Understanding Associations between Traumatic Brain Injury, Cognition, and Offending Behaviour

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And thank you to my family for their love and support in navigating to this stage beside me.

Waiho i te toipoto, kaua i te toiroa.

Personal Reflection Statement

I began working on this thesis in 2020, during the worst of the COVID-19 epidemic. I am deeply appreciative of the stay-at-home orders that helped minimise the lives lost in Aotearoa New Zealand, particularly considering the devastation it impacted on areas with fewer restrictions or healthcare resources. Nonetheless, my research was affected – an intended qualitative component of my prison-based research was not feasible during a period of semi-regular lockdowns in the city of Auckland. However, with tremendous support from my supervision team and a relocation from Auckland to Taupō, I was able to complete this thesis and achieve the goals I had laid out for myself.

The educational journey to this thesis was certainly circuitous. The initial incident that incited my interest in brain injury occurred in 2007, when one of my favourite pro-wrestlers committed a double-murder suicide and the surrounding media became quite fixated on the role a history of concussion may have played in his mental state. 16 years later and interviewing volunteers from Tongariro Prison for this thesis, many have themselves heard stories about an All Black or NFL star struggling to grapple with a history of repetitive TBI and feel they may have found an explanation for their own feelings and behaviour – a hypothesised correlation that informed many of my own initial research questions.

My research to answer these questions has revealed a convoluted web of factors of uncertain directionality, injury histories difficult to quantify in numerical terms, and an appreciation for the frustratingly complex but unerringly honest life stories that led these participants to sit across from me. I am endlessly grateful to the participants from Tongariro Prison that made this thesis possible, as well as the participants of the BIONIC study who also contributed their stories so that work like this could exist. I hope this work presents some novel outcomes that will push forward our collective understanding of TBI and how it might affect each of us.

For Shannon, Nancy, and Daniel.

Rest in Peace.

E huri tō aroaro ki te ra,

tukuna tō ataarangi

ki muri i a koe

Glossary

ACC	Accident Compensation Corporation
ANAM	Automated Neuropsychological Assessment Metrics
ASSIST	Alcohol, Smoking and Substance Involvement Screening Test
AUDIT	Alcohol Use Disorders Identification Test
AUDIT-C	Alcohol Use Disorders Identification Test - Consumption
BADS	Behavioural Assessment of the Dysexecutive Syndrome
BIONIC	Brain Injury Outcomes New Zealand In the Community
BISI	Brain Injury Screening Index
BISQ	Brain Injury Screening Questionnaire
CASP	Critical Appraisal Skills Programme
CDE	Common Data Element
CHAT	Comprehensive Health Assessment Tool
CNS-VS	CNS Vital Signs
COWAT	Controlled Oral Word Association Test
CPT	Continuous Performance Test
CSO	Child Sex Offender
CVLT	California Verbal Learning Test
CWIT	Colour-Word Interference Test
DASS	Depression, Anxiety, and Stress Scale
D-KEFS	Delis-Kaplan Executive Function System
DV	Domestic Violence
EF	Executive Functioning
EMR	Electronic Medical Record
FSIQ	Full-Scale Intelligence Quotient
GAI	General Ability Index
GBD	Global Burden of Disease
GCS	Glascow Coma Scale
HADS	Hospital Anxiety and Depression Scale
HRNB	Halstead-Reitan Neuropsychological Battery
ICD-10	International Statistical Classification of Diseases and Related Health Problems 10th Revision
IGT	Iowa Gambling Task
ImPACT	Immediate Post-concussion Assessment and Cognitive Test
IPV	Intimate Partner Violence
LOC	Loss of Consciousness
MMSE	Mini-Mental State Exam
MoCA	Montreal Cognitive Assessment
mTBI	Mild Traumatic Brain Injury

NAB	Neuropsychological Assessment Battery
NAB-SM	Neuropsychological Assessment Battery – Screening Module
NCI	Neurocognitive Index
NZ	New Zealand
OHI	Open Head Injury
OSU TBI-ID	Ohio State University Traumatic Brain Injury Identification
PASAT	Paced Auditory Serial Addition Test
PCS	Post Concussion Symptoms
PFC	Pre-Frontal Cortex
PIQ	Performance IQ
PTA	Post Traumatic Amnesia
PTSD	Post-Traumatic Stress Disorder
PVT	Performance Validity Testing
RAVLT	Rey Auditory Verbal Learning Test
RBANS	Repeatable Battery for the Assessment of Neuropsychological Status
RDS	Reliable Digit Span
RDS-R	Reliable Digit Span – Revised
ROCF	Rey–Osterrieth Complex Figure
RPQ	Rivermead Post Concussion Symptoms Questionnaire
SAT	Shifting Attention Test
SCOLP	Speed and Capacity of Language Processing
SDMT	Symbol Digit Modalities Test
STAB	Subtypes of Anti-social Behaviour
STW	Spot-the-Word
TBI	Traumatic Brain Injury
TBIQ	Traumatic Brain Injury Questionnaire
TMT	Trail-Making Test
TOMM	Test Of Memory Malingering
USA	United States of America
VIQ	Verbal IQ
WAIS-III	Wechsler Adult Intelligence Scale - Third Edition
WAIS-IV	Wechsler Adult Intelligence Scale - Fourth Edition
WAIS-R	Wechsler Adult Intelligence Scale - Revised
WASI	Wechsler Abbreviated Scale of Intelligence
WCST	Wisconsin Card Sorting Test
WMS	Wechsler Memory Scale
WRAT-4	Wide Range Achievement Test – Fourth Edition

Abstract

Traumatic Brain Injury (TBI) is a major public health concern that is disproportionately prevalent in offending populations. TBI can have persistent disabling effects that impact greatly on the wellbeing of those affected. Despite this, TBI is often undiagnosed and under-treated. This thesis aims to better understand the potential effects of TBI on offending populations and whether TBI are leading to the sorts of deficits that may predispose someone to offending behaviour.

This thesis includes three studies intended to investigate the relationship between the effects of TBI and anti-social or criminal behaviours. The first is a systematic review of the existing studies that have assessed the cognitive effects of TBI in offending populations, for the purpose of determining which domains appear to be most affected, and what assessment tools are most appropriate with a TBI-affected offending population. Study two is a prospective longitudinal cohort study investigating whether domains of post-acute cognitive functioning are associated with long-term anti-social offending behaviour in a New Zealand population. Study three is a cross-sectional assessment of the cognitive profile of a New Zealand prison population by TBI status.

Study one identified a pool of literature that is deeply heterogenous in both methods and quality, indicating a field of study that is in its formative stages. Due to inconsistency in both tools of cognitive assessment and of TBI measures, meta-analysis of this literature was not appropriate. As with the general population, studies of TBI and cognition in offending populations are weakened by inconsistent or poor methodology. However, this review was effective in identifying several areas of cognitive functioning that could be focussed on in the later stages of the PhD. This review also indicated the need to better delineate self-reported TBI by factors such as childhood injury, repetitive injury, and injury severity.

Study two assessed cognition at the post-acute stage of TBI recovery in a general population sample to determine whether there were differences in cognitive profiles of those who went on to engage in antisocial behaviour 10 years later and those that did not. Despite finding differences in performance on assessments of processing speed, reaction time, and cognitive flexibility as expected, these differences did not remain significant following adjustment for other relevant confounders such as sex. This study suggests that broader demographic and social factors should be considered when assessing the relationship between TBI, cognition and behaviour.

Study three assessed a New Zealand men's prison population with a bespoke battery of standardised cognitive assessments and investigated differences across TBI exposure

characteristics, including TBI frequency, severity, and pervasiveness. Within this population, performance on the Delis-Kaplan Executive Function System (D-KEFS) Colour-Word Interference Test (CWIT) was significantly lower in participants who reported a history of pervasive or repetitive TBI exposure.

The findings across the three studies suggest that the links between TBI, cognition and behaviour are likely to be part of a complex network of factors where injury, social, and environmental factors intersect to influence a person's life trajectory. The challenges of being able to accurately assess and quantify historical TBI in these populations who have experienced high TBI exposure adds to this complexity. Future research in this area will require adaptations and bespoke tools that are fit for purpose with populations with pervasive TBI exposure, such as offenders. Studies with large sample sizes are needed to enable more detailed explorations of how different injury, socio-cultural, environmental and lifestyle factors interact with each other to influence behaviour. Consideration of exposure to pervasive TBI needs to be considered when in future studies exploring links between TBI, cognition, and behaviour.

Contents

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Introduction

This thesis will contribute to the existing body of research by exploring TBI history, cognition and offending behaviour using both prospective data from a general population sample and a cross-sectional study of men in prison. By improving our understanding in this way, there is the potential to inform key points in a person's life trajectory where intervention could help prevent longer term criminal behaviour. Different populations are discussed within this thesis and for the purposes of clarity and uniformity they are described in the following ways: study populations that are actively serving a custodial sentence (in a prison or other secure facility) are referred to as prison populations, study populations with a history of criminal offending behaviour, but may or may not have been arrested or sentenced under the judicial system are referred to as offending populations. Where a particular subgroup of offender is being discussed, such as juvenile offending populations, or sexual offenders, these will be specified.

This thesis contributes three original studies to the body of research around TBI and cognition and antisocial or offending behaviour and they comprise the following thesis chapters:

Chapter Five: A Systematic Review of TBI History and Cognitive Functioning in Criminal Offenders. Several studies have been conducted that explore the cognitive performance of offenders by different aspects of TBI history. This systematic literature review provides a thorough exploration of this literature and how this body of research provides guidance for future study in this space. As detailed in chapter one, TBI exposure may be categorised in several ways, such as cause of injury, age when injured, recency of injury, or number of TBIs. Cognitive performance can also be assessed in a variety of ways, targeting a variety of functions. As discussed in chapter two, some cognitive domains are more sensitive to TBI exposure than others; this review explores how existing research has chosen to approach these variables and whether the areas of cognition sensitive to TBI have been adequately assessed.

Chapter Six: Assessing Cognitive Functioning Following Acute mTBI as a Predictor of Long-Term Offending Behaviour. This study is a rare example of prospective longitudinal follow-up for offending behaviour following mTBI, and it is based on the data from the Brain Injury Outcomes New Zealand in the Community (BIONIC) study. The BIONIC study involved participants completing cognitive assessment in the post-acute stage of recovery from mTBI and these participants were then followed up at 10-years. This study looked to see whether there were any differences in acute cognition between those who went on engage in anti-social behaviour and those who did not. As discussed in chapter three, there is a proposed association between aspects of cognition, TBI, and offending behaviours that is difficult to evaluate in terms

of directionality. Use of a prospective general population cohort was helpful in determining if acute cognitive functioning influenced longer term behaviour after TBI.

Chapter Seven: Assessing the Relationship between TBI History and Cognition in an Aotearoa New Zealand Men's Prison Population. The final study in this thesis is a cross-sectional assessment of cognitive performance by TBI severity, frequency, and pervasiveness, in a NZ men's prison population. Informed by the systematic review in chapter five, this study used the Ohio State University TBI Identification Method as a validated tool to record components of TBI history such as severity (the worst TBI experienced based on period of LOC), frequency (total number or TBI reported), and TBI pervasiveness (whether the individual experienced a period of repetitive TBI within a narrow span of time). These cognitive assessments were also targeted to assess key aspects of cognition identified within the systematic review whilst ensuring cultural responsiveness for the NZ population.

Chapter One: Definitions, Classifications and Epidemiology of TBI

This chapter will explore the different causes and categorisations of TBI, and the epidemiology of these injuries from both a global perspective, and within New Zealand (NZ) specifically.

Defining TBI

TBI refers to "an alteration in brain function, or other evidence of brain pathology, caused by an external force" (Menon et al., 2010). TBI can refer to open head injuries (OHIs), in which the skull is damaged, and the dura mater of the head is penetrated (Andriessen et al., 2010; Bešenski, 2002). OHIs often cause focal damage to tissue (Andriessen et al., 2010; Bešenski, 2002). In contrast, closed head injuries typically lead to more diffuse damage of brain tissue due to acceleration/deceleration of tissue inside the skull (Andriessen et al., 2010; Bešenski, 2002; Drew & Drew, 2004; Menon et al., 2010). Focal damage might also occur due to coup and contrecoup injury where the brain hits the front and back of the skull (Andriessen et al., 2010; Bešenski, 2002; Drew & Drew, 2004; Menon et al., 2010). OHI are less common, especially outside of military settings, and are typically fatal, with an 88% acute mortality rate in Americans with OHI attributable to gunshot (Aldrich et al., 1992). Closed head injuries are the far more common form of TBI and can range from mild, with no long-term symptoms, to severe and accompanied by serious neurological symptoms or death (Majdan et al., 2011). Clinical indicators that would constitute "an alteration in brain function" include confusion or disorientation, loss of consciousness (LOC), and post-traumatic amnesia (PTA) (Menon et al., 2010). Although LOC may occur, it is not a prerequisite to meet diagnostic criteria for TBI (Barnes et al., 2018).

Classifying TBI

As TBI constitutes a breadth of brain and neurovascular injuries, there are many dimensions on which TBI can be categorised and defined, including mechanism, severity, and pathology (Saatman et al., 2008). With regards to mechanisms of injury, TBI can occur across a wide range of contexts with the most common causes including traffic accidents and falls, with violent assaults, and sport and recreational activity also contributing significantly to incidence (Tagliaferri et al., 2006). One of the challenges in exploring the global epidemiological literature on TBI is that there is often inconsistency in how mechanisms of injury are categorised, both within individual studies and in meta-analyses. Studies typically attribute TBI mechanism either to the context of the injury (such as sport and recreation), or to the process (such as a fall), and this heterogeneity of practice can make comparison and analysis across research challenging (Theadom et al., 2020). Increased uniformity would substantially improve the possible analysis of TBI research (Brazinova et al., 2021; Theadom et al., 2020).

Several metrics are used in clinical practice to categorise injury severity (Cassidy et al., 2004). These metrics typically evaluate duration of LOC, duration of PTA, or use a symptom scoring system such as the Glasgow Coma Scale (GCS) (Table 1 and Table 2). The GCS is used in a clinical setting to assess a person's level of consciousness across three domains of function following TBI: eye opening, verbal response, and motor response (Jain & Iverson, 2018). These domains can then be compiled into a total GCS score, with a score of eight or less constituting a severe TBI, nine to 12 being a moderate TBI, and 13 to 15 being an mTBI (Jain & Iverson, 2018). In the NZ context, acute assessments of severity typically use an Abbreviated Westmead PTA Scale which incorporates a GCS (Shores et al., 2008).

While these approaches to categorising TBI severity provide a useful gradient on which rehabilitative outcomes for moderate and severe TBI can be predicted, floor and ceiling effects reduce the utility of tools such as the GCS (particularly for mTBI) and inconsistent clinical practice in applying the tools affect the generalisability of the outputs in research settings (Marion & Carlier, 1994; Nell et al., 2000; Reith et al., 2017). These methods of classification are usually sound when applied to moderate and severe TBI, as these injuries can be validated by objective metrics in biomarkers and neuroimaging, with these factors providing a clear neuroanatomical aetiology for long term symptoms (McCrea, 2008), but attempting to apply these same classification criteria to mTBI is less useful in predicting rehabilitative outcomes, with non-acute injury factors being more predictive of long-term outcomes of mTBI, such as preexisting psychological diagnoses, substance use disorder, or litigation involvement (McCrea, 2008).

Table 1.

The Glasgow Coma Scale

Parameters	Response Scores
Eye Response	1. No eye opening.
	2. Eye opening to pain.
	3. Eye opening to sound.
	4. Eyes open spontaneously.
Verbal Response	1. No verbal response.
	2. Incomprehensible sounds.
	3. Inappropriate words.
	4. Confused.
	5. Orientated.

Motor Response	1. No motor response. 2. Abnormal extension to pain. 3. Abnormal flexion to pain. 4. Withdrawal from pain. 5. Localizing pain. 6. Obeys commands.

Table 2.

TBI Severity Classification Criteria

Criteria	Mild	Moderate	Severe
LOC	<30mins	30mins-24hours	>24hours
PTA	0-1day	1day-7days	>7days
GCS	13-15	9-12	3-8

An additional challenge is that many cases of mTBI are not recorded in the electronic medical record (EMR) or do not present to hospital. This may be due to injuries being overshadowed by more severe injuries within a polytrauma, intentional obfuscation for fear of not being able to return to work or sport, the affected individual not feeling the injury is severe enough to be clinically meaningful, or not having access to healthcare services to report an injury (Brazinova et al., 2021; Riley & Hagger, 2015; Stergiou-Kita et al., 2017). A prospective cohort study in Scotland found one in five TBIs were not recorded within hospital records, identifying a key issue when relying on the medical record for TBI history (Thornhill et al., 2000). Furthermore, the injuries that are recorded within the EMR do not reflect the full epidemiological profile of TBI, with evidence showing injured people that require hospitalisation are older, with significant comorbidities, and have a more frequent injury mechanism being falls (Lee et al., 2024). Consequently, many studies attempting to understand TBI, and especially mTBI, must integrate or rely upon measures of self-report, as relying on the medical record alone could lead to an underestimated prevalence (Corrigan et al., 2010).

Due to the underrepresentation of TBI (particularly mTBI) within the EMR, it is often necessary to rely on additional sources of information when exploring TBI epidemiology. In these circumstances, a self-reported history of LOC or PTA may be an appropriate alternative metric for assessing TBI severity, as they have both been found to be a reliable predictor of functional outcome akin to the GCS (Challakere Ramaswamy et al., 2023; Sherer et al., 2008). Several tools have been developed to assist in standardising self-report of historical TBI, examples include the Ohio State University TBI Identification (OSU TBI-ID) structured interview method (Bogner & Corrigan, 2009), the Brain Injury Screening Questionnaire (BISQ) (Dams-O'Connor et al., 2023),

the Traumatic Brain Injury Questionnaire (TBIQ) (Diamond et al., 2007), or tools targeting specific populations such as the Military Acute Concussion Exam (MACE), for TBI in military contexts (French et al., 2008; Goldin et al., 2016). Tools of this sort intend to formalize a process for generating a history of the patient's number of injuries, injury severity, acute effects of injury, persisting effects of injury, age at injury, and time since most recent injuries (Bogner & Corrigan, 2009). By obtaining a more in-depth patient TBI history these tools hope to account for TBI history better than the medical record alone (Bogner & Corrigan, 2009).

Even when techniques are standardised and validated, self-reporting of TBI history is not without issues. An individual attempting to report their TBI history may not have a complete record of their injury history, especially when injuries may occur far into the past, including childhood and infancy (McKinlay & Horwood, 2017). Self-report tools often use length of LOC as a measure of TBI severity and it is not always feasible for an individual to be able to accurately recall this detail, especially if they were alone at the time of injury and did not have a third party nearby to confirm this information (McKinlay et al., 2016). This creates a reliance on third-party interpretation of acute symptoms and evidence has shown lay-populations perform poorly at identifying these symptoms when witnessing LOC (Thijs et al., 2008). Some individuals may also be incentivised to misrepresent their TBI history, such as athletes that may underrepresent this history to avoid being stood down from play (Meier et al., 2015). Additionally, those involved in litigation might misrepresent their injury or symptoms to benefit their legal standing (Kreutzer et al., 1990; Matsuzawa & Dijkers, 2014). Nonetheless, self-reporting TBI history remains an essential component of accurately assessing TBI exposure and needs to be considered in both clinical and research settings.

International Incidence of TBI

TBI constitutes a major global public health issue, with the 2016 Global Burden of Disease (GBD) study finding an estimated 27 million new cases worldwide occurring in 2016 alone (James et al., 2019). This is representative of a global age-standardised incidence rate of 369 TBIs per 100,000 individuals; given the potential long-term effects of TBI, this accounts for a substantial global disease burden (James et al., 2019). This burden is not shared equally amongst all countries, with central Europe, eastern Europe, and central Asia having the highest incidence of TBI, and Syria being identified as the country with the highest incidence of TBI at 1,322 cases per 100,000 people (James et al., 2019). The global distribution of TBI is correlated with risk factors such as traffic concentration, population density, alcohol use, war, and terrorism (James et al., 2019). There also appears to be a bias attributable to survivorship, where nations lacking the medical resources to prevent a death in the event of polytrauma, such as a traffic collision are less likely to record the patient as having a TBI (James et al., 2019). Although

most developed countries exhibited a similar profile in causes of TBI, with falls being the largest contributor internationally, there are notable disparities in the proportions of TBI attributable to war, terrorism, and conflict in developing countries (James et al., 2019).

Determining the incidence of TBI by severity is challenging, largely due to difficulties in identifying mTBI, which has led to many studies accounting for only the most severe instances of TBI (Peeters et al., 2015). Nonetheless, severity of TBI distribution in meta-analysis has found an international annual incidence rate of mTBI at 982 per 100 000 person-years, moderate TBI at 41 per 100 000 person-years, and severe TBI at 6 per 100 000 person-years (Nguyen et al., 2016) – demonstrating the tremendous proportion of injury incidence accounted for by mTBI. In studies that account for mTBI, these injuries make up the vast majority, between 71% and 97.5% (Peeters et al., 2015). There is also speculation that much of the existing literature is overestimating the proportion of TBI that are moderate or severe, with studies relying on hospital records reporting as many as 20% falling within these categories, a figure unsupported by broader population-based studies (Peeters et al., 2015; Williams, Caplan, et al., 2015). This distribution of severity suggests future studies must ensure their method of TBI reporting and categorisation is reliable to guarantee inclusion of mTBI.

Sex and gender differences are important factors associated with both the incidence of TBI and long-term outcomes of TBI. Existing literature suggests the relationship between TBI and gender changes meaningfully across age groups, in early childhood the GBD study found no significant differences in incidence by gender but by the teenage years, men begin to show substantially higher rates of TBI (James et al., 2019). The sex differences in TBI incidence continue until about age 60, when the largest causes of TBI have shifted towards a falls risk and away from the risk-taking behaviours and occupational hazards that disproportionately affect younger adult men over younger women (Feigin et al., 2013; James et al., 2019). TBI severity also differs meaningfully by sex, with men being approximately twice as likely to experience an mTBI but three times as likely to experience moderate or severe TBI (Feigin et al., 2013). These sex disparities differ meaningfully between studies depending on their method of recruitment and TBI classification (Bruns Jr & Hauser, 2003). Studies that collect data from emergency departments show a smaller difference by sex than studies of hospital admissions, generally attributed to the differences in aetiology that would lead to presentation in these settings e.g., motor vehicle collisions (Bruns Jr & Hauser, 2003). Few studies have been devoted to the epidemiology of TBI in transgender and gender-nonconforming populations, this is partially attributable to the manner in which gender is recorded within the electronic health record, however there is some evidence of worse neuro-behavioural outcomes for transgender groups when compared to the cisgender population (Meltzer & Juengst, 2021).

Existing studies have shown that minority ethnic groups are experiencing a disproportionate TBI burden in many countries, with several large studies showing differences in TBI incidence between majority ethnic groups and minority groups. A retrospective study of a Pennsylvania, USA trauma database found patients coded with a TBI were disproportionately likely to be Black and unlikely to be White or Asian, as of 2016 (Brenner et al., 2020). In a systematic literature review of TBI outcomes by race and/or ethnicity in USA, Indigenous Americans were found to be the most likely ethnic group to experience TBI and had the highest rates of death attributable to TBI (Maldonado et al., 2023). Between 1992 and 1994, Black Americans were 35% more likely to report to an emergency department with a TBI than their White counterparts (Jager et al., 2000), and in a study focussing on child populations Black Americans had significantly higher death and hospitalisation rates as compared to White Americans, a difference largely attributable to motor-vehicle accidents in children aged 0-4 (Langlois et al., 2005). Similarly, a Johannesburg, South Africa population found Africans had a TBI incidence rate 3.3 times that of their White populous (Nell & Brown, 1991).

International Prevalence of TBI

While many studies have assessed the incidence of TBI, fewer have attempted to assess TBI prevalence, meaning the proportion of the population with TBI history or the proportion living with TBI-related symptoms (Frost et al., 2013; James et al., 2019). A study of TBI prevalence differs from incidence as it aims to evaluate lifetime history, ideally through birth cohort studies but often relying on methods of historical TBI self-reporting – which can lead to heterogenous approaches to TBI assessment and classification, potentially making TBI prevalence research prone to more sources of bias and confounding (Corrigan et al., 2010; Frost et al., 2013). James et al. (2019) found TBI-related disability had a worldwide prevalence of 368 per 100,000 people, corresponding to approximately 55 million people living with TBI-related disability in 2016. This figure is also an 8.4% increase since the year 1990, indicative of a growing disease burden due to TBI and increased detection of TBI (James et al., 2019). A 2012 meta-analysis of TBI prevalence in adult populations analysed 15 studies and reported a prevalence of 12.1% of a total sample of 25,134 (Frost et al., 2013). This meta-analysis did however set LOC as a prerequisite for inclusion as a TBI case, which will have had a significant effect on these figures (Frost et al., 2013). By requiring a TBI with LOC, Frost et al. (2013) have excluded a significant portion of mTBI that may have led to amnesia, disorientation, and persisting disability. This is likely to underestimate the chronic difficulties that can occur for some people after a mTBI (James et al., 2019; Peeters et al., 2015). A 2010 literature review (Corrigan et al., 2010) identified two birth cohort studies which present high-quality data for TBI prevalence, a Finland-based cohort that experienced a TBI prevalence of 269 per 100,000 at age 34 (Winqvist et al., 2007), and a New

Zealand-based population that reported a 31.6% prevalence of TBI history at age 25 (McKinlay et al., 2008). Studies using retrospective self-reported TBI history have also been used to assess prevalence, and these have identified rates of TBI with LOC or confusion at 8.5%, in an American population (Silver et al., 2001), and rates of TBI with LOC>15 minutes at 5.7% in an Australian population (Anstey et al., 2004).

An important aspect of this literature is the inconsistent criteria used to evaluate TBI prevalence, the GBD assessed for the prevalence of TBI-related disability, the Finnish cohort assessed for the prevalence of TBI-related hospitalisations, the New Zealand cohort for the prevalence of healthcare-attended TBI, and the Australian study for TBI with LOC>15 minutes (Anstey et al., 2004; Corrigan et al., 2010; James et al., 2019; Winqvist et al., 2007). While these studies are using related figures, they are meaningfully distinct, and the underlying heterogeneity creates difficulties for trying to evaluate the implications of experiencing TBI.

TBI Epidemiology within New Zealand

Several studies have explored TBI in the NZ context. A population-based study of total TBI incidence was conducted across the Waikato region of the North Island from 2010-2011, the BIONIC study (Feigin et al., 2013). The BIONIC study estimated the NZ incidence of TBI to be 790 cases per 100,000 person-years, with 749 per 100,000 in the mild range of severity and 41 per 100,000 in the moderate to severe range (Feigin et al., 2013). This forms a substantial proportion of the national disability burden and accounts for over half of NZ's serious injury claims through the national no-fault compensation scheme, ACC (Accident Compensation Corporation, 2017). There is also some evidence that NZ experiences an especially high rate of TBI when compared to other similarly wealthy nations, with more TBI attributable to assaults (Feigin et al., 2013). The incidence of recurrent TBI in NZ has also been found to be high, with approximately 10% of people experiencing at least one further TBI in the subsequent 12 months following initial injury (Theadom et al., 2015).

This TBI burden is not evenly distributed with many demographics at a higher risk of more TBI of greater severity. Māori (the indigenous population of NZ) have a significantly greater incidence of TBI than other ethnicities at 1,206 per 100,000 person-years (Barker-Collo et al., 2019; Feigin et al., 2013). Adolescent and young-adult Māori also experience a greater rate of TBI due to assault (Feigin et al., 2013). In total, these differences represent a 1.23 risk ratio of TBI incidence between Māori and European New Zealanders (Feigin et al., 2013). Significant disparities can also be seen by gender, with men 1.73 times more likely to experience a mTBI and 2.87 times more likely to experience moderate-severe TBI, these differences being due to more injuries from assault, transport injury, and injuries from mechanical forces (Feigin et al., 2013). Pacific people also experience a total incidence rate higher than NZ Europeans, 1,242 per

100,000 and 842 per 100,000 respectively, and these outcomes were found without underlying differences in severity, mechanism, or acute healthcare use (Lagolago et al., 2015).

Conclusion

This chapter introduced the definition of TBI and many of the ways TBI is classified in clinical and research settings. The epidemiology of TBI was then explored with consideration made to how heterogenous research methods have resulted in an inconsistent body of epidemiological literature, from both the national and international perspective. This heterogeneity means additional scrutiny is needed when evaluating the epidemiology of TBI, to ensure the same construct is being measured. On the individual level, this inconsistency has also caused issues in evaluating the profile of individual patients and research participants.

Chapter Two: Long-term Cognitive Effects of TBI

This chapter will discuss the relationship between TBI and long-term cognitive outcomes and explore the tools that have been used to assess cognition within TBI populations. TBI has been shown to affect a wide range of cognitive processes such as executive function, processing speed, attention, working memory, and verbal memory (Rabinowitz & Levin, 2014). Existing literature shows a strong correlation between moderate and severe TBI and persisting cognitive sequelae (Binder, 1997; Schretlen & Shapiro, 2003; Svingos et al., 2019). However, even following an mTBI nearly half of sufferers still report persistent symptoms 12 months post-injury, with a significant impact on their ability to work, study, and engage in their premorbid activities (McMahon et al., 2014; Nudo, 2013; Theadom et al., 2017). Whether mTBI is associated with persisting cognitive sequelae specifically is complex, with indications that performance on cognitive tasks following mTBI returns to typical levels within three months of injury, despite continued self-reported symptoms (Schretlen & Shapiro, 2003; Walker et al., 2023). This has been shown to differ with some mTBI, as mTBI with positive brain imaging (complicated mTBI) has been shown to be associated with lower performance on cognitive tasks than uncomplicated mTBI – but still higher performance than moderate and severe TBI (Hacker et al., 2023).

