Symptoms and engagement in anti-social behaviour 10 years following mild traumatic brain injury within a community civilian sample: a prospective cohort study with age-sex matched control group

Alice Theadom PhD , Kelly Jones PhD , Nicola Starkey PhD , Suzanne Barker-Collo PhD , Shanthi Ameratunga PhD , Josh Faulkner PhD , Braden Te Ao PhD , Valery Feigin MD, PhD

PII: S0003-9993(23)00457-4
DOI: https://doi.org/10.1016/j.apmr.2023.07.016
Reference: YAPMR 58892

To appear in: *Archives of Physical Medicine and Rehabilitation*

Received date: 19 February 2023
Revised date: 26 July 2023
Accepted date: 31 July 2023

Please cite this article as: Alice Theadom PhD , Kelly Jones PhD , Nicola Starkey PhD , Suzanne Barker-Collo PhD , Shanthi Ameratunga PhD , Josh Faulkner PhD , Braden Te Ao PhD , Valery Feigin MD, PhD , Symptoms and engagement in anti-social behaviour 10 years following mild traumatic brain injury within a community civilian sample: a prospective cohort study with age-sex matched control group, *Archives of Physical Medicine and Rehabilitation* (2023), doi: https://doi.org/10.1016/j.apmr.2023.07.016

Symptoms and engagement in anti-social behaviour 10 years following mild traumatic brain injury within a community civilian sample: a prospective cohort study with age-sex matched control group

Alice Theadom PhD[1,2*] Kelly Jones PhD[2] Nicola Starkey PhD[3] Suzanne Barker-Collo PhD[4] Shanthi Ameratunga PhD[5] Josh Faulkner PhD[6] Braden Te Ao PhD[7] Valery Feigin MD, PhD[2]

[1] Traumatic Brain Injury Network, School of Clinical Sciences, Auckland University of Technology, Auckland, New Zealand

[2] National Institute for Stroke and Applied Neuroscience, Auckland University of Technology, Auckland, New Zealand

[3] School of Psychology, University of Waikato, Hamilton, New Zealand

[4] School of Psychology, University of Auckland, Auckland, New Zealand

[5] Department of Epidemiology and Biostatistics, University of Auckland and Te Whatu Ora, Auckland, New Zealand

[6] School of Psychology, Victoria University of Wellington, Wellington, New Zealand

[7] School of Population Health, Faculty of Medical and Health Sciences, University of Auckland, Auckland, New Zealand

Corresponding author

Professor Alice Theadom, email: alice.theadom@aut.ac.nz

Keywords: mild traumatic brain injury, concussion, anti-social behaviour, symptoms, participation, longitudinal

Abbreviations:

ANCOVA= Analysis of Covariance

AUDIT-C = Alcohol Use Disorders Identification Test

ASSIST = Alcohol, Smoking and Substance Involvement Screening Test

mTBI = mild traumatic brain injury

NZ= New Zealand

RPQ = Rivermead Post-Concussion Symptom Questionnaire

WHODAS 2.0 = WHO Disability Assessment Schedule Version 2

Acknowledgements

This study was funded as part of a Rutherford Discovery Fellowship awarded to the lead author administered by The Royal Society of New Zealand – Te Apārangi. We would like to thank the BIONIC participants who so generously continue to offer us their time and insights. We would also like to acknowledge the authors of the original BIONIC incidence study who established the participant cohort and enabled this longitudinal prospective study to be conducted.

Abstract

Objective: To determine if there are longer-term impacts on symptoms, health status, mood and behaviour 10-years following a mild traumatic brain injury (mTBI).

Design: Prospective cohort study

Setting: Community-based, civilian sample

Participants: Adults aged ≥16 years at follow up who experienced a mTBI 10-years ago, and an age and sex-matched non-injured control group.

Interventions: Not applicable

Main Outcome Measures: MTBI cases and controls were asked to complete self-report assessments of functioning (WHODAS 2.0), symptoms (Rivermead Post-Concussion Symptom Questionnaire), health status (100-point scale), alcohol (AUDIT-C) and substance use (ASSIST), and whether they had engaged in any anti-social behaviours over the past 12-months.

Results: Data were analysed for 368 participants (184 mTBI cases and 184 age-sex matched controls). Just over a third of mTBI cases (64, 34.8%) reported that they were still affected by their index mTBI 10-years later. After adjusting for education and ethnicity, the mTBI group had statistically higher overall symptom burden ($F=22.32$, $p<0.001$, $\eta p^2 = 0.07$) compared to controls. This difference remained after excluding those who experienced a recurrent TBI. The mTBI group were more than three times as likely to have engaged in anti-social behaviour during the previous 12-months ($F=5.89$, $p=0.02$). There were no group differences in health status, functioning, or problematic alcohol or substance use 10-years post-injury.

