural Risk Factor Surveillance System). **Results.** Online OSU TBI-ID feasibility was high (minimal missing data and attrition, high completion rate). A TBI history was successfully recorded by approximately 60% of participants. Validity testing, via investigation of expected associations with risk factors controlled, found that selected indices [Worst TBI, Multiple TBIs] were positively associated with worse post-concussion symptoms: *P*'s < 0.05, small–medium effects. Worst TBI was significantly related to one behavioural health risk, smoking. There were no other significant correlations between online OSU TBI-ID indices and secondary outcomes when accounting for covariates (*P*'s > 0.05). **Conclusion.** Initial support was found for the feasibility and validity of an online screening measure of lifetime TBI exposure (LTE) in an Australian sample. Cautious interpretation is warranted because of study limitations, especially the small unrepresentative sample. Further studies could increase confidence in the feasibility and validity of online LTE screening.

Keywords: closed-head injury, concussion, head trauma, lifetime exposure, mild traumatic brain injury, minor head injury, online assessment, repetitive injury.

Introduction

Traumatic brain injury (TBI) is associated with lifelong consequences and is considered the leading cause of death and disability worldwide (Langlois *et al.* 2006). Even 'mild' TBI (mTBI) has been linked to long-term complications and negative consequences (Langlois *et al.* 2006). Predicting outcomes from one, let alone multiple TBIs, is challenging (Dennis *et al.* 2022). Further, cumulative TBI exposure is a suggested mechanism or risk factor for late life health consequences, including chronic traumatic encephalopathy (Dams-O'Connor *et al.* 2013). The very strong potential for serious long-term negative consequences from multiple TBIs has inspired discussion about the best methods for measuring lifetime TBI exposure (LTE; Dennis *et al.* 2022).

There are well-documented challenges in single TBI assessment and additional issues for lifetime assessment. These issues include weak consensus for defining TBI (Menon *et al.* 2010); reliance on symptom-based criteria (Dennis *et al.* 2022); selection biases in TBI research due to unrecognised, unreported, or untreated injuries (Dams-O'Connor *et al.* 2014); and parameter variation (e.g. selection criteria; Corrigan *et al.* 2003). TBI effects can be masked, misattributed, or otherwise altered by numerous factors, such as

incentives to over- (Jurick *et al.* 2016) or under-report symptoms (Meier *et al.* 2015), use of interviews vs questionnaires (Edmed and Sullivan 2014), and cognitive distortions (Voormolen *et al.* 2020). For LTE, there is also the challenge of retrospective assessment over an extended period, including childhood (McKinlay *et al.* 2016).

Despite the challenges, several LTE assessment methods have been proposed. These methods range from a single item (e.g. 'How many times, if ever…have you had…[a] head injury?') (Schofield *et al.* 2006*b*; Ilie *et al.* 2018); small-item sets (McKinlay *et al.* 2016); and structured, multi-item methods mimicking the clinical interview (e.g. Brain Injury Screening Questionnaire, Dams-O'Connor *et al.* 2014); Ohio State University Traumatic Brain Injury Identification Method (OSU TBI-ID), Corrigan and Bogner 2007). A prior study (Dams-O'Connor *et al.* 2014) reported that single item methods can miss >35% of cases identified by multi-item methods. Another study found that 15% of older adults ($n = 559$) screened positive for LTE using a multi-item method, about 80% of whom were previously unidentified (Schneider-Cline *et al.* 2019). Taken together, it seems that multi-item methods will be vital to advance understanding of LTE correlates for all TBIs (mild–severe).

The OSU TBI-ID short form is emerging as a leading LTE measure. This well-validated tool systematically elicits TBI history via a structured interview (Corrigan and Bogner 2007; Corrigan *et al.* 2013; McKinlay *et al.* 2017). The OSU TBI-ID can quantify TBI history in several ways via multiple indices, for example via a count of TBI exposures irrespective of severity. The OSU TBI-ID has been adopted in multi-centre, longitudinal TBI studies (Corrigan *et al.* 2013; Dams-O'Connor *et al.* 2013; Rabinowitz *et al.* 2020; Ohio State University Wexner Medical Centre 2022), and its usage is recommended by leading agencies (e.g. the National Institute of Neurological Disorder and Stroke 2019).

The findings from LTE studies that have used the OSU TBI-ID typically show that LTE is associated with increased behavioural health risks (BHRs), such as substance misuse, and poorer long-term health from a heightened risk of other conditions (Corrigan *et al.* 2013; Manchester *et al.* 2020). However, it remains unclear which indices are critical and whether increased BHRs are expected from exposure to any TBI or specific TBIs (e.g. severe injury or mild injury with loss of consciousness [LOC]; Rabinowitz *et al.* 2020). A recent study found that LTE metrics – with LOC- – were associated with increased risks, such as heavy drinking and poor general mental health (Feiss *et al.* 2022). Further studies must clarify the relation between LTE and BHRs, including which injuries (and by extension which OSU TBI-ID indices) show these relations.

A potential limiting factor for LTE research is that the OSU TBI-ID was designed as an in-person interview (Lequerica *et al.* 2018). To address this issue, a handful of studies have deployed other OSU TBI-ID formats, including a computer-assisted, telephone-administered version (Cuthbert *et al.* 2016) and online versions (Lequerica *et al.* 2018; Lequerica *et al.* 2021). These new formats could increase the ease of data collection from participants in distributed geographic regions (Lequerica *et al.* 2018). However, changing the OSU TBI-ID to other formats could introduce additional challenges. The interview can support conditional (follow-up/clarification) questions – a feature considered by some as critical for success (Ohio State University Wexner Medical Centre 2022) – and online surveys have specific biases (e.g. they may be susceptible to participant inattention and other data integrity threats; Oppenheimer *et al.* 2009; McKibben and Silvia 2017; Griffin *et al.* 2021).

To date, there have been a few studies on the feasibility and validity of an online form of the OSU TBI-ID (O-OSU TBI-ID). These studies, mostly from North America, have evaluated the completion rate (Lequerica *et al.* 2018, 2021) and replicated expected associations (e.g. between LTE and post-concussion symptoms (PCS); Lequerica *et al.* 2018). In general, the findings have been favourable (Lequerica *et al.* 2018), but none have included the data integrity checks now commonly deployed in online surveys (Griffin *et al.* 2021).