Cognitive Effects of mTBI

The existing body of literature presents quite heterogenous evidence of long-term cognitive effects of TBI by injury severity. While there is little argument as to the long-term effects of severe TBI on cognition (as will be discussed in this chapter), the proposed relationship between mTBI and long-term cognitive issues is academically contentious, with schools of thought arguing both for and against the evidence of an association. One body of evidence suggests that the cognitive effects of mTBI resolve quickly, a meta-analysis of 39 studies of predominately cross-sectional design found that by three months post-injury those people who sustained an mTBI generally returned to premorbid levels of cognitive function, which differed from those patients who experienced moderate to severe TBI and faced persistent cognitive symptoms (Binder, 1997; Schretlen & Shapiro, 2003). These findings are further supported by a 2016 meta-analysis on long-term cognitive outcomes following TBI, which found Full-Scale Intelligence Quotient (FSIQ) scores on the Wechsler Intelligence Scales were largely unimpaired in those with an mTBI, compared to meaningful chronic deficits for those with a severe TBI (Königs et al., 2016). A scoping review by McInnes et al. (2017) found conflicting evidence - that chronic cognitive issues were not limited to those with a history of moderate or severe TBI, they reported the results of 45 studies and found that as many as half of mTBI cases were associated with lasting deficits in cognitive performance (McInnes et al., 2017). While the relationship between mTBI and long-term cognition has not been completely elucidated, when giving weight

to studies with more thorough methodology, the evidence for an association in the general population is not entirely convincing (Boone et al., 2024).

This inconsistency within the literature may be reflective of several underlying complex factors, particularly heterogeneity in studies targeting mTBI. This is demonstrated in the academic discourse surrounding meta-analyses which found have no association between mTBI and cognitive performance (Binder et al., 1997; Frencham et al., 2005), and the responses that contend that these studies had foundational limitations due to their methodology (Bigler et al., 2013; Pertab et al., 2009). Bigler et al. (2013) argue that many of the early studies within these meta-analyses would not meet a necessary quality of methodology to ensure meaningful and accurate meta-analysis. A further issue within the meta-analysed body of literature is that individual study results differed significantly by TBI severity measure, type of cognitive outcome measurement, and outcome construct (Bigler et al., 2013; Cappa et al., 2011).. Analysis of more recent studies have further supported the critical view, that the literature is heterogenous with many studies of lower quality muddying efforts to meta-analyse (Boone et al., 2024).

It is also notable that there is a research base indicating persisting cognitive issues following complicated mTBI. A growing body of literature has identified that when lesions can be identified in imaging following an mTBI, these are associated with executive functioning difficulties, including behavioural disinhibition (Bryant et al., 2022; Kwak et al., 2020). Imaging typically identifies these lesions in the prefrontal cortex, with frontal and temporal lobe lesions also accounting for a meaningful proportion (Bryant et al., 2022; Kwak et al., 2020). This is notable given the majority of mTBI not being identifiable on imaging, and the underlying complexities of localising brain activity on imaging, meaning as imaging techniques and technology evolve, as will our ability to understand how both focal and diffuse tissue damage following TBI are contributing to cognitive outcomes (Alouani & Elfouly, 2022; Brett et al., 2002).

Effects of TBI on Memory

The association between TBI and memory deficits has been well documented in the literature. Early papers such as Martland (1928) and Parker (1934) first identified an association between TBI, particularly repetitive TBI, and poor memory. These early studies explored memory deficits which lasted long past the acute TBI recovery period, such as in early boxers that would be labelled “punch-drunk” (Martland, 1928; Parker, 1934). In contemporary research, there is a more nuanced understanding of the importance of both TBI severity, and of the diversity of memory as a construct. Memory in this context refers to how information is recorded, retained, and retrieved, with consideration for the multitude of neural networks that support these processes (Gabrieli, 1998). It is important to acknowledge that memory is not a unitary system, and in fact reflects several inter-related cognitive processes that can be

operationalised in a number of ways - memory might be assessed through immediate memory, delayed memory, verbal memory, visual memory, learning rate, forgetting rate, semantic organisation, and working memory (Vakil, 2005). The literature in TBI primarily discusses memory in terms of immediate, delayed, and working memory.

The first effect of TBI on memory can occur immediately following impact, as TBI patients may experience a period of PTA, depending on the nature and severity of injury. PTA is a period of recovery defined by confusion, disorientation, and an inability to store new information, this period is typically transient but the length of PTA is strongly predictive of poorer functional outcomes (Azouvi et al., 2017; Katz & Alexander, 1994; Ponsford et al., 2016). What is less well understood is the relationship between TBI, especially mTBI, and long-term effects on memory.

Immediate memory, or short-term memory, is concerned with the storage of information for immediate and short-term use that may be limited by the individual's capacity and may be subject to temporal decay (Cowan, 2008). While delayed, or long-term, memory refers to the ability to store information for retrieval at a later time-point without the information requiring active effort by an individual (Cowan, 2008). Immediate and working memory are related concepts, in this context working memory refers specifically to a cognitive ability that incorporates immediate memory but acknowledges that storage of knowledge for immediate use reflects aspects of processing speed and attentional control (Cowan, 2008).

Issues with memory are the most prevalent self-reported cognitive symptoms following severe TBI, at a rate of 67.5% (Jourdan et al., 2016) and this is supported in studies of performance across several aspects of memory (Vakil et al., 2019). A 2019 meta-analysis examining memory impairment in moderate and severe TBI patients, showed that individuals with TBI demonstrated significant deficits in delayed verbal recall (in word lists format or story format) compared to controls (Vakil et al., 2019). Younger age was shown to be associated with a greater effect size of immediate and delayed verbal (word-list) recall, but older age was associated with greater effect size of delayed story recall – further illustrating the complexity of underlying and interacting factors that predict long-term outcomes (Vakil et al., 2019). These deficits have shown to persist into the long-term stage of recovery. In a meta-analysis of those with moderate-severe TBI, injured participants performed significantly lower on tests of verbal and visuospatial immediate memory, and visuospatial working memory (Dunning et al., 2016). There is a growing body of research into the underlying mechanisms of memory dysfunction following moderate-severe TBI, as evidence has shown impaired memory consolidation in those affected, meaning that information was no longer shifting from immediate working memory to

long-term episodic memory and that this may be mediated by diminished working memory capacity (Azouvi et al., 2017; Chiou et al., 2015; Vanderploeg et al., 2014).

What is less clear is the relationship between memory (typically verbal memory) outcomes and mTBI. In the acute stage of recovery there is evidence of significantly reduced performance in immediate and delayed verbal memory, and working memory (de Freitas Cardoso et al., 2019; Mavroudis et al., 2024), but there is less evidence of lower performance in the long-term stage of mTBI recovery (Dikmen et al., 2009; Hacker et al., 2023; Mavroudis et al., 2024). Less recent studies have typically concluded that memory is largely unaffected in the long-term stage of mTBI recovery, per a systematic review by Dikmen et al. (2009), however some recent studies have identified long-term impacts on episodic memory (Fortier-Lebel et al., 2021) and visual memory (Ponsford et al., 2011; Rieger et al., 2013). Furthermore, some neurological evidence has shown an association between mTBI, variation in brain imaging of relevant regions, and performance on measures of verbal memory (Niogi et al., 2008).

Several studies of persisting effects from mTBI on memory have come from research into sports-related TBI, for example, a study of 758 retired professional football players found a significant relationship between recurrent mTBI and self-reported mild cognitive impairment and memory problems (Guskiewicz et al., 2005). Furthermore, athletes who had experienced three or more mTBI reported a three times higher prevalence of memory issues and five times higher prevalence of mild cognitive impairment (Guskiewicz et al., 2005). Some evidence has also shown that although mTBI populations do not consistently perform worse on tasks of working memory, their patterns of neurological activation on brain imaging suggest the same cognitive task may be requiring significantly more effort than controls (McAllister et al., 1999; McAllister et al., 2001).

In a longitudinal study population based in New Zealand, individuals with mTBI history did not perform lower on tests of working memory, and this is attributed in part to having access to detailed sociodemographic and lifestyle factors information on participants that many studies would not (Theadom et al., 2024). Meta-analytic comparison of cognitive outcomes following uncomplicated and complicated mTBI has shown that while complicated mTBI is associated with statistically significantly lower levels of performance across memory, this difference appears small enough to be clinically insignificant and unlikely to contribute to disability (Hacker et al., 2023).

Effects of TBI on Processing Speed

Processing speed is a cognitive domain which refers to the time needed to perceive, understand, and respond to stimulus, and it is commonly affected following a TBI (Forchelli et

al., 2022). A 2007 meta-analysis of studies assessing processing speed in severe TBI populations found these groups perform, on average, one standard deviation below the level achieved by healthy controls (Mathias & Wheaton, 2007), and recent investigation supports the conclusion that moderate and severe TBI is associated with lower performance on measures of processing speed (Azouvi et al., 2017; Carlozzi et al., 2015; Skandsen et al., 2010; Tsai et al., 2021). As with many post-TBI cognitive sequelae, the evidence for processing speed impairment following mTBI is less plentiful, due to studies primarily targeting moderate-severe TBI populations (Madigan et al., 2000; Mathias & Wheaton, 2007; Rassovsky et al., 2006; Tsai et al., 2021), however studies have shown some mTBI-affected groups to show processing speed deficit, such as in the subgroup of mTBI patients who report mental fatigue (Johansson et al., 2009), those in the post-acute stage of recovery (Anderson & Cockle, 2021), or those presenting with positive brain imaging (Miotto et al., 2010).

Effects of TBI on Perceptual Reasoning Skills

Perceptual reasoning refers to the ability to analyse, interpret, and solve problems using visual-spatial information (Wechsler, 2008). It involves skills such as: non-verbal problem-solving, visual processing, spatial awareness, and abstract reasoning (Wechsler, 2008). Perceptual reasoning has been shown to be insensitive to mTBI and conditionally sensitive to moderate and severe TBI, depending on the specific assessment tool in use (Carlozzi et al., 2015; Costa et al., 2015; Holdnack et al., 2013; Mittenberg et al., 2001). While most measures of perceptual reasoning show some sensitivity to moderate and severe TBI, the Matrix Reasoning task from the WAIS-IV has been specifically identified as being comparatively insensitive to TBI (Carlozzi et al., 2015; Mittenberg et al., 2001; Ryan et al., 2005).

This relationship between TBI and perceptual reasoning task performance has been found to be inconsistent, which may be attributable to the sensitivity of visual attention to TBI (Alnawmasi et al., 2022). A 2022 meta-analysis of visual attention following TBI identified a body of literature that was extremely heterogenous but with large effect sizes (Alnawmasi et al., 2022). This review determined TBI populations performed lower on measures of visual attention than unaffected groups, and moderate-severe TBI populations perform significantly lower on measures of visual attention than those with mTBI (Alnawmasi et al., 2022). This analysis also identified that particular domains of visual attention, including selective attention and orientation of visual attention, were more affected by TBI history, with reaction time also showing sensitivity to TBI exposure, suggesting underlying processing speed issues may account for this difference – particularly for those with mTBI (Alnawmasi et al., 2022). This relationship has also been seen in imaging studies, which show an asymmetrical relationship wherein disruption to neurological networks of working memory have a follow-on effect to reasoning

skills, but that disruption to reasoning networks does not have the same follow-on effect to working memory systems (Jolly et al., 2020). This further emphasises the importance of selecting appropriate measures, particularly when TBI can have such localised and heterogenous outcomes.

Effects of TBI on Attention

Attention can be defined in several ways, typically either focussing on attention as the capacity of information that can be processed, or as the ability to control prioritisation of information (Oberauer, 2019). As a non-unitary cognitive domain, attention can be assessed through several related but distinct functions, including attention span, sustained attention, visual attention, and attentional control (Alnawmasi et al., 2022; Mathias & Wheaton, 2007; Stierwalt & Murray, 2002). Attention has been shown to be particularly sensitive to the effects of TBI, even when other cognitive deficits do not emerge (Alnawmasi et al., 2022; Binder et al., 1997; Ginstfeldt & Emanuelson, 2010).

The relationship between TBI and attention span has been frequently examined. A systematic review identified 13 studies assessing attention span through some combination of digit span, reading span, word span, and letter span, reporting that reading, word, and digit span had shown the strongest effect from severe TBI, with letter span showing smaller effects (Mathias & Wheaton, 2007). Post-TBI attention deficits were also explored for their effect on communication in a 2020 systematic review (VanSolkema et al., 2020), which identified attention influenced communication difficulties following moderate and severe TBI in several areas including verbal reasoning, social communication, comprehension, and interpretation of social cues/emotions. Studies have shown children with moderate or severe TBI history demonstrate both behavioural attention symptoms, measured by the Child Behaviour Checklist, and cognitive attention symptoms measured by performance on tasks including the Consonant Trigrams Test (Paniak et al., 1997), F-A-S Word Fluency Test (Tombaugh et al., 1999), Underlining Test (Hayman-Abello, 2003), and Contingency Naming Test (Anderson et al., 2000), with performance on all being significantly associated with increased attentional problems in moderate and severe TBI affected children (Yeates et al., 2005). The effect of TBI in paediatric populations was further explored in a 2010 review (Ginstfeldt & Emanuelson, 2010) that found subdomains of attention were differently affected, identifying divided and sustained attention as most vulnerable, and attention span as most resilient. These attentional difficulties in paediatric TBI populations is also reflected in a high diagnosis rate of attention disorders, although directionality of this relationship requires further exploration (Adeyemo et al., 2014; Asarnow et al., 2021). The theme of divided attention deficits is particularly plentiful within the mTBI-focussed literature (Cicerone, 1996; Frencham et al., 2005; Vanderploeg et al., 2005).

While attention is an often-identified area of deficit following TBI, it is important to contextualise the specific subdomain being assessed to better understand the real-life implications for the recovering individual.

Effects of TBI on Executive Function

Executive functioning (EF) is a broad domain which covers aspects of cognitive function including memory acquisition and retrieval, inhibitory control, reasoning, planning, judgement, alternating attention, and problem solving (Rabinowitz & Levin, 2014). These functions are related to the prefrontal cortex (PFC) of the brain and its related networks (Friedman & Robbins, 2022). The PFC is implicated in many aspects of psychopathology, with lesions in this region being associated with a range of psychological outcomes, affecting EF in a variety of ways, often in ways specific to lesion localisation (Friedman & Robbins, 2022).

A key component of EF is inhibitory control, and in TBI research it is important to differentiate two components of inhibition, social inhibition and response inhibition (Osborne-Crowley & McDonald, 2018). While literature will often use terminology differently or interchangeably, in this instance social inhibition refers to social cognition and one's ability to align their behaviour with social norms and expectations (Arciniegas & Wortzel, 2014) and response inhibition refers to an issue of top-down cognitive control i.e., one's ability to control a prepotent response, including delaying a response and interference control (Barkley, 1999). Both social disinhibition and response disinhibition have been explored as TBI sequelae, social disinhibition through self-report and informant report measures, and response inhibition through neuropsychological testing (Osborne-Crowley & McDonald, 2018). As this thesis is primarily concerned with potential cognitive correlates of TBI, response inhibition will be the focus of investigation here.

Response inhibition has been shown to be sensitive to TBI, in a meta-analysis of response processing tests such as the Stroop test, Conners Continuous Performance Task, Go-No-Go task, and Sustained Attention to Response Task, TBI had a statistically significant weighted mean effect of 0.58 (p<.001), it is important to note that when analysed by severity, moderate and severe TBI exposure had a significant effect on response processing, but not mTBI (Dimoska-Di Marco et al., 2011). Interestingly, meta-analysis of response inhibition through the Stroop interference task has not shown a significant effect by TBI exposure, suggesting that different aspects of inhibitory control may be mediated by different underlying cognitive processes (Dimoska-Di Marco et al., 2011; Verbruggen et al., 2005).

Several studies have investigated the relationship between decision-making and problem-solving TBI. Individuals have been shown to perform lower on the Iowa Gambling Task

(IGT), a measure of decision-making, and that performance on this task did not differ between mTBI participants and severe TBI participants (Cotrena et al., 2014), an insensitivity to TBI severity that has been seen in other studies (Sigurdardottir et al., 2010). Another study of participants with severe TBI did not find differences in IGT performance against controls, but did identify lower performance on the Social Decision Making Task, a decision-making task with a social component not present in tasks such as the IGT (Kelly et al., 2014). A case-control assessment of moderate and severe TBI patients has demonstrated that those with this TBI history made decisions that more favoured immediate reward over long-term reward when compared to controls, importantly this correlation is not mediated by other executive function and aligns well with self-reported measures of impulsivity (Wood & McHugh, 2013). Tasks such as the IGT or Social Decision-Making Task reflect performance in decision making related to immediate feedback. Alternative measures may need to be used to assess decision making with a temporal component to account for impulsivity as an aspect of decision making.

Another component of EF is problem-solving. Problem-solving may be evaluated through as the ability of an individual to understand and navigate situations in a manner that identifies the pertinent information and appropriate course of action, or through a cognitive lens that measures an individual's ability to achieve a target outcome that often requires planning, mental flexibility, and attentional control (Catroppa & Anderson, 2006; Channon & Crawford, 2010). Both children and adults with moderate or severe TBI perform lower than controls in measures of social problem-solving ability (Channon & Crawford, 2010; Janusz et al., 2002; Warschausky et al., 1997). Moderate and severe TBI have also been shown to affect outcomes of performance-based measures of problem-solving ability, particularly in child and adolescent populations (Catroppa & Anderson, 2006; Garth et al., 1997). Common assessments of planning and problem solving ability include the Wisconsin Card Sorting Test (WCST) (Grant & Berg, 1948), the Porteus Maze Test (Porteus, 1950), and the Tower of Hanoi (Humes et al., 1997; Zook et al., 2004), all of which have shown some sensitivity to moderate and severe TBI (Gómez-de-Regil, 2020; Ord et al., 2010; Sherer et al., 2003), although these results are not universal (Calvillo & Irimia, 2020; R. Kumar et al., 2009). Performance on these measures of planning and problem-solving performance does appear to be less sensitive, and possibly insensitive to mTBI (Kraus et al., 2007; R. Kumar et al., 2009; Ord et al., 2010). As with many aspects of post-TBI cognitive assessment, meta-analysis of planning and decision-making is fraught due to methodological heterogeneity (Calvillo & Irimia, 2020).

Cognitive Assessment Tools in TBI Populations

The distinction between cognitive assessment approaches in the acute and post-acute or chronic stage of TBI recovery is important for understanding much of the existing literature

on TBI and cognition. The acute stage of recovery, within 4 weeks of injury, is extremely important to the long-term rehabilitation of an individual and a large body of research is devoted to this stage (Johnson & Hall, 2022). It is notable that a significant portion of this literature uses the GCS (Table 1) as a measure of post-acute cognition, which is not the primary purpose of the scale (Jain & Iverson, 2018). The GCS is intended as a measure of consciousness, not cognition, (Jain & Iverson, 2018) and that a large proportion of the literature uses GCS score as a de-facto measure of gross functional ability is important context for interpreting this literature (Johnson & Hall, 2022).

A comprehensive neuropsychological assessment battery is the gold standard for evaluating cognition after an injury and there are several common data elements (CDEs) that have been proposed for use to increase uniformity in studies of cognition and TBI. A CDE is a data element that is used across settings to improve data quality and comparability. An assessment battery to assess for post-TBI cognitive symptoms will typically include assessments of:

- Memory, such as the Wechsler Memory Scale (WMS), the Rey Auditory Verbal Learning Test (RAVLT), the California Verbal Learning Test (CVLT), or the Rey-Osterrieth Complex Figure Test (ROCF).
- Processing speed, such as Wechsler Adult Intelligence Scale-IV (WAIS-IV) Coding and Symbol Search subtests, the Paced Auditory Serial Addition Test (PASAT), or the Symbol Digit Modalities Test (SDMT).
- Working memory, such as the WAIS-IV Digit Span and Letter-Number Sequencing subtests.
- Executive functioning, such as the Wisconsin Card Sorting Test (WCST), Trail Making Test (TMT), the Stroop Colour Word Test, the Colour Word Interference Test (CWIT), the Controlled Oral Word Association Test (COWAT).

(D'Souza et al., 2019; Hicks et al., 2013; Rabinowitz & Levin, 2014; Tulsky et al., 2017).

Due to the heterogeneity of TBI, identifying tasks that are appropriate and sensitive across the breadth of TBI severity is difficult, but that several tests have shown particular utility in specific areas of TBI research, such as acute hospitalised patients or mTBI-targeted research (Hicks et al., 2013), and efforts are being made to identify CDEs with utility across TBI treatment and rehabilitation (Tulsky et al., 2017; Yue et al., 2013).

In a systematic review of cognitive assessment tools in use across longitudinal TBI research, D'Souza et al. (2019) identified that although these studies established the construct validity of their measures, none of the instruments had been evaluated and met the necessary

properties of convergent or divergent validity, known-groups validity, test-retest reliability, and responsiveness to change over time in TBI populations. These issues demonstrate some of the ongoing areas of development needed to improve cognitive assessment strategies in TBI research (D'Souza et al., 2019).

Computerised Cognitive Assessment

A notable change in the field of cognitive assessment is the increasing number of computerised assessment tasks in use (Johnson & Hall, 2022). Computerised tools can provide several advantages over traditional pen-and-paper testing, such as increased sensitivity, and decreased administration and scoring time (Collie et al., 2001; Del Giovane et al., 2023). There is also an increased interest in gamified computerised tools that have been shown to improve engagement during testing (Feenstra et al., 2017; Hampshire et al., 2012; Lumsden et al., 2016). By using relatively resource cheap computerised strategies for cognitive testing, patients and care providers can better monitor the long-term effects of many neurological conditions. Within TBI research, there are several tools that have been or are being developed that show sensitivity to the effects of TBI and may therefore provider an effective way of monitoring TBI outcomes in a uniform way.

However, it is important to consider the appropriateness of computerised tools with the assessment group at hand, as comfortability with electronic devices has been shown to impact performance on computerised measures of post-TBI cognition (Wallace et al., 2019). For example, people with visual difficulties following mTBI may find that using screens for a prolonged period exacerbates visual symptoms and headache (Macleod et al., 2021). In qualitative research participants and clinicians have raised concerns of cultural appropriateness, such as the need for localised accents for certain tasks, and issues with computerised assessments that rely on devices that may exacerbate photosensitivity as a symptom of TBI (Macleod et al., 2021).

Performance Validity Testing (PVT) and TBI

Valid neuropsychological test performance is of major importance in neuropsychological assessment, and several tools have been developed to assist in determining the validity of participant performance when completing neuropsychological testing. Prior to the development of performance validity measures, subjective clinical judgement of observed behaviours during testing were the only avenue for clinicians and researchers to assess performance validity (Bigler, 2014; Sweet et al., 2021). PVTs can be standalone assessments, designed for the purpose of validity testing, or embedded tests inside of existing tasks that identify implausibly low performance on that task (Sweet et al., 2021). PVTs may also be forced-choice tasks which assess whether a respondent is intentionally avoiding a correct response, or

they may be non-forced-choice and determine whether responses are unrealistically slow, random, and inconsistent with the performance profile of known disorders (Sweet et al., 2021). PVTs are considered medically necessary for clinical evaluation, and of particular value when working with forensic populations, due to greater incentive for symptom exaggeration within these groups (Bush et al., 2005; Sweet et al., 2021).

Those with TBI, and particularly mTBI, can be a complex validity testing population due to the high rate of involvement by patients in workers' compensation and personal injury litigation and the underlying incentives therein that may lead to performance invalidity (McBride III et al., 2013). Within the NZ context this incentive may be presented when participants are engaged with ACC, the national no-fault personal injury cover provider (Barker-Collo & Fernando, 2015). A growing body of evidence is demonstrating that PVTs are functioning as intended in individuals with TBI history, PVT outcomes have shown no association with increased TBI severity, identifiable lesion on neuroimaging, or neuroimaging by lesion location (Flaro et al., 2007; Green et al., 1999; McBride III et al., 2013).

Bearing this evidence in mind, a concern with several PVTs is the lack of validation data for many minority ethnicity populations, and that frequently used cut-scores may not be appropriate across cultural contexts (Nijdam-Jones et al., 2017; Salazar et al., 2021). Across Latin American countries, performance on the Test of Memory Malingering (TOMM) has been shown to vary significantly based on country development, as measured by United Nations Human Development Index, which contributes to a wide variation in test sensitivity between nations (76.0%-99.7%) (Nijdam-Jones et al., 2017). This is important as the TOMM is not a language-based assessment, which suggests other underlying factors are affecting cross-cultural validity (Tombaugh, 1996). This is not to say minority ethnicities, or non-English speakers, will necessarily perform poorer on measures of performance validity, in fact a growing body of evidence is demonstrating performance on several PVTs is not meaningfully associated with ethnicity (Bosworth & Dodd, 2020; Hood et al., 2022). Nonetheless, potential cultural bias remains an underlying concern when utilising several PVTs and given the evidence of a disproportionate TBI burden in minority ethnicities, assessing performance validity appropriately is a necessary consideration in TBI research (Jager et al., 2000; Langlois et al., 2005; Maldonado et al., 2023).

Another important demographic to consider performance validity with are offenders. Offending populations can be highly incentivised to engage in poor performance validity, with real and perceived effects on their sentencing and treatment, meaning PVT becomes an essential component of neuropsychological assessment in this group (Denney & Fazio, 2021). Poor performance validity rates differ meaningfully by the immediacy of incentive to show poor

performance, with assessments conducted on those with active criminal charges showing particularly poor performance validity at a rate of 31% (Marcopulos et al., 2014), and a sample assessed for competency to stand trial failed to meet cut-off scores on the TOMM at a rate of 36%, as compared to a 6% rate in non-incentivised offenders (Weinborn et al., 2003). Despite the implicit incentive for many offenders to show poor performance validity, the high rates of apparent poor PVT are complicated by the demographic, and neuropsychological profile of offenders; these high rates of poor PVT could be affected by the extremely high rates of TBI, high rates of mood and anxiety disorders, substance abuse histories, low education, and cultural bias, therefore PVT needs to be approached with caution in any analysis of forensic populations (Denney & Fazio, 2021; Lippa, 2018).

Conclusion

This chapter presented the tools used when assessing cognitive outcomes following TBI and discussed evidence of cognitive domains that are sensitive to injury. Although several domains show sensitivity to the most severe TBIs, the majority of TBIs are mild and the cognitive sequelae of mTBI are less clear. Heterogenous evidence of association between TBI and cognitive performance also appears to be attributable to evolving methods of cognitive assessment across each domain of functioning.

Chapter Three: Determinants of Cognitive Outcome following TBI

This chapter is an exploration of the multitude of factors that can affect cognitive outcomes following TBI. TBI effects on cognition are mediated by several factors such as a prior history of TBI, TBI severity, age when injured, sex, substance use history, and cognitive reserve (Fraser et al., 2019; Theadom et al., 2019).

TBI Severity

As discussed in Chapter One, TBI severity may be quantified in several ways, albeit typically on a three-point continuum of mild, moderate, and severe. Placement on this continuum is generally determined by the acute symptoms demonstrated at the time of injury, such as length of LOC, PTA, or scored on a tool such as the GCS which assesses the overall responsiveness of the individual at the time of injury (McCrea, 2008). A further severity category of note is complicated mTBI, referring to mTBI with abnormalities on brain imaging, which have been shown to have poorer rehabilitative outcomes than uncomplicated mTBI (Iverson et al., 2012; Veeramuthu et al., 2017). The clinical utility of current TBI severity labels has been criticised for not reflecting the complexity and variability of pathophysiology following TBI (Tenovuo et al., 2021).

Severity of TBI is a major determinant of rehabilitative prognosis, as detailed in Chapter Two: Long-term Cognitive Effects of TBI, with a large body of evidence demonstrating long-term cognitive effects of moderate and severe TBI, but heterogenous outcomes in mTBI research (Carroll et al., 2014; Karr et al., 2014; Ruttan et al., 2008; Skandsen et al., 2010; Tsai et al., 2021). A 2021 meta-analysis (Tsai et al., 2021) evaluated the pooled prevalence of cognitive deficit following TBI at the acute (≤3 months), subacute (>3 to ≤6 months) and chronic (>6 to 12 months) stages of TBI recovery, from 15 studies this meta-analysis covered the domains of memory, attention, processing speed, and executive function and showed individuals with moderate-severe TBI history demonstrated lower scores across all stages of recovery, while those with mTBI history demonstrated low scores in the acute and post-acute stage, with few studies evaluating cognitive effects of mTBI into the chronic stage of recovery (Tsai et al., 2021). This literature has been noted to be heterogenous in study outcomes and quality, with several mTBI studies relying on self-reported cognitive symptoms in lieu of performance-based measures (Carroll et al., 2014; Karr et al., 2014; Tsai et al., 2021).

A prospective cohort study (*N*=15,764) of individuals aged 50 to 90 years were evaluated for risk factors of cognitive decline, a history of moderate-severe TBI was associated with lower performance on measures of attention, executive functioning, and processing speed, while those with mTBI history demonstrated only lower attention scores (Lennon et al., 2023). This

dose-response relationship between TBI severity and cognitive outcomes is supported throughout the literature (Svingos et al., 2019; Tsai et al., 2021). An important consideration when reviewing this literature is that comparatively few studies evaluate cognitive outcomes across the full breadth of severity, which poses an issue due to the methodological heterogeneity across the literature, limiting the utility of comparing results across study populations (Carroll et al., 2014; Tsai et al., 2021).

TBI Frequency

In addition to severity, two further components of prior TBI exposure: frequency and pervasiveness, are potential determinants of rehabilitative outcome. While these two aspects of TBI history are related, and might be broadly categorised as repetitive TBI exposure, there is a meaningful distinction which is not always considered within this literature and will be discussed in the following subsections.