Conclusions: This study provides evidence of potential longer-term associations between mTBI, post-concussion symptoms and anti-social behaviour which warrants further evaluation. Future research should also examine if longer-term effects may be preventable with access to early rehabilitation post-injury.

Keywords: traumatic brain injury, concussion, TBI, longitudinal, symptoms, substance use, work

Introduction

There is increasing evidence that mild traumatic brain injury (mTBI, which includes concussion), may not always be mild in terms of its impact.[1] Longitudinal studies have revealed that 47.9% of adults report four or more post-concussion symptoms at one year, 40.3% have low satisfaction with life [2] and 22.4% have reduced functioning one-year post-mTBI.[3] Community participation and employment have been found to be lower in mTBI samples compared with controls at both four and eight years post-injury.[4,5] However, whether the observed differences in symptom profiles and participation persist in the longer-term remains unclear.

There may also be wider longer-term impacts from mTBI on behaviour. Studies of people who experienced a mTBI in childhood or adolescence propose an increased risk of engaging in antisocial behaviour later in life.[6,7] In adults attending hospital for a TBI of any severity (including moderate and severe TBI) an increased risk of violent criminal convictions relative to non-injured controls was identified.[8] Additionally, initial evidence suggests a link between childhood and adolescent mTBI and higher levels of substance and alcohol use in mTBI cases compared with controls.[9] Sports-related mTBI studies have also identified a potential link

between mTBI and increased later life depression.[10] However current longitudinal studies of mTBI have only explored links in the short term (few years post-injury), or much longer term (in older age). Few prospective longitudinal studies have explored whether there are any medium-term impacts within a civilian sample particularly in cases of mTBI where there is no evidence of abnormality on a CT scan or where a CT scan was not conducted.[11] Consequently, this study aims to determine if there are differences in outcome in a population-based cohort 10-years after a mTBI compared to non-injured controls.

Methods

This study received ethical approval from the Northern B Health and Disability Ethics Committee (Ref: 19NTB166) and the Auckland University of Technology Ethics Committee (Ref: 19/408).

MTBI cases were recruited via a TBI incidence and outcomes study[12] which aimed to identify cases of TBI over a 12-month period. MTBI was defined as an injury from a mechanical force to the head or body resulting in an altered level of consciousness or other focal neurological signs such as seizure with a Glasgow Coma Score of ≥13 and/or Post-traumatic amnesia <24 hours.[13] Altered level of consciousness was determined based on evidence of confusion, disorientation, loss of consciousness and post-traumatic amnesia. In cases where there was no medical diagnosis, the case was reviewed by a Diagnostic Adjudication Group.[14] Participants were assessed over the first 12-months post-injury and at four and eight years post-injury.[4,5,15] At the 10 year post-injury timepoint, participants who were aged ≥6 years at the time of injury (aged ≥16 years at time of the 10-year follow up assessment), who had experienced a mTBI and gave permission to be contacted regarding further follow up at

their previous assessment, were invited to participate. In New Zealand people are able to give informed consent from age 16 years.

Participants were contacted by a researcher 10-years (±3 months) after their index mTBI (index injury dates occurred between March 1st 2010 and 31st May 2011). Participants were contacted via landline and mobile phone, email, next of kin and via social media accounts based on details given at a previous assessment. Eligible participants were offered the option to complete the assessment in-person, via telephone or to self-complete on paper via post or online. Offering different assessment modalities facilitated participant choice, provided flexibility and enabled the study to continue during changing COVID-19 pandemic restrictions. Participants were excluded if they had experienced a moderate or severe TBI or a complicated mTBI.

Controls were recruited through advertisements distributed in community settings, such as public libraries, sports centres, and via social media. Assessments were completed with cases and controls in parallel to control for effects of the coronavirus pandemic on assessment data. To be eligible to take part, control participants were required to be aged ≥16 years at the time of the assessment and not to have experienced a TBI of any severity over the past 10-years. A control participant was matched 1:1 to each of the mTBI cases based on sex and age (matched within ±5 years). Recurrent mTBI cases were retained in the analysis as removal of these cases would reduce generalisability of the findings.[16] Sensitivity analysis was conducted excluding the recurrent mTBI cases to determine influence on outcome.

Measures

Sociodemographic and mTBI incidence data including mechanism, context of injury and whether the person received follow up treatment (after their initial appointment) were extracted from the incidence study database.

Recurrent TBI

At each assessment participants were asked if they had experienced any injuries where they lost consciousness, felt dazed or confused or could not remember the incident. Data on recurrent TBI in the mTBI group was extracted from datasets at one, four- and eight-years post-injury and at the 10-year follow up. Controls were asked if they had experienced any injuries where they lost consciousness, felt dazed or confused or could not remember the incident in the last 10-years.