In Australia, there is a paucity of research on LTE and its correlates. There are three prior studies with selected (criminal justice [CJ]; Perkes *et al.* 2011; Moore *et al.* 2014) or unselected (community) samples (Butterworth *et al.* 2004) and two with adults (cf. Moore *et al.* 2014). One study surveyed 200 men in the CJ system (Schofield *et al.* 2006*a*, 2006*b*) and a comparative sample (200 community-dwelling men; Perkes *et al.* 2011). Using a single-item LTE and follow-up questions for ≥five incidents, the study found a high prevalence of LTE with LOC (65% CJ vs 32% community) and all TBI exposures (82% CJ vs 72% community) as well as increased risk of neuropsychiatric sequalae when TBI exposed (CJ sample). Another cross-sectional survey (Anstey *et al.* 2004; Butterworth *et al.* 2004) in ~8000 randomly selected community members used a single-item LTE measure: '…ever had a serious head injury where you became unconscious for >15 minutes?'. Consistent with general population studies outside of Australia, LTE with LOC was associated with poorer general physical and mental health on screening tests (Anstey *et al.* 2004; Butterworth *et al.* 2004). Given that the Australian data are almost 20 years old and not obtained using a multi-item method or a current definition for 'serious' TBI, there is merit in revisiting this issue, including the methodology for LTE screening.

This study had two aims. First, to conduct an initial pilot investigation of O-OSU TBI-ID as a potential tool for LTE measurement in Australia via a small-scale replication and extension of the O-OSU TBI-ID feasibility and validity study by Lequerica *et al.* (2018). Thus, it was expected that the O-OSU TBI-ID would be feasible (i.e. data captured in all sections) and there would be a positive association between *Worst TBI* and PCS (Lequerica *et al.* 2018). The extension added data integrity checks and examined relations between other LTE indices (e.g. *Multiple TBIs*) and correlates (i.e. BHRs, PCS).

Method

Participants

Participants were recruited at a major metropolitan university, including via a for-credit, university-hosted research participation pool (SONA), and externally via electronic communication within the researchers' networks. A snowball method was employed, whereby the recipients of study information were encouraged to share it with their networks. Eligible participants were people aged ≥18 years with a valid protocol.

Measures

Single-item TBI (SI-TBI) history

Based on prior research (Butterworth *et al.* 2004; Ilie *et al.* 2015; Osborn *et al.* 2018), a SI-TBI history was assessed: 'Have you ever had a Traumatic Brain Injury (TBI) also referred to as a head injury?'.

Ohio State University TBI identification method short form (OSU TBI-ID; Ohio State University Wexner Medical Centre 2022)

The OSU TBI-ID is a 3–5 min structured (three-step) tool to determine LTE (Corrigan and Bogner 2007). The interview form has strong inter-rater reliability and acceptable test/retest reliability (Corrigan and Bogner 2007). Step 1 assesses LTE and injury cause (five yes/no questions; e.g. 'In your lifetime, have you ever injured your head or neck in a car accident or…crashing…a bicycle…?' A *yes* at Step 1 triggers deployment of Step 2 (event details; e.g. 'Were you knocked out…?'). All participants complete Step 3 about a history of multiple TBIs. Three summary indices of LTE were used in this study: *Worst TBI [WTBI]*; *Multiple TBIs [MultiTBI]; TBI number by severity [TBINS]* (Corrigan and Bogner 2007).

Rivermead Post-Concussion Symptoms Questionnaire (RPQ; King, *et al.* 1995)

The RPQ assesses the frequency and severity of 16 PCS. The RPQ has good psychometric properties (King *et al.* 1995). An example RPQ item is: '…Do you now (i.e. over the last 24 hours) suffer from headaches?' Participants indicate symptom frequency and severity (0 = *not experienced at all* to 4 = *a severe problem*). The wording of the introduction to the RPQ was altered slightly to ensure participants without a TBI history would also record their experience of these symptoms. The total score range is 0–64, with higher scores indicating greater problems (King *et al.* 1995). In this study the RPQ was found to be reliable ($\alpha = 0.96$).

The depression, anxiety, and stress scales (DASS; Lovibond and Lovibond 1995)

The DASS is a 42-item self-report measure of three negative emotional states with good to excellent internal consistency (Lovibond and Lovibond 1995). An example item is, 'I felt that I had nothing to look forward to.' Participants rate each item for personal applicability over the past week (0 = *did not apply…* to 3 = *applied…very much, or most of the time*). Prior OSU TBI-ID studies have used the Beck Depression Inventory (e.g. Konrad *et al.* 2011); however, since the DASS was developed and normed in Australia, it was chosen for this study. The DASS subscales are scored by summing the responses (total score range = 0–42). Higher scores indicate a more negative emotional state (Lovibond and Lovibond 1995). In this study, the Cronbach's alpha for each DASS subscale was >0.80.

Behavioural Risk Factor Surveillance System (BRFSS; Centres for Disease Control and Prevention 2014)

The BRFSS is a telephone survey of BHRs and chronic health conditions (Centres for Disease Control and Prevention 2014). Several studies (Bogner *et al.* 2020; Manchester *et al.* 2020; Feiss *et al.* 2022) have used specific BRFSS items to examine relationships between TBI exposure and BHRs (e.g. substance use, depression, and days of poor mental health; Bogner *et al.* 2020). The current study used selected 2014 BRFSS items from the following sections: Health Status, Healthy Days, Health-Related Quality of Life (HRQoL), Tobacco Use, Marijuana Use, and Alcohol Consumption, since they were previously used in LTE studies. An example HRQoL item is, 'How many days in the past 30 days was your physical health…not good?'. BRFSS items are individually interpreted. Higher scores on the BHR items indicate increased health risk.