TBI frequency refers to the number of instances of TBI that an individual has experienced throughout their life, and has been operationalised in research by identifying whether an individual has any TBI history prior to the injury of interest, creating a dichotomous (prior TBI/no prior TBI) outcome (Karr et al., 2014). Several studies have investigated the effect of having prior TBI exposure on cognitive rehabilitative outcomes and evidence of a meaningful effect is mixed. A 2014 review of reviews (Karr et al., 2014) found that studies excluding participants with prior history of TBI reported a smaller effect size on cognitive outcomes than those that did not, but also concluded that the difference in cognitive outcomes between multiple mTBI and single mTBI was very small and non-significant (Belanger et al., 2010; Belanger & Vanderploeg, 2005; Karr et al., 2014). It is also notable that few studies have investigated multiple TBI exposure beyond the dichotomous variable of prior TBI history (Karr et al., 2014). Given the increasing interest in understanding the relationship between chronic TBI, particularly sports-related TBI, and neurodegeneration, a better understanding of the dose-response relationship between TBI frequency and cognitive outcomes is needed (Belanger & Vanderploeg, 2005; Karr et al., 2014).

TBI Pervasiveness

Pervasiveness is a term used within this thesis to refer to periods of TBI exposure in which an individual has likely experienced several TBI or subconcussive injuries within a narrow period, often such that quantifying the specific number of unique injuries would be infeasible. Effects of pervasive TBI have been investigated through animal experiments, with mice being exposed to repetitive mTBI and showing behavioural disinhibition and slower performance on working memory tasks without observable structural damage on MRI (Nolan et al., 2018). In human populations this pervasive TBI exposure is often studied in the context of contact sport athletes, although groups such as victims of domestic violence (DV) may also have history of

pervasive injury (Baxter et al., 2019; Gallo et al., 2020; Ntikas et al., 2022). This is reflected in the strategy implemented by the increasingly prevalent OSU TBI-ID interview method for evaluating TBI history (Allely, 2016; Bogner & Corrigan, 2009; Glover et al., 2018; McKinlay et al., 2017; Smith & Rothschild, 2023). The OSU TBI-ID asks the respondent to provide their recollection of any past instances of TBI and separately prompts the respondent with the question "Have you ever had a period of time in which you experienced multiple, repeated impacts to your head (e.g., history of abuse, contact sports, military duty)?" to determine injury pervasiveness (Corrigan & Bogner, 2007a). A 2020 cross-sectional study of participants aged 40 and older involved in the University of California, San Francisco Brain Health Registry (*N*=13,323), identified that experiencing a period of pervasive head injury (per the OSU TBI-ID method) was associated with significantly worse performance on a battery of computerised cognitive tests, and that this effect interacted significantly with experiencing TBI with LOC (Alosco et al., 2020).

An increasingly large body of evidence is devoted to neurocognitive outcomes associated with sports-related TBI, in particular the potential role of repetitive TBI exposure in neurodegenerative disease (McAllister & McCrea, 2017; Ntikas et al., 2022). While this research is showing evidence of a dose-response relationship between non-concussive head injury, mTBI, and several biomarkers and neuroanatomical abnormalities, the effect of pervasive injury in sports on cognitive function needs to be investigated further (Hack et al., 2024; McAllister & McCrea, 2017; Papa et al., 2015). A tentative relationship has been demonstrated between sports-related TBI and cognitive outcomes in certain sports, including rugby, American football, and boxing (Gallo et al., 2020). It is important to note however that studies investigating long-term cognitive effects of sports-related TBI have been found to be of generally low quality, per a systematic review by Gallo et al. (2020).

Another population of particular importance when considering pervasive TBI are those with experience of intimate partner violence (IPV), a vulnerable population in which chronic cognitive symptoms have been identified (Karr et al., 2024). Female IPV survivors have demonstrated lower performance on several cognitive measures including of executive functioning, and immediate and delayed memory when compared to non-IPV controls (Karr et al., 2024). Review of the existing literature has identified post-TBI cognitive deficits in IPV populations with TBI history, but note the lack of consistent screening strategies in place to accurately identify the magnitude of post-TBI support needs in this population (Haag et al., 2022). IPV-based TBI research has the additional complicating factor of IPV-related strangulation injuries, which initial research has demonstrated worsens the cognitive impacts of TBI (Valera & Kucyi, 2017; Valera et al., 2022).

Experiencing a second TBI while in recovery from an initial TBI has been proposed to contribute to a phenomena known as second impact syndrome, resulting in potentially deadly cerebral oedema (Engelhardt et al., 2021; McLendon et al., 2016). Studies of second impact syndrome are rare, and focussed primarily on teenaged and young-adult athletes, as more evidence is gathered on second impact syndrome, a greater consideration of the unique cognitive effects of these types of injuries will be needed (Engelhardt et al., 2021; McLendon et al., 2016).

Sex

There is a growing body of literature exploring the role of sex (and although often not distinguished, gender) and TBI. Existing clinical research studies have recruited largely male samples and use male rodents in most animal studies of TBI outcomes (Becker et al., 2016; Beery & Zucker, 2011; Gupte et al., 2019; Mollayeva et al., 2018). These issues are worsened by a body of evidence on TBI rehabilitative outcomes that relies heavily on data gathered from patient populations in emergency medical settings, where individuals experiencing IPV – who are disproportionately female - are less likely to present (Biegon, 2021; Campbell et al., 2022; Esopenko et al., 2024; Gabbe et al., 2022; Monahan et al., 2017). Although epidemiological study has consistently found a higher rate of TBI in male populations, a growing body of evidence is suggesting that sex plays a role in many rehabilitative outcomes, including cognitive outcomes (Biegon, 2021; Feigin et al., 2013; Gabbe et al., 2022; James et al., 2019). Systematic review has shown disagreement within the literature on how sex interacts with cognition following mTBI (Haynes & Goodwin, 2023). Different studies show women experience poorer cognitive outcomes following TBI (Mikolić et al., 2021; Sicard et al., 2018), men have poorer outcomes (Niemeier et al., 2007), and some studies are mixed (Brooks et al., 2018; Tanveer et al., 2017).

These inconsistent findings may be attributable to several factors including variable hormonal factors that are going unaccounted for (Bazarian et al., 2010; Mollayeva et al., 2018; Niemeier et al., 2013; Stein, 2001). It has been hypothesised that sex hormones play a role in mediating cognitive outcomes from TBI and therefore female populations may have their cognitive outcomes in part mediated by stage of menstrual cycle, menopausal status, and use of hormone replacement therapies, all of which are areas requiring further study (Bazarian et al., 2010; Mollayeva et al., 2018; Niemeier et al., 2013; Stein, 2001). This inconsistency may also be due to heterogenous methodology in the extant literature, as mentioned earlier, studies of TBI outcomes are often not comparable due to differing methods of categorising TBI and neurocognitive outcomes (Goh et al., 2021; Karr et al., 2014; McInnes et al., 2017; Tsai et al., 2021).

Race and Ethnicity

As with incidence of TBI, the long-term effects of TBI are inequitably burdening minority ethnicity groups. In a 2007 prospective study of an American sample, despite similar injury severity and rates of rehabilitation centre placement, minority ethnicity patients experienced universally worse long-term functional outcomes across all outcomes measured (Staudenmayer et al., 2007). Standard of living, engagement in leisure, and returning to work and school were the domains of greatest disparity (Staudenmayer et al., 2007). A 2009 literature review of disparities by ethnicity in the USA found these trends are apparent throughout the literature, with African Americans and Hispanic Americans regularly reporting poorer functional outcomes and community reintegration, in addition to poorer rates of rehabilitation service access and post-TBI employment (Gary et al., 2009). This is possibly attributable to not only worse healthcare accessibility (Gary et al., 2009) but also neuropsychological tools with cultural biases disadvantaging minority groups (Ardila, 2005; Gary et al., 2009; Kennepohl et al., 2004). These differences are reflected in treatment, with Black Americans being less likely to be referred for ongoing care, or returned to the referring physician upon discharge when compared to White Americans (Bazarian et al., 2003; Brenner et al., 2020).

This double-burden of increased exposure and lower healthcare accessibility may be contributing to negative rehabilitative outcomes for minority ethnicities, with Black Americans reporting lower levels of life satisfaction one-year post-injury (Arango-Lasprilla et al., 2009), and worse functional outcomes (Maldonado et al., 2023). It has been proposed that Black Americans are also at greater risk of poor TBI rehabilitative outcomes due to greater levels of inflammation and oxidative stress, when compared to White Americans (Maldonado et al., 2023). There has also been a trend of studies of TBI not reporting ethnicity data, which may contribute to poorer understanding of the underlying TBI outcome trends (Brenner et al., 2020). Within the local NZ context, there is evidence that Māori report lower levels of competency with activities of daily living than NZ Europeans following moderate and severe TBI, despite equal performance in cognitive testing (Prigatano & Leathern, 1993), this might suggest some outcomes are being affected by cultural values and perceptions related to these injuries and not cognitive sequelae.

Substance Abuse History

Both TBI and substance abuse can have meaningful effects on long-term cognitive performance (Kuhns et al., 2022; Morin et al., 2019; Potvin et al., 2018). This is reflected in worse post-TBI cognitive performance in individuals with substance abuse history (Unsworth & Mathias, 2017; Weil et al., 2018). In meta-analysis, EF and memory have been identified as the cognitive domains most likely to be lower in TBI populations with substance abuse history than controls (Unsworth & Mathias, 2017). There are some limitations to this literature; there is

significant heterogeneity among studies of alcohol and substance abuse, few studies thoroughly assessed outcomes by TBI severity, and pre-injury substance abuse history is often unaccounted for (Unsworth & Mathias, 2017). Notably, intoxication at the time of injury has also been associated with poorer cognitive recovery following moderate-severe TBI than controls, suggesting avenues for further investigation to better understand the role of substance misuse in long-term TBI recovery (Joseph et al., 2015).

The relationships between TBI, substance use, and cognition are complex and interactive. Populations with TBI history report elevated levels of substance use, and populations with substance use behaviours report higher rates of experiencing TBI (Ilie, Adlaf, et al., 2015; Ilie, Mann, et al., 2015; Waltzman et al., 2021). It is therefore notable that meta-analysis has shown that substance use decreases after a moderate-severe TBI, while substance use behaviours do not change following mTBI, suggesting post-TBI symptoms may contribute to a reduction in substance use (VanderVeen, 2021).

Age of TBI

Age at time of injury appears to play a meaningful role in cognitive outcome following TBI. It has been proposed that the neuroplasticity of youth allows for improved outcomes to neurological injuries, known as the Kennard principle (Kennard, 1936), but the relationship between age and TBI outcomes appears to be more complex than this. Meta-analysis of 81 articles sampling 3890 total patients found that the Kennard principle held true for cases of mTBI but that following severe TBI younger participants experienced worse cognitive symptoms (Königs et al., 2016). Adults appear to have better cognitive outcomes following severe TBI than children, which is reflected in a childhood history of TBI being associated with lower levels of educational attainment and higher rates of unemployment (Königs et al., 2016; Taylor et al., 2015).

It is important to note that age and cognitive symptoms following mTBI do not seem to show a linear relationship. Several studies have shown that although school-aged children show a resilience to mTBI, infants and toddlers may in fact be more vulnerable to their effects (Crowe, Catroppa, Babl, & Anderson, 2012; Crowe, Catroppa, Babl, Rosenfeld, et al., 2012; Séguin et al., 2022). It therefore remains essential to account for age at time of injury, but it is also apparent that the role of neurodevelopment on long-term TBI rehabilitation needs to be considered in greater depth.

Cognitive Reserve

Another key factor in cognitive outcomes following TBI is cognitive reserve. Cognitive reserve provides a theoretical framework to consider the way cognitive networks can be

protective against neurodegeneration, and why similar injuries can have different cognitive outcomes (Mathias & Wheaton, 2015; Steward et al., 2018). Cognitive reserve may be conceptualised through a neural reserve model, in which greater efficiency and capacity of cognitive systems lead to fewer cognitive deficits following tissue damage (Stern et al., 2005; Steward et al., 2018). Alternatively, cognitive reserve may be conceptualised through a neural compensation model, wherein some individuals are predisposed to a greater level of neuroplasticity and can therefore recover quickly due to more immediate network reorganisation and adaptation (Steffener & Stern, 2012; Stern et al., 2005). These models can also be considered in concert with each other (Steward et al., 2018). Cognitive reserve is typically assessed retrospectively, as most individuals will not have engaged with preinjury assessment of their cognitive abilities, this may be through evaluation of the individual's occupation and level of educational achievement, or through estimates of premorbid functioning by utilising tasks insensitive to insult (Levi et al., 2013). This is distinct from what might be considered biological reserve, which similarly conceptualises protective factors from pathoneurological conditions, but is concerned with genetic, age, and sex characteristics (Mathias & Wheaton, 2015).

A growing body of research has explored the relationship between TBI and cognitive reserve, suggesting that cognitive reserve plays a role in predicting cognitive outcomes following TBI. A 2015 meta-analysis identified education and premorbid functioning were significantly (p<.001) but modestly positively associated with cognitive outcomes (Mathias & Wheaton, 2015). An Australian study conducted between 2009 and 2015 on adults with mild to severe TBI performed cognitive testing immediately following injury and two to five years post-TBI and found that premorbid IQ was protective against the cognitive effects of TBI (Fraser et al., 2019). This suggests therefore that greater cognitive reserve acts as a protective factor which can mitigate short and long-term cognitive deficits following a TBI (Fraser et al., 2019; Mathias & Wheaton, 2015).

A 2013 study used structural modelling techniques to determine the aspects of cognitive reserve most protective against moderate-severe TBI. The three factors of premorbid intelligence, socioeconomic status, and leisure activity engagements produced a best fitting model (Comparative Fit Index=0.96, p=.001) (Levi et al., 2013). This reflects the complex and non-unitary nature of cognitive reserve, demonstrating why different studies may conceptualise cognitive reserve in different ways. Due to the protective nature of cognitive reserve, it is important to evaluate the premorbid function of participants in TBI research.

Conclusion

This chapter explored several of the key determinants of long-term cognitive outcomes following TBI. A breadth of factors can influence cognitive recovery and rehabilitation, many of which are preexisting such as sex, ethnicity, substance use history, cognitive reserve, and prior TBI history; some factors are pertinent to the injury at hand such as severity and age when injured; while post-injury substance use, and post-injury mental health conditions can affect long-term cognitive outcomes following injury. This list is by no means exhaustive but serves to demonstrate the multitude of factors that might be accounted for when trying to predict cognitive outcomes following TBI and how to support individuals in the post-acute and chronic stages of recovery to achieve their best possible outcomes.

Chapter Four: TBI and Cognition in Offending Populations

This chapter examines TBI profiles of prison and broader offending populations. This will involve investigating the prevalence of TBI in offending populations and the methods used to assess this. The distinct cognitive profile and underlying risk profile of offenders will also be described. Lastly, the relationship between TBI, cognition, and offending behaviour will be discussed.

Prevalence of TBI in Prisons

The prevalence of TBI in prison populations has been frequently investigated, with varying results in the available literature. The prevalence of TBI in these studies ranges from 5.7% - 100% which is reflective of the heterogeneity in their design (Allely, 2016; Durand et al., 2017; Moynan & McMillan, 2018; O'Rourke et al., 2016). The highest prevalence identified is from a 1986 study of death row inmates, all of whom reported histories of TBI (Lewis et al., 1986), while the lowest is the result of a large longitudinal study (*N*=17, 569), which reported a prevalence of 5.7% of medically attended TBI across several prisons (Shiroma, Pickelsimer, et al., 2010). A 2018 systematic review examining prevalence of TBI and associated disability in prison population reported TBI prevalence rates ranging from 25%-86% even when applying a more conservative study inclusion criteria (Moynan & McMillan, 2018). This variability can be attributed to several reasons, including differing definitions of TBI, sample size, non-standardised assessments, and non-representative samples (Allely, 2016; Durand et al., 2017; Lewis et al., 1986; Moynan & McMillan, 2018; O'Rourke et al., 2016; Shiroma, Pickelsimer, et al., 2010).

While there is strong evidence of the increased frequency of TBI in offending populations, there is less investigation into any differences in severity between offenders and non-offenders. A 2017 study of a NZ prison population reported 14.9% of their most recent TBIs were moderate or severe (Mitchell et al., 2017). It is unclear how this differs from the general population due to studies of TBI prevalence often forgoing severity categorisation but moderate-severe TBI has accounted for 14% (Whiteneck et al., 2016), 15% (Corrigan et al., 2018), and 10% (Winqvist et al., 2007) of injuries in identified studies. This suggests that although offending populations experience more TBIs, they distribution of severity may be similar to the general population. Additional research is needed to determine how this differs by category of offending.

Several studies conducted in NZ have also examined prevalence of TBI in prisons and results have shown high rates of TBI exposure across severity levels (Barnfield & Leathem, 1998a; Mitchell et al., 2017; National Health Committee, 2010). In a 1998 Wanganui prison

sample, 86% reported a TBI history (Barnfield & Leathem, 1998a). This study categorised some TBI as "light", a severity level below mild, this term is not used elsewhere in the literature but within this study refers to TBI without LOC (Barnfield & Leathem, 1998a). In a 2015 study in an Auckland, NZ, men's prison population, routine screening on admission of inmates into the facility showed that 64% reported a history of TBI (Mitchell et al., 2017). This study involved a standardised TBI screening process for every participant admitted to the prison (*N*=1,054) (Mitchell et al., 2017). The results from this study were consistent with those reported in a New Zealand 2005 prisoner health survey that identified 64.0% of prisoners with any lifetime TBI (National Health Committee, 2010).

There is often a concern that prison populations may misrepresent their TBI history for a perceived benefit, which may skew a body of literature that largely relies upon self-reporting of historical TBI (Denney & Fazio, 2021; Rogers & Bender, 2008; Tussey et al., 2017). In fact, the existing evidence points toward this group being honest and reliable in their reporting of their medical history (Schofield et al., 2011). In a study of 200 participants from New South Wales prisons, 70% of injuries reported by respondents were supported by hospital records (Schofield et al., 2011). Participants were also extremely reliable in their self-report of the cause of TBI, aligning with hospital records in 96% of cases (Schofield et al., 2011). The most accurate reports were found to be those with fewer TBIs with a loss of consciousness and those with higher levels of educational attainment (Schofield et al., 2011). While it would be ideal to repeat these findings across different offending populations, currently it appears that low consistency between studies of TBI prevalence in prison populations is driven more by heterogenous TBI reporting methods then unreliable reporting by respondents, akin to studies of the general population (Allely, 2016; Brazinova et al., 2021; Corrigan et al., 2010; Durand et al., 2017).

TBI, Impulsivity, and Behaviour

As discussed in Chapter Two, TBI can be associated with chronic deficits in executive functions such as managing disinhibition, impulsivity, and socially inappropriate behaviour that can be associated with offending (Dimoska-Di Marco et al., 2011; Meijers et al., 2015; Osborne-Crowley & McDonald, 2018; Williams et al., 2018).

While issues with executive function may lead to poorer retention of information, problems solving and planning, the behavioural aspects of executive function compounds these difficulties (Osborne-Crowley & McDonald, 2018; Rabinowitz & Levin, 2014; Williams et al., 2018). These issues often present as irritability and frustration that may progress into impulsive aggression and in some cases, violence (Wortzel & Silver, 2024). Frustration intolerance, combined with other deficits in executive function can be difficult for those with TBI to manage

and puts additional stress on their support network (Osborne-Crowley & McDonald, 2018; Rabinowitz & Levin, 2014).

Prevalence rates of aggression following TBI have been estimated between 11%-34% (Brooke et al., 1992; Rao et al., 2009; Tateno et al., 2003), with most of this aggression being verbally-based (Rao et al., 2009). This aggression can often be exacerbated by physiological triggers including light and sound sensitivity, sleep deprivation, severe headaches, and fatigue, leading to those with chronic TBI symptoms having to constantly manage potential triggers of their irritability in the environment (Rabinowitz & Levin, 2014; Van Gils et al., 2020). Post-TBI aggression has further been shown to be associated with depressive disorders, substance misuse, and premorbid social functioning (Tateno et al., 2003). It is important to note that the directionality of anti-social behaviour and aggression as correlates of TBI is challenging to determine, as aggression serves as both a sequelae of pre-frontal cortex damage and as a risk factor of TBI (Williams et al., 2018; Wortzel & Silver, 2024).

Criminal Offending and TBI

Despite the over-representation of TBI in the prison population, there is still uncertainty whether there is a causal relationship between TBI and criminal behaviour. One hypothesis is that TBI can cause long-lasting damage in the frontal lobe, resulting in frontal lobe dysfunction (W. H. Williams et al., 2010). Damage to the frontal lobe from TBI is likely to affect impulse control, understanding consequences, and long-term planning (Raine et al., 1994; Williams, Hughes, et al., 2015; W. H. Williams et al., 2010). While this may be a reasonable explanation for individuals experiencing moderate and severe TBI, evidence is weaker regarding mTBI. Given the vast proportion of TBI in offending populations being mild, this theory cannot solely account for differences in offending by TBI history (Allely, 2016; Durand et al., 2017; Moynan & McMillan, 2018).

TBI and criminal offending have several common risk factors including being young, male, socially deprived and a history of drug and alcohol abuse (Baguley et al., 2006; Langlois et al., 2006). A longitudinal prospective study by Vaughn et al. (2014) found young males were twice as likely as young females to experience TBI and that these injuries were linked to higher levels of impulsivity and negative emotions. This same study also found young people with a history of TBI reported a much higher rate of victimization themselves (Vaughn et al., 2014). Substance abusing behaviour is also a shared risk factor for TBI and offending, with meta-analysis (Fazel et al., 2017) across prisons internationally reporting a pooled prevalence rate of alcohol abuse of 24%, and of heterogenic drug abuse between sexes at 30% for men, and 51% for women (Ilie, Adlaf, et al., 2015; Ilie, Mann, et al., 2015; Waltzman et al., 2021). Not only is acute intoxication a risk factor for experiencing TBI, one-third to one-half of TBI patients meet

alcohol use disorder diagnostic criteria, or being at risk of alcohol use disorder (Bombardier et al., 2003; Dikmen et al., 1995). Illicit drug use is also a prevalent concern for those in prison or experiencing TBI, teenagers who have experienced TBI report illegal substance use at 2.7 times the rate of uninjured teenagers (Ilie, Mann, et al., 2015), while a prospective study found that substance abuse was common in a moderate-severe TBI population (38.5%), and this figure dropped significantly post injury (9.6%) (Ponsford et al., 2018). The directionality of the association between substance abuse and TBI is not entirely clear, with a body of evidence arguing that substance use typically predates TBI (Ponsford et al., 2018; Rogers & Read, 2007), while others argue there are also mechanisms by which TBI might put people at risk of substance abusing behaviour (Olsen & Corrigan, 2022).

There is also evidence that individuals who are in prison are more likely to have a history of TBI and a greater number of TBIs (Durand et al., 2017; McMillan & Wood, 2013; Moynan & McMillan, 2018). Inmates with moderate to severe TBI history have been shown to have more major incidents in prison, and greater rates of recidivism which may in turn be associated with deficits in behavioural inhibition, memory issues, and problems with controlling anger (Morrell et al., 1998; Piccolino & Solberg, 2014).

The directionality of TBI and criminal behaviour is unclear from the existing literature. Those with a history of moderate to severe TBI may be predisposed to aggression, disinhibition, impulsivity, and low empathy leading to criminal behaviour (Dimoska-Di Marco et al., 2011; Feilhauer et al., 2012; Reynolds & McCrea, 2018; Seruca & Silva, 2016). Conversely engagement in criminal behaviour may also result in an increased risk of sustaining a TBI (Baguley et al., 2006; Osborne-Crowley & McDonald, 2018; H. Williams et al., 2010; Williams et al., 2018). A 2011 Swedish longitudinal population-based study (n=22,914) found those with a history of TBI were twice as likely to be involved with a violent crime (Fazel et al., 2011). These findings provide some prospective evidence to suggest that TBI exposure increases the risk of violent crimes, although more evidence of this directionality is needed.

Cognition in Offending Populations

Research examining cognitive function in offenders is primarily conducted within prison populations and has frequently demonstrated high levels of cognitive disability. In a Norwegian prison population, 10.8% of inmates performed at or below the level of intellectual disability (FSIQ≤70) on the Wechsler Abbreviated Scale of Intelligence (WASI) (Søndenaa et al., 2008). In a British prison population the rate of intellectual disability was 7.1%, with a further 23.6% in the borderline disability range (Hayes et al., 2007), and similar figures were present in a study of British young male offenders with 10% performing below the level of disability and 24% performing at the borderline level (Herrington, 2009).

Offending populations also demonstrate a distinct profile of executive dysfunction. A Canadian study reported their offending population performed significantly worse than norms and controls on the D-KEFS (Shumlich et al., 2019). In another Canadian study, both adolescent and adult offenders performed lower on the Porteus Mazes and WCST, when compared to controls (Bergeron & Valliant, 2001). A 2011 meta-analysis of studies of anti-social behaviour and EF identified a mean effect size of .61 for criminal behaviour specifically (Ogilvie et al., 2011).

Different types of offending populations present with different cognitive profiles. For example, several studies have shown that sex offenders may have some level of cognitive impairment when comparing to non-offenders and non-sexual offenders (Cohen et al., 2010; Eastvold et al., 2011; Gillespie & McKenzie, 2000; Rodriguez et al., 2017). A 2014 meta-analysis of studies examining cognitive performance within the sex offending population, found a large amount of heterogeneity that could be largely attributed to differences between child sex offenders (CSOs) and non-child sex offenders (Joyal et al., 2014). Studies of cognition in CSOs have primarily targeted EF as the outcome of interest (Cohen et al., 2010; Dillien et al., 2020; Suchy, Eastvold, et al., 2014). Several studies in CSOs identified impairment in the executive functions of response inhibition and cognitive set shifting (Dillien et al., 2020; Turner, Roszyk, Szumski, et al., 2020). However additional research is needed to determine how unique these deficits are to CSOs as compared to other kinds of sex offenders.

The prison environment itself also appears to have an impact on cognitive function. Research has shown the beneficial effects of environments that encourage physical activity, decision-making, and self-regulation on cognition, and this is often lacking in prison environments (Cox & Wallace, 2022; Gubert & Hannan, 2019; Petrosini et al., 2009; Zentall, 2021). Several studies have investigated the effects of long-term incarceration on cognitive performance. Despite the hypothesis that cognition is being negatively affected by the prison environment, differences in cognition appear to be largely dependent upon other factors, such as premorbid functioning and educational level (Cox & Wallace, 2022; Morgan & Lilienfeld, 2000; Umbach et al., 2018).

These trends might be expected given high levels of socio-economic disadvantage in prison populations, including low education level, underemployment, and high rates of domestic violence and childhood neglect (Behan, 2021; Fazel & Baillargeon, 2011; Fazel et al., 2017; Lang et al., 2002). These factors in combination with a history of mental illness and substance-use contribute to prison populations demonstrating cognitive support needs that often go unaccounted for (Baranyi et al., 2022; Fazel & Baillargeon, 2011; Fazel et al., 2017).

Some cognitive assessment tasks may not be appropriate or effective in the distinct prison environment with individuals with TBI, this might be due to tasks not having been validated on offending populations, being culturally inappropriate, disproportionately evaluating skills informed by education level, or not completable within the time-restrictions that many prisons operate under (Catalano et al., 2020a; van Esch et al., 2018). A 2020 literature review of cognitive tests used in prison populations identified 15 cognitive measures appropriate for use in the prison context (Catalano et al., 2020a). The authors suggested that instruments should be used with consideration for their appropriateness to measure cognitive function within prison populations. This includes a preference of more visual measures to more verbal measures (Catalano et al., 2020a). Another consideration is the acceptability of these cognitive measures within minority cultures and ethnicities that may be overrepresented in prison environments. Two cognitive batteries have been identified by Catalano et al. (2020a) as having been effective for assessing specific domains of cognition in indigenous Australian and non-English speaking prison populations. These include the computerised CogState Brief Battery (if electronics are permitted) which is largely independent of verbal comprehension, and the D-KEFS (Catalano et al., 2020a; Dingwall & Cairney, 2010; Ogloff et al., 2017).

Conclusion and Future Research

This chapter examined TBI and cognition in prison populations. Within the available literature there is heterogeneity as to the prevalence of TBI and cognitive impairment within prison populations, which can be attributed to heterogenous study design, small sample sizes, and often inappropriate assessment tools. Furthermore, the effect of these deficits on behaviour and offending remains unclear. The disproportionately affected prison population stands to benefit from an improved understanding of TBI outcomes. By improving our understanding of the neuropsychological effects of TBI, we can better contextualize aspects of offender's own life histories, which often include their own history of victimization. With an improved understanding of the interplay between TBI, cognition, and criminal offending we stand to improve rehabilitative approaches for anyone experiencing the effects of TBI and create better strategies to reduce offending and recidivism through an empowering approach to cognitive symptom management.

Chapter Five: A Systematic Review of TBI History and Cognitive Functioning in Criminal Offenders

Study Introduction

Offending populations demonstrate a unique history of TBI and experience many risk factors for poor cognitive outcomes following TBI. Offending populations report higher levels of experiencing any TBI, and more instances of TBI than the general population while being more likely to have a history of substance abuse, historical mental illness, and possibly lower cognitive reserve. In scoping the literature in the general population, the relationship between TBI (especially mTBI) and cognitive outcomes is unclear. By systematically reviewing literature on the relationship between TBI and cognition in offending populations, we may improve our understanding of the effects of TBI in an especially vulnerable population and potentially identify the most important factors in determining cognitive outcomes for everyone experiencing TBI.

Aims

The aims of this review were to:

1. Determine how TBI history has been assessed in studies exploring cognitive functioning in criminal offender populations.
2. Identify the cognitive domains studied and the tools used to assess if there is a cognitive impact following TBI in criminal offenders.
3. Determine if there is evidence of cognitive impacts following TBI in criminal offenders and the consistency of any findings.
4. Assess the overall quality of the existing literature exploring the relationship between TBI and cognition in offending populations.