Functioning

The World Health Organisation Disability Assessment Schedule (WHODAS 2.0)[17] asks participants to rate the level of difficulty that they experienced on 36 items from none (1) to extreme difficulty or unable to perform (5). Items were summed to yield six domain specific scores (understanding and communication, ability to get around, self-care, getting along with others, life activities within the household and at school/work and community participation)..

Symptom experience

Current symptoms experienced were assessed using the 16 item Rivermead Post-Concussion Symptoms Questionnaire (RPQ).[18] Due to the long timeframe since the injury and to enable relevance to the control participants, the instructions were adapted to read "We would like to know if you experience any of the symptoms listed below. Please select the answer that most closely represents what you have experienced in the last 7 days". Responses were scored of a scale of 0 = not at all, or no more of a problem) to 4=severe. Scores were converted to an interval scale.[19]

Mood was assessed using the Hospital Anxiety and Depression Scale (HADS).[20] This scale encompasses two separate sub-scales (7 items assessing levels of anxiety and 7 items assessing depression). Participants were asked to rate how much they feel each of a series of descriptors over the past week. Responses to each item were scored on a scale of 0-3 and summed to yield a subscale score (up to a possible total of 21) with higher scores indicative of poorer mood.

Anti-social behaviour

Participants were asked to rate how frequently they had engaged in seven listed behaviours over the past 12-months on a scale of 1 (never), to 5 (nearly all the time). Behaviours included threatening others, getting into a physical fight, stealing something from a person or building, carrying a weapon, selling illegal drugs, being suspended from school or work, damaging property or littering on purpose. As a high proportion of both groups did not report engaging in these behaviours in the past 12-months, data were dichotomised to indicate whether the person had engaged in any one of the listed behaviours (sometimes or more frequently, score of 3 or more) in the past 12-months or not.

Physical health

To determine current physical health status participants were asked to rate their health at the time of the assessment on a scale of (0-100). Participants were asked if they had any other mental or physical comorbidities at the time of the assessment.

Alcohol use

Levels of problematic alcohol use was determined using the Alcohol Use Disorders Identification Test (AUDIT-C).[21] Participants were asked to state how often they have a drink containing alcohol, how many drinks containing alcohol they have on a typical day and how often they have five or more drinks on one occasion. Item scores were summed to yield a

total score between 0 and 12. Scores of ≥3 for females and ≥4 for males were deemed as problematic alcohol use.[22]

Substance use

Problematic substance use was assessed using the Alcohol Smoking and Substance Involvement Screening Test (ASSIST).[23] Participants were asked how often in the past 3-months they had used a range of substances including cannabis, cocaine, amphetamine or other substance used off label such as inhalants, sedatives or hallucinogens or opioids on a scale of 0 (never) to 6 (daily or almost daily). Responses were dichotomised into no use/casual use or regular use (monthly or more).

Perceived impact of mTBI

Participants were also asked if they still felt affected by the brain injury that they sustained 10-years ago, with a yes/no answer. If they answered yes, participants were asked to describe how they felt they were affected in their own words.

Statistical analysis

A priori power calculation to detect a medium effect size (0.2), with an alpha of =0.05, based on two groups, with two covariates, determined that a minimum sample size of N=244 (122 per group) would be required. Numbers and frequencies were used to describe sample characteristics and outcomes for categorical data, with means and standard deviations used for continuous outcomes. T-tests and chi-square analyses were used to determine if there were any sociodemographic differences between the two groups or by age at injury. Data for symptoms, mood and functioning scores were negatively skewed and data on physical health ratings were positively skewed. As the direction and degree of the skew was similar for each group, the sample size was large, there were no extreme outliers and F-tests remain robust with moderately skewed data, ANCOVAs with partial eta squared (ηp^2) were used to identify

any differences between the groups.[24] Quade's ANCOVAs for non-parametric data and unadjusted odds ratios were used to determine if there were any differences between the groups on the categorical outcomes. A statistical significance level of $p<0.05$ was used to identify relationships between mTBI and 10-year outcomes worthy of further exploration. Effect sizes of 0.1 were considered to be small, 0.20 medium and 0.30 large in accordance with recommendations.[25]

Results

There were 264 (65.3%) participants identified from the original incidence study who were able to be contacted and invited to complete the follow up assessment 10-years post-injury. Assessments were completed with 184 mTBI participants 10-years post-injury (see Figure 1) and matched with 184 controls based on age and sex (Total N=368), yielding a 70.8% consent rate (see figure 1). Participants ranged in age between 16 and 86 years. Most assessments (84.2% of cases and 84.8% of controls) were self-completed online due to COVID-19 social distancing restrictions.

Insert Figure 1 About Here

Key sociodemographic characteristics for mTBI cases and controls are presented in Table 1. Whilst age and sex were controlled for between groups by the matching process, there were a higher number of Europeans, lower levels of education and higher employment in the mTBI group. Ethnicity and education were included as covariates in the primary analyses to take these into account. Employment was highly correlated with education and was included as part of the participation outcome so was consequently not also included as a covariate. Just over half of cases and controls were male (N=101, 54.9%). Only one participant was recorded to have received support from a rehabilitation service following injury.