Procedure

Project applications were lodged, reviewed, and approved by the Queensland University of Technology (ethical clearance no: 4145; health and safety clearance no: 1782). The survey was hosted on the online platform Qualtrics™ (Provo, UT) and opened from October 2021 to May 2022. An opt-in method (e.g. activating a link) provided access to study information (e.g. risks, benefits). Consent was probed with a forced-choice item (*agree* [to continue] or *disagree* [to exit]). Continuing participants completed a validity check (reCAPTCHA plugin[1]) and the SI-TBI, O-OSU TBI-ID, RPQ, DASS, and BRFSS. Skip logic was programed for conditional questions, including O-OSU TBI-ID Step 2. The duration of LOC was presented with three options (i.e. no LOC, <30 min–24 h, and >24 h). The participants quit the study

[1]CAPTCHA = Completely Automated Public Turing test to tell Computers and Humans Apart.

directly or after opting in to receive a study summary and/or small reimbursement (i.e. prize draw entry [chance to win one of two $100 shopping vouchers] or 0.5% course credit [if eligible]).

Data analysis

The data were transferred to the Statistical Package for the Social Sciences (IBM SPSS Statistics™ version 28) and inspected for missing values, input errors, eligibility, and invalidity. Feasibility was established through examination of completed sections (see Lequerica *et al.* 2018). Analysis of Covariance (ANCOVA) tested for group differences in symptoms (RPQ or DASS subscale [dependent variables]) based on LTE, while controlling for age, gender, and membership of a TBI 'at risk' group (e.g. contact-sport players). The ANCOVA independent variable (group) was LTE (i.e. *WTBI*, four levels: no TBI, mTBI (no LOC), mild–moderate TBI [LOC < 30 min–24 h], or severe TBI [LOC > 24 h]; *MultiTBI*, three levels: 0, 1, or 2+ TBIs; or *TBINS*, three levels: multiple mTBIs [no LOC], multiple mild–moderate TBIs [LOC < 30 min–24 h], or multiple severe TBI [LOC > 24 h]). ANCOVA assumptions (Field 2018) were met with the exception of normality violations (RPQ, DASS subscales, positive skew, Shapiro–Wilk, *P*'s < 0.001). A square-root (RPQ, DASS-Depression, DASS-Stress) or logarithmic transformation (DASS-Anxiety) yielded approximately normal distributions. Analyses were run with and without transformations, with no differences noted. Therefore, non-transformed data were reported. Multivariable binomial logistic regression determined the association between LTE and BHRs while controlling for 'at risk' status, age, and gender. The reference group was 'No TBI' (*WTBI, MultiTBI*, *TBINS*). As per precedent (Bogner *et al.* 2020; Waltzman *et al.* 2021), frequencies and weighted percentages were estimated for BHRs and compared across subgroups. A significance level of <0.05 was used.

Results

Data screening

Nine participants were excluded because of extreme missing data, an invalid protocol (failed integrity check), or an implausible survey completion time of <3 min (a value we could only obtain with indiscriminate responding). One underage (17 years) and one older participant (outlier aged >95% trimmed sample mean age) were also excluded. The selection of participants is shown in Fig. 1.

The completion rate for the OSU TBI-ID was examined with controls applied (e.g. where skip logic was used). Questions about TBI from all causes were answered (see Fig. 1). The average survey completion time (OSU TBI-ID plus other measures) was approximately 148 min (5% trimmed mean, range ~4–5398 min). The lengthy completions are likely due to the failure to close the survey browser.

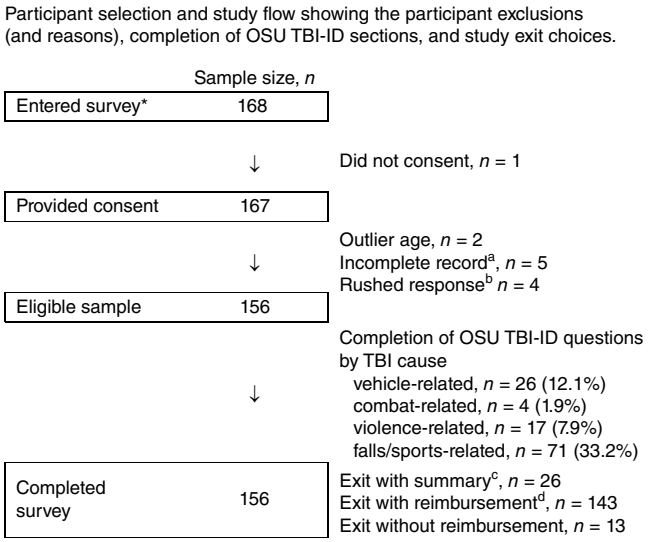

Fig. 1. Participant selection and study flow showing the participant exclusions (and reasons), completion of OSU TBI-ID sections, and study exit choices. Notes: OSU TBI-ID = Ohio State University Traumatic Brain Injury Identification Method. * = accessed the survey (e.g., by clicking the survey link). [a] = significant missing data, i.e., no response to almost all questions; 3.10% missing data); [b] = rushed response, survey duration <3 minutes (minimum pilot response time); [c] = study summary 16.6%, 2022; [d] = reimbursement with either course credit (*n* = 81) or entry (*n* = 62) for a prize draw 91.6%, 2022. Sixty-two participants entered the prize draw, which was drawn on 20 June 2022; 81 participants were awarded course credit (29 April 2022), and the study summary was provided to twenty-six participants (20 June 2022).

Descriptive statistics: sample characteristics and LTE

The sample comprised 156 young–middle-aged adults (M_{age} = 25.27, s.d. = 9.89, range = 18–65 years, 73% women). Most participants were studying (68.6%). Most participants (~70%) were at risk for TBI, primarily from playing contact sport (62.2%). Approximately 60% reported at least one TBI (9%, SI-TBI; 59.6% OSU TBI-ID). This estimate was dependent on the assessment method, $\chi^2(2) = 18.42$, $P < 0.001$, with one participant recording a TBI on the SI-TBI only. The most common TBI cause was 'falls/sport' (33.2%). Of the sample, 46.8% recorded a mTBI (no LOC), 13.5% mild—moderate TBI (with LOC), and 0% severe TBI. Meanwhile, 44.2% reported 1 TBI and 16% reported 2+ TBIs. The percentage of men vs women with 2+ TBIs was 18.4% vs 14.9%, $\chi^2(4) = 3.26$, $P = 0.515$. The percentage of women vs men with mild–moderate TBI (with LOC) exposure was 12.2% vs 18.4%, but this difference was not significant; $\chi^2(4) = 2.72$, $P = 0.606$. Demographic information is shown in Table 1. Average scores for RPQ, DASS, and BRFSS are shown in Table 2. Table 3 displays BHR frequency data by three measures of LTE.