Methods

This review searched four electronic databases: CINAHL (Cumulative Index to Nursing and Allied Health Literature), PsycInfo, PubMed, and Web of Science. The Google Scholar search engine was also searched for relevant articles.

Inclusion and Exclusion Criteria

Articles were included that assessed cognitive functioning using performance-based tests of cognition in criminal, including juvenile, offenders specifying their history of TBI using a cross-sectional or cohort study design. All severities of TBI were included. Articles were excluded if they were not available in English or if the clinical population did not distinguish TBI from other conditions such as organic brain syndromes. Literature reviews and meta-analyses were screened and any relevant articles extracted that were not accounted for within the literature search. Case studies were excluded from the review due to cases being unrepresentative of the

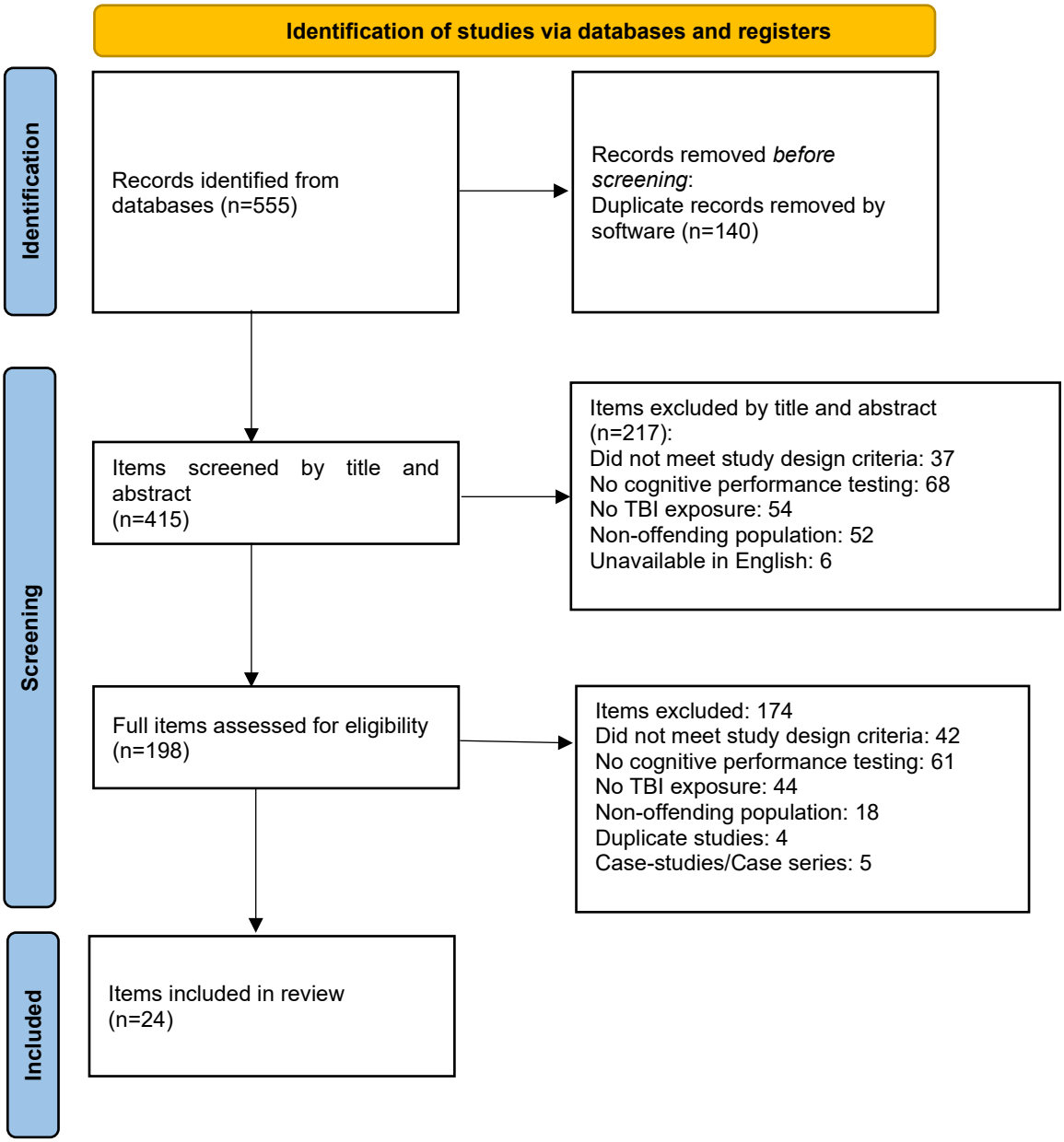
offending population. Studies that assessed both cognitive function and TBI history but did not report cognitive performance by any aspect of TBI history were excluded as not fulfilling the study design criteria.

Search Strategy

The search included original articles published from database inception until January 2022. The search terms used were TBI OR "brain injur*" OR mTBI OR "head injur*" OR "brain damage*" OR "neurologic* abnormalit*" OR "neurologic* damage*" OR "neurologic* injur*" OR ABI OR concuss* OR "hemisphere injur*" OR "cumulative trauma disorder*" OR "cerebrovascular trauma*" OR "craniocerebral trauma*" OR "brain oedema*" OR "diffuse axonal injur*" OR coma OR "cerebral haemorrhage*" AND "prison*" OR "incarcerat*" OR "inmate*" OR "crim*" OR "offend*" AND cognition OR cognitive* OR "executive function*" OR intelligence.

Due to search length limitations with Google Scholar, four unique searches were necessary to include all the terms and only the first 25 results were included from each. No earliest publication date for inclusion was set as the scoping review suggested few, if any, criteria-matching articles would be too old to be relevant in the context of offending populations. Identified citations were downloaded into the web application Rayyan, which automatically removed identical articles and suggested likely duplicates for others. Once all duplicates were removed, the articles were screened by title and abstract against the inclusion and exclusion criteria. Full-text articles were then reviewed from potentially eligible abstracts. A second reviewer checked a randomly selected 10% of identified citations to ensure congruence with the inclusion criteria. The search strategy was developed in consultation with an AUT university librarian. Article identification according to the PRISMA process can be seen in Figure 1.

Figure 1. PRISMA Flow Diagram



Quality Assessment

The Critical Appraisal Skills Programme (CASP) quality checklist was applied to each included article to determine study quality.

The CASP Cross-Sectional Studies Checklist is the following –

1. Did the study address a clearly focused issue?
2. Did the authors use an appropriate method to answer their question?
3. Were the subjects recruited in an acceptable way?

4. Were the measures accurately measured to reduce bias?
5. Were the data collected in a way that addressed the research issue?
6. Did the study have enough participants to minimise the play of chance?
7. How are the results presented and what is the main result?
8. Was the data analysis sufficiently rigorous?
9. Is there a clear statement of findings?
10. Can the results be applied to the local population?
11. How valuable is the research?

(Critical Appraisal Skills Programme, 2024)

The number of checklist items met by each study is recorded in Table 3, items which are open ended (How valuable is the research? and How are the results presented and what is the main result?) have been excluded from this final tally as non-dichotomous measures of quality, creating a final score for each study out of nine. Full checklists for each study can be found in Appendix F - CASP Quality Checklists.

Results

Study Characteristics

There were 24 unique studies identified that met the inclusion criteria. These 24 items were diverse in the methods used, samples studied and study quality.

Gender

These studies did not distinguish gender from sex, gender is therefore treated as the de facto metric, where relevant. Demographically, the study samples skewed heavily towards males, with nine (37.5%) studies being exclusively male. Only three studies were exclusively female (12.5%). Most mixed gender studies included more male participants; with these studies being 77.7% male on average and ranging from 45.0-96.3% male. There were two studies that did not detail the gender distribution of their sample (Barnfield & Leathem, 1998b; Smith, 2016).

Study Designs and Sample Populations

The studies were largely cross-sectional in design (23/24), with one cohort study also included. 14 of the studies originated from the United States, with five based in the United Kingdom, two originating in New Zealand, and one from each of Australia, Sweden, and Poland.

These studies were conducted on a variety of study populations. Some studies targeted specific types of offending including sexual offending, violent assault, homicide, and domestic abuse. Variations were also evident in study populations which include those on probation,

military offenders, those engaged in treatment programmes for offenders, halfway houses, in addition to typical prison (secure custodial) environments.

Quality

As seen in Table 3, the literature differed greatly in quality as assessed by the CASP. This heterogenous quality is attributable to many factors, some studies primarily aimed to assess outcomes beyond cognition by TBI status but fulfilled the inclusion criteria through secondary assessments; for example, one study has a primary focus of investigating the validity of the OSU-TBI identification method in prison populations (Bogner & Corrigan, 2009). Others were limited by their design, which was largely cross-sectional, and many were underpowered or did not provide a sample size calculation to ensure ability to detect meaningful differences between exposure groups. As the literature covers many components of cognitive function, the CASP scores do not reflect whether the cognitive assessment tools are the most likely to identify TBI-related cognitive deficits. Furthermore, the CASP checklist items evaluate the quality of the study to achieve its study aims and given that cognitive performance by TBI status was not the primary relationship being investigated in several of these studies, their ultimate usefulness as literature for this purpose is limited and not fully captured in the CASP score.

TBI Assessment

There was significant heterogeneity in how TBI history was assessed. Seven studies used a single self-report measure of TBI history to determine whether participants had ever experienced a brain injury or a brain injury that led to LOC, it does not appear that these studies used a validated method of TBI history capture. Seven studies further validated the TBI history of participants by clinical records to determine TBI history where these were available e.g., for those with military or forensic histories. Eight studies utilised a clinical interview to elucidate TBI history, this method was often utilised with studies investigating a wide range of clinical concerns in addition to TBI and the specific nature of each interview was not always clear. Finally, seven studies used a standardised validated measure of TBI history such as the OSU-TBI ID, the Brain Injury Screening Index (BISI), the Comprehensive Health Assessment Tool (CHAT), or the TBI Questionnaire (TBIQ). Of the standardised tools, the OSU-TBI ID method was the most frequently used, with four studies using a version of this tool.

TBI History

As discussed, the severity of TBI is generally classified clinically on a three-point continuum of mild, moderate, and severe (Cassidy et al., 2004), however there was no uniformity in how TBI severity, or other components of TBI exposure, were categorised for statistical comparison within these studies. A breadth of methodologies were used when

comparing groups by their level of TBI exposure, a plurality of ten studies chose to compare a group with any TBI to a group with no history of TBI (Cohen et al., 2003; Cohen et al., 1999; Fitzsimons, 2017; Gorgens et al., 2021; Katzin et al., 2020; Marsh & Martinovich, 2006; McMillan et al., 2021; Pitman et al., 2015; Shiroma, Pickelsimer, et al., 2010; Smith, 2016). Several other studies measured TBI exposure by incorporating TBI frequency and within this group there was further methodological heterogeneity; one study compared those with no TBI history, to those with a single TBI, and those with multiple TBI (Schofield et al., 2019); one study set their comparison groups at fewer than 6 instances of TBI, compared to those with 6-20 TBIs, and those with greater than 20 TBIs (Johnson, 2016). One study was particularly interested in the post-acute effects of TBI and therefore compared participants with prior year TBI to those without (Slaughter et al., 2003). One study was an evaluation of reliability and validity of the OSU TBI-ID and the subsequent regression analysis utilised a breadth of summary indices of TBI history: number of TBIs, number of TBIs with LOC, number of moderate/severe TBIs, most severe TBI, severity weighted TBI, severity weighted TBI before age 15, TBI before age 15, TBI with LOC before age 15, number of TBIs between ages 10-14 inclusive, time since last TBI, number of initial symptoms, number of persisting symptoms, number of initial functional effects (Bogner & Corrigan, 2009).

Study Outcomes

The cognitive assessment tools used within this literature assessed various domains of cognitive function. These results have therefore been categorised into the domains of EF, Verbal and Visual Memory, Attention, Processing Speed, and assessments of Global Cognition. To identify differences between participants with and without a history of TBI, studies used varying statistical procedures including *t*-tests of differences between means; Analysis of Variance; Multivariate Analysis of Variance; Analysis of Covariance; Mann-Whitney *U*-tests; Chi-squared tests; and regression modelling.

Executive Functioning

The most frequently used assessment of EF within the literature was the Trail-Making Test Part B (TMT-B). In the TMT-B, participants are asked to use a pencil to connect 25 encircled numbers and letters in alphabetical and increasing numerical order, alternating between numbers and letters i.e., connect circle “1” to circle “A” to circle “2” to circle “B” and so on, with time to completion being the scored variable (Bowie & Harvey, 2006). The TMT-B is primarily an assessment of set-shifting, the ability to alternate attention between simultaneous goals, and has shown deficits by TBI status in community populations (Arbuthnott & Frank, 2000; Lange et al., 2005). The TMT-B was used by eight studies either as a standalone measure or alongside

other tests of EF, none of which found statistically significant differences in performance by TBI status, although sample sizes were generally small to medium (40-109 participants).

The WCST was also used as an EF assessment tool with three studies using the measure and unable to identify any differences by TBI status. The WCST is an assessment of the categorization and set-shifting components of EF, it involves sorting a deck of cards by various attributes without instruction, cards differ in figure depicted (stars/crosses/triangles/circles), number of figures depicted (one to four), and colour of figure (red/blue/yellow/green), initially the respondent must sort by colour, and once sorted correctly 10 times the sorting criteria will shift to figure, and then to number (Anderson et al., 1991).

Another common assessment used to measure EF was the Behavioural Assessment of the Dysexecutive Syndrome (BADS). The BADS is comprised of six subtests assessing five domains of EF, these domains are cognitive flexibility, novel problem solving, planning, judgement and estimation, and behavioural regulation (Norris & Tate, 2000). The BADS demonstrated differences in outcomes by TBI status in one of the three studies where it was used. The study that found a difference, compared performance on the BADS across several United Kingdom men's prisons (Pitman et al., 2015). This study primarily differed from the others in its use of a TBI index score instead of TBI severity, or number of injuries, it was also a larger study sample (*N*=103) than those that did not report a difference by TBI status on the BADS (Pitman et al., 2015). One study did not find differences on the BADS but did detect differences on two additional measures of EF (Marsh & Martinovich, 2006); in this study of offenders with a history of domestic violence, the TBI-affected participants performed significantly worse on the Hayling Sentence Completion test, measuring the EF domain of inhibition, and the Brixton Spatial Anticipation test, measuring the EF domain of logical rule abstraction (Marsh & Martinovich, 2006; Odhuba et al., 2005).

A component of EF that has frequently been explored within this literature is verbal fluency, which is the function of retrieving specific information from memory. Verbal fluency is typically assessed as semantic fluency, one's ability to generate items from within a given semantic category e.g., animals, or phonemic fluency, one's ability to generate words beginning with a given letter (Patterson, 2011). The most frequently used assessment of verbal fluency is the COWAT and despite its use in five of these studies, no studies using the COWAT detected any significant differences by TBI status (Cohen et al., 2003; Cohen et al., 1999; Johnson, 2016; McMillan et al., 2021; Slaughter et al., 2003).

No further differences were found in assessments in studies assessing differences in EF by TBI status, despite the use of several other assessment tools, including ROCF, which assesses

functions of planning and organisation (Barnfield & Leathem, 1998b), the Behavioural Dyscontrol Scale-Electronic Version, assessing motor learning and inhibition (Suchy et al., 2007), the Ruff Figural Fluency Test, assessing figural fluency, and the Stroop, assessing cognitive interference inhibition (Suchy et al., 2007).

Memory

Only one study found statistically significant differences in memory performance by TBI status in offenders and this study used the RAVLT, which is an assessment that involves the participant repeating back a 15-item word list, to assess learning, then doing the same with an interference list before being asked to recall the original 15-items, to assess recall with interference, and a 20 minute delay before being asked to repeat the list once more, to assess recognition and delayed recall (Bowler, 2021). Barnfield and Leathem (1998b) found their TBI exposed sample performed below norms in immediate and delayed recall, and recognition (p<0.01), but performance did not differ by TBI severity. However no control group was used, limiting the conclusions that can be drawn (Barnfield & Leathem, 1998b). One study found particularly counter-intuitive results regarding working memory, reporting that greater TBI exposure was weakly but significantly associated with improved working memory, as assessed by the Digit Span and Letter-Number Sequencing subtests of the WAIS-III, but the low coefficient suggests this is not likely to be a clinically significant relationship (Adjusted R^2=0.138, p<0.0001) (Bogner & Corrigan, 2009).

Processing Speed

As with the TMT-B and EF, several studies use the Trail Making Test Part A (TMT-A) as an assessment of processing speed. The TMT-A involves the participant using a pencil to connect encircled numbers in ascending order from one to 25, the numbers are distributed semi-randomly about a single page (Bowie & Harvey, 2006). One study did find differences in performance by TBI status on the TMT-A, in their sample of male prisoners with substance abuse history, La Point (2014) found participants with a moderate or severe history of TBI performed worse than those with no or mTBI history, finding a history of moderate or severe TBI accounted for 3.4% of variance in outcomes on the TMT-A (La Point, 2014). This study was distinct in its focus on the effect of TBI in offenders with a history of substance abuse issues, which may account for this difference in outcome not seen in the remaining studies. No other studies found statistically significant differences in processing speed performance, as assessed by several tasks, including the Digit Symbol and Symbol Search Tasks of the WAIS (Bogner & Corrigan, 2009; Suchy, Euler, et al., 2014), the PASAT (Cohen et al., 2003), the SDMT, and the Adult Memory and Information Processing Battery (McMillan et al., 2021).

Attention

Few studies assessed attention as a cognitive domain of importance in TBI-affected offending populations, which is notable considering the relationship seen between TBI and attention deficits in the general population (Alnawmasi et al., 2022; Ginstfeldt & Emanuelson, 2010; VanSolkema et al., 2020). Again, an important subtest in the assessment of attention is the TMT-A, as above, the sole study that detected difference in measures of attention was by La Point (2014). Other assessments of attention included were the Adaptive Rate Continuous Performance Test (Cohen et al., 2003), the d2 Test of Attention (Turner, Roszyk, Szumski, et al., 2020), and the Digit Symbol subtest of the WAIS (Barnfield & Leathem, 1998b).

General Cognition

Finally, many of these studies presented differences in performance across multiple domains of cognition, or measures of overall cognitive function by TBI status, sometimes alongside subtest outcomes but often as standalone measures of the impact of TBI. In the study from Pitman et al. (2015), significant differences in performance were found by TBI status across two cognitive assessment tools, the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) (d=1.06) and the WASI (d=0.62) at a significance level of 0.0167. The RBANS consists of 12 subtests comprising five indices of Immediate Memory, Visuospatial/Constructional, Language, Attention, and Delayed Memory, intending to serve as a thorough but abbreviated cognitive assessment battery (Randolph et al., 1998), while the WASI is an abbreviated version of the WAIS comprised only of the Similarities and Vocabulary subtests of the Verbal Comprehension Index and the Block Design and Matrix Reasoning subtests of the Perceptual Reasoning Index. Similar results were reported in a 2006 study of domestic violence offenders, which found differences by TBI status on the Vocabulary and Block Design subtests of the short form WAIS-R (p=0.03) (Marsh & Martinovich, 2006). Across six probation sites, Gorgens et al. (2021) assessed cognitive performance on either the Automated Neuropsychological Assessment Metrics (ANAM) or the Neuropsychological Assessment Battery – Screening Module (NAB-SM) and found 71% of their TBI-affected sample scored 2 standard deviations below the normed mean. The ANAM consists of seven subtests assessing Reaction Time, Learning, Attention/Processing Speed, Working Memory, Spatial Working Memory, Delayed Memory, and Inhibition (Gorgens et al., 2021; Kabat et al., 2001), while the NAB-SM consists of five domains Attention, Language, Memory, Spatial, and Executive Function, informed by two subtests each (Grills & Armistead-Jehle, 2016). A 2007 study used Ward's method Cluster Analysis to assess cognitive performance as measured on the Halstead-Reitan Neuropsychological Battery (HRNB), WAIS-R, or WAIS-III and formed four cluster groups in their sample of 55 homicide offenders, these clusters were defined by severe impairment, borderline

impairment, specific verbal learning difficulties, and being neuropsychologically typical, and found the severely impaired cluster demonstrated a significantly more severe TBI history (p<.05) (Warnick, 2007).

Notably, one study of a young Swedish offending population reported that their TBI-affected sample performed better than unaffected offenders on the WAIS-GAI (General Ability Index) (Katzin et al., 2020). The WAIS-GAI is an abbreviated version of the WAIS that consists of the Verbal Comprehension and Perceptual Organisation indices, eschewing the Working Memory and Processing Speed components of the Full-Scale IQ score as being less reflective of the participants' cognitive ability (Tulsky et al., 2001). Whether the use of the WAIS-GAI or the juvenile population is more responsible for this noteworthy outcome is a point for future investigation. No other studies found differences by overall cognition within this literature

Table 3.

Studies Reporting Cognitive Performance in Offending TBI Populations

Study	Participant Description	TBI Assessment	Instrument (Subtests administered if incomplete instrument)	Relevant results	CASP Checklist
Barnfield and Leathem (1998b)	Wanganui, New Zealand 50 prisoners with TBI LOC>30 minutes or endorsement of several post-TBI symptoms.	Self-report	AVLT, HRNB (finger tapping), ROCF, WAIS-R (Digit Symbol & Similarities).	Exposure: Substance abusers/mTBI vs Moderate TBI/Severe TBI Prisoners with TBI performed lower than norms on tasks of verbal memory (AVLT) & verbal abstract reasoning (Similarities task). Delayed free recall on AVLT was significantly poorer in moderate/severe TBI group compared to no/mTBI group (p=0.03).	6/9
Bernett (2013)	Several sites, USA n=118 women & n=106 men across six prisons.	TBIQ and interview	GAMA, Grooved Pegboard, HVLT-R, SDMT, TMT, WCST-64.	Exposure: No TBI vs mTBI vs Moderate/Severe TBI No significant differences in tests of executive functioning.	9/9
Bogner and Corrigan (2009)	Ohio, USA Two state prison populations n=105 men, n=105 women. 18-55 years.	OSU-TBI ID	WAIS-III (Digit Symbol, Symbol Search, Digit Span, Letter-Number Sequencing).	Exposure: Regression by summary indices of TBI history. Regression analysis found greater severity weighted TBI associated with better Working Memory (p < .0001).	8/9

Cohen et al. (1999)	Unspecified, USA *n*=39 male domestic violence (DV) offenders, *n*=63 non-violent males. Offenders recruited from outpatient treatment programme for anger management.	Clinical interview	ARCPT, Consonant Trigrams, COWAT, NVSRT, RMT-W, RMT-F, SRVLT, SILS, WAIS-R (Digit Symbol), WCST.	Exposure: No TBI vs Any TBI TBI and/or history of DV differed from non-DV without TBI in overall neuropsychological functioning ($p < .001$). DV offender with TBI not associated with cognitive deficits more than DV offending alone or being a non-offender with TBI.	9/9
Cohen et al. (2003)	Massachusetts, USA *n*=41 male DV offenders (outpatient treatment program). *n*=20 male non-DV offenders through advertisement.	Self-report and clinical record	ARCPT, COWAT, Go–No-Go, PASAT, Porteus Mazes, Stroop, TMT, WAIS–R.	Exposure: No TBI vs Any TBI No significant performance differences were found between DV men with (*n*=17) and without (*n*=24) TBI.	8/9
Fitzsimons (2017)	South England, UK *N*=56 female inmates. *n*=29 TBI and *n*=27 non-TBI.	Clinical interview	BADS (DEX), RBANS, TOPF, WASI-II.	Exposure: No TBI vs Any TBI TBI group performed poorer on the DEX (*p*=.004), indicating executive function deficits.	8/9
Gorgens et al. (2021)	Colorado, USA *N*=314 (73% male). 18-75 years. Recruited across 6 probation sites.	Modified OSU-TBI ID.	ANAM, NAB-SM.	Exposure: No TBI vs Any TBI 71% of participants with TBI history had 1 or more domain score -2.0 SD on ANAM Core Battery or NAB-SM.	7/9
Johnson (2016)	California, USA *N*=40 participants (*n*=18 male) on probation. Recruited via drug court. *n*=39 with any TBI history. 45% record TBI with LOC.	Self-report	COWAT, TMT.	Exposure: TBI<6 vs 6-20 TBI vs >20 TBI. No statistically significant result was found for persons with >20 TBI compared to persons who with fewer.	4/9

Katzin et al. (2020)	Western Sweden *N*=269 male violent offenders 18-25 years	Interview and clinical record	WAIS-III (GAI).	Exposure: No TBI vs Any TBI; No LOC vs Any LOC. Offenders with TBI had higher GAI scores (p=.004), but not clinically significant). M(TBI group)=94.6; SD=10.8, and M(non-TBI)=90.0; SD=11.1.	9/9
La Point (2014)	Virginia, USA *N*=213 male prisoners in a substance abuse programme. *n*=54 moderate/severe TBI cases, *n*=159 mTBI/no TBI cases.	OSU-TBI ID	TMT - A & B.	Exposure: No TBI/mTBI vs Moderate TBI/Severe TBI ANOVA indicated moderate/severe TBI had significant effect on TMT-A scores but not TMT-B. Moderate/severe TBI accounted for 3.4% of the variance on TMT-A.	9/9
LeMay and Stinson (2021)	Unspecified, USA *N*=246 psychiatric inpatients at a forensic residential site. *n*=25 with TBI.	Clinical record	WAIS-III for those with ID or TBI.	Exposure: Any TBI vs Norms Extremely low to borderline. FSIQ ranges 50-59: 3 cases, 60-69: 2 cases, 70-85: 4 cases, >85: 3 cases. 13 missing IQ assessments.	4/9
Marsh and Martinovich (2006)	Hamilton, New Zealand *N*=38 men with criminal convictions for violence enrolled in a partner abuse intervention programme. 58% report one or more TBI with LOC. 32% mild, 18% moderate, 50% severe.	Clinical interview	BADS, Hayling & Brixton, WAIS-R (Vocabulary & Block Design).	Exposure: No TBI vs Any TBI No differences in premorbid IQ. FSIQ lower in TBI versus non-TBI (p<0.05). 27% of TBI sample were within impaired range of the Hayling and Brixton tests.	8/9
McMillan et al. (2021)	Scotland, UK	OSU-TBI ID	AMIPB, COWAT, SDMT, TMT B.	Exposure: No TBI vs Any TBI	9/9

	N=109 female prisoners within Scottish corrections system. *n*=85 with TBI, *n*=24 non-TBI sample.			No statistically significant difference in mean overall cognition.	
O'Sullivan et al. (2021)	Unspecified, UK *N*=56 female prisoners. *n*=10 TBI-LOC, *n*=41 no TBI-LOC. *n*=5 lost to PVT.	Clinical interview	BADS (DEX), RBANS, WASI-II.	Exposure: LOC<10 minutes vs LOC>10 minutes No statistically significant differences between groups on cognitive performance.	6/9
Pitman et al. (2015)	Unspecified, UK *n*=103 male prisoners with TBI history. *n*=50 male prison controls.	Brain Injury Screening Index (BISI)	BADS, RBANS, WASI.	Exposure: No TBI vs Any TBI; Correlations by severity weighted TBI. Participants with TBI history performed poorer across all tasks (p<0.0167) TBI participants: RBANS M=77.27; BADS M= 84.82; WASI=88.58. Controls: RBANS M=92.08; BADS M= 99.02; WASI M=96.26.	9/9
Schofield et al. (2019)	New South Wales, Australia *N*=788 (85% male) young people on a supervised community order. TBIs grouped by none (*n*=481), single (*n*=308), or multiple (*n*=116)	Self-report	WASI, WIAT.	Exposure: No TBI vs Single TBI vs Multiple TBI. Those with TBI performed better on the WASI, attributable to Verbal IQ (p=.001) No TBI: 77.63 (SD=13.69) Single TBI: 80.61 (SD=13.24) Multiple TBI: 82.14 (SD=13.09)	7/9

Shiroma, Pickelsimer, et al. (2010)	South Carolina, USA *n*=20,098 males and *n*=1512 females in state corrections facilities. TBI grouped by AIS and ICD-9 coding with most severe record taking precedence. 5.60% TBI in males, 6.61% in females.	Clinical record	WRAT	Exposure: No TBI vs Any TBI No statistically significant differences in reading level by TBI status.	9/9
Slaughter et al. (2003)	Washington State, USA *N*=50 prisoners (88% male) within a local Washington jail. *n*=25 with TBI in past 12 months (*n*=20 mTBI compared to *n*=25 no TBI).	Self-report	COWAT; TMT; WMS-R (Logical Memory I and II)	Exposure: No prior year TBI vs Prior year TBI. No statistically significant differences.	6/9
Smith (2016)	California, USA *N*=433 prisoners (any gender, distribution not reported) within the California Central Valley County jail.	Clinical interview and prison file review	MOCA	Exposure: No TBI vs Any TBI No statistically significant differences.	8/9
Suchy, Euler, et al. (2014)	Utah, USA *N*=38 male prisoners. *n*=19 mTBI, compared to *n*=19 non-TBI controls.	Self-report	D-KEFS (TMT, Verbal Fluency, Colour-Word), WAIS-III (Digit Span, Letter Number	Exposure: No TBI vs <3 mTBI No statistically significant differences.	8/9

			Sequencing, Digit Symbol Coding, Symbol Search).		
Turner, Roszyk, Szumski, et al. (2020)	Nationwide, Poland *N*=243 male prisoners and community controls. *n*=70 child sex offenders, *n*=49 adult sex offenders, *n*=54 non-sexual offenders, *n*=70 non-offenders.	Self-report	d2, IGT, TMT, Verbal Fluency Task, Stroop, Tower of London, WCST.	Exposure: No TBI vs TBI w/o LOC vs TBI w/LOC; Correlations by total # of TBI. No statistically significant differences.	8/9
Umbrasas (2020)	Military Service, USA *N*=80 offending active-duty US military service members (96% men). *n*=16 cases with mTBI.	Department of Defence clinical records.	WAIS-IV (WMI)	Exposure: No TBI vs mTBI No statistically significant differences.	7/9
Warnick (2007)	Nevada, USA *N*=55 (95% males) homicide offenders referred for evaluation (1997-2005).	Clinical records, forensic records, interview	HRNB, WAIS-R, WAIS-III.	Exposure: No TBI vs mTBI vs Moderate TBI vs Severe TBI (Unclear method of categorisation) Sample clustered into "Severely Impaired", "Borderline IQ/Impaired", "Verbal Learning", and "Neuropsychologically Normal" on cognitive performance. “Severely impaired” had significantly more severe TBI history than Neuropsychologically Normal" and 'Verbal Learning" clusters. ANOVA (p<.05)	8/9

Chitsabesan et al. (2015)	Northwest England, UK *N*=93 male 15-18 years in custodial secure facility. No TBI/mTBI *n*=62 Moderate/severe TBI *n*=14	CHAT	K-Bit-2, TOWK.	Exposure: No TBI/mTBI vs Moderate TBI/Severe TBI. *n*=33 no/mTBI were below average language score, *n*=8 mTBI below average IQ. *n*=5 moderate/severe TBI below average language score, *n*=1 below average IQ. No further analysis due to low statistical power.	6/9

Notes: AMIPB: Adult Memory and Information Processing Battery; ANAM: Automated Neuropsychological Assessment Metrics; ARCPT: Adaptive Rate Continuous Performance Test; AVLT: Auditory Verbal Learning Test; BADS (DEX): Behavioural Assessment of the Dysexecutive Syndrome (Dysexecutive Questionnaire); BDS-EV: Behavioural Dyscontrol Scale – Electronic Version; BVMT-R: Brief Visuospatial Memory Test – Revised; COWAT: Controlled Oral Word Association Test; CVLT: California Verbal Learning Test; d2: Test of Attention; D-KEFS: Delis-Kaplan Executive Function System; GAI: General Ability Index (of the WAIS); GAMA: General Ability Measure for Adults; HRNB: Halstead-Reitan Neuropsychological Test Battery; HVLT-R: Hopkins Verbal Learning Test–Revised; IGT: Iowa Gambling Test; K-Bit-2: Kaufman Brief Intelligence Test Second Edition; LNNB: Luria-Nebraska neuropsychological battery; MOCA: Montreal Cognitive Assessment; NAB-SM: Neuropsychological Assessment Battery – Screening Module; NFI: Neurobehavioral Function Inventory; NVSRT: Non-Verbal Selective Reminding Test; PASAT: Paced Auditory Serial Addition Test; RBANS: Repeatable Battery for the Assessment of Neuropsychological Status; RCFT: Rey Complex Figure Test and Recognition Trial; RMT-F: Recognition Memory Test – Faces; RMT-W: Recognition Memory Test – Words; ROCF: Rey–Osterrieth Complex Figure; SDMT: Symbol Digit Modalities Test; SILS: Shipley Institute of Living Scale; SRVLT: Selective Reminding Verbal Learning Test; TMT: Trail Making Test; TOPF: Test of Premorbid Functioning; TOWK: Test of Word Knowledge; WAIS: Wechsler Adult Intelligence Scale; WASI: Wechsler Abbreviated Scale of Intelligence; WBIS: Wechsler-Bellevue Intelligence Scale; WCST: Wisconsin Card Sorting Test; WIAT: Wechsler Individual Achievement Test; WMS: Wechsler Memory Scale; WJB: Woodcock-Johnson Psychoeducational Battery; WRAT: Wide Range Achievement Test; WTAR: Wechsler Test of Adult Reading.