Insert Table 1 About Here

Just over a third of mTBI cases (N=64, 34.8%) reported that they felt that they were still affected by their index mTBI based on the study specific question. To determine if there were any differences between the effects of mTBI sustained in childhood (≤16 years) versus adulthood (>16 years), unadjusted comparisons were made between cases across all continuous outcome measures. As shown in Table 2, there were no between-group differences in outcome.

Insert Table 2 About Here

Based on the finding that there were no age of injury related differences in outcome, cases and controls of all ages were included in the analysis to increase generalisability to a civilian sample, statistical power and enable control of ethnicity and education in the analysis.

As shown in Table 3, mTBI cases reported higher symptoms and reduced functioning on the domain of getting around 10-years post-injury than non-injured controls, after controlling for ethnicity and education, with medium to large effect sizes. The differences observed on the outcome measures mirrored open text responses to the question as to whether they felt they were still affected by their brain injury from 10-years ago. Most answers to this question reflected an impact of ongoing symptoms such as “I feel tired more easily” and “I struggle to drive long distances”. There were no differences between the groups in current physical health status, functioning or depression. Controls were found to have greater difficulties at school/work than mTBI cases.

Insert Table 3 About Here

There were 57 cases (31.0%) in the mTBI sample who had experienced at least one subsequent TBI during the 10-year follow up period. Sensitivity analysis was conducted on outcomes removing the recurrent TBI cases to determine the specific effect of mTBIs

sustained 10-years ago (Table 4). There remained a large effect size in symptom burden, with single mTBI cases experiencing greater symptom burden 10-years post-injury than controls. However, the difference in getting around no longer remained. A medium difference also remained on the school/work participation domain of the WHODAS with controls reporting greater difficulties.

Insert Table 4 About Here

There were no differences between those who experienced a mTBI ≤16 years and those injured >16 years of age on antisocial behaviour (χ^2= 2.92, p=0.89), substance use (χ^2=1.05, p=0.31), or alcohol use (χ^2=2.14, p=0.14). Based on analysis of the whole mTBI sample compared to controls. mTBI cases were more likely to have engaged in antisocial behaviours in the past 12-months after adjusting for ethnicity and education. However, there was no differences between the two groups with regards to regular substance use and problematic alcohol use (Table 5).

Insert Table 5 About Here

Discussion

This study aimed to determine if people who sustained a mTBI 10-years previously differed on measures of physical health, post-concussion symptoms, functioning, mood and behaviour compared with age and sex matched controls. We found that mTBI cases had significantly higher symptom burden and engagement in anti-social behaviour than controls after taking ethnicity and education into account. There were no longer-term differences observed in physical health, mood, or functioning or alcohol/substance use.

The findings of this study support previous evidence of the impacts of mTBI on increased symptoms previously identified at one, four- and eight-years post-injury.[4,5,15] The identified increased risk of longer-term engagement in antisocial behaviour following TBI of all severities or in childhood has been previously observed.[26] The present study revealed that there is an increased risk even if the mTBI was sustained later in life. The links between mTBI and antisocial behaviour are likely to be highly complex, with an mTBI likely to exacerbate other risk factors such as social deprivation.[26] In contrast to previous longitudinal studies on the impacts of mTBI sustained in childhood, we did not identify an increased risk of substance use in later life.[9] This difference may reflect that in this current analysis we controlled for the influence of ethnicity and education on outcomes. No differences were found in terms of levels of problematic alcohol use between the two groups as identified in previous studies of retired sports athletes.[10,27] Prior reported links between mTBI, mood and alcohol may therefore reflect differences more specific to retired sports athletes, where alcohol use is higher than in the general population.[28]

The higher reported difficulties in work/school participation in controls compared to mTBI cases was interesting. Control participants reporting the highest difficulties on this outcome domain were students. Research has shown students and younger people were particularly affected by COVID-19 lockdown restrictions,[29] with two thirds of students reporting difficulty following course content and completing learning outcomes.[30] The WHODAS questions such as ability to get tasks done quickly and doing tasks well. Consequently, the differences in school/work participation observed between cases and controls may therefore reflect the wider context and higher proportion of students in the control group.

Previous studies have shown that 9.9% of adults experience a recurrent TBI within the year following an incident injury.[16] The current study revealed that 31.0% of participants had

experienced at least one recurrent injury over the 10-years. Data on self-reported recurrent injuries were collected at one, four, eight and 10-year assessments reducing the risk of recall bias over the 10-year period for mTBI cases. However, recall bias may have affected controls who were asked to recount injuries over the past 10-years. We did not have on-going access to participant's medical records and were reliant on self-reported recurrent TBI data.