Table 1. Demographic characteristics of study participants ($N = 156$).

Characteristic	*n*	% sample
Gender[A]		
Male	38	24.4
Female	114	73.1
Age (years)		
18–25	101	64.7
26–35	38	24.4
36–45	7	4.5
45+	9	5.8
Country of birth		
Australia	124	79.5
Other	30	19.2
Highest level of education completed		
High school graduate	71	45.5
TAFE/Certificate/Diploma/Advanced Diploma	35	22.4
3-year or 4-year undergraduate degree[B]	38	24.4
Postgraduate degree[C]	10	6.4
Primary occupation[A]		
Working	43	27.6
Studying	107	68.6
History of membership of an 'at risk' population	112	71.8
Contact sport	97	62.2
Learning disability	8	5.1
Drug or alcohol use	7	4.5
Psychiatric condition	38	24.4
Military service history	7	4.5
Contact with the criminal justice system	5	3.2
Lifetime TBI exposure		
Single-item measure (SI-TBI)[D]		
Yes	14	9
Maybe	14	9
No	125	80.1
Missing	3	1.9
Multi-item measure (OSU TBI-ID)		
Worst TBI		
No TBI	62	39.7
Mild (no LOC)	73	46.8
Mild–Moderate (LOC <30 min–24 h)	21	13.5
Severe (LOC >24 h)	0	0
Multiple TBI (Number, any severity)		
No TBI	62	39.7
1 TBI	69	44.2
2+ TBIs	25	16
TBI number by severity		
Multiple mTBIs (no LOC)	23	14.7
Multiple mild–moderate TBIs (LOC <30 min–24 h)	2	1.3
Multiple severe TBIs (LOC >24 h)	0	0
TBI cause/situation[E]		
Vehicle-related	26	12.1
Combat-related	4	1.9
Violence-related	17	7.9
Fall/sports-related	71	33.2
Presence of TBI in each 'at risk' subgroup[F]		
Contact sports	61	62.9
Learning disability	3	37.5
Drug or alcohol use	5	71.4
Psychiatric condition	26	68.4
Military service history	7	100
Contact with the criminal justice system	3	60

Notes: $N = 156$ TBI = traumatic brain injury; LOC = loss of consciousness, duration in minutes or hours; TAFE = Technical and Further Education.
[A]Other, gender, $n = 3$; Other, primary occupation, $n = 4$.
[B]3-year degree $n = 21$; 4-year degree $n = 17$.
[C]Master degree, $n = 8$; PhD/Doctorate, $n = 2$.
[D]SI-TBI item: 'Have you ever had a Traumatic Brain Injury also referred to as a head injury?'.
[E]Combat item: '… have you been nearby when an explosion or blast occurred? If you served in the military, think about any combat- or training-related incidents'; Violence item: '… have you ever injured your head or neck in a fight, from being hit by someone, or from being shaken violently? Have you ever been shot in the head?'.
[F]Subgroup *n* varies as reported.

Relationship between LTE (*WTBI, MultiTBI, TBINS*) and correlates (RPQ, DASS, BRFSS)

There was a statistically significant small–medium relationship between *WTBI* and PCS, $F(2,148) = 3.39$, $P = 0.036$, partial $\eta^2 = 0.044$ (Table 4). Follow-up tests found one significant pairwise comparison; participants with a mild–moderate LTE (LOC < 30 min–24 h) had significantly higher RPQ scores (Mdiff = 8.37, s.e. = 3.22, $P = 0.031$) than the 'no TBI' group. There was a marginal (small–medium) effect of *MultiTBI* on PCS, $F(2,148) = 2.91$, $P = 0.05$, partial $\eta^2 = 0.038$. There was one significant follow-up pairwise comparison; participants with 2+ TBIs had significantly higher RPQ scores (Mdiff = 7.15

Table 2. Descriptive statistics for TBI correlates.

	M	s.d.	Minimum	Maximum
RPQ, post-concussion symptoms	31.79	12.73	16	69
DASS, negative emotional states				
Depression	9.03	10.09	0	41
Anxiety	7.53	6.89	0	28
Stress	9.72	7.78	0	34
BRFSS, behavioural health risk factors and outcomes				
Poor physical health, *n* (days)*	5.86	8.09	0	30
Poor mental health, *n* (days)*	11.38	9.72	0	30
Binge drinking, ≥5 (men) or 4 alcoholic drinks (women) on an occasion**	1.56	3.63	0	29
Smoked cigarettes***	0.12	0.40	0	2
Used marijuana or cannabis, *n* (days)*	0.43	2.63	0	25

N = 156. RPQ = Rivermead Post-concussion Symptoms Questionnaire. DASS = depression, anxiety, and stress scales. BRFSS = 2014 Behavioural Risk Factor Surveillance System. Item stem: *No. of days in the last 30 days…. **How many times in the past 30 days did you have… ***Item response scale: 0 = not at all, 1 = some days, 2 = every day.

s.e. = 2.97, $P = 0.05$) than the 'no TBI' group. There was no significant effect of *TBINS* on PCS, $F(2,147) = 1.95$, $P = 0.125$. There were no significant group differences on DASS subscales (all P's > 0.05).

Multivariable binomial logistic regression found that *WTBI* was related to one BHR, smoking, $\chi^2(10) = 18.06$, $P = 0.05$. Upon examination of the likelihood ratio rests and the covariates (age, gender, at risk group membership), *WTBI* was a significant contributor to smoking over and above the covariates, $\chi^2(4) = 11.35$, $P = 0.023$. Multivariable binomial logistic regression for the other indices (*MultiTBI* and *TBINS*) were not related to BHRs (Table 5).