Discussion

The purpose of this systematic review was to identify how TBI has been measured in existing studies of cognition in offenders, determine how cognition has been assessed in studies of TBI-affected offenders, assess the evidence of cognitive differences by TBI history in offenders, and assess the quality of previous studies of cognition in TBI-affected offenders. This systematic review identified significant heterogeneity in measures of TBI history for this population, inconsistencies in cognitive assessment strategies used, inconsistent outcomes across cognitive domains by TBI history, and a breadth of quality that suggests some areas of pertinent investigation moving forward.

The findings from this review highlighted that in studies that identified differences in performance by cognitive status, these difficulties were primarily on tests of EF (Fitzsimons, 2017; La Point, 2014; Marsh & Martinovich, 2006), while two further studies reported deficits in overall cognition by TBI exposure (Gorgens et al., 2021; Pitman et al., 2015). However, most studies did not find any statistically significant differences in any areas of cognitive functioning between those reporting a TBI history and those who did not, with a small number reporting counterintuitive results of increased cognitive performance associated with increased TBI exposure (Bogner & Corrigan, 2009; Katzin et al., 2020). It is notable that many of these studies did not report significant differences in cognitive performance by TBI history, as several studies included a moderate and severe TBI sample with whom we would expect these cognitive tests to be sensitive (Bernett, 2013; La Point, 2014). Areas of development for future research are the application of systematic and validated methods of TBI history reporting and categorisation, increased study of women offenders, and targeted investigation into domains such as attention.

TBI Assessment Method

There was significant heterogeneity within the literature in how TBI status has been recorded. Methods included use of self-report questionnaires, medical notes, interviews, and screening tools such as the OSU TBI-ID, BISI, CHAT, or TBIQ (Bernett, 2013; Chitsabesan et al., 2015; Gorgens et al., 2021; Pitman et al., 2015). Using the medical record alone for ascertaining TBI history has shown significant limitations as many mTBIs are not disclosed in this population and are therefore both unrecorded and untreated (Thornhill et al., 2000). Other approaches in determining TBI history, such as interviews, are reliant on the recollection of the individual, and their accuracy may be influenced by the level of prompting provided by the clinician or researcher (McKinlay & Horwood, 2017; McKinlay et al., 2016). A self-report questionnaire generally refers to a participant being given a brief checklist to indicate whether they have experienced an incident that is likely to have been a TBI i.e., any impact to the head with LOC

(Johnson, 2016; Schofield et al., 2019). Clinical interviews are a lengthier process through which an interviewer may ask if the participant has ever had an injury with LOC while also probing further into their history to ensure that there are no incidents of TBI that are not initially recalled e.g., Have they experienced a car crash? Did they participate in contact sports? Do they have any experience of domestic violence? (O'Sullivan et al., 2021). Tools such as the TBIQ or OSU-TBI ID method provide a validated framework for prompting the individual to recall instances of possible TBI that they may not initially consider when reporting their history, these methodologies allow for a greater level of confidence in the reliability of TBI reporting (Diamond et al., 2007; Glover et al., 2018; Thornhill et al., 2000). Consequently, facilitated self-report methods, supported by clinical records are most likely to give an accurate history of TBI, including injuries not medically reported (Corrigan & Bogner, 2007b; McKinlay et al., 2016). The breadth of methods used in recording TBI history and severity makes comparisons between study findings more challenging, therefore standardised procedures should be identified that will elicit TBI history most accurately.

Most studies identified in this systematic review categorised TBI exposure by the most severe incident that the participant had experienced, or simply by whether the individual has any TBI history at all e.g., reducing no TBI, mTBI, moderate, and severe TBI to a dichotomous Yes/No variable. Due to the higher prevalence of TBI in offending populations and the increased likelihood of experiencing multiple TBIs, the combined effect of severity and frequency requires further investigation (Farrer & Hedges, 2011; W. H. Williams et al., 2010). The TBI index, as utilised by Pitman et al. (2015), suggests there is value in incorporating frequency into the TBI exposure variable, as they demonstrated statistically meaningful differences in performance across several cognitive assessment measures with the foremost methodological change from similar studies being the use of the TBI index (Fitzsimons, 2017; McMillan & Wood, 2013; Pitman et al., 2015). One further study categorised TBI history using lifelong frequency of TBI on a scale of one to five, six to 20, and 21 or more instances of TBI (Johnson, 2016), and while there is some evidence that number of reported TBIs is associated with more violent offences, these comparisons have been made between those with two or fewer TBIs and those with three or more (H. Williams et al., 2010). The need to assess for repetitive TBI is critical to understanding the impact of TBI in offenders, as evidence from sporting populations suggest the cognitive effects of TBI are greater in athletes with a history of repetitive TBI (Hume et al., 2017; McAllister & McCrea, 2017; Wright et al., 2020). This also raises the question whether there is a threshold effect of TBI frequency mediating the relationship between TBI history and offending, or TBI and cognition in offending populations. Future research should include more comprehensive assessments of TBI history to enable further exploration of their potential cognitive impacts.

One study within this literature assessed differences in cognitive outcomes between those with past year TBI and those without, which was a unique approach within the identified literature, and this study found no significant differences across several assessments (Slaughter et al., 2003). Despite this, recent evidence indicates TBI symptoms may still be resolving beyond 12 months post-TBI, indicating a need to better distinguish those in the post-acute stage of TBI rehabilitation and those experiencing chronic effects of TBI exposure (Dean & Sterr, 2013; Konrad et al., 2011; McInnes et al., 2017). For this reason, and the high overall prevalence of TBI in offending populations, future studies may wish to control for TBI recency as a covariate in analysis of results, to better understand the rehabilitative profile of TBI-affected offending populations.

Association of TBI and Cognition

Given the high prevalence of TBI in offending populations, it is surprising that most of the literature identified in this review found no association between TBI history and cognitive performance, even in moderate-severe cases. For some of these studies this reflects a primary focus on other variables (Shiroma, Pickelsimer, et al., 2010), or a lack of statistical power (Chitsabesan et al., 2015; LeMay & Stinson, 2021; Umbrasas, 2020). It is therefore necessary to investigate the quality of those studies that did reject a null hypothesis, to determine if there is a difference in study methodology, or quality, that might better explain the relationship between TBI and cognition in offenders.

Of the studies that did identify statistically significant associations between TBI history and cognitive performance, two were of young and juvenile offending populations in which TBI history was associated with higher scores on measures of Performance IQ and Verbal IQ (Katzin et al., 2020; Schofield et al., 2019). While notable, these differences were not clinically significant. However, these studies may indicate that TBI-affected juvenile offenders present a different profile to older offenders, further demonstrating that age at time of assessment and age of TBI occurrence are important variables to consider in future studies (Königs et al., 2016; Taylor et al., 2015).

From the remaining studies we can assess the quality of evidence they present for a significant relationship between TBI and cognitive outcomes in offending populations. The evidence from two of these studies is weakened by the lack of an appropriate control group for comparisons (Barnfield & Leathem, 1998b; Gorgens et al., 2021), these studies compared the results from forensic populations to the normed results for their assessment measures, given the multitude of confounding factors that likely impact on the performance of forensic populations for these assessments, it is important to consider these outcomes in context (Allen et al., 2016; Unsworth & Mathias, 2017; Weil et al., 2018). Other studies did present statistically

significant differences by TBI status but differences that are unlikely to be clinically meaningful, one study found moderate or severe TBI history accounted for 3.4% of the variance in performance on the TMT-A (La Point, 2014). Another study reported a statistically significant coefficient of determination of 0.138, which does not indicate a clinically meaningful association between TBI and test performance (Bogner & Corrigan, 2009).

Of the remaining studies, the study populations were distinct, recruiting from community intervention programmes (Marsh & Martinovich, 2006), homicide offenders (Warnick, 2007), and general prison populations (Pitman et al., 2015). Despite issues such as limited confidentiality, third-party observation, and a day-to-day prison environment that may be sedentary – or provide otherwise unavailable rehabilitative support - this suggests that any cognitive relationship is not completely being mediated by the assessment environment, and that the prison environment itself is not mediating outcomes as hypothesised (Meijers et al., 2015; Vanderhoff et al., 2011). It is important to note that these remaining studies were almost universally male-only study samples, with only one mixed gender study, which itself recruited 95% male participants (Warnick, 2007). This is further evidence of the need for more devoted investigation into female offending populations as they appear to be under-served by existing studies.

These four studies were not uniform in their cognitive assessment tools either, covering a breadth of tools both general and targeted. One study used cluster analysis to identify that participants with severe cognitive impairment were more likely to have experienced TBI (Warnick, 2007). Two other studies assessed specific domains of cognition and found differences on assessments from the Verbal Comprehension and Perceptual Reasoning indices from the WAIS-R or WASI-II (Marsh & Martinovich, 2006; Pitman et al., 2015). This is notable as these are the domains least expected to be affected by TBI and given that these studies did not assess the Working Memory and Processing Speed Indices, there may be differences in cognitive performance in these groups that these studies did not identify. The study by Pitman et al. (2015) also utilised the RBANS, which found meaningful differences in performance by TBI index score. This is a notable outcome as the RBANS has been found to have utility in assessing cognitive performance in populations experiencing dementia, Huntington's disease, schizoaffective disorders, and severe brain injuries, but there is less evidence for its sensitivity to mTBI (Lippa et al., 2013; McKay et al., 2008). As the RBANS is a comparatively short assessment of overall cognitive function, if it can accurately discern cognitive differences in forensic populations by TBI index score, it would be of tremendous value as a brief tool to identify potential TBI-related cognitive issues in this population.

Of the instruments that detected differences by TBI history in this literature, assessments of EF are more represented (Marsh & Martinovich, 2006; Pitman et al., 2015). The tests of EF that were used in studies that found a relationship by TBI status in offenders were the Hayling Sentence Completion test, the Brixton Spatial Anticipation test (Marsh & Martinovich, 2006), and the BADS (Pitman et al., 2015). The Hayling and Brixton tests are more focussed assessments that are intended to assess inhibition response, and impulsivity respectively (Bagshaw et al., 2014; Burgess & Shallice, 1996), while the BADS assesses EF more generally over several tests (Norris & Tate, 2000). It is unclear whether these studies detected differences unseen in much of the literature because of the specific domains of EF being assessed, or because of other aspects of these study designs, given the expectation of EF deficits in those with frontal lobe injury, future studies should be informed by these domains and assessment strategies.

Assessment Tool Appropriateness with Offending Populations

Despite demonstrating high levels of TBI exposure, including to more severe TBI, most of the studies within this literature did not identify any differences in performance by TBI status. Although partially dependent on offence type, offending populations demonstrate typically lower Verbal IQ (VIQ) with generally better results on Performance IQ (PIQ) measures than controls (Isen, 2010; Urruela et al., 2024; Walsh et al., 1987), which is reflected in a preference for visual over verbal measures in prison populations (Catalano et al., 2020a, 2020b). A 2010 meta-analysis of studies investigating the PIQ-VIQ discrepancy further analysed these differences by sub-test performance and found anti-social populations invariably struggled most with the sub-tests of verbal comprehension (Vocabulary and Information), tests associated with schooling (Isen, 2010). While these populations performed best on measures of perceptual reasoning (Picture Completion and Object Assembly) (Isen, 2010). These results provide important context for understanding the PIQ-VIQ discrepancy, as TBI complicates this trend as TBI is associated with lower performance in both working memory (a component of VIQ) and processing speed (a component of PIQ) tasks (Isen, 2010).

Given tests of processing speed such as the Digit Symbol or the SDMT measure areas of relative strength for offending populations, but are often affected by TBI, we would expect they may be sensitive to TBI in offenders, however this was not the case within the existing literature. Several studies utilising these tests found no statistically significant differences by TBI history (Barnfield & Leathem, 1998b; Bogner & Corrigan, 2009; McMillan et al., 2021; Suchy, Euler, et al., 2014). While some of these outcomes may be attributable to issues of study quality, such as small sample sizes (Suchy, Euler, et al., 2014) or a lack of an appropriate control group (Barnfield & Leathem, 1998b), it is possible TBI is not affecting offending populations performance in these

domains of cognition in the same ways as non-offending groups. Further study is needed that targets the domains most often affected by TBI, and if offending populations are not experiencing the same differences in cognition by TBI status as non-offenders, this would be an important phenomenon to investigate.

Several studies reported cognitive performance on measures of general cognitive performance such as the WAIS, or WASI, while others used a screening measure such as the MOCA, meaning only associations by global cognition could be reported (Katzin et al., 2020; LeMay & Stinson, 2021; Smith, 2016). By reporting scores such as the FSIQ alone, these studies limit their utility in detecting domain specific deficits that might be expected in offending populations (Isen, 2010; Kavanagh et al., 2010; Urruela et al., 2024). These studies did not find statistically significant differences on these measures despite evidence from community-based studies that TBI history is predictive of lower FSIQ scores in both subacute and chronic stages of TBI recovery (Königs et al., 2016). The use of the WASI and the GAI of the WAIS represents a potential reporting issue within this literature, due to the localised nature of the cognitive effects of TBI (Isen, 2010; Kavanagh et al., 2010; Urruela et al., 2024). Both the WASI and the GAI solely measure the domains of Verbal Comprehension and Perceptual Reasoning, those least likely to be influenced by mTBI (Carlozzi et al., 2015; Donders & Strong, 2015). While these batteries assess important domains of functioning, it would be more appropriate to assess their counterpart domains that make up the Cognitive Proficiency index, which are Working Memory and Processing Speed (Carlozzi et al., 2015; Donders & Strong, 2015). It would be ideal to utilise assessment batteries that can improve understanding of how targeted TBI-related cognitive sequelae are in studies of offending populations. Furthermore, when studies do use targeted assessment batteries, they should be targeted at the domains of interest for the specific offending population (Isen, 2010; Kavanagh et al., 2010; Urruela et al., 2024).

Within the existing literature, working memory is the most thoroughly explored component of memory, which is reflective of its role in EF and the impact that frontal lobe injury, as a common form of TBI, can have on working memory performance (Chung et al., 2019; Dunning et al., 2016; McDowell et al., 1997). Community-based studies have frequently shown working memory difficulties in the acute, post-acute, and chronic phase of TBI recovery across the range of TBI severities, with inconsistent results for mTBI populations (Draper & Ponsford, 2008; S. Kumar et al., 2009; Marsh et al., 2016; McDowell et al., 1997). It is therefore notable that it was not a more prevalent issue identified within the forensic populations of this literature, and while much of the community-based literature investigates the acute stages of recovery, there is evidence from these community-based studies that working memory issues perpetuate into the chronic stage (Draper & Ponsford, 2008; Ponsford et al., 2024; Vanderploeg et al., 2005).

It is unclear why the association between working memory and TBI exposure is present in studies of community-based populations but not offending populations. This difference may be attributable to confounding factors, such as mental health conditions, that should be accounted for. These populations differ in underlying and undiagnosed psychiatric conditions, prison populations experience higher rates of conditions such as ADHD, autism spectrum disorder, or substance abuse disorder, all of which are likely to contribute to working memory difficulties, but are not consistently controlled for within the forensic literature (Allely, 2018; Baranyi et al., 2022; Fazel & Favril, 2023; Ginsberg et al., 2010; Young et al., 2015). Based on the existing forensic literature, greater importance must be placed on relevant confounders before dismissing the role TBI may have in the working memory of offending populations.

Differences in EF were expected as deficits are a shared risk factor of TBI and offending behaviour, that most studies did not report any EF deficit is notable. A frequently used tool of EF assessment is the WCST, which was ineffective in identifying EF deficits across several studies (Bernett, 2013; Cohen et al., 1999; Turner, Roszyk, Szumski, et al., 2020), while this may be attributable to deficiencies in study quality in some cases, there is evidence to suggest the traditional WCST would be ineffectual in identifying the relevant deficits (Eling et al., 2008; Nyhus & Barceló, 2009). The WCST has been criticised for being overly lengthy, particularly for impaired participants who are prone to fatigue or frustration with its administration time (Robinson et al., 1991). To resolve this issue, abbreviated versions such as the WCST-64 have been created, however the WCST-64 has been found to be an inappropriate tool for use with TBI-affected populations, due to a lack of criterion validity (Merrick et al., 2003). For these reasons, the WCST may not be an appropriate assessment tool for future studies of this population.

Another frequently used tool to assess EF was the TMT. The TMT is a popular tool in assessing processing speed, sequencing, and visuo-motor skills, consisting of a Test A and Test B, with the TMT-B subtest also being associated with the alternating attention and set-shifting component of EF (Bowie & Harvey, 2006). Within the literature, one study found differences in performance on TMT-A (La Point, 2014), but not by TMT-B, and in several studies no association was found with either (Bernett, 2013; Cohen et al., 2003; Johnson, 2016; McMillan et al., 2021; Slaughter et al., 2003; Suchy, Euler, et al., 2014). The TMT does not however, have the same risk of fatigue that the WCST does, and has been demonstrated as effective in distinguishing TBI-related differences in general populations (Lange et al., 2005; Periáñez et al., 2007), but evidence from prison populations is lacking (Meijers et al., 2015). Overall, the TMT-B may be an appropriate assessment tool of set-shifting in TBI-affected offenders.

While the TMT and WCST are notable tests of set-shifting, EF was also assessed through tests of inhibition, such as the Go-No-Go, and tests of interference control, such as the Stroop test. Notably, no deficits were found across these tests within this literature, which is at odds with our expectations given the outcomes in studies of community populations (Azouvi et al., 2016; Filipčíková & McDonald, 2023; Xu et al., 2017). A 2011 meta-analysis found substantial effect sizes with nonsignificant heterogeneity across tests of response inhibition, but the effect of TBI on the Stroop interference task was small and statistically insignificant (Azouvi et al., 2016; Dimoska-Di Marco et al., 2011). Notably, this meta-analysis did find differences in Stroop performance by TBI status if the outcome variable is specifically the time taken to complete the task, shifting the test from an assessment of interference control, to one that integrates additional components of response speed and fatigue (Dimoska-Di Marco et al., 2011).

Despite the tests popularity, the Stroop may not be appropriate as a tool to distinguish between offending populations, and this has been shown previously when it has been used to assess inhibition by mental health status in offenders (Molleman et al., 2022), whereas tools such as the Go-No-Go or the IGT have shown sensitivity to TBI and been used to successfully differentiate between sub-groups such as sexual and non-sexual offenders (Filipčíková & McDonald, 2023; Turner et al., 2018). In the context of offending populations, the expectation is that there will be greater deficits in managing inhibitions, however the Stroop may not be an effective tool at assessing this, particularly in TBI-affected offenders (Ben-David et al., 2011; Dimoska-Di Marco et al., 2011).

Another important domain of EF is verbal fluency, which was assessed frequently within the literature with no studies demonstrating significant differences by TBI status (Cohen et al., 2003; Cohen et al., 1999; Johnson, 2016; McMillan et al., 2021; Slaughter et al., 2003). This is notable as tests of verbal fluency, such as the COWAT, are particularly sensitive to the presence of TBI in community populations (Anderson et al., 2017; Cermak et al., 2021; Marsh et al., 2016). A 2004 meta-analysis of verbal fluency performance in 1,269 participants with TBI history found significant impairments of phonemic and semantic fluency that could not be accounted for by deficits in other domains of function (Henry & Crawford, 2004). In a review of studies comparing the EF of violent and non-violent offenders, violent offenders performed worse on assessments of verbal fluency with medium to large effect sizes of mixed statistical significance (Burgess, 2020). So, despite evidence of the utility of verbal fluency measures in identifying TBI-related deficits in community populations, there is mixed evidence for their use in assessing offending populations, therefore verbal fluency may be a domain of use in identifying why cognitive trends within the general TBI-affected population may not hold true for offenders.

Given the evidence from community-based studies and the vulnerability of the frontal lobe and its executive functions to injury, it is notable that the relationship between TBI and executive dysfunction has been demonstrated rarely in offenders (Henry & Crawford, 2004). It is important to note that few studies have thoroughly investigated the EF of prison populations against community controls, with a 2015 systematic review finding only seven relevant English-language studies (Meijers et al., 2015). It is apparent that EF in offending populations requires more investigation before an ideal assessment battery can be identified. It may be that TBI and non-TBI offending populations perform similarly on tests of EF, but the existing evidence is inconclusive, and that future research should adjust for relevant confounders and choose the most appropriate assessment tools.

Gender

Very few studies of the identified studies were explicitly focussed on women, and women were often underrepresented in mixed gender studies (LeMay & Stinson, 2021; Schofield et al., 2019; Umbrasas, 2020). This is a particular issue due to the different profiles presented by male TBI prison populations compared to women. Women in prisons report similar if not higher rates of overall TBI, and some evidence shows that women may be more at risk to the effects of TBI (Dougan et al., 2014; Shiroma, Ferguson, et al., 2010). Unfortunately, studies seem to have largely forgone female TBI offending populations; perhaps due to the larger, more accessible, male offending groups and while the existing literature indicates new avenues for investigating TBI in male offending populations, the shortage of existing studies targeting female offending populations indicates our understanding of this groups needs is lagging. Community-based studies have been inconclusive as to the importance of gender on cognitive outcomes following TBI, with studies variously finding women experience greater TBI-related deficits in VIQ, FSIQ, and attention (Schopp et al., 2001), working memory (Hsu et al., 2015), and visual memory (Covassin & Bay, 2012) while others report women outperform men following TBI in visual memory (Moore et al., 2010). Community-based populations have also demonstrated that women may be more vulnerable to depressive symptoms following TBI, while men appear to be disproportionately affected by other forms of psychological distress (Schopp et al., 2001). Given the lack of existing studies of female offenders and the inconsistent evidence from community populations, more thorough investigation into the effects of TBI by sex and gender in offenders will be an important component of future research.

Offending Populations

Another notable aspect of this literature is the use of prison-based populations over community-based offenders. 17 of the studies targeted a prison or secure psychiatric population, while seven were based in the community, including those on probation. Given that

TBI is a risk factor for executive dysfunction, which in turn is associated with offending, it is concerning that most participants are sampled outside of the community contexts in which most of their offending occurred (Dimoska-Di Marco et al., 2011; Meijers et al., 2015; Osborne-Crowley & McDonald, 2018; Williams et al., 2018). Although a prison population may be more accessible to researchers than community-based offenders, there is evidence that EF is positively related with environmental enrichment i.e., environments that provide positive physical, social, and cognitive stimulation (Hillman et al., 2008; Meijers et al., 2015; Petrosini et al., 2009). In an inflexible and sedentary environment, as prison can be, it seems likely that prisoners would perform differently on these assessments of cognitive functioning then they would in their communities (Meijers et al., 2015; Woodall et al., 2014). More community-based assessments would be valuable in determining how the key cognitive domains are changing as offenders move from their community, where they would have first offended, to the prison environment which will meaningfully differ in opportunities for cognitive enrichment than where those offences occurred.

Study Quality

Due to the heterogenous nature of this literature, the CASP was used as a framework to assess the validity and reliability of these studies (Critical Appraisal Skills Programme, 2024). Several studies had issues that largely preclude them from meaningfully contributing to our understanding of the potential relationship between TBI and cognition in offenders. A 2021 study of 56 female prisoners included only 10 TBI-affected participants, unfortunately weakening an already sparse pool of research into female populations (O'Sullivan et al., 2021). Similarly, the study by LeMay and Stinson (2021) assessed a group of 246 forensic psychiatric inpatients, however only 25 of these reported history of TBI and only 12 of these had undergone cognitive assessment - allowing only incidental conclusions to be drawn about TBI and cognition. Two of these studies (Chitsabesan et al., 2015; La Point, 2014) made their comparisons between groups with no TBI or mTBI against those with moderate or severe TBI. This choice likely has implications for their findings as some mTBI, particular complicated mTBI, have shown some effects on cognitive performance and therefore may be confounding these studies results (Hacker et al., 2023).

The study by Shiroma, Pickelsimer, et al. (2010) has a different issue, this was a rare longitudinal study that aimed to assess prison infractions by TBI status, but also presented results on the WRAT-4 by TBI status. While the WRAT-4 is a performance-based cognitive assessment, it is insensitive to the cognitive effects of TBI and has demonstrated validity as a measure of premorbid function for those recovering from TBI (Berg et al., 2016; Golden & Bennett, 2024; Orme et al., 2004). Furthermore, this study included only TBI appearing in

emergency department and hospital databases, which is likely to vastly underestimate the prevalence of TBI in offending populations (Feigin et al., 2010; Puljula et al., 2012; Shiroma, Pickelsimer, et al., 2010; Xun et al., 2023). Therefore, this study failed to collect data in a way that allowed for conclusions about the relationship between cognition and TBI to be drawn. Other studies were limited by their statistical approach and failed to meet the criteria of rigorous data analysis, the study by Barnfield and Leathem (1998b) conducted 13 tests of difference and do not report any correction multiple for multiple comparisons. By applying multiple correction, Barnfield and Leathem (1998b) may have reduced their number of significant findings, as was the case elsewhere (Fitzsimons, 2017).

While this literature differentially adjusted for several confounding variables, it is especially important to consider how these studies accounted for performance validity. Given that offending populations might feel incentivised to perform poorly on assessments of cognitive function to influence their sentencing, an assessment of effort is essential to ensure valid results. Of 56 participants, Fitzsimons (2017) reported only two below the suggested cut-off score of 45 on the TOMM and based on embedded effort measures within the RBANS and Digit Span task that indicated appropriate effort, they determined that these participants could be included in data analyses. Pitman et al. (2015) also used the embedded effort measure of the RBANS and determined that the TBI-affected population were performing significantly poorer on effort measures, however upon removing the nine participants that failed to meet the effort cut-off score, they did not identify any changes in trends between the TBI and non-TBI effected study groups. One other study also used a combination of the TOMM and embedded measure of the RBANS, finding a female prison population of 51 all demonstrated sufficient effort on the RBANS, with five participants being excluded for not meeting the cut-off of the TOMM, it was not reported whether these participants had TBI exposure (O'Sullivan et al., 2021). An assessment of an offending military population used both the TOMM and the Validity Indicator Profile as indicators of validity, however an assessment of performance validity was administered at the discretion of the clinician, and it is unclear how many participants were not assessed for effort or were excluded from data analysis due to suspect performance validity (Umbrasas, 2020). While the TOMM was a popular tool for assessing validity, alternative options such as the Rey-15 (Marsh & Martinovich, 2006) and Word Memory Test (McMillan et al., 2021) were also utilised, with neither finding any systematic issues in performance validity from their study populations. No other studies within this literature pool reported any use of effort measures. These results indicate that forensic populations are not frequently showing poor performance validity, and the perception of this group as being likely to under-perform may be misplaced. Despite this, it remains important to consider performance validity when trying to

accurately assess cognitive performance in any population and more widespread usage of performance validity tools would increase the overall quality of this literature pool.