Study Limitations

. Less than 20% of the original eligible sample took part in the 10 year follow up assessment which may limit generalisability of the findings. Whilst cases and controls were recruited and completed the outcome assessments simultaneously, unlike the mTBI cases, we do not have data for the control group for the previous 10-years. We were also not able to control for other factors that may influence outcome following mTBI such as income, social support and psychiatric history. Additionally, as the potential links between mTBI and behaviour were not known when the mTBI cohort were recruited, data on pre-injury engagement in anti-social behaviour was not collected. The lack of a standardised measure to assess prior TBI is a limitation, however when the original incidence study was conducted measures to assess TBI history were in their infancy. There are considerable physiological and psychosocial changes that occur over the lifespan, particularly in childhood which the study was not able to take into account and other outcome measures may have yielded different results. However, the use of a general population sample, with a defined time since injury, focus on mTBI and prospective longitudinal design enabled the study to address some previous gaps in the existing literature and identified potential areas of longer-term outcome worthy of more detailed investigation. The findings provide evidence of the need to enable access to early rehabilitation for those who do not recover naturally to prevent longer-term difficulties.

Conclusions

The findings provide evidence of longer-term impacts of mTBI on symptom burden and higher risk of engaging in antisocial behaviour.

References

1. Maas AIR, Menon DK, Adelson PD, et al. Traumatic brain injury: integrated approaches to improve prevention, clinical care, and research. *The Lancet Neurology* 2017; **16**(12): 987–1048.
2. McMahon P, Hricik A, Yue JK, et al. Symptomatology and Functional Outcome in Mild Traumatic Brain Injury: Results from the Prospective TRACK-TBI Study. *Journal of Neurotrauma* 2014; **31**(1): 26-33.
3. Schneider ALC, Huie JR, Boscardin WJ, et al. Cognitive Outcome 1 Year After Mild Traumatic Brain Injury: Results From the TRACK-TBI Study. *Neurology* 2022; **98**(12): e1248-e61.
4. Theadom A, Starkey N, Barker-Collo S, et al. Population-based cohort study of the impacts of mild traumatic brain injury in adults four years post-injury. *PLoS One* 2018; **13**(1): e0191655.
5. Starkey NJ, Duffy B, Jones K, et al. Sex differences in outcomes from mild traumatic brain injury eight years post-injury. *PLoS One* 2022; **17**(5): e0269101.
6. McKinlay A, Grace RC, McLellan T, et al. Predicting adult offending behavior for individuals who experienced a traumatic brain injury during childhood. *Journal of Head Trauma and Rehabilitation* 2014; **29**(6): 507-513.
7. Timonen M, Miettunen J, Hakko H, et al. The association of preceding traumatic brain injury with mental disorders, alcoholism and criminality: the Northern Finland 1966 Birth Cohort Study. *Psychiatry Research* 2002; **113**(3): 217-226.
8. Schofield PW, Malacova E, Preen DB, et al. Does Traumatic Brain Injury Lead to Criminality? A Whole-Population Retrospective Cohort Study Using Linked Data. *PLoS One* 2015. DOI: 10.1371/journal.pone.0132558.
9. Kennedy E, Heron J, Munafo M. Substance use, criminal behaviour and psychiatric symptoms following childhood traumatic brain injury: findings from the ALSPAC cohort. *European Child and Adolescent Psychiatry* 2017; 26(10):1197-1206.
10. Guskiewicz KM, Marshall SW, Bailes J, et al. Recurrent concussion and risk of depression in retired professional football players. *Medicine and Science in Sports and Exercise* 2007; **39**(6): 903-909.
11. Voormolen DC, Zeldovich M, Haagsma JA, et al. Outcomes After Complicated and Uncomplicated Mild Traumatic Brain Injury at Three- and Six-Months Post-Injury: Results from the CENTER-TBI Study. *Journal of Clinical Medicine* 2020; **9**(5):1525.
12. Feigin VL, Theadom A, Barker-Collo S, et al. Incidence of traumatic brain injury in New Zealand: a population-based study. *The Lancet Neurology* 2013; **12**(1): 53-64.