All three indices (*WTBI, MultiTBI,* and *TBINS*) were significantly related to poor mental health: overall model, *WTBI,* $\chi^2(10) = 22.62$, $P = 0.012$, *MultiTBI,* $\chi^2(10) = 22.63$, $P = 0.012$ and *TBINS*, $\chi^2(12) = 25.25$, $P = 0.014$; however, the likelihood ratio test showed this was due to the covariates and not LTE. All other analyses determined no significant relationships between indices *WTBI, MultiTBIs* and *TBINS* and BHRs, when accounting for covariates.

Discussion

This study had two aims. The primary aim was to conduct an initial pilot investigation of O-OSU TBI-ID as a potential tool for LTE screening in Australia. This was done via a small-scale replication and extension of Lequerica *et al.* (2018). We also performed an extension of Lequerica *et al.* (2018) by adding data integrity checks and examining novel relations between LTE indices (e.g. *MultiTBIs*) and the outcomes used in other LTE studies (e.g. BHRs). In broad terms, this study found initial support for the O-OSU TBI-ID.

We examined the feasibility of the O-OSU TBI-ID via the inspection of completion rates as per Lequerica *et al.* (2018). The O-OSU TBI-ID prompted participants to recall and record details about TBIs from all causes. Further, a data verification check was trialled with no issues reported. Although this study could not determine if this inclusion improved the data integrity, it did prevent bot completion. Adding this type of feature in future O-OSU TBI-ID applications would reflect best practice in online data collection (McKibben and Silvia 2017; Griffin *et al.* 2021).

We also tested for known associations between LTE indices and correlates, such as PCS. We found a positive association between *WTBI* and PCS, as previously demonstrated (Lequerica *et al.* 2018). Compared to people with no history of TBI, when covariates were controlled (age, sex, at risk status) a history of mild—moderate TBI (with LOC) was associated with worse PCS. Further, in the extension with the original controls (Lequerica *et al.* 2018), a lifetime history of TBI (2+ TBIs) was associated with worse PCS. However, lifetime *TBINS* was not significantly related to PCS, and no indices were significantly related to negative emotional states (depression, anxiety, or stress). A history of mild—moderate TBI (with LOC) (*WTBI*) was associated with one BHR (smoking). This analysis reveals further support for selected O-OSU TBI-ID indices (*WTBI, MultiTBI*), since they were correlated as expected with PCS.

To our knowledge, this study was the first deployment of the OSU TBI-ID in any format in Australia. We showed that about 1 in 10 people (13.5%) experienced at least one TBI with LOC (up to 24 h) in their lifetime. Prior North American OSU TBI-ID studies in larger samples have reported LTE rates that are higher (1 in 5 adults; Corrigan *et al.* 2018), lower (1 in 20 adults; Corrigan *et al.* 2013), or

Table 3. Frequencies and percentages for the number of days with poor behavioural health outcomes by three indices of LTE (O-OSU TBI-ID).

		Multiple TBIs				Worst TBI				TBI number by severity			
2014 BRFSS item	*N* days	No TBI	1 TBI	2 + TBIs	% (2 + TBIs)	Mild (no LOC)	%	Mild–Moderate (LOC > 30 min–24 h)	%	Multiple Mild (no LOC)	%	Multiple Mild–Moderate (LOC > 30 min–24 h)	%
Poor physical health	0	20	19	13	25	24	46.2	8	15.3	12	23.1	1	1.9
	>2	30	36	10	13.2	37	48.7	9	11.8	9	11.8	1	1.3
	>14	12.5	10	12	2	11	41.7	3	12.5	2	8.3	0	0
Poor mental health	0	9	9	2	10	7	35	4	20	2	10	0	0
	>2	23	33	15	21.1	40	56.3	8	11.3	13	18.3	2	2.8
	>14	26	25	8	13.6	25	42.4	8	13.6	8	13.6	0	0
Smoking behaviour	Not at all	60	57	22	0.6	63	45.3	16	11.5	20	14.4	2	1.4
	Some days	1	8	2	1.3	8	72.7	2	18.2	2	18.2	0	0
	Everyday	0	4	1	13.5	2	40	3	60	0	0	0	0
Binge drinking	0	35	36	17	19.3	41	46.6	12	13.6	17	19.3	0	0
	1–4	18	22	5	11.2	22	48.9	5	11.2	4	8.9	1	2.2
	5–10	2	9	1	8.3	8	66.7	2	16.7	1	8.3	0	0
	>10	2	0	0	0	0	0	0	0	0	0	0	0
Cannabis use	0	55	60	25	17.9	67	47.9	18	12.9	23	16.4	2	1.4
	>2	0	3	0	0	2	66.7	1	33.3	0	0	0	0
	>14	1	1	0	0	0	0	1	50	0	0	0	0

Notes: TBI, traumatic brain injury; LOC, loss of consciousness; mTBI, mild TBI; BRFSS, Behavioural Risk Factor Surveillance System;O-OSU TBI-ID , Online Ohio State University TBI Identification Method.

Table 4. Full ANCOVA predicting RPQ total score in three models of LTE models (Model 1, Worst TBI; Model 2, Multiple TBIs; Model 3, TBI number by severity).

Model	Source	Sums of squares	d.f.	Mean square	*F*	*P*-value
1	Age	45.75	1	45.75	0.31	0.578
	Gender	739.36	1	739.36	5.02	0.027
	Risk	912.73	1	912.73	6.19	0.014
	Worst TBI	998.67	2	499.33	3.39	0.036
2	Age	18.34	1	18.34	0.12	0.726
	Gender	656.85	1	656.85	4.43	0.037
	Risk	1003.27	1	1003.27	6.77	0.010
	Multiple TBIs	860.99	2	430.49	2.91	0.05
3	Age	21.03	1	21.03	0.14	0.708
	Gender	663.22	1	663.22	4.45	0.037
	Risk	989.04	1	989.04	6.63	0.011
	TBI number by severity	870.99	3	327.14	1.95	0.125

Notes: ANCOVA, Analysis of Covariance; RPQ, Rivermead Post-Concussion Symptoms Questionnaire; d.f., degrees of freedom; TBI, traumatic brain injury; Worst TBI and Multiple TBIs are index scores from the O-OSU TBI-ID = Online Ohio State University TBI Identification Method.