An additional variable of interest within these studies would be premorbid functioning, the level of cognitive performance prior to any injury, and given the seemingly intertwined factors of cognitive functioning, TBI exposure, and offending behaviour it is necessary to identify the directionality of any possible relationship. Most of these studies were cross-sectional and as most individuals have no history of psychometric assessment prior to injury, several tools for estimating premorbid function were used. Within this literature, the most popular assessment of premorbid function was the TOPF, being used by three studies, none of which identified statistically significant differences in premorbid function by TBI status (Fitzsimons, 2017; O'Sullivan et al., 2021; Pitman et al., 2015). One other study analysed results of the National Adult Reading Test, with further analysis using the Barona Index of the WAIS-R for those with pre-existing reading disorders, no significant differences were found by TBI status (Marsh & Martinovich, 2006). The only other study that suggested a measure of premorbid function utilised the Oklahoma Premorbid Intelligence Estimate, however it is unclear if any analysis incorporated results from this (Slaughter et al., 2003). This lack of relationship indicates that cognitive differences prior to TBI are not accountable for any differences in lifetime TBI exposure. This suggests future studies should be designed with the understanding that in this possibly bidirectional relationship, TBI is more likely to contribute to differences in cognitive performance than cognitive performance is likely to act as a major risk factor to experiencing TBI.

Conclusion

The purpose of this review was to identify and determine the strengths and weaknesses of studies that assessed cognitive performance by TBI status in offending populations. The literature was found to be heterogenous in methodology and inconclusive in outcome. The studies were also diverse in quality, with several being unlikely to meaningfully contribute to an understanding of the relationship between TBI, cognition, and offending. This review did identify several important considerations for future studies in this field, including the need to uniformly adopt thorough TBI assessment protocols, the potential importance of repetitive TBI in cognitive outcomes, a need for targeted and population-appropriate cognitive assessment tools, and the under-representation of female and community-based offending populations in the existing literature. Given the inconsistent relationship between cognitive outcomes and TBI status within this literature it is important to consider these results within the context of the existing community-based evidence to see how these studies align with the wider understanding of TBI

and cognition. With this knowledge, future studies can be designed more appropriately and improve our understanding of the ways in which TBI may be affecting offending populations.

Chapter Six: Assessing Cognitive Functioning Following Acute mTBI as a Predictor of Long-Term Offending Behaviour

Introduction

Individual studies have shown acute and post-acute mTBI patients perform more poorly on measures of processing speed, attention, working memory, immediate memory, delayed memory, and EF (Anderson, 2021; de Freitas Cardoso et al., 2019; Studer et al., 2014). In a case-control study of 421 patients with medically attended mTBI and 120 trauma controls, those with complicated TBI and/or a GCS score below 15 performed lower than controls across a comprehensive battery of cognitive assessments (Dikmen et al., 2017). In a prospective longitudinal study, Keatley et al. (2023) identified four trajectories of post-concussion symptom recovery following mTBI: minimal acute symptoms that decrease over time; mild acute symptoms that decrease over time; high acute symptoms that decrease over time; and 13% of their sample had high acute symptoms that worsened over time (Dikmen et al., 2017; Keatley et al., 2023).

The existing body of research demonstrates that offending populations experience more mTBIs than non-offending populations (Allely, 2016; Durand et al., 2017; Moynan & McMillan, 2018), and that offending populations demonstrate lower performance on various tests of cognition, particularly tests of EF (Cohen et al., 1999; Meijers et al., 2015; Meijers et al., 2017; Shumlich et al., 2019). Whether mTBI is playing a meaningful role in the association between mTBI, cognitive performance and offending requires further investigation.

Most research in this space is cross-sectional, which makes the directionality of the relationship between injury and offending unclear i.e., do mTBI-affected populations demonstrate executive dysfunction due to the effects of injury, or are those with executive dysfunction more likely to engage in behaviours that lead to mTBI (Fishbein et al., 2016; Ray & Richardson, 2017; Schwartz et al., 2018). In a rare longitudinal investigation of this matter, Schwartz et al. (2018) undertook a seven-year follow-up study of teenagers (recruited age 14-17) that found self-reported disinhibition was not statistically significantly associated with experiencing a future TBI (Schwartz et al., 2018). However, experiencing a TBI however was statistically significantly associated with future levels of disinhibition (Schwartz et al., 2018). Understanding this relationship between TBI and disinhibition is important because of the consistent evidence of low self-control and disinhibition (components of EF) being associated with anti-social and offending behaviour in meta-analyses (De Ridder et al., 2012; Pratt & Cullen, 2000; Vazsonyi et al., 2017).

While executive dysfunction following mTBI is of particular importance due to the relationship with disinhibition and anti-social behaviour, other domains of cognition have also shown long-term effects of mTBI. Although studies have not universally found an association between mTBI and long-term cognitive performance, several studies have shown a relationship at one-year or longer post-injury (Anderson et al., 2001; Dikmen et al., 2017; Konrad et al., 2011; Vanderploeg et al., 2005). This long-term lower performance has been identified in episodic memory (Dikmen et al., 2017), verbal learning (Anderson et al., 2001; Dikmen et al., 2017; Konrad et al., 2011), working memory (Vanderploeg et al., 2005), and attention (Vanderploeg et al., 2005). While these domains do not align as directly with anti-social behaviour as executive dysfunction, the scope and duration of these possible deficits into the long-term stage of recovery requires further investigation.

This chapter is an analysis of longitudinal data from the BIONIC (Feigin et al., 2013). The BIONIC identified all new instances of mTBI over a year-long period in the Waikato region of NZ (Feigin et al., 2013). In the acute and post-acute stage of recovery, study participants completed a computerised assessment of their cognitive abilities. At 10-years post-injury, participants completed a survey of their engagement in several anti-social and illegal behaviours, or it was recorded that were currently in prison at the time. The current analysis aims to evaluate the relationship between post-acute TBI cognitive performance and long-term anti-social offending behaviour. This longitudinal approach provides a rare and valuable opportunity due to the difficulty in discerning directionality in the relationship between TBI and offending behaviour.

The BIONIC study also assessed several relevant covariates that may also affect the relationship between mTBI, cognitive performance, and anti-social behaviour. These include mood (Emery et al., 2016; Grandhi et al., 2017; Moore et al., 2014), post-concussion symptoms (Davies et al., 2012; Fournier, 2021), alcohol abuse (Boden et al., 2013; Kuhns et al., 2014), and illicit substance abuse (Beaulieu-Bonneau et al., 2018; Ilie, Mann, et al., 2015; McKinlay, Corrigan, et al., 2014). Analysis of the relationship between cognitive performance and anti-social offending behaviour therefore requires controlling for these variables.

The approach of this study is that by evaluating cognitive performance in the acute and post-acute stage of recovery, the role of post-acute cognitive symptoms in determining long-term anti-social offending behaviour can be better understood. Based on the existing evidence it is reasonable to suggest TBI is associated with and precedes issues of executive dysfunction, such as disinhibition, and to therefore hypothesise that these cognitive sequelae put individuals at a greater likelihood of engaging in offending behaviour. The current study provides a unique opportunity to assess how performance-based measures of cognition relate to long-term anti-social and offending behaviour, rather than relying upon self-reported measures of cognitive

symptoms and cross-sectional data (Schwartz et al., 2018). This study also examines cognitive performance in the acute and post-acute stages of mTBI recovery, when cognitive symptoms are their most prevalent, to identify whether this stage of recovery is predictive of long-term behavioural outcomes.

Based on the existing literature the primary hypothesis was that levels of cognitive flexibility and executive functioning in the acute phase of mTBI will be significantly lower in people who engaged in antisocial behaviour 10 years post-injury

Methods

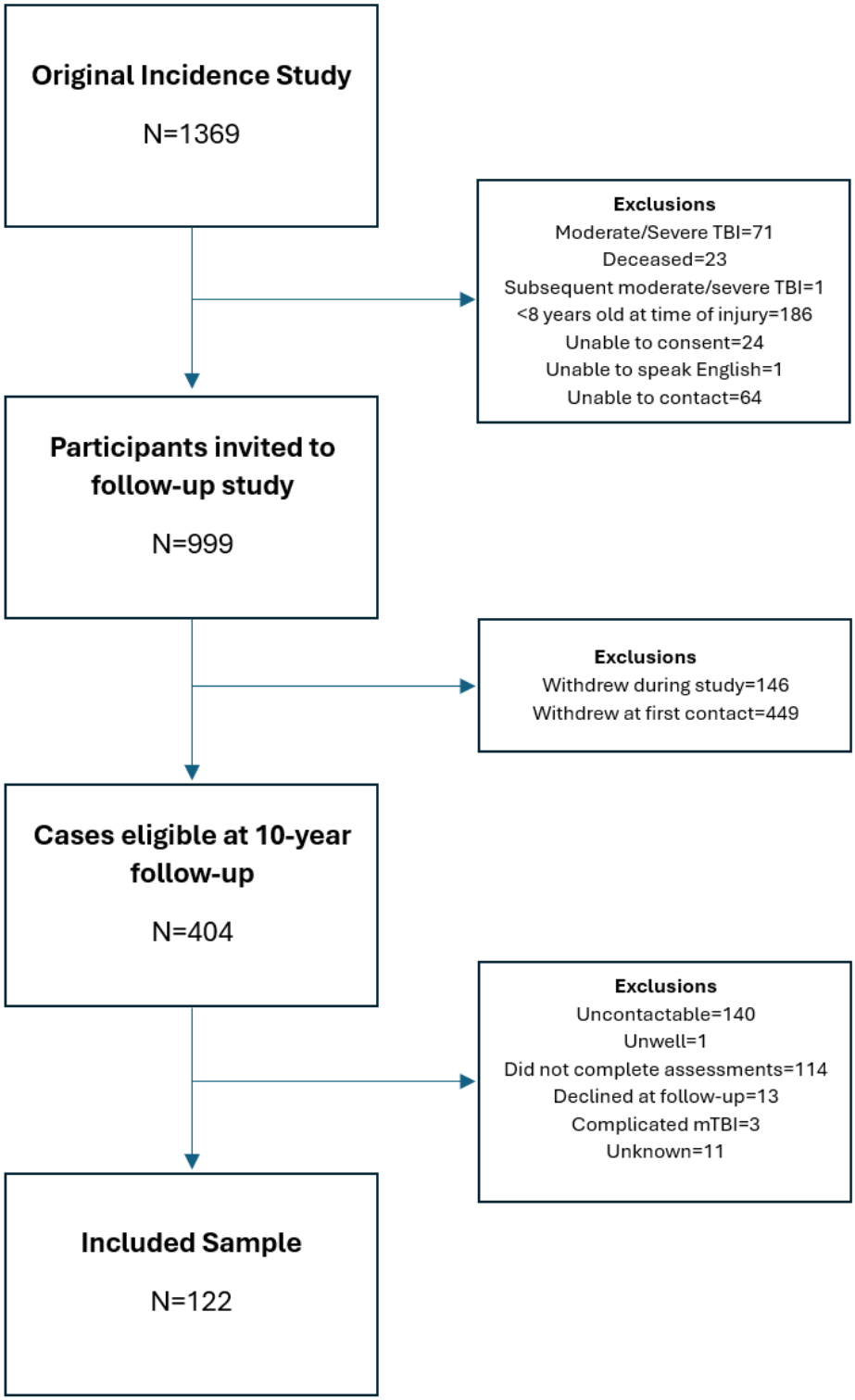
The BIONIC study collected data on all new cases of TBI (including mild, moderate, and severe) across the Waikato region of New Zealand between March 1, 2010, and February 28, 2011. People who consented to the incidence study were invited to take part in follow-up assessments at baseline (within 2 weeks), at 1-month, 6-month, 12-months, 4-, 8- and 10-years post-injury. For the purposes of this study, sociodemographic, mood, and injury data were extracted from the baseline dataset and cognitive assessment data was extracted from the 1-month assessment (or baseline assessment where one month data was not available). Anti-social behaviour, symptom severity, mood symptoms, and alcohol and illicit substance use were extracted from the 10-year follow up data. Baseline assessments were conducted between 2010 and 2011, and the 10-year assessments were completed between March 2020 and February 2021.

Identification of mTBI cases: The BIONIC study aimed to register every instance of TBI, of any severity, within the Waikato region of New Zealand over a 12-month period. Several methods of identifying TBI cases were used to capture TBI across the levels of severity. This included screening private and public hospital admissions and emergency department discharge lists, search of the coroners records for death certificates identifying TBI as a cause of death, community healthcare services including General Practitioners and concussion services, Accident Compensation Corporation, and the New Zealand Health Information Service. Checks were made to identify and exclude duplicate cases. To meet the definition of TBI for inclusion in the study, participants were required to have a mechanism of injury likely to lead to TBI with evidence of an altered level of consciousness including signs of confusion/disorientation, LOC, PTA, and/or neurological symptoms attributable to an external physical force (Feigin et al., 2013). As many cases of TBI go undiagnosed, cases where the diagnosis of TBI may have been missed were reviewed by a Diagnostic Adjudication Group on a weekly basis. Mild TBI was classified as having a GCS of 13-15 or PTA less than 24 hours (Feigin et al., 2013). If severity could not be confirmed i.e., no PTA or GCS score was recorded, those cases were categorised as mTBI

(Feigin et al., 2013). Of the 1369 cases of TBI identified, mTBI accounted for the vast majority (*n*=1298, 94.8%); over moderate (*n*=26, 1.9%); or severe TBI (*n*=45, 3.3%) (Feigin et al., 2013).

Participant Sample: Inclusion criteria for this study included participants aged ≥18 years at the 10-year follow-up, classified as having a mTBI, not eligible for CT scan or negative CT result (classified as an uncomplicated mTBI), have completed cognitive assessments at baseline or one-month timepoints, and completed the anti-social behaviour assessment at 10-year follow-up. As shown in Figure 2, 404 participants from the BIONIC study were eligible to take part in the 10-year follow up assessment, 122 (30.2%) of which were successfully recruited. Reasons for attrition at 10 years included participants being uncontactable, declining to take part, or not completing the anti-social behaviour assessment. The 10-year follow up assessments were completed during the peak of the COVID pandemic which may have influenced participant's ability to take part at this timepoint.

Figure 2. Study Recruitment and Exclusion



Demographically, differences in gender representation between the time of injury and the present analysis were not significant when assessed through a chi-square (p>.05), as shown in Table 4. However, there were significant differences in ethnicity (p<.01), between the timepoints, with an overrepresentation of European participants. There was a non-significant

difference in age at time of injury between the original post-acute sample (*M*=27.5 years, *SD*=21.3) and the 10-year follow-up (*M*=29.4 years, *SD*=24.5), assessed by an unpaired *t*-test of mean difference (*p*=.35). This suggests that attrition bias by age and gender is unlikely to be an issue, but that results of this analysis may not be generalisable across ethnicities.

Table 4.

Demography Comparison of 2010 Incidence Study and Current Sample

Demographic Variables		2010	Current Sample
Sex	Female	37.5%	39.3%
	Male	62.5%	60.7%
Ethnicity*	European	60.7%	74.6%
	Māori	31.1%	23.0%
	Other Ethnicities	8.2%	2.4%
Mean Age at Time of Injury		27.5	29.4

* Significant difference at the *p*<.01 level

Primary Outcome Measure

Offending behaviour was assessed using items from the Subtypes of Anti-social Behaviour (STAB). The STAB is a 32-item questionnaire which assesses a range of anti-social behaviours from overt, physically aggressive behaviours to covert, rule-breaking behaviours (Burt & Donnellan, 2009). These items are rated using a five-point Likert scale: 1 – Never, 2 – Hardly ever, 3 – Sometimes, 4 – Frequently, 5 – Nearly all the time. Six items from the STAB were identified as appropriate indicators of criminal offending behaviour for this study, they include threatening others, being in a physical fight, stealing, carrying a weapon, damaging or littering property, and selling illegal drugs (Burt & Donnellan, 2009). Participants were grouped into anti-social behaviour if they responded sometimes, frequently, or nearly all the time, on any of the six items, any participant who was unable to complete the assessment due to imprisonment

Cognitive Assessment and Risk Factors

Potential risk factors for longer term anti-social behaviour were measured within one month of injury including cognitive functioning, substance abuse, symptom severity, and mood.

Cognitive function: Cognitive function was assessed using the CNS-Vital Signs (CNS-VS) (CNS Vital Signs, 2014; Gualtieri & Johnson, 2006)**,** a comprehensive computerised battery comprised of seven core subtests. These subtests and their relevant domain of functioning are detailed below.

1. Verbal Memory (VBM): Word Recognition, Immediate and Delayed Recall. An adaptation of the RAVLT.
2. Visual Memory (VIM): Shape Recognition, Immediate and Delayed Recall. An adaptation of the RVDLT.
3. Finger Tapping: (FTT): Motor Speed and Fine Motor Control.
4. Symbol Digit Coding (SDC): Processing Speed and Complex Attention. A variant of the Wechsler DSST.
5. Stroop Test (ST): Executive Function, Disinhibition, and Reaction Time.
6. Shifting Attention Test (SAT): Executive Function and Reaction Time. No equivalent existing conventional test.
7. Continuous Performance Test (CPT): Attention and Impulsivity.

It is important to note that the Stroop test within the CNS-VS has some notable differences from the traditional Stroop test (CNS Vital Signs, 2014; Gualtieri & Johnson, 2006). The CNS-VS Stroop test has three components, the first is a simple reaction speed task in which colour words (red, yellow, blue, green) appear on screen one at a time and the participants must press the spacebar of their computer as soon as a word appears (CNS Vital Signs, 2014; Gualtieri & Johnson, 2006). For the second task, colour words appear on screen, however this time they are printed in colour, and the participant is asked to press the spacebar as soon as a colour word appears in its corresponding colour on screen (CNS Vital Signs, 2014; Gualtieri & Johnson, 2006). The final task involves colour words appearing on screen, and the participant must press the space bar when the word and colour do not correspond (CNS Vital Signs, 2014; Gualtieri & Johnson, 2006). Although a “Stroop effect” is being assessed with this task, it is important to acknowledge that it is not identical to the traditional pen-and-paper Stroop task.

Scores were automatically generated by CNS-VS software based on subtest scores or a combination of composite scores. The composite domain scores include Cognitive Flexibility, Complex Attention, Psychomotor Speed, and Composite Memory. An overall total score, Neurocognitive Index (NCI), was also calculated using scores across domains. Details of these domains, how they are assessed and calculated is shown below in Table 5 (Brooks et al., 2014; CNS Vital Signs, 2014). Use of a computerised cognitive assessment assisted in the detection of small changes in cognition from mTBI and ensured consistency of test administration between researchers (Gualtieri & Johnson, 2006).

Table 5.

CNS-VS Domains of Cognition

Domain	Component Tests	Calculation	Measure
Composite Memory	VBM & VIM	Sum of domain scores	Ability to recognise, remember and retrieve shapes and words.
Psychomotor Speed	FTT & SDC	Sum of finger taps and correct SDC responses	Ability to perceive and respond to complex stimuli and perform fine motor skills.
Complex Attention	CPT, SAT, & ST	Sum of errors on constituent domains	Ability to track stimuli over time and perform complex tasks accurately.
Cognitive Flexibility	SAT & ST	Correct SAT responses minus SAT and ST errors	Ability to manage complex and changing directions and manipulate information.
NCI	All domains	Sum of the five domains	Overall neurocognitive status.

Notes: VBM: Verbal Memory; VIM: Visual Memory; FTT: Finger Tapping Test; SDC: Symbol Digit Coding; CPT: Continuous Performance Test; SAT: Shifting Attention Test; ST: Stroop Test; NCI: Neurocognitive Index.

The CNS-VS takes approximately 30 minutes to administer and has been well validated across varying populations, including children, adolescents, and geriatric populations (Gualtieri & Johnson, 2006). It has also demonstrated discriminant validity across several conditions including dementia, and TBI, and depression (Brooks et al., 2014; Gualtieri & Johnson, 2006). The CNS-VS includes measures of performance validity for each task, as detailed in Table 6 (Brooks et al., 2014; CNS Vital Signs, 2014; Gualtieri & Johnson, 2006). For the purposes of this study, those participants who did not meet the threshold for performance validity for each task were excluded from any analysis including that task.

Table 6.

CNS-VS Task Performance Validity

Test	Performance Validity Indicator
VBM	VBM Correct Hits Immediate + VBM Correct Passes Immediate + VBM Correct Hits Delay + VBM Correct Passes Delay > 30
VIM	VIM Correct Hits Immediate + VIM Correct Passes Immediate + VIM Correct Hits Delay + VIM Correct Passes Delay > 30
FTT	FTT Right Taps Average + FTT Left Taps Average >= 40
SDC	SDC Correct Responses >= 20 AND Correct Responses > Errors*
ST	[Simple RT < (Complex RT Correct *0.1) + Complex RT Correct] AND [Complex RT Correct < (Stroop RT Correct *0.1) + Stroop RT Correct] AND (Complex Correct > Complex Errors) AND (Stroop Correct > Stroop Errors)
SAT	SAT Correct Responses > SAT Errors
CPT	if >= 10 yrs old, CPT is valid if Correct Responses - Commission Errors* >= 30, if < 10 yrs old CPT is valid if Correct Responses - Commission Errors* >= 25

Mood: As assessed by the Hospital Anxiety and Depression Scale (HADS). The HADS is a 14-item self-report questionnaire that measures for symptoms of depression (7-items) and anxiety (7-items) (Bjelland et al., 2002; Snaith, 2003). The HADS has been well validated for its use with many clinical settings, including hospital, and general practice, and in psychiatric patients (Bjelland et al., 2002).

Symptoms: As assessed by the Rivermead Post Concussion Symptoms Questionnaire (RPQ). The RPQ is a 16-item self-report measure of Post-Concussion Symptoms (PCS). The RPQ covers a range of symptoms including cognitive, psychological (depression), and physical (sleep disturbance, nausea, sensory disturbances, dizziness, and headaches) (Barker-Collo et al., 2018). RASCH-adjusted RPQ scores were used in all analyses (Balalla et al., 2020).

Alcohol Use: As assessed by the Alcohol Use Disorders Identification Test-Consumption (AUDIT-C). The AUDIT-C is a questionnaire used to screen for hazardous alcohol use. The AUDIT-C is a brief version of the full 10-item AUDIT. Questions include:

1. How often did you have a drink containing alcohol in the past year?
2. How many drinks did you have on a typical day when you were drinking in the past year?
3. How often did you have 6 or more drinks on one occasion in the past year?

The AUDIT-C has been found to have comparable sensitivity to the full version in detecting active alcohol dependence, but a lower specificity (Bush et al., 1998). The AUDIT-C has performed well in screening problem drinking behaviour across gender, age, ethnicity, and those

with TBI (Eyer et al., 2017; Frank et al., 2008; Gómez et al., 2006). Within the regression model, problem alcohol use was defined as scoring above eight on the AUDIT-C at 10-years after the initial mTBI.

Substance Use: As assessed by the Alcohol, Smoking and Substance Involvement Screening Test (ASSIST)**.** The ASSIST is a self-report screening tool developed by the World Health Organisation to assess substance use behaviour across the domains of involvement, current frequency of use, dependence, and abuse. The ASSIST has demonstrated good concurrent validity with several substance use screening tools such as the Addiction Severity Index, Severity of Dependence Scale, MINI International Neuropsychiatric Interview, AUDIT, and the Revised Fagerstrom Tolerance Questionnaire (Humeniuk et al., 2008). The ASSIST has also shown good discriminant validity in its ability to differentiate between symptoms of substance use, abuse and dependence (Humeniuk et al., 2008). For the current study, items from the ASSIST were used to determine an individual's use of illicit substances such as cocaine, cannabis, and heroin. To create a dichotomised variable, problem substance use was defined as use that was equal to or greater than monthly.

All baseline and one-month assessments were completed either in person or online. Due to social distancing restrictions at the 10-year follow up assessment timepoint, assessments were completed over the phone or online.

Analysis

All analysis was completed using IBM-SPSS Statistics 29.0. Range, logic, and missing data checks were completed for all variables. One-sided *t*-tests were used to identify differences in levels of cognitive functioning on each domain comparing participants who engaged in anti-social behaviour 10 years post-TBI and those who did not. One-sided tests were utilised as it was hypothesised that lower cognitive functioning in the acute phase post-injury would be associated with higher engagement in offending behaviour over the longer term.

A priori power calculation was completed, which identified that, based on a medium effect size of 0.6, with 80% power and alpha of 0.05, a minimum total sample of *N*=72 (with 36 participants in each group) would be required to ensure statistical power. Due to a low number of people reporting engagement in anti-social behaviour at 10 year follow up, there were not sufficient participants in the anti-social behaviour group to reach statistical power. As this analysis was based on an existing sample, it was not possible to increase the sample size. Results will consequently be interpreted with caution.

A binary logistic regression was used to determine if cognitive functioning (baseline or 1-month) was associated to anti-social offending behaviour (using the STAB) at 10-years post-

mTBI while controlling for confounders. Correlational analysis was utilised to check for multicollinearity between variables which would then be used in the regression analysis. Age had already been adjusted for through the CNS-VS. Potential confounders included in the regression models included alcohol and substance use, acute symptoms of anxiety and depression, acute post-concussion symptoms, sex, and ethnicity. Within the 122 participants, there was a moderate amount of non-response and missing data on the confounding variables. This affected the models by reducing the sample size in Model 1 (*n*=96), Model 2 (*n*=95), and Model 3 (*n*=89).

Results

122 participants met the inclusion criteria and were included in this analysis. From the total sample, 19.67% (*n*=24) reported engaging in anti-social behaviour 10 years post-injury. As shown in Table 7, the study sample skewed towards male and younger participants.

Table 7.

Participant Summary Statistics

	Anti-social behaviour *n*=24	No anti-social behaviour *n*=98	Total sample *N*=122
Mean Age (*SD*)	25.96 (13.35)	30.23 (16.62)	29.39 (16.07)
Sex			
Male	19 (79.17%)	55 (56.12%)	74 (60.66)
Female	5 (20.83%)	43 (43.88%)	48 (39.34)
Ethnicity			
European	14 (58.33%)	77 (78.57%)	91 (74.59%)
Non-European	10 (41.67%)	21 (21.43%)	31(25.41%)
Mean Anxiety Score (*SD*)	8.47 (4.64)	6.23 (4.00)	6.63 (4.18)
Mean Depression Score (*SD*)	6.41 (4.00)	3.88 (3.82)	4.34 (3.95)
Mean Symptom Score (RPQ) (*SD*)	35.90 (6.25)	31.38 (9.73)	32.18 (9.34)
Regular Substance Use	7/18 (38.89%)	14/96 (14.58%)	21/114 (18.42%)
Mean Alcohol Use Score (AUDIT) (*SD*)	3.74 (3.33)	3.26 (2.79)	3.33 (2.87)

The group reporting anti-social behaviour skewed particularly towards males and disproportionately in non-Europeans. Those with anti-social behaviours also reported higher scores on measures of depression, anxiety, TBI symptoms, and alcohol and substance use.

Multicollinearity Testing

To check for multicollinearity, the Variance Inflation Factor (VIF) for each of the cognitive domains was referred to, these domains were: Complex Attention, Cognitive Flexibility, Composite Memory, Executive Function, Processing Speed, Psychomotor Speed, and Reaction Time. The only domains that demonstrated collinearity (VIF>5) were Cognitive Flexibility (VIF=52.25) and Executive Function (VIF=43.50), this is likely attributable to the inclusion of the Shifting Attention task in both domains (Kim, 2019). This was expected given the overlap in definition and operationalisation of cognitive flexibility and executive functioning by the CNS-VS.

Due to collinearity, Executive Function was removed from the model and multicollinearity was again calculated. No variables demonstrated multicollinearity in the model minus Executive Function. Cognitive Flexibility was chosen for inclusion in the model over Executive Function as in the CNS-VS assessment as it is a multiple-test domain, while Executive Functioning reflects performance only on the Shifting Attention task.

Tests of Difference

Analysis began with a one-sided *t*-test test performed to determine the mean differences in CNS-VS results by anti-social behaviour, as detailed in Table 8. A one-sided test was chosen as it is unlikely that low cognitive performance would be associated with a decrease in long-term anti-social offending behaviour.

Table 8.

Differences in Cognitive Functioning by Anti-social Behaviour

						95% C.I.	
Variables	*t*	df	One-Sided *p* value	Mean Difference	Std. Error Difference	Lower	Upper
NCI	1.32	119	.095	8.46	6.42	-4.25	21.16
Composite Memory	0.67	119	.253	2.93	4.39	-5.76	11.61
Processing Speed	2.75	120	.003	9.86	3.58	2.76	16.95
Reaction Time	2.30	120	.012	12.08	5.26	1.68	22.49
Complex Attention	0.34	120	.366	6.68	19.53	-31.99	45.36
Cognitive Flexibility	1.93	120	.028	11.31	5.87	-0.33	22.94

Although no differences were detected by total NCI score, statistically significant differences (p<.05) were identified between those who engaged in anti-social behaviour at 10 years and those who did not in the individual domains of Processing Speed, Reaction Time, and Cognitive Flexibility.

Binary Regressions

A series of three binary logistic regression models were created. In the first model, the CNS-VS cognitive domain scores and key demographic and injury-related variables, including sex, ethnicity, and acute symptom severity, were regressed with a binary variable capturing any illegal anti-social behaviour. This model produced a Cox and Snell *R*-square of .232. None of the cognitive domains were independently associated with anti-social behaviour 10 years after injury in this model. Only sex and symptom severity were independently associated with anti-social behaviour 10 years post-injury, as shown in Table 9.

Table 9.