13. Carroll LJ, Cassidy JD, Holm L, et al. Methodological issues and research recommendations for mild traumatic brain injury: the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. *Journal of Rehabilitation Medicine*, 2004; (43 Suppl): 113-25.
14. Theadom A, Barker-Collo S, Feigin VL, et al. The spectrum captured: a methodological approach to studying incidence and outcomes of traumatic brain injury on a population level. *Neuroepidemiology* 2012; 38(1):18-29.
15. Theadom A, Parag V, Dowell T, et al. Persistent problems 1 year after mild traumatic brain injury: a longitudinal population study in New Zealand. *British Journal of General Practice* 2016; **66**(642): e16-23.
16. Theadom A, Parmar P, Jones K, et al. Frequency and impact of recurrent traumatic brain injury in a population-based sample. *Journal of Neurotrauma* 2015; **32**(10): 674-681.
17. World Health Organisation. Manual for WHO Disability Assessment Schedule (WHODAS 2.0) / edited by Ustun TB, Kostanjsek N, Chatterji S, Rehm J. World Health Orgnisation; 2010. https://www.who.int/publications/i/item/measuring-health-and-disability-manual-for-who-disability-assessment-schedule-(-whodas-2.0).
18. King NS, Crawford S, Wenden FJ, et al. The Rivermead Post Concussion Symptoms Questionnaire: a measure of symptoms commonly experienced after head injury and its reliability. *Journal of Neurology* 1995; **242**(9): 587-592.
19. Balalla S, Krägeloh C, Medvedev O, et al. Is the Rivermead Post-Concussion Symptoms Questionnaire a Reliable and Valid Measure to Assess Long-Term Symptoms in Traumatic Brain Injury and Orthopedic Injury Patients? A Novel Investigation Using Rasch Analysis. *Neurotrauma Reports* 2020; **11**(1): 63-72.
20. Zigmond AS, Snaith RP. The Hospital Anxiety and Depression Scale. *Acta Psychiatrica Scandinavica* 1983; **67**(6): 361-70.
21. Babor TF, Higgins-Biddle JC, J.B. Saunders et al. AUDIT, Alcohol Use Disorders Identification Test, Guidelines for Use in Primary Care, Second Edition: Department of Mental Health and Substance Dependence, 2001.
22. Bush K, Kivlahan D, McDonell M, et al. The AUDIT alcohol consumption questions (AUDIT-C): an effective brief screening test for problem drinking. *Archives of Internal Medicine* 1998; **158**(16): 1789-1795.
23. World Health Organisation. The Alcohol, smoking and substance involvement screening test (ASSIST). Manual for use in primary care. World Health Organisation, 2010
24. Olejnik SF, Algina J. Parametric ANCOVA and the rank transform ANCOVA when the data are conditionally non-normal and heteroscedastic. *Journal of Educational Statistics* 1984; **9**: 129-149.
25. Funder DC, Ozer DJ. Evaluating effect size in psychological research: sense and nonsense. *Advances in Methods and Practices in Psychological Science* 2019; **2**(2): 158-168.
26. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *Journal of the American Medical Association* 2003; **290**(19): 2549-2555.
27. Williams WH, Chitsabesan P, Fazel S, et al. Traumatic brain injury" a potential cause of violent crime? *Lancet Psychiatry* 2018; 5(10):836-844.
28. Hume P, Theadom A, Lewis GN, et al. A Comparison of Cognitive Function in Former Rugby Union Players Compared with Former Non-Contact-Sport Players and the Impact of Concussion History. *Sports Medicine* 2016; 47(6):1209-1220.
29. Sønderlund AL, O'Brien K, Kremer P, et al. The association between sports participation, alcohol use and aggression and violence: A systematic review. *Journal of Science and Medicing in Sport* 2014; **17**(1): 2-7.

30. Saeed H, Eslami A, Nassif NT, et al. Anxiety Linked to COVID-19: A Systematic Review Comparing Anxiety Rates in Different Populations. *International Journal of Environmental Research and Public Health* 2022; **19**(4): 2189.
31. Gadi N, Saleh S, Johnson J, et al. The impact of the COVID-19 pandemic on the lifestyle and behaviours, mental health and education of students studying healthcare-related courses at a British university. *BMC Medical Education* 2022; **22**(115). DOI: 10.1186/s12909-022-03179-z.