Table 5. Multivariable binomial logistic regressions of relations between Worst TBI, Multiple TBIs, TBI number by severity, and BHRs.

O-OSU TBI-ID Index	BHRs	−2 Log likelihood	χ^2	d.f.	*P*-value
Worst TBI	Poor physical health	213.23	11.82	10	0.297
	Poor mental health	198.94	22.62	10	0.012
	Smoking behaviour	89.41	18.06	10	0.05
	Binge drinking	172.09	17.66	15	0.281
	Cannabis use	27.49	14.54	10	0.150
Multiple TBIs	Poor physical health	213.92	16.12	10	0.097
	Poor mental health	194.44	22.63	10	0.012
	Smoking behaviour	86.73	17.15	10	0.071
	Binge drinking	166.13	21.09	15	0.134
	Cannabis use	24.52	13.36	10	0.204
TBI number by severity	Poor physical health	212.47	16.56	12	0.167
	Poor mental health	193.20	25.25	12	0.014
	Smoking behaviour	85.91	17.97	12	0.117
	Binge drinking	164.09	24.51	18	0.139
	Cannabis use	24.52	13.36	12	0.343

Notes: d.f., degrees of freedom; TBI, traumatic brain injury; Worst TBI and Multiple TBIs are index scores from the Ohio State University TBI Identification Method; administered in online format for this study (O-OSU TBI-ID).

similar (1 in 15 older adults; Schneider-Cline *et al.* 2019). Our rate is higher than the prior Australian study with community members (i.e. between 5 and 6% prevalence; Anstey *et al.* 2004; Butterworth *et al.* 2004) and lower than the selected men-only sample (~32%; Perkes *et al.* 2011). If our findings are replicated, it could indicate that Australia has a higher potential burden from LTE than previously modelled. This could be due to changes in the injury rate, reporting practices, or a research artefact (ie. use of a multi-item vs single item LTE measure).

This study has several limitations. Online surveys carry a specific risk of bias. This survey deployed bot detection; but other validation techniques should be trialled (e.g. 'honey pots'; Griffin *et al.* 2021). A true equivalence test would

compare the LTE estimate from an online- vs interview-administration of the OSU TBI-ID, and the self-reported LTE estimate could also be cross-checked with LTE data from another source (e.g. medical history, if available). These comparisons are suggested for future research. The LTE data are self-reported, conferring a risk of error and inaccuracy (e.g. recall bias, uncorroborated injury). Some measures referred to 'head injury' when the intent was to measure TBI, including our single-item measure and parts of the original OSU-TBI. The wording of our single-item measure could have been confusing for some participants, and this may have reduced the validity of some measures. This study used an online version of the BRFSS, which to our knowledge has not been tried before. This change in the BRFSS administration format from the original telephone interview could affect our results. Cross-sectional studies cannot answer questions of causation; thus, the findings do not show that LTE caused poorer mental health, only that it was associated with it. Some O-OSU TBI-ID scores will differ from those in other studies (i.e. we could not distinguish between mild vs a moderate TBI (with LOC) because of administrative error; and our WTBI measure did include severe TBI). The small sample size and composition (largely female university students) is a limitation, and we excluded a handful of responses as 'invalid attempts' (e.g. extremely quick completions or mostly blank protocols), whereas these responses could in fact signal a problem with feasibility (i.e. that the measure could not actually be completed by all of the participants). Whilst the sample may be sufficient for an initial Australian pilot test of the O-OSU TBI-ID, including its feasibility, it does not support generalisable conclusions about LTE nor does it show how the test would function in specific groups with a heightened TBI exposure (e.g. adolescent contact-sports players or unsteady, older persons). Future studies with larger, representative samples are now needed to determine if the O-OSU TBI-ID can be used as a population screening tool for LTE.

This study suggests that estimates of LTE prevalence depend on assessment method (single- vs multi-item). Whichever method is used, the implementation should address the potential for expectancy bias or iatrogenesis (Dams-O'Connor *et al.* 2014). A suggested strategy is to provide participants with information about this risk, including that taking the survey does not prove causation (Dams-O'Connor *et al.* 2014).

There is strong interest in understanding LTE effects on health and functioning. The current study finds initial support for the feasibility of the O-OSU TBI-ID, including with added data validation, and in a new context (Australian sample). We successfully replicated some expected associations (Lequerica *et al.* 2018) and recommend further studies to identify key indices. However, the study limitations must also be kept in mind when considering the implications, including that this study was a small pilot investigation. The results of this pilot trial of this tool in Australia gives some confidence that the O-OSU TBI-ID could be successfully deployed in a larger population survey. In the longer term, this could eventually support improved LTE screening and understanding of LTE correlates, which in turn could improve resource planning and supports for people with TBI exposure.

References

Anstey KJ, Butterworth P, Jorm AF, Christensen H, Rodgers B, Windsor TD (2004) A population survey found an association between self-reports of traumatic brain injury and increased psychiatric symptoms. *Journal of Clinical Epidemiology* **57**(11), 1202–1209. doi:10.1016/j.jclinepi.2003.11.011

Bogner J, Corrigan JD, Yi H, Singichetti B, Manchester K, Huang L, Yang J (2020) Lifetime history of traumatic brain injury and behavioral health problems in a population-based sample. *Journal of Head Trauma and Rehabilitation* **35**(1), E43–E50. doi:10.1097/htr.0000000000000488

Butterworth P, Anstey K, Jorm AF, Rodgers B (2004) A community survey demonstrated cohort differences in the lifetime prevalence of self-reported head injury. *Journal of Clinical Epidemiology* **57**(7), 742–748. doi:10.1016/j.jclinepi.2003.10.015

Centres for Disease Control and Prevention (2014) At Behavioral Risk Factor Surveillance System Survey Questionnaire. Retrieved from Atlanta, Georgia.