Model 1. Cognition and Behaviour, adjusting for Demography and Symptom Severity

Variables	*B*	S.E.	Wald	Sig.	Exp(*B*)
Composite Memory	0.02	0.02	1.28	.256	1.02
Psychomotor Speed	-0.01	0.02	0.08	.777	0.99
Reaction Time	0.01	0.02	0.13	.720	1.01
Complex Attention	0.01	0.01	0.67	.414	1.01
Cognitive Flexibility	-0.02	0.02	0.60	.437	0.98
Processing Speed	-0.04	0.03	1.62	.204	0.96
Sex*	-2.56	0.93	7.55	.006	0.08
Ethnicity	-1.41	0.76	3.48	.062	0.25
Symptom Severity*	0.09	0.05	4.11	.043	1.10
Constant	0.80	2.65	0.09	.763	2.23

*Significant at the p<.05 level

The lifestyle factors of alcohol and substance use were included in a second regression model shown in Table 10. This model produced a Cox and Snell *R*-square of .162. Once alcohol and substance use were controlled for, only sex remained independently significant in the final model.

Table 10.

Model 2. Cognition and Behaviour, controlling for Alcohol Use, Substance Use, and Symptom Severity

Variables	B	S.E.	Wald	Sig.	Exp(B)
Composite Memory	0.02	0.02	1.02	.312	1.03
Psychomotor Speed	0.00	0.03	0.00	.994	1.00
Reaction Time	0.02	0.02	0.46	.500	1.02
Complex Attention	0.00	0.01	0.08	.779	1.00
Cognitive Flexibility	0.00	0.03	0.00”	.952	1.00
Processing Speed	-0.04	0.04	1.06	.304	0.96
Sex*	-2.04	1.04	3.88	.049	0.13
Ethnicity	-1.08	0.86	1.57	.211	0.34
Symptom Severity	0.10	0.05	3.43	.064	1.10
Alcohol use	0.03	0.13	0.05	.828	1.03
Substance use	1.04	0.86	1.47	.226	2.82
Constant	-3.62	3.60	1.01	.314	0.03

*Significant at the *p*<.05 level

In the third regression (Table 11), after anxiety and depression were entered into the model, the model produced a Cox and Snell *R*-square of .232. Despite this, sex remained the only variable significantly associated with anti-social behaviour 10 years after the injury, with males at greater likelihood of anti-social behaviour.

Table 11.

Model 3. Cognition and Behaviour, controlling for Mood, Anxiety, and Symptom Severity

Variables	*B*	S.E.	Wald	Sig.	Exp(*B*)
Composite Memory	0.02	0.02	1.16	.282	1.02
Psychomotor Speed	0.00	0.03	0.01	.916	1.00
Reaction Time	0.00	0.02	0.03	.859	1.00
Complex Attention	0.01	0.01	0.72	.395	1.01
Cognitive Flexibility	-0.02	0.02	0.59	.443	0.98
Processing Speed	-0.05	0.04	2.10	.147	0.95
Sex*	-2.49	0.96	6.74	.009	0.08
Ethnicity	-1.29	0.77	2.82	.093	0.28
Symptom Severity	0.06	0.06	1.00	.318	1.06
HADS Anxiety	0.01	0.10	0.02	.891	1.01
HADS Depression	0.11	0.12	0.86	.354	1.11
Constant	1.19	2.71	0.19	.659	3.30

*Significant at the *p*<.05 level

Discussion

This study aimed to explore if cognitive functioning assessed in the acute stages following mTBI was associated with longer term engagement in anti-social offending behaviour. It was identified that 19.7% of the sample reported regularly engaging in anti-social offending behaviour at 10 years post-injury. Tests of difference showed that those engaging in anti-social offending behaviour have lower cognitive flexibility, processing speed and reaction time compared to controls. However, the group differences did not remain significant once sociodemographic and lifestyle factors were considered in regression modelling. Sex was the only variable that remained significant following control of sociodemographic, injury, and mood variables, with males at greater risk of engaging in anti-social behaviour in the longer term. Males are well-known to demonstrate higher rates of anti-social behaviour, so this outcome was not surprising (Bongers et al., 2004; Burt et al., 2018; Eley et al., 2003). The results did not support the hypothesis that performance on measures of EF in the post-acute stage of TBI recovery would be linked to an increased risk of anti-social behaviour later in life, nor were other aspects of cognitive performance. Unfortunately, analysis was under-powered to detect differences due to a low number of individuals reporting anti-social offending behaviour.

Implications of Results

Whilst the initial analysis did detect differences in cognitive flexibility, processing speed and reaction time by anti-social behaviour, none of the differences remained after controlling for relevant confounders. Previous studies have found post-acute cognitive function to be associated with long-term anti-social behaviour in youth (Ryan et al., 2015; Tomaszewski et al., 2014), but those studies assessed non-offending anti-social behaviour. Additionally, those studies used measures of anti-social behaviour which rely on third-party reporting rather than self-reporting of individual behaviour (Ryan et al., 2015; Tomaszewski et al., 2014). These inconsistencies reflect differing operationalisations of anti-social behaviour by different studies, and it remains unclear if a broader definition of anti-social behaviour had been used as to whether an association would have been observed in the present study (Morgan & Lilienfeld, 2000; Ryan et al., 2015; Tomaszewski et al., 2014). Given the high rate of TBI in offending populations, the decision was made to limit the scope of anti-social behaviour within this analysis to illegal behaviour. This involved excluding several items from the STAB in the analysis, such as getting angry quickly or being rude to others.

Anti-social behaviour measurement tools that have been used in the existing literature include the Adult Behaviour Checklist (Ryan et al., 2015), the Child Behaviour Checklist (Ryan et al., 2015), and the Frontal Behaviour Inventory (Tomaszewski et al., 2014). All these tools utilise

third-party reporting of anti-social behaviour and have shown relationships with TBI. When anti-social behaviour is self-reported, the relationship with cognitive performance in TBI populations has not always been detected (McKinlay, Grace, et al., 2014). Additional research is also needed into populations experiencing TBI in adulthood, as much of the longitudinal study in this space targets TBI-affected youth populations, which have a distinct recovery profile from those experiencing TBI in adulthood (McKinlay, Grace, et al., 2014; Ryan et al., 2015; Tomaszewski et al., 2014). These measures are also querying different behaviours, ranging from comparatively benign anti-social behaviour, such as bragging or boasting (from the Adult Behaviour Checklist) to offending resulting in conviction (from McKinlay, Grace, et al., 2014)).

To further distinguish the methodology of this study from the existing literature, prior studies utilised traditional paper-and-pencil methods of cognitive assessment, and it is possible that the computerised nature of the CNS-VS assessment battery influenced the study outcomes. The CNS-VS is most widely applied as a research metric rather than as a clinical tool, as the CNS-VS has been criticised for a lack of convergent and discriminant validity when compared to traditional assessment methods, limiting its clinical utility (Arrieux et al., 2017). This lack of overall correlation to traditional metrics of cognitive performance may, in part, account for the lack of hypothesised association between cognitive performance on offending behaviour in this population. It may also be the case that whilst there may have been an initial decline in cognitive functioning post mTBI, this is likely to have resolved in most cases over time (Keatley et al., 2023; Rabinowitz & Levin, 2014; Svingos et al., 2019). The timing of the 10-year follow-up assessments during the COVID pandemic meant that further cognitive functioning assessments were unable to be completed at follow-up, which would have provided valuable additional data. Further research is needed to determine if the unresolved cognitive impacts of mTBI have a greater influence on anti-social behaviour in the longer term.

Strengths and Limitations

Strengths of this study include the novel focus on the impact of anti-social behaviour following mTBI in a population-based cohort, specifically illegal anti-social behaviours, and the rare prospective longitudinal design in TBI research. Furthermore, the initial BIONIC sample utilised a gold-standard method of recruitment to identify instances of TBI that may likely have been missed (Brazinova et al., 2021; Riley & Hagger, 2015; Stergiou-Kita et al., 2017). Existing studies often rely on TBI samples that present to emergency departments or outpatient care following the development of symptoms (Marin et al., 2014; Tavender et al., 2014; Taylor, 2017). These types of research designs are likely to exclude the most uncomplicated and asymptomatic cases of TBI, limiting the generalisability of their study outcomes (Brazinova et al., 2021; McKinlay, Corrigan, et al., 2014).

A key limitation of this study was the sample size, particularly regarding the number of participants who had engaged in anti-social behaviour 10 years after injury. This reduced the statistical power of the study to detect differences and patterns in the data. It remains unclear if participants who were lost to follow-up had higher levels of engagement in anti-social behaviour than those who remained in the study or differed in other important ways that may have skewed these results. Longitudinal research of any population may be vulnerable to attrition, and this may worsen in anti-social and offending populations (Clark et al., 2020; Gustavson et al., 2012). It is important to acknowledge that attrition is not a random process and can therefore damage the generalisability of study findings (Cordray & Polk, 1983; Cotter et al., 2005; Gustavson et al., 2012). Risk factors for longitudinal study attrition include being male (Claus et al., 2002; Crisanti et al., 2014; Mein et al., 2012), lower socio-economic status (Claus et al., 2002; Graaf et al., 2000; Young et al., 2006), lower education level (Claus et al., 2002; Graaf et al., 2000), history of mental illness (Claus et al., 2002), residential instability (Claus et al., 2002; Crisanti et al., 2014), and criminal justice involvement (Crisanti et al., 2014). Given that these factors disproportionately affect offending populations, longitudinal study of the relationship between TBI and offending populations requires significant resource investment to support participant follow-up and reduce attrition bias (Clark et al., 2020).

Several aspects of this study limit the generalisability of these results. The CNS-VS uses an adaptation of the Stroop test to assess EF and cognitive flexibility. However, in a meta-analysis of studies measuring EF by anti-social and criminal behaviour the Stroop demonstrated a weaker effect size (*d*=.35) than tests such as the Porteous Mazes (which assesses the planning and foresight aspects of EF)(*d*=.80) (Morgan & Lilienfeld, 2000). This issue was also identified by Seruca and Silva (2016) who found significant differences in performance on the Porteus Mazes and TMT but not on the Stroop task when comparing offenders to non-offending controls. Consequently, the Stroop task and Cognitive Flexibility domain of the CNS-VS may not be the most effective ways of identifying the specific EF differences that may be present in offending populations. The current study adds to this pool of evidence and may be indicative of a weakness in the CNS-VS Stroop-based approach to EF assessment.

A limitation of the AUDIT as a measure of alcohol misuse within this study is that it looks at use within the past year and does not consider lifetime history of use or periods of dependence (Bush et al., 1998). Furthermore, participants who were imprisoned at 10-years could not be assessed for alcohol misuse, meaning for individuals whose offending behaviour was sufficiently severe, associations with alcohol could not be recorded. This is a major issue when much of the evidence around the relationship between alcohol misuse and offending is focussed on imprisoned populations (Abracen et al., 2017; Boden et al., 2013; Kuhns et al., 2014;

Lumsden et al., 2005; MacAskill et al., 2011). Evidence has also shown alcohol use to decrease following TBI, especially severe TBI (Beaulieu-Bonneau et al., 2018; Ponsford et al., 2007; VanderVeen, 2021). It is therefore possible that changes in alcohol use following injury affect this relationship (Bombardier et al., 2003; Dikmen et al., 1995; Ponsford et al., 2007). Consequently, it would be important to consider when assessments of alcohol use are being conducted in future studies.

Drug use within this analysis was categorised by self-reported substance use within the 10-year period following TBI and was expected to have some association with long-term offending. However, this method limited the number of offending participants that could be included within this regression, as six participants that demonstrated anti-social behaviour at 10-year follow-up could not be assessed due to imprisonment or incomplete data. Given the limitations of this dataset and the existing evidence, it is unlikely that the lack of relationship between substance use and long-term offending in this sample is generalisable, and that the study was in fact underpowered to detect an association. Furthermore, directionality of the relationship between TBI, alcohol misuse, and offending also requires further exploration.

Given the existing evidence of a relationship between mood and TBI in offenders, the lack of association within the regression model is notable and may be attributable to limitations of the current study. Differences may not have emerged due to the current analysis identifying immediate mood levels, and not underlying or historic mental health diagnosis – which is the prominent association seen in the existing literature (Emery et al., 2016; Grandhi et al., 2017; Kreutzer et al., 2001; Moore et al., 2014; Silver et al., 2001). This trend may also reflect the use of the STAB to assess broader and often milder anti-social offending in the general population as compared to most existing research using sentenced or imprisoned populations. A component of cognition not assessed within the BIONIC studies was social cognition skills, such as emotional recognition and communication skills, which have been shown to be associated with long-term offending and externalising behaviours in youth exposed to severe TBI (Ryan et al., 2014). Future research may be needed which targets these skills.

Unfortunately, this analysis was not able to explore the role of premorbid functioning, education, and socioeconomic status, in determining offending. Further investigation of pre-morbid functioning, education, and socioeconomic status may further clarify the relationship between cognition and offending in TBI-affected groups. This study was also limited by an underrepresentation of non-European ethnicities at the 10-year follow-up when compared to the study population at the time of injury, meaning results may be affected by the attrition bias.

Conclusion

This study presented the results of a novel analysis of anti-social offending behaviour by cognitive performance in an mTBI-affected population at 10-years post-injury. Whilst initial group differences were observed, TBI history and cognitive functioning domain did not independently predict behaviour when other factors were taken into account. These findings may be attributable to several limitations, including the sample being underpowered, methods of categorising anti-social behaviour, cognitive measures used, and concerns of response bias. Nonetheless, longitudinal analysis is rare in mTBI, and offending research and this study provides novel results and considerations for future research in both areas.

Chapter Seven: Assessing the Relationship between TBI History and cognition in an Aotearoa New Zealand Men's Prison Population

Introduction

As discussed in Chapter One, the literature has demonstrated that offending populations experience a high rate of TBI, when compared to the general population (Frost et al., 2013). In the NZ context, screening a 2015 prison population revealed that 64% of men had experienced at least one TBI (Mitchell et al., 2017), which contrasts with 13% revealed in a study of the general NZ population (Te Ao et al., 2015). Whilst rates of TBI do vary in offenders, a review of 33 studies identified an average TBI prevalence of 46% across the literature (Durand et al., 2017), while another review calculated a prevalence of TBI at 64% from 15 studies of male prison populations, and 70% from four studies of female prison populations (Shiroma, Ferguson, et al., 2010). In addition to high rates of experiencing a single TBI (of any severity) over a person's lifetime, prison populations report significantly higher rates of repetitive TBI (Pitman et al., 2015). For example in a UK male prison population, 60% of respondents had experienced multiple TBIs with LOC (Pitman et al., 2015), in a NZ prison population 33% reported multiple TBI, and 31% of a USA prison population with comorbid substance abuse reported multiple TBI (Walker et al., 2003).

Despite high rates of self-reported TBI in offenders, few studies have meaningfully assessed TBI by injury severity in these populations. Of the few studies that have been identified, evidence reveals that between 7% (Bogner & Corrigan, 2009) and 41% (Pitman et al., 2015) of offending populations experienced a moderate or severe injury in the past. Despite this unique TBI history profile, the existing literature (as reviewed in Chapter Five) has several limitations, foremost that it is deeply heterogenous, with little consensus on measures of TBI history or cognitive assessment. These methodological issues have resulted in studies reporting no associations between TBI and cognition in offenders (Bernett, 2013), TBI exposure being associated with lower cognitive performance (Fitzsimons, 2017; Pitman et al., 2015), and higher cognitive performance (Katzin et al., 2020). These conflicting results suggest further exploration of this relationship is needed. Examining TBI history in a more nuanced way may assist in understanding the links between TBI history and cognition to make sense of the contrasting findings in the literature.

This study aimed to determine whether cognitive performance is associated with frequency and severity of TBI history in a men's prison population. Based on the current evidence it was hypothesised that:

1) Participants who had experienced at least one TBI over their lifetime would demonstrate poorer cognitive functioning than those without a TBI history.
2) An increased number of TBIs will be associated with poorer overall cognitive performance and performance on tests of executive functioning.
3) Exposure to moderate and severe TBI will be associated with poorer overall cognitive performance and performance on tests of executive functioning.
4) Experiencing at least one period of pervasive, repetitive TBI will be associated with poorer overall cognitive performance and performance on tests of executive functioning.

Methods

This study consists of a cross-sectional assessment of the cognitive performance of prisoners within Tongariro Prison. Tongariro Prison is a men's minimum-low medium security facility in Tūrangi, New Zealand. Tongariro Prison provides services for 5% of the New Zealand total prison population as of June 2023 (Department of Corrections, Personal Correspondence, January 31st, 2024).

Ethics approval was received from Auckland University of Technology Ethics Committee (23/41), and the Ministry of Health – Northern B Health and Disability Ethics Committee (2023 FULL 15093). Research was further approved by Ara Poutama Department of Corrections - Research and Analysis.

Participant recruitment and procedures

Participants were recruited with support of the Tongariro Prison site healthcare team. An advertisement (Appendix A – Study Flyer) was distributed throughout the prison through an internal mail system and volunteers could write their name and return it through mail system to the healthcare team, the site Health Centre Manager would then forward the participants onto the Primary Researcher. In response to the initial advertisement, 87 individuals expressed interest in participating across the prison's four units. A time was then coordinated to meet with each volunteer to discuss the study and complete the interview if the participant wished to proceed. Participants could also take the Participant Information Sheet (Appendix C – Participant Information Sheet) and Consent Form (Appendix E – Consent Form) to review and discuss with others before choosing to participate at another time.

Participants were eligible for inclusion if they were aged 18 years or older at the time of testing, could speak English, could hold a pen or pencil, and were able to provide informed consent. Interviews were typically conducted over a single meeting that ranged between 75 minutes to two hours. Participants could opt to complete the interview over multiple days, due

to availability or fatigability, at the participant's discretion. As the initial volunteer interviews were completed, an additional 13 participants expressed interest through the healthcare team and were also recruited. This is attributable to word-of-mouth, and relocation and replacement of prisoners. Participant recruitment continued until all men who expressed an interest in taking part had been assessed.

Compared to the overall NZ prison population, Tongariro Prison is distinct in its security level, the lack of remand prisoners, and in offence profile. The Tongariro Prison population has more than double the prevalence of sexual assault convictions when compared to the overall NZ prison population, as seen in Table 12. Due to time constraints, privacy, rapport necessity, and the nature of these offences, it was decided that collecting the offence history from the participants would not be of net benefit to the study process, particularly as gaining access to prison records to confirm offending history would require identifying participants to the Department of Corrections directly. It does remain, however, a point of consideration when interpreting the generalisability of any study findings.

Table 12.

Tongariro Prison Offence Profile

	Tongariro Prison[1] (Jan 2024)	NZ Prison Total (Dec 2023)
Sexual Assault and Related Offences	50.9%	21.0%
Homicide and Related Offences	13.7%	8.8%
Acts Intended to Cause Injury	10.6%	20.4%
Illicit Drug Offences	5.8%	8.2%
Unlawful Entry with Intent/Burglary, Break and Enter	5.0%	10.7%
Robbery, Extortion and Related Offences	4.2%	6.6%
Other Offences	9.8%	24.3%

Figures reflect the most serious offence a prisoner is convicted of.

[1](Department of Corrections, Personal Correspondence, January 31st, 2024)

Outcome Measures

A bespoke assessment battery was designed with support from an advisory team including members from Auckland University of Technology (AUT), The University of Auckland, The University of Waikato, and Ara Poutama Aotearoa (The New Zealand Department of Corrections), as detailed in Table 13. Assessments were chosen to enable assessment of a range of cognitive domains, whilst reducing dependence on language, which may disadvantage those with a lower education level or whose primary language is not English. Decisions of tests to be

included were also based on logistics of delivery within the prison environment e.g., electronic devices are not permitted and time available to conduct the assessment within visiting hours.

Table 13.

Advisory Team

Member	Position	Affiliation
Marilyn Farmer	Registered Clinical Psychologist	Ara Poutama, Department of Corrections
Ryan Botha	Principal Advisor, Psychology Research,	Ara Poutama, Department of Corrections
Tangi Noomotu	Manager Mental Health Quality & Practice	Ara Poutama, Department of Corrections
Te Kani Kingi	Executive Director – Research and Innovation	Ara Poutama, Department of Corrections
Terry Huriwai	Senior Cultural Advisor	Ara Poutama, Department of Corrections
Alice Theadom	Professor of Brain Health and Registered Psychologist	Auckland University of Technology
Susan Mahon	Senior Lecturer and Registered Neuropsychologist	Auckland University of Technology and Mahon Psychology
Makarena Dudley	Senior Lecturer and Registered Neuropsychologist	University of Auckland
Nicola Starkey	Professor of Psychology	University of Waikato

Assessment Tools

OSU-TBI ID (Bogner & Corrigan, 2009)

The OSU TBI-ID was chosen as the standardised measure of eliciting lifetime TBI history for this study. The OSU TBI-ID is an interview method that consists of three steps. Step one involves asking five questions to identify potential causes of lifetime TBI, including injuries leading to hospitalisation, traffic collisions, falling and sports injuries, being assaulted or shot, or being near an explosion (Corrigan & Bogner, 2007a; Ohio Valley Center for Brain Injury Prevention and Rehabilitation). If any potential sources of TBI are identified, step two involves determining the LOC of each injury, and whether the injury was accompanied by a period of PTA, and at what age the injury occurred. Step three involves asking whether the individual experienced any history of repetitive injury in which the experienced multiple impacts to the head in a narrow period, and what the typical and most severe effect of these injuries were.

The OSU TBI-ID provides a standardised method of identifying lifetime incidents of TBI, and their severity, in a validated and standardised manner (Corrigan & Bogner, 2007a, 2007b). It has also shown validity and reliability with prison populations (Bogner & Corrigan, 2009; Monaghan, 2021). The OSU TBI-ID can also provide several validated indices on which TBI history can be categorised, this provides additional utility in prison populations that may often experience frequent TBI from an early age (Corrigan & Bogner, 2007a).

Speed and Capacity of Language Processing (SCOLP) (Baddeley et al., 1993)

Spot-the-Word subtest: This is an assessment of premorbid functioning. This task involves the participant reviewing 60 pairs of words, with one of each pair being a real English word, the participant is asked to identify which is which (Baddeley et al., 1993).

This task is a hold test, an assessment of crystallised verbal knowledge that is less prone to impairment due to age, TBI, and other causes of cognitive decline. Its purpose within this battery is to provide control for a source of potential confounding, premorbid intellectual functioning (Schwartz et al., 2016).

Wechsler Adult Intelligence Scale | Fourth Edition (WAIS-IV) (Wechsler, 2008)

Coding subtest: This is an assessment of processing speed. This task involves the participant being provided symbols that have been allocated to the digits 1-9. The participant is then provided with a sequence of digits and asked to draw the corresponding symbol that matches with each as quickly as possible within a 2-minute time limit.

Symbol Search subtest: This is an assessment of processing speed. This task involves participants being provided with rows of five symbols and two target symbols that the participant is instructed to find in the row, or to indicate that neither symbol is present. This is a timed task with participants asked to complete as many rows as they can within 2 minutes.

Together, the Coding and Symbol Search subtests comprise the Processing Speed Index (PSI) of the WAIS-IV. Processing speed is a key domain to investigate, as non-offending TBI populations have regularly shown deficits in this area, which has not consistently borne out in studies of offending populations (Bai et al., 2020; Mathias & Wheaton, 2007; O'Rourke et al., 2016). If offending populations do experience different cognitive sequelae of TBI, processing speed will be an important domain to investigate further. The Coding subtest is an effective task that largely isolates processing speed from other cognitive domains, being only marginally influenced by domains of working memory and psychomotor speed (Joy et al., 2004; Kennedy et al., 2003). The strong criterion validity of the PSI in the assessment of TBI sequelae, provides support for the proposal of using this score in lieu of an overall FSIQ score in a TBI-affected sample (Donders et al., 2001; Martin et al., 2000).

Picture Completion subtest: This is an assessment of perceptual reasoning. This task consists of the participant being provided with a series of visual stimuli where each has a component missing, such as a face missing a nose, a comb missing a tooth, or a table missing a leg. The participant is shown and then asked to indicate what component of each image is missing within 20 seconds per stimulus image.

Matrix Reasoning subtest: This is an assessment of perceptual reasoning. This task involves giving the participant a visual stimulus, or 'matrix' in which a section has intentionally been left blank, the participant is asked what the most appropriate missing symbol would be from multiple options.

Picture Completion and Matrix Reasoning are components of the Perceptual Reasoning Index of the WAIS-IV. Perceptual reasoning is an area of relative strength for those with a history of mild or moderate TBI, and individuals with even severe TBI history may perform comparably to controls on the Matrix Reasoning subtest (Carlozzi et al., 2015; Donders & Strong, 2015). This performance suggests Matrix Reasoning task performance is not prone to declining with injury (Holdnack et al., 2013; Ryan et al., 2005). Results of these tasks will provide important insight as to whether a prison TBI population is prone to different perceptual reasoning outcomes than community groups, and if not, reinforce this domain as one of relative strength for those working through TBI rehabilitation.

Digit Span subtest: This is an assessment of attention (forwards span) and working memory (backwards and sequencing spans). The first trials, the forwards span, consist of the interviewer reading aloud from a list of digits, firstly the participant is asked to repeat back the digits in the order in which they were read i.e., Interviewer: "5, 9, 6", Correct response: "5, 9, 6". This is repeated with lists of longer digits, up to a maximum of 9, or until two incorrect responses on trials of the same length.

Secondly, a similar list is read by the interviewer with the participant being asked to repeat the digits back in reverse order, these are the backwards span i.e., Interviewer: "5, 9, 6", Correct response: "6, 9, 5". Again, this is repeated with lists of longer digits, up to a maximum of 8, or until two incorrect responses on trials of the same length.

Finally, another list is read, with the participant being asked to repeat back the digits in ascending order, these are the sequence span i.e., Interviewer: "5, 9, 6", Correct response: "5, 6, 9". Likewise, this is repeated with lists of longer digits, up to a maximum of 9, or until two incorrect responses on trials of the same length.

The Digit Span provides value as both an assessment of working memory and as an embedded measure of effort. Performance on the Digit Span by a similar New Zealand TBI prison population was in the normal range, unaffected by TBI (Barnfield & Leathem, 1998b). As an embedded measure of performance validity, the Reliable Digit Span has shown success in detecting poor validity in TBI-affected populations (Heinly et al., 2005; Mathias et al., 2002).

Delis-Kaplan Executive Functioning System (D-KEFS) (Delis et al., 2001)

Colour-Word Interference Test (CWIT): This is an assessment of inhibition, a component of EF. This task consists of the participant being presented with a stimulus of colour swatches (red-blue-green) and being asked to identify the colours in reading order as quickly as they can. They are then presented with a list of these colours written in word form and to read through as quickly as possible. The participant is then provided with a stimulus of colour words written in non-corresponding ink colours and asked to state the ink colours as quickly as possible. The final stimulus also has incongruent word and ink colours, but the participant is asked to read the word of those listed with a box surrounding, and the ink colour for those listed without a box.

Neuropsychological Assessment Battery (NAB) (Stern & White, 2003)

Mazes subtest: This is an assessment of planning and problem solving, components of executive functioning. This task consists of several mazes of increasing complexity that the participant is asked to complete as quickly as possible, without taking their pencil off the page.

Judgement subtest: This is an assessment of judgement and decision making, components of EF. This task involves asking participants about their understanding of health and safety risks, or appropriate behaviour in situations where health or safety risk might be present i.e., Interviewer: “Why should you blow out candles before going to bed?” Possible answer: “There is a risk a fire could spread that would be dangerous while you sleep”.

These two tasks are components of the NAB Executive Functions Index which has been found to be significantly affected by a TBI history (Donders & Levitt, 2012; Zgaljardic & Temple, 2010); the Mazes subtest in particular has been sensitive to more complex and severe TBI. If this population struggles in performing on these tasks it may suggest that mTBI in offending populations may be contributing to cognitive outcomes more similar to moderate and severe TBI in non-offending groups, or groups with significant comorbidities (MacDougall & Mansbach, 2013; Roye et al., 2022).

California Verbal Learning Test – Third Edition (CVLT-3) (Delis et al., 2017)

This is an assessment of verbal memory and learning. This task involves reading off a list (List A) of 16 items and having the participant attempt to recall as many of the items on the list as possible, this is done five times. The respondent is then read a different list (List B) of 16 items

that is similar in content to the first and asked to recall as many of these as possible. The participant is then asked to recall as many items as they can from List A, without having it read to them. The participant is then asked to recall items from List A, without having them read again, but are provided with categories that the items fall into e.g., animals, furniture.

After approximately 30 minutes, the participant is again asked how many items they recall from List A. They are then provided with the categories once more and asked what items they recall from List A. The participant is then read a list of 48 items, one at a time, and asked if each item was in List A or not. After a further 10 minutes, the participant is provided with a list of 16 pairs of words and asked to identify which of the items was present in List A and which was not, this final Forced Choice Recognition task also behaves as an additional embedded measure of performance validity (Schwartz et al., 2016).

Colour Trails Test (D'Elia et al., 1996)

This is an assessment of sustained attention and cognitive flexibility. This task consists of two trials. Firstly, the participant is presented with a sheet on which 25 numbered circles are semi-randomly scattered and asked to connect the circles in ascending order from 1-25. The second trial asks the participant to connect circles on a similar sheet but to also alternate between circles that are coloured yellow and circles that are coloured pink.

The order of the cognitive tasks in the interviews was:

1. SCOLP Spot-the-Word
2. California Verbal Learning Test
3. NAB Mazes
4. Colour Trails Test
5. WAIS-IV Picture Completion
6. California Verbal Learning Test
7. WAIS-IV Symbol Search
8. WAIS-IV Coding
9. WAIS-IV Digit Span
10. D-KEFS Colour Word Interference Test
11. WAIS-IV Matrix Reasoning
12. California Verbal Learning Test
13. NAB Judgement

In the first three interviews the AUDIT, ASSIST, and DASS-21 preceded the cognitive assessment battery. After noticing some diminished mood and motivation in response to

completing these questionnaires, they were moved to the end of the interview session and appeared to be received more favourably.