Figure Legends

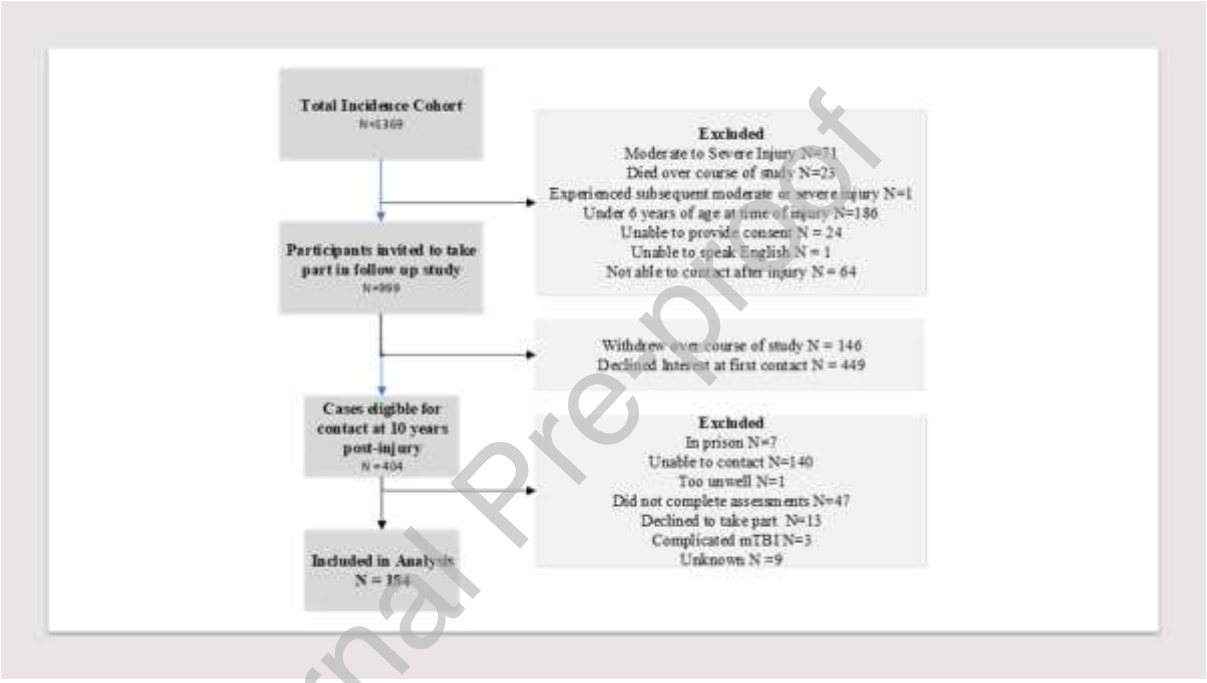

Figure 1. Participant flow diagram for mTBI cases from identification in the incidence study to assessment at 10-year follow up

Table 1. Participant Characteristics

	Total mTBI cases (N=184)	**Controls (N=184)**	**Test of Difference**

Age at time of assessment in years (Mean and Standard deviation)	38.92 (16.89)	38.28 (16.89)	t=0.36 p=0.72
Age range at time of assessment			
16-21 (6-11 years at time of injury)	24 (13.0)	24 (13.0)	
22-25 (12-16 years at time of injury)	26 (14.1)	26 (14.1)	
26+ (16 years+ at time of injury)	134 (72.8)	134 (72.8)	
Ethnicity (N, %)			
European	135 (73.4)	113 (61.4)	X^2=5.33
Non-European	49 (26.6)	69 (37.5)	p=0.02
Missing	0 (0.0)	2 (1.1)	
Highest level of education at time of follow up assessment (N, %)			
High School	55 (29.9)	43 (23.4)	X^2=15.46
Professional/college	51 (27.7)	42 (22.8)	p=<0.01
University	50 (27.2)	97 (52.7)	
Unknown/missing	28 (15.2)	2 (1.1)	
Current Employment status (N, %)			
Full or part time	114 (62.0)	100 (54.3)	X^2=20.34
Student	13 (7.0)	40 (21.7)	p<0.01
Unemployed	15 (8.2)	10 (5.6)	
Retired or Homemaker	23 (12.5)	26 (14.1)	
Other or unknown	19 (10.3)	8 (4.3)	
Comorbidities (N, %)			
Yes	68 (37.0)	53 (28.8)	X^2=2.50
No	113 (61.4)	129 (70.1)	p=0.11

Missing	3 (1.6)	2 (1.1)	
How mTBI case was identified (N, %)	111 (60.3)		
Emergency Department	48 (26.1)		
GP or Accident Clinic	13 (7.1)		
National accident database	12 (6.5)		
Verified self-report			
Mechanism of injury			
Fall	63 (34.2)		
Vehicle accident	38 (20.6)		
Being hit by or hitting head on object	44 (23.9)		
	32 (17.4)		
Assault	7 (3.8)		
Other/unknown			
Recurrent mTBI over 10 years			
None	122 (66.3)		
1	15 (8.2)		
2	10 (5.4)		
3 or more	15 (8.2)		
Not sure	22 (12.0)		

Table 2. Comparison between participants sustaining their index mTBI in childhood compared to those sustaining their injury >16 years of age

	mTBI Cases sustained ≤16 years N=50 Mean (SD)	mTBI cases sustained 16+ years N=134 Mean (SD)	Test of significance and p value	Cohen's d Effect size
Functioning (WHODAS)				
Communication	10.69 (4.38)	9.92 (3.96)	t=-1.14, p=0.26	0.18
Getting around	6.86 (3.54)	8.04 (3.95)	t=0.08, p=0.07	0.31
Self-care	4.86 (1.41)	4.91 (1.95)	t=0.17, p=0.86	0.03
Getting along with others	7.66 (3.90)	7.55 (3.54)	t=-0.19, p=0.85	0.03
Household activities	6.21 (3.47)	6.29 (3.36)	t=0.14, p=0.89	0.02
School/work activities	6.50 (2.95)	5.78 (2.47)	t=-1.67, p=0.10	0.26
Participation	10.71 (4.24)	11.77 (4.85)	t=1.36, p=0.17	0.23
Symptom Total Score converted to RASCH scale (RPQ)	29.43 (11.84)	30.75 (9.60)	t=0.78, p=0.44	0.12
Overall health rating	73.98 (15.41)	71.27 (19.28)	t=0.89, p=0.37	0.16
Mood (HADS)				
Anxiety	7.97 (4.96)	6.50 (4.31)	t=-1.97, p=0.05	0.32
Depression	7.05 (3.07)	6.44 (2.99)	t=-1.22, p=0.22	0.20