Corrigan JD, Bogner J (2007) Initial reliability and validity of the Ohio State University TBI Identification Method. *Journal of Head Trauma and Rehabilitation* **22**(6), 318–329. doi:10.1097/01.Htr.0000300227.67748.77

Corrigan JD, Harrison-Felix C, Bogner J, Dijkers M, Terrill MS, Whiteneck G (2003) Systematic bias in traumatic brain injury outcome studies because of loss to follow-up. *Archives of Physical Medicine and Rehabilitation* **84**, 153–160. doi:10.1053/apmr.2003.50093

Corrigan JD, Bogner J, Mellick D, Bushnik T, Dams-O'Connor K, Hammond FM, *et al.* (2013) Prior history of traumatic brain injury among persons in the Traumatic Brain Injury Model Systems National Database. *Archives of Physical Medicine and Rehabilitation* **94**(10), 1940–1950. doi:10.1016/j.apmr.2013.05.018

Corrigan JD, Yang J, Singichetti B, Manchester K, Bogner J (2018) Lifetime prevalence of traumatic brain injury with loss of consciousness. *Injury Prevention* **24**(6), 396–404. doi:10.1136/injuryprev-2017-042371

Cuthbert JP, Whiteneck GG, Corrigan JD, Bogner J (2016) The reliability of a computer-assisted telephone interview version of the Ohio State University Traumatic Brain Injury Identification Method. *Journal of Head Trauma and Rehabilitation* **31**(1), E36–E42. doi:10.1097/htr.0000000000000075

Dams-O'Connor K, Spielman L, Singh A, Gordon WA, Lingsma HF, Maas AI, *et al.* (2013) The impact of previous traumatic brain injury on health and functioning: a TRACK-TBI study. *Journal of Neurotrauma* **30**(24), 2014–2020. doi:10.1089/neu.2013.3049

Dams-O'Connor K, Cantor JB, Brown M, Dijkers MP, Spielman LA, Gordon WA (2014) Screening for traumatic brain injury: findings and public health implications. *Journal of Head Trauma and Rehabilitation* **29**(6), 479–489. doi:10.1097/HTR.0000000000000099

Dennis EL, Baron D, Bartnik-Olson B, Caeyenberghs K, Esopenko C, Hillary FG, *et al.* (2022) ENIGMA brain injury: Framework, challenges, and opportunities. *Journal of Human Brain Mapping* **43**(1), 149–166. doi:10.1002/hbm.25046

Edmed SL, Sullivan KA (2014) Method of symptom assessment influences cognitive, affective and somatic post-concussion-like symptom base rates. *Brain Injury* **28**(10), 1277–1282. doi:10.3109/02699052.2014.915988

Feiss R, Corrigan JD, Ding K, Beaulieu CL, Bogner J, Yang J (2022) Rural-urban differences in behavioral outcomes among adults with lifetime history of traumatic brain injury with loss of consciousness: 2016-2019 Ohio BRFSS. *International Journal of Environmental Research and Public Health* **19**(3), 1678. doi:10.3390/ijerph19031678

Field AP (2018) 'Discovering statistics using IBM SPSS statistics', 5th edn. (Sage Publications: London, England)

Griffin M, Martino RJ, LoSchiavo C, Comer-Carruthers C, Krause KD, Stults CB, Halkitis PN (2021) Ensuring survey research data integrity in the era of internet bots. *Quality & Quantity* **56**, 2841–2852. doi:10.1007/s11135-021-01252-1

Ilie G, Adlaf EM, Mann RE, Ialomiteanu A, Hamilton H, Rehm J, Asbridge M, Cusimano MD (2015) Associations between a History of Traumatic Brain Injuries and Current Cigarette Smoking, Substance Use, and Elevated Psychological Distress in a Population Sample of Canadian Adults. *Journal of Neurotrauma* **32**(14), 1130–1134. doi:10.1089/neu.2014.3619

Ilie G, Adlaf EM, Mann RE, Ialomiteanu A, Hamilton H, Rehm J, *et al.* (2018) Associations between self-reported lifetime history of traumatic brain injuries and current disability assessment in a population sample of Canadian adults. *PLoS One* **13**(1), e0188908. doi:10.1371/journal.pone.0188908

Jurick SM, Twamley EW, Crocker LD, Hays CC, Orff HJ, Golshan S, *et al.* (2016) Postconcussive symptom overreporting in Iraq/Afghanistan Veterans with mild traumatic brain injury. *Journal of Rehabilitation Research* **53**(5), 571–584. doi:10.1682/JRRD.2015.05.0094

King NS, Crawford S, Wenden FJ, Moss NEG, Wade DT (1995) The Rivermead Post Concussion Symptoms Questionnaire: a measure of symptoms commonly experienced after head injury and its reliability. *Journal of Neurology* **242**(9), 587–592. doi:10.1007/BF00868811

Konrad C, Geburek AJ, Rist F, Blumenroth H, Fischer B, Husstedt I, Arolt V, Schiffbauer H, Lohmann H (2011) Long-term cognitive and emotional consequences of mild traumatic brain injury *Psychological Medicine* **41**(6), 1197–1211. doi:10.1017/s0033291710001728

Langlois JA, Rutland-Brown W, Wald MM (2006) The epidemiology and impact of traumatic brain injury: A brief overview. *Journal of Head Trauma and Rehabilitation* **21**(5), 375–378. doi:10.1097/00001199-200609000-00001

Lequerica AH, Lucca C, Chiaravalloti ND, Ward I, Corrigan JD (2018) Feasibility and Preliminary Validation of an Online Version of the Ohio State University Traumatic Brain Injury Identification Method. *Archives of Physical Medicine and Rehabilitation* **99**(9), 1811–1817. doi:10.1016/j.apmr.2018.03.023

Lequerica AH, Arango-Lasprilla JC, Krch D, Corrigan JD (2021) Assessing lifetime exposure to traumatic brain injury among an international sample of Spanish speakers. *NeuroRehabilitation* **48**(1), 109–117. doi:10.3233/nre-201539

Lovibond PF, Lovibond SH (1995) The structure of negative emotional states: comparison of the Depression Anxiety Stress Scales (DASS) with the Beck Depression and Anxiety Inventories. *Behaviour Research and Therapy* **33**(3), 335–343. doi:10.1016/0005-7967(94)00075-u