Table 3. Comparison of functioning, symptoms, mood and health status between mTBI cases and controls

	mTBI Cases N=184 Mean (SD)	**Controls N=184 Mean (SD)**	**Parametric ANCOVA**	**Partial eta square**
Functioning (WHODAS)				
Communication	10.14 (4.08)	9.31 (3.45)	F=0.94, p=0.33	ηp^2= <0.01
Getting around	7.80 (3.90)	7.05 (3.43)	F=4.54, p=0.03	ηp^2 =0.02
Self-care	4.91 (1.85)	4.89 (2.19)	F=0.44, p=0.51	ηp^2=<0.01
Getting along with others	7.60 (3.57)	8.09 (3.54)	F=1.87, p=0.17	ηp^2=<0.01
Household activities	6.30 (3.40)	6.37 (3.10)	F=0.23, p=0.64	ηp^2=<0.01
School/work activities	5.98 (2.63)	6.70 (3.05)	F=6.46, p=0.01	ηp^2=0.03
Participation	11.52 (4.76)	12.22 (5.12)	F=0.82, p=0.37	ηp^2=<0.01
Symptom Total Score converted to RASCH scale (RPQ)	30.38 (10.23)	24.32 (10.78)	F=20.32, p<0.001	ηp^2 =0.07
Overall health rating	71.8 (18.55)	73.89 (18.72)	F=0.43, p=0.51	ηp^2 =<0.01
Mood (HADS)				
Anxiety	6.87 (4.51)	6.13 (4.41)	F=0.56. p=0.46	ηp^2=<0.01

Depression	6.61 (3.03)	6.25 (3.43)	F=0.11, p=0.74	ηp^2 =<0.01

Table 4. Differences between cases and controls on outcome after removal of recurrent mTBI cases.

	mTBI Cases N=127 Mean (SD)	**Controls N=127 Mean (SD)**	**Parametric ANCOVA**	**Partial eta square**
Functioning (WHODAS)				
Communication	9.94 (4.21)	9.21 (3.38)	F=0.01, p=0.93	ηp^2= <0.01
Getting around	7.53 (3.72)	6.83 (3.01)	F=2.18, p=0.14	ηp^2 =0.01
Self-care	4.88 (1.74)	4.90 (2.25)	F=0.99, p=0.32	ηp^2=<0.01
Getting along with others	7.52 (3.70)	7.94 (3.42)	F=1.76, p=0.19	ηp^2=<0.01
Household activities	6.07 (3.28)	6.09 (2.87)	F=0.91, p=0.34	ηp^2=<0.01
School/work activities	5.74 (2.51)	6.52 (2.88)	F=4.15, p=0.04	ηp^2=0.03
Participation	11.14 (4.63)	11.72 (4.56)	F=1.20, p=0.27	ηp^2=<0.01
Symptom Total Score converted to RASCH scale (RPQ)	29.73 (10.31)	23.45 (10.40)	F=15.12, p<0.001	ηp^2 =0.07
Overall health rating	73.8 (17.79)	76.03 (17.33)	F=0.32, p=0.57	ηp^2 =<0.01

Mood (HADS)				
Anxiety	7.31 (4.49)	5.77 (4.18)	F=2.89. p=0.09	ηp2=0.01
Depression	6.41 (2.96)	6.02 (3.27)	F=0.06, p=0.80	ηp^2 =<0.01

Table 5. Comparison of lifestyle and behaviour categorical outcomes between mTBI cases and non-injured controls

	mTBI Cases N =184 N (%)	**Controls N (%) N=184 N (%)**	**Quade's Nonparametric ANCOVA (significance value)**	**Unadjusted Odds Ratio**
Antisocial behaviour in past 12 months				
Yes	30 (16.3)	12 (6.5)	F=5.89, p=0.02	3.07
No	137 (74.5)	168		
Missing	17 (9.2)	(91.3)		
		4 (2.2)		
Problematic alcohol use				
Yes	87 (47.3)	69 (37.5)	F=0.21, p=0.65	0.66
No	80 (43.5)	87 (47.3)		
Missing	17 (9.2)	28 (15.2)		
Regular substance use				
Yes	38 (20.7)	20 (10.9)	F=3.24, p=0.07	2.33
No	129 (70.1)	158		
Missing	17 (9.2)	(85.9) 6		
		(3.3)		