Manchester K, Corrigan JD, Singichetti B, Huang L, Bogner J, Yi H, Yang J (2020) Current health status and history of traumatic brain injury among Ohio adults. *Injury Prevention* **26**(2), 129–137. doi:10.1136/injuryprev-2018-043056

McKibben WB, Silvia PJ (2017) Evaluating the distorting effects of inattentive responding and social desirability on self-report scales in creativity and the arts. *The Journal of Creative Behavior* **51**(1), 57–69. doi:10.1002/jocb.86

McKinlay A, Horwood L, Fergusson D (2016) Accuracy of self-report as a method of screening for lifetime occurrence of traumatic brain injury events that resulted in hospitalization. *Journal of the International Neuropsychological Society* **22**, 717–23. doi:10.1017/S1355617716000497

McKinlay A, Corrigan JD, Bogner JA, Horwood LJ (2017) Obtaining a history of childhood traumatic brain injury using the Ohio State University TBI Identification Method to elicit adult recall. *Journal of Head Trauma and Rehabilitation* **32**(6), E24–E28. doi:10.1097/htr.0000000000000284

Meier TB, Brummel BJ, Singh R, Nerio CJ, Polanski DW, Bellgowan PS (2015) The underreporting of self-reported symptoms following sports-related concussion. *Journal of Science and Medicine in Sport* **18**(5), 507–511. doi:10.1016/j.jsams.2014.07.008

Menon DK, Schwab K, Wright DW, Maas AI (2010) Position statement: Definition of traumatic brain injury. *Archives of Physical Medicine and Rehabilitation* **91**(11), 1637–1640. doi:10.1016/j.apmr.2010.05.017

Moore E, Indig D, Haysom L (2014) Traumatic Brain Injury, Mental Health, Substance Use, and Offending Among Incarcerated Young People. *Journal of Head Trauma Rehabilitation* **29**(3), 239–247. doi:10.1097/HTR.0b013e31828f9876

National Institute of Neurological Disorder and Stroke (2019) Ohio State University TBI Identification Method Short Form. NINDS Common Data Elements. Retrieved from https://commondataelements.ninds.nih.gov/report-viewer/22972/Ohio%20State%20University%20TBI%20Identification%20Method%20Short%20Form

Ohio State University Wexner Medical Centre (2022) Screening for TBI Using the OSU TBI-ID Method. Retrieved from https://wexnermedical.osu.edu/neurological-institute/neuroscience-research-institute/research-centers/ohio-valley-center-for-brain-injury-prevention-and-rehabilitation/for-professionals/screening-for-tbi

Oppenheimer DM, Meyvis T, Davidenko N (2009) Instructional manipulation checks: Detecting satisficing to increase statistical power. *Journal of Experimental Social Psychology* **45**(4), 867–872. doi:10.1016/j.jesp.2009.03.009

Osborn AJ, Mathias JL, Fairweather-Schmidt AK, Anstey KJ (2018) Traumatic Brain Injury and Depression in a Community-Based Sample: A Cohort Study Across the Adult Life Span *Journal of Head Trauma Rehabilitation* **33**(1), 62–72. doi:10.1097/htr.0000000000000311

Perkes I, Schofield PW, Butler T, Hollis SJ (2011) Traumatic brain injury rates and sequelae: A comparison of prisoners with a matched community sample in Australia. *Brain Injury* **25**(2), 131–141. doi:10.3109/02699052.2010.536193

Rabinowitz AR, Chervoneva I, Hart T, O'Neil-Pirozzi TM, Bogner J, Dams-O'Connor K, *et al.* (2020) Influence of prior and intercurrent brain injury on 5-year outcome trajectories after moderate to severe traumatic brain injury. *Journal of Head Trauma and Rehabilitation* **35**(4), E342–E351. doi:10.1097/htr.0000000000000556

Schneider-Cline W, Bush E, McKelvey M (2019) Using the OSU TBI-ID method for screening rural, older adults: a mixed methods feasibility study. *Brain Injury* **33**(7), 899–915. doi:10.1080/02699052.2019.1606450

Schofield PW, Butler TG, Hollis SJ, Smith NE, Lee SJ, Kelso WM (2006*a*) Neuropsychiatric correlates of traumatic brain injury (TBI) among Australian prison entrants. *Brain Injury* **20**(13-14), 1409–1418. doi:10.1080/02699050601130443

Schofield PW, Butler TG, Hollis SJ, Smith NE, Lee SJ, Kelso WM (2006*b*) Traumatic brain injury among Australian prisoners: Rates, recurrence and sequelae. *Brain Injury* **20**(5), 499–506. doi:10.1080/02699050600664749

Voormolen DC, Cnossen MC, Spikman J, Polinder S, Iverson GL, de Koning M, van der Naalt J (2020) Rating of pre-injury symptoms over time in patients with mild traumatic brain injury: the good-old-days bias revisited. *Brain Injury* **34**(8), 1001–1009. doi:10.1080/02699052.2020.1761563

Waltzman D, Daugherty J, Sarmiento K, Proescholdbell S (2021) Lifetime history of traumatic brain injury with loss of consciousness and the likelihood for lifetime depression and risk behaviors: 2017 BRFSS North Carolina. *Journal of Head Trauma and Rehabilitation* **36**(1), E40–E49. doi:10.1097/htr.0000000000000603

Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

Conflicts of interest. The authors have no conflicts of interest to declare.

Declaration of funding. The authors did not receive external funding for this research, but the authors were provided internal funding for the gift cards.

Ethics standard. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

Acknowledgements. The authors thank study participants for volunteering their time to participate in this study and Ms Catherine Kennon for assistance with data integrity measures. The authors acknowledge A/Prof Obst for her statistical review of this manuscript. Both authors contributed to the conception, execution, and write up of this research.

Author affiliation
[A]School of Psychology and Counselling, Queensland University of Technology, O Block B Wing, Kelvin Grove Campus, Victoria Park Road, Kelvin Grove, Brisbane, 4059, Australia. Email: elysia.caltabiano@connect.qut.edu.au