Performance Validity Testing

Two embedded measures within the battery contributed to performance validity testing, the CVLT-3 - Forced Choice (Delis et al., 2017) and the Reliable Digit Span – Revised (RDS-R) (Young et al., 2012). The RDS-R is an embedded measure from the WAIS Digit Span task that requires summing the longest Forward, Backwards, and Sequencing Digit Spans on which the participant answered both trials correctly. This is a revision of the shorter traditional RDS that summed Forwards and Backwards Digit Spans only, predating the introduction of the Sequencing Digit Span in the WAIS-IV.

Several cut scores on the RDS have been used to assess valid performance: a cut of ≤7 was originally used, with some arguing that ≤6 demonstrating better specificity with clinical populations (Schroeder et al., 2012). Given the relatively recent introduction of the Sequencing Digit Spans and the RDS-R there is even less consensus as to the most appropriate cut-offs for performance validity testing. This study population is prison-based with high rates of TBI exposure, including moderate-severe TBI, therefore the most appropriate RDS-R cut-off score needed to be identified. An RDS-R cut score of ≤9 across a mixed population of cognitively impaired and unimpaired veterans showed the optimal area-under-curve of .81 at a sensitivity of .62, specificity of .86 (Shura et al., 2020), notably in a cognitively impaired population the optimal cut score was ≤8 (Webber & Soble, 2018; Young et al., 2012). A cut score of ≤9 has been chosen for this study. The use of a somewhat liberal cut score does raise the risk of low performance validity within the sample, however the existing evidence for the sensitivity of these cut scores in impaired populations supports the use of such a score to minimise the possibility of inappropriately excluding genuine low performers.

The CVLT Forced Choice Recognition (FCR) trial is an optional component of the CVLT-3 that involves identifying each of the stimulus words from the CVLT proper when the word is paired with a previously unseen word, therefore the FCR is scored out of a possible 16. Although no specific cut-off is endorsed by the designers of the task, cut-offs of both ≤13 and ≤14 have been used in existing literature, for this study a cut-off of ≤14 was chosen (Schwartz et al., 2016).

Three further items were included within the interview to account for the key confounders of alcohol and substance use assessed by the AUDIT-C and ASSIST, and mood (Depression, Anxiety, and Stress) was assessed by the DASS-21.

ASSIST (Humeniuk et al., 2008)

Illicit substance use was assessed by the ASSIST (Humeniuk et al., 2008)**.** The ASSIST is a self-report screening tool developed by the World Health Organisation to assess substance use behaviour across the domains of involvement, current frequency of use, dependence, and abuse. The ASSIST has demonstrated good concurrent validity with several substance use screening tools such as the Addiction Severity Index, Severity of Dependence Scale, MINI International Neuropsychiatric Interview, AUDIT, and the Revised Fagerstrom Tolerance Questionnaire (Humeniuk et al., 2008). The ASSIST has also shown good discriminant validity in its ability to differentiate between symptoms of substance use, abuse and dependence (Humeniuk et al., 2008).

AUDIT-C (Bush et al., 1998)

Alcohol use was further assessed by the Alcohol Use Disorders Identification Test-Consumption (AUDIT-C) (Bush et al., 1998). The AUDIT-C is a questionnaire used to screen for hazardous alcohol use. The AUDIT-C is a brief version of the full 10-item AUDIT. Questions include:

1. How often did you have a drink containing alcohol in the past year?
2. How many drinks did you have on a typical day when you were drinking in the past year?
3. How often did you have 6 or more drinks on one occasion in the past year?

The AUDIT-C has been found to have comparable sensitivity to the full version in detecting active alcohol dependence, but a lower specificity (Bush et al., 1998). The AUDIT-C has performed well in screening problem drinking behaviour across gender, age, ethnicity, and those with TBI (Eyer et al., 2017; Frank et al., 2008; Gómez et al., 2006). Due to the recency component of the AUDIT-C, it ultimately had limited utility within the Tongariro prison sample due to their profile as long-stay inmates, with only four participants reporting a non-zero score, alcohol use is adjusted for elsewhere however, within the ASSIST tool, which captures a greater amount of historical alcohol use data.

DASS-21 (Lovibond & Lovibond, 1995)

Mood symptoms were assessed by the Depression, Anxiety and Stress Scale – 21 Items (DASS-21) (Lovibond & Lovibond, 1995). The DASS-21 is a 21 item self-report questionnaire in which respondents respond on a four-point scale (Never, Sometimes, Often, Almost Always) to items representing a three part model of Depression (low positive affect), Anxiety (physiological hyperarousal), and Stress (negative affect) (Henry & Crawford, 2005). These subscales have shown validity across non-clinical populations, mTBI populations, and moderate-severe TBI populations (Dahm et al., 2013; Henry & Crawford, 2005; Randall et al., 2017).

Results of the CVLT-3 and WAIS-IV tasks were processed through the Q-Global software, the NAB tasks through the NAB Software Portfolio (Version 2.20.036), while the Colour Trails and D-KEFS were scored by hand, according to their respective manuals. Māori participants' scores on the WAIS-IV tasks were normed to 2022 Māori normative scores (Dudley et al., 2022).

Statistical Analysis

A one-tailed priori sample size calculation was performed based on a linear regression with nine predictor variables, an alpha of 0.05 to determine an f^2 effect size of 0.12 with 80% power. It was revealed that a total sample size of N=54 would be required to ensure sufficient statistical power.

One sample *t*-tests of difference were used to assess cognitive differences by TBI history variables as reported by the OSU TBI-ID, shown in Table 20. Tests of difference were calculated by TBI frequency (≤2 vs ≥3 recalled instances of TBI), most severe TBI (mTBI vs moderate-severe TBI, as determined by length of LOC and/or PTA), and TBI pervasiveness (whether the participant answered affirmatively to the OSU TBI-ID question "Have you ever had a period of time in which you experienced multiple, repeated impacts to your head e.g., history of abuse, contact sports, military duty?"). Cognitive variables assessed include Processing Speed, Immediate Recall, Delayed Recall, Mazes, Colour Trails 2, Digit Span, Matrix Reasoning, Picture Completion, Judgement, and the CWIT. Due to the large number of *t*-tests performed, the Benjamini-Hochberg correction was applied to reduce the rate of false discovery (Benjamini & Hochberg, 2000).

Pearson correlation coefficients were calculated for each of the cognitive tasks to determine the validity of creating composite cognitive domain outcomes, and this is what determined the cognitive variables of interest in the tests of difference and linear regressions. Linear regressions were performed between the relevant variables and each of the cognitive outcome variables, with Benjamini-Hochberg correction again used to reduce the rate of false discovery (Benjamini & Hochberg, 2000).

Results

The population of Tongariro Prison was 379 at the conclusion of data collection. Of the 100 men who expressed interest in participating, 71 (71.0%) attended an appointment with the interviewer, 19 (19.0%) were transferred or released before interviewing could occur, and 10 (10.0%) chose to decline participating after discussing the study further with the interviewer. Of the 71 participants who attended an appointment with an interviewer, two were not able to complete the assessment due to communication and language difficulties that prevented their meaningful engagement. Data for six participants were excluded from the data analysis as the

performance validity cut-offs were not met. This provided a final sample size of 63 participants for the analysis, which was above the required minimum sample size identified by the priori sample size calculation.

The demography of the study sample broadly reflected the age and ethnicity of the total Tongariro Prison population as shown in Table 14. The mean age of study participants was 48.30 years (Median=48; *SD*=14.14), and there were no significant differences in age as determined by a chi-square comparison (X^2=3.46, df=6, *p*=.75). Similarly, the differences by ethnicity were not significant when analysed on a chi-square (X^2=5.98, df=4, *p*=.20).

Table 14.

Study and Prison Population Age Distribution

		Tongariro Prison Count (%) (Jan 2024)[1] *N*=379	Study Sample Count (%) (Jun 2023- Feb 2024) *N*=63
Age	<20	1 (0.3)	0 (0.0)
	20 - 24	17 (4.5)	2 (3.2)
	25 - 29	30 (7.9)	3 (4.8)
	30 - 39	83 (21.9)	12 (19.0)
	40 - 49	88 (23.2)	20 (31.7)
	50 - 59	80 (21.1)	13(20.6)
	>59	80 (21.1)	13 (20.6)
Ethnicity	Māori	183 (48.3)	33 (52.4)
	European	154(40.6)	29 (46.0)
	Pacific	20 (5.3)	1 (1.6)
	Other (incl. Asian)	20 (5.3)	0 (0.0)
	Not recorded	2 (0.26)	0 (0.0)

[1](Department of Corrections, Personal Correspondence, January 31st, 2024)

76.1% (48/63) of participants reported experiencing more than one instance of TBI, with an average of 2.83 (*SD*=1.97, Median=3.00, Range=10) instances of TBI per participant as assessed by the OSU TBI-ID. The high rate of TBI history precluded analysis to determine if there were differences in cognitive performance between men with and without a lifetime history of TBI to test hypothesis one. Almost half (46.1%) of the participants reported experiencing a TBI before 13 years of age. Further details of the TBI histories of participants identified through the OSU TBI-ID are shown in Table 15.

Table 15.

TBI History in Tongariro Prison

TBI History Variables	TBI Categories	% (*n*)
Cause of All TBI	Traffic	57.1 (36)
	Falls	23.8 (15)
	Mechanical Forces (including sport related TBI)	49.2 (31)
	Assaults (including DV)	73.0 (46)
	Unknown	1.6 (1)
Frequency of TBI	None	9.5 (5)
	1	15.9 (10)
	2	25.4 (16)
	≥3	50.8 (32)
Most Severe TBI	None	7.9 (5)
	Mild	66.7 (42)
	Moderate	11.1 (7)
	Severe	14.3 (9)
Age at first TBI	≤3	3.2 (2)
	4-12	42.9 (27)
	13-18	27.0 (17)
	≥19	19.0 (12)
	No TBI	7.9 (5)
Period of Pervasiveness	Pervasive TBI	49.2 (31)
	No Pervasive TBI	50.8 (32)

The cognitive performance on the assessments for this sample is reported in Table 16. Each result is reported as a standard score[1], which controls for age and, in some instances, gender and education - as per the task's scoring procedure. Response rates to the SCOLP are lower than the other tasks due to the task only being validated up to age 64. A further three participants also opted out of completing the task due to literacy issues or concerns with dyslexia. Four participants did not complete the NAB Judgment task due to running out of time. A small number of other cognitive tasks were not completed due to lack of time, participant decline, or administration error. Task completion figures are reported as *n* in Table 16.

[1] These standard scores use a mean 10, range of 1-19, with each unit representing a ±0.33 *z*-score.

Table 16.

Performance on Cognitive Tests

Primary Domain	Task	*n*	Mean Scaled Score
Executive Functioning	NAB Mazes	60	12.15
	Colour Trails Part 2	63	11.38
	CWIT Inhibition vs Naming	60	10.20
Verbal Memory	CVLT-3 Immediate Recall	61	8.15
	CVLT-3 Delayed Recall	60	8.57
Working Memory	WAIS-IV Digit Span (Backwards & Sequencing)	62	8.69
Perceptual Reasoning	WAIS Matrix Reasoning	62	8.98
	WAIS Picture Completion	63	9.48
Processing Speed	WAIS Coding	63	8.17
	WAIS Symbol Search	63	8.67
	Colour Trails Part 1	63	11.89
Judgment	NAB Judgment	59	9.90
Premorbid Function	SCOLP Spot-the-Word	50	8.24

As many of the tasks within the assessment battery generate several outputs across a range of cognitive domains, the most pertinent outputs needed to be identified for analysis in this study. Key domains of functioning that each task corresponds to is shown in Table 16. To determine whether performance on these tasks could be grouped in a statistically valid manner, several assessments of correlation were conducted (Table 17, Table 18, and Table 19).

As mood is often linked with cognitive performance, DASS-21 subscale scores for Depression, Anxiety, and Stress were used. Of the 63 participants in the final dataset, 62 completed a full DASS-21, across the subscales the population reported a mean Depression subscale score of 6.15 (*SD*=6.00, Median=5.00), mean Anxiety subscale score of 5.05 (*SD*=4.84, Median=3.50) and mean Stress subscale score of 7.31 (*SD*=5.86, Median=7.00). This places the mean scores of this population in the Mild range for Depression and Anxiety, while Stress symptoms were in the Normal range, when rounded to the nearest integer (Henry & Crawford, 2005; Lovibond & Lovibond, 1995).

To determine whether it would be feasible to produce an aggregate variable for overall EF, tasks assessing components of executive functioning were analysed for association, as shown in Table 17. Tests included the WAIS-IV Backwards and Sequencing subtests of the Digit Span test, the CWIT Colour Naming adjusted score on the Inhibition subtest was taken (representing the Stroop effect), and Trail 2 speed from the Colour Trails test. Three statistically significant

Pearson correlations were found, Digit Span/CWIT, Digit Span/Colour Trails, and Mazes/Colour Trails. None of these significant relationships were strong, suggesting that they should not be combined into an aggregate variable of overall executive functioning performance as they may be measuring different aspects of EF. For these reasons, performance on these tasks were analysed separately.

Table 17.

Pearson Correlation of Executive Functioning Tasks

Tasks	Digit Span (B+S)	Mazes	Judgement	CWIT Inhibition by Colour Naming	Colour Trails 2
Digit Span (B+S)		.138	.301*	.063	.524**
Mazes	.138		-.174	.085	.460**
Judgement	.301*	-.174		-.178	-.010
CWIT Inhibition by Colour Naming	.063	.085	-.178		.214
Colour Trails 2	.524**	.460**	-.010	.214	

*Significant at .05 level (2-tailed)

**Significant at .01 level (2-tailed)

Further correlations were calculated for components of TBI history, as shown in Table 18. Given that the variables of Frequency and Severity were significantly, but weakly, correlated, it suggests there would be utility in analysing these variables separately, rather than as a combined TBI index variable. The exclusion of a TBI index score from the final regressions was also supported by calculations of VIF for these four TBI history variables with Index being the only VIF>5 (VIF=5.16).

Table 18.

TBI History Pearson Correlations

	Frequency	Severity	Index
Frequency			
Severity	.344**		
Index	.768**	.713**	
Pervasiveness	.169	.280*	.197

*Significant at .05 level (2-tailed)

**Significant at .01 level (2-tailed)

To determine how best to analyse the domain of processing speed, the three tasks of Colour Trails 1, Symbol Search, and Coding were also assessed for correlation. As expected, the

Coding and Symbol Search tasks were significantly correlated, however Colour Trails 1 was not. Given the pre-existing body of evidence for the combination of the two WAIS tasks into a single Processing Speed Index, the two WAIS tests were combined into a Processing Speed Index excluding Colour Trails 1. The mean scaled score on this Processing Speed domain was 8.54 (*n*=63), in the average range of performance.

Table 19.

Processing Speed Pearson Correlations

	Colour Trail 1	Symbol Search
Colour Trail 1		
Symbol Search	.113	
Coding	.211	.627**

**Significant at .01 level (2-tailed)

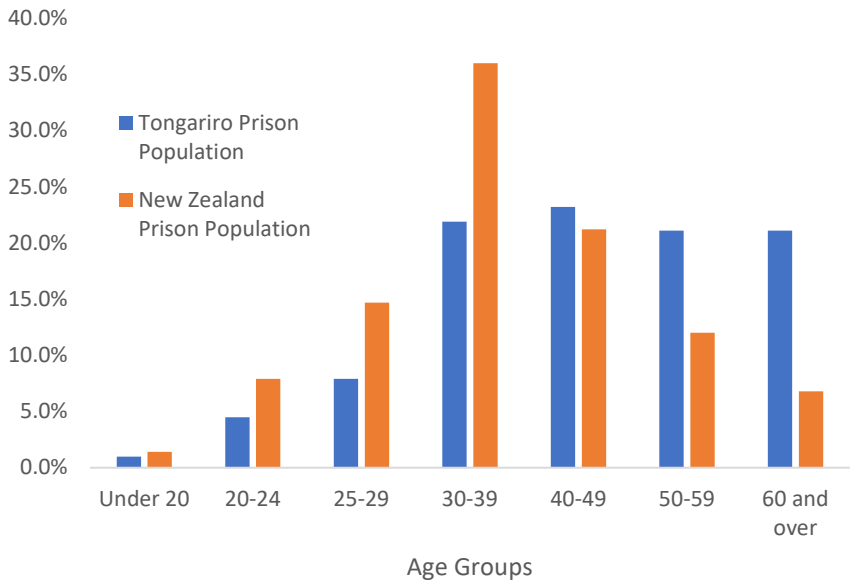
Likewise, Pearson correlations were run on the Perceptual Reasoning tasks of Matrix Reasoning and Picture Completion, and although they demonstrated a statistically significant correlation at the .05 level, the weak strength (Pearson's *r*=.270) of the correlation did not support a composite variable and the tests will be considered separately.

Prison Population

Tongariro Prison houses the highest number of segregated prisoners in NZ which accounts for 51.1% (210/411) of all prisoners at the Tongariro site (Department of Corrections, 2024b). Prisoners are typically segregated based on fears for their personal safety, raised either by the prisoner themselves or by a prison manager (Department of Corrections, 2024b). As this is a population self-selected for concerns regarding personal safety, it is likely that they differ from the non-segregated prison population both demographically and by TBI history.

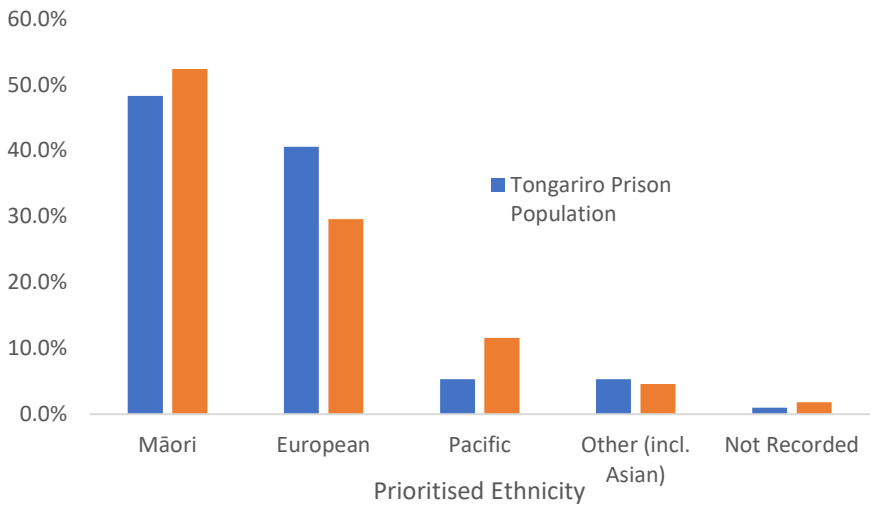
The Tongariro Prison population is distinct in age distribution, when compared to the overall NZ prison population, as shown in Figure 3. Tongariro Prison – Age Distribution. This significant overrepresentation of prisoners aged 50-59 and over 60 has implications for the generalisability of these results, as does the underrepresentation of those in mid-adulthood (aged 25-29 and 30-39). This also emphasises some important variables to consider in future research, such as whether the length of time spent incarcerated is affecting recovery outcomes, and whether time spent incarcerated is meaningfully associated with a particular TBI profile. One might hypothesise younger offenders with TBI history to stifle under the often cognitively unstimulating prison environment, while older offenders might benefit from an environment with the inbuilt healthcare supports that may be less accessible to them in the community (Meijers et al., 2015).

Figure 3. Tongariro Prison – Age Distribution



Similarly, Tongariro Prison has some differences in distribution of ethnicity when compared to the total New Zealand prison population, as shown in Figure 4. Tongariro Prison – Ethnicity Distribution. Not only did the current study sample have an underrepresentation of Pacific ethnicity participants, Tongariro Prison itself has disproportionately few Pacific prisoners (5.3%), compared to the overall New Zealand prison population (11.6%), as of March 2024. It is unclear why Pacific prisoners are underrepresented in this way, however it is notable that Tongariro Prison did not contain a Pacific Focus Unit at the time of this investigation, while it did feature a Māori Focus Unit. Future research in New Zealand prison populations may choose to target a prison site with a Pacific Focus Unit, such as the Saili Matagi group at Spring Hill Prison, to account for this underrepresentation.

Figure 4. Tongariro Prison – Ethnicity Distribution



Although practical and ethical reasons determined that confirming offending history of individual participants would not be appropriate, given the attributes of the Tongariro prison population, many of the respondents will have been sexual offenders. This is important because of the evidence that sexual offenders often experience domains of cognitive impairment (Adjorlolo & Egbenya, 2016; Cohen et al., 2010; Eastvold et al., 2011; Gillespie & McKenzie, 2000; Rodriguez et al., 2017). CSOs in particular demonstrate lower performance on tests of executive functioning (Adjorlolo & Egbenya, 2016; Dillien et al., 2020; Turner, Roszyk, Szumski, et al., 2020). Some studies have found that these differences in EF do not emerge in juvenile sex offenders (Adjorlolo & Egbenya, 2016; Morais et al., 2016; Rimmer, 1998) and therefore the older age distribution of the current study may in part contribute to the finding of differences in CWIT performance by pervasive TBI history. For these reasons the long-term cognitive effects of TBI may present differently in sex offending populations. This indicates that consideration of offending profile will be an important aspect of future study in this space.

Differences in Cognition by TBI History

One-sided independent samples *t*-tests of difference were conducted for each of the cognitive tasks. It was found that there were no differences by frequency of TBI experienced on any of the cognitive tasks.

Table 20.

T-tests of difference by TBI Frequency

	TBI ≤2 Scaled Score Mean (*SD*)	TBI≥3 Scaled Score Mean (*SD*)	Mean Difference (95% CI)	*SE*	*t*	df	*d*	*p*	p^1
Processing Speed	8.65 (1.87)	8.44 (2.42)	0.21 (-0.89, 1.30)	0.55	0.38	61	.10	.35	.43
Immediate Recall	7.90 (2.68)	8.39 (2.76)	-0.49 (-1.88, 0.91)	0.70	-0.70	59	-.18	.24	.43
Delayed Recall	8.03 (2.62)	9.10 (2.62)	-1.07 (-2.42, 0.29)	0.68	-1.58	58	-.41	.06	.28
Mazes	12.00 (2.56)	12.30 (2.85)	-0.30 (-1.70, 1.10)	0.70	-0.43	58	-.11	.34	.43
Colour Trails 2	11.16 (3.00)	11.59 (2.37)	-0.43(-1.79, 0.93)	0.68	-0.64	61	-.16	.26	.43
Digit Span	16.71 (3.73)	18.00 (4.48)	-1.29 (-3.37, 0.79)	1.04	-1.24	61	-.31	.11	.40
Matrix Reasoning	9.03 (3.72)	8.94 (3.36)	0.10 (-1.70, 1.90)	0.90	0.11	60	.03	.46	.48
Picture Completion	9.90 (3.07)	9.06 (3.51)	0.84 (-0.82, 2.50)	0.83	1.01	61	.26	.16	.40
Judgement	9.97 (3.91)	9.83 (2.84)	0.13 (-1.62, 1.89)	0.88	0.15	59	.04	.44	.48
CWIT (Stroop Effect)	10.43 (2.53)	9.97 (3.01)	0.47 (-0.97, 1.90)	0.72	0.65	58	.17	.26	.43

[1]Adjusted *p*-value according to the Benjamini–Hochberg procedure

*Equal Variances not assumed per Levene's Test for Equality of Variances

Contrary to expectation, those who had experienced a moderate to severe injury were found to have higher scores on the Mazes and Matrix Reasoning tasks.

Table 21.

T-tests of difference by Most Severe TBI

	Mild TBI Scaled Score Mean (*SD*)	Moderate-Severe TBI Scaled Score Mean (*SD*)	Mean Difference (95% C.I)	*SE*	*t*	*df*	*d*	*p*	p^1
Processing Speed	8.36 (2.38)	8.94 (1.69)	-0.58 (-1.88, 0.72)	0.65	-0.89	56	-0.26	.19	0.42
Immediate Recall	8.00 (2.75)	9.00 (2.68)	-1.00 (-2.62, 0.62)	0.81	-1.24	54	-0.37	.11	0.40
Delayed Recall	8.53 (2.59)	9.40 (2.64)	-0.88 (-2.46, 0.71)	0.79	-1.11	53	-0.34	.14	0.40
Mazes	11.90 (2.81)	13.47 (1.60)	-1.57 (-3.11, -0.02)	0.77	-2.03	53	-0.62	.02	0.22
Colour Trails 2	11.29 (2.51)	12.13 (3.05)	-0.84 (-2.41, 0.73)	0.78	-1.07	56	-0.31	.14	0.40
Digit Span	17.33 (4.49)	17.75 (3.66)	-0.42 (-2.94, 2.11)	1.26	-0.33	56	-0.10	.37	0.44
Matrix Reasoning	8.54 (3.56)	10.38 (3.05)	-1.84 (-3.87, 0.19)	1.01	-1.82	55	-0.54	.04	0.28
Picture Completion	9.33 (3.42)	10.00 (3.41)	-0.67 (-2.68, 1.34)	1.00	-0.66	56	-0.20	.25	0.43
Judgement	9.33 (3.47)	11.00 (3.03)	-1.68 (-3.66, 0.31)	0.99	-1.69	54	-0.50	.05	0.28
CWIT (Stroop Effect)	10.32 (2.66)	9.57 (3.06)	0.75 (-0.97, 2.46)	0.85	0.87	53	0.27	.19	0.42

[1]Adjusted *p*-value according to the Benjamini–Hochberg procedure

Those who had experienced a period of pervasiveness had lower scores on Digit Span and the CWIT (Stroop effect) task with a medium-large effect size of 0.68. However, as shown in Table 22 these significant differences no longer remained significant once the Benjamini-Hochberg (BH) procedure was performed to reduce the rate of false discoveries attributable to the large number of tests conducted (Benjamini & Hochberg, 2000).

Table 22.

T-tests of difference by TBI Pervasiveness

	No Pervasive TBI Scaled Score Mean (*SD*)	Any Pervasive TBI Scaled Score Mean (*SD*)	Mean Difference (95% C.I)	*SE*	*t*	df	*d*	*p*	p^1
Processing Speed	8.69 (2.26)	8.39 (2.06)	0.30 (-0.79, 1.39	0.55	0.55	61	.14	.29	.43
Immediate Recall	8.13 (2.88)	8.17 (2.57)	-0.04 (-1.44, 1.36	0.70	-0.05	59	-.01	.48	.48
Delayed Recall	8.74 (3.05)	8.38 (2.18)	0.36 (-1.02, 1.74)	0.69	0.53	58	.14	.30	.43
Mazes	12.00 (2.76)	12.31 (2.66)	-0.31 (-1.71, 1.09)	0.70	-0.44	58	-.11	.33	.43
Colour Trails 2	11.56 (2.38)	11.19 (2.99)	0.37 (-0.99, 1.73)	0.68	0.54	61	.14	.30	.43
Digit Span	18.25 (4.19)	16.45 (3.96)	1.80 (-0.26, 3.85)	1.03	1.75	61	.44	.04	.28
Matrix Reasoning	8.69 (3.37)	9.30 (3.69)	-0.61 (-2.41, 1.18)	0.90	-0.68	60	-.17	.25	.43
Picture Completion	9.38 (3.27)	9.58 (3.38)	-0.21 (-1.88, 1.47)	0.84	-0.25	61	-.06	.40	.46
Judgement	9.94 (3.56)	9.86 (3.27)	0.08 (-1.68, 1.83)	0.88	0.09	59	.02	.47	.48
CWIT (Stroop Effect)	11.03 (2.83)	9.25 (2.40)	1.78 (0.41, 3.15)	0.68	2.61	58	.68	.01	.17

[1]Adjusted *p*-value according to the Benjamini–Hochberg procedure

Linear Regression of TBI History and Cognition Controlling for Alcohol and Substance Use, Mood and Premorbid Functioning

Table 23 demonstrates that only depressive symptoms were associated with higher performance on the processing speed components of the assessment battery.

Table 23.

Linear Regression of Processing Speed with TBI History

	B (95% C.I)	*SE B*	β	*p*
Constant	9.06 (6.03, 12.08)	1.50		<.01
Number of TBI	0.11 (-0.23, 0.46)	0.17	.12	.50
Most Severe TBI	0.29 (-0.59, 1.16)	0.43	.11	.51
Any Period of TBI Pervasiveness	-0.17 (-1.48, 1.15)	0.65	-.04	.80
Ethnicity	-0.20 (-1.60, 1.21)	0.69	-.05	.78
ASSIST	-0.04(-0.22, 0.15)	0.09	-.07	.67
DASS Depression*	0.17(0.003, 0.33)	0.08	.47	<.05
DASS Anxiety	-0.01(-0.23, 0.20)	0.10	-.03	.89
DASS Stress	-0.20(-0.40, 0.01)	0.10	-.54	.06
Spot-the-Word	-0.06(-0.31, 0.20)	0.13	-.08	.64

Note: R^2=.158, *n*=49

*Significant at the *p*<.05 level

Table 24 found no associations between TBI history or the measured predictors with immediate memory performance, except premorbid function.

Table 24.

Linear Regression of CVLT – Immediate Recall with TBI History

	B (95% C.I)	*SE B*	β	*p*
Constant	4.39 (0.44, 8.33)	1.95		.03
Number of TBI	0.04 (-0.40, 0.49)	0.22	.03	.84
Most Severe TBI	0.55 (-0.60, 1.69)	0.56	.16	.34
Any Period of TBI Pervasiveness	0.47 (-1.25, 2.19)	0.85	.08	.59
Ethnicity	-0.58 (-2.41, 1.25)	0.90	-.10	.53
ASSIST	0.09 (-0.15, 0.33)	0.12	.11	.46
DASS Depression	-0.13 (-0.35, 0.09)	0.11	-.26	.23
DASS Anxiety	-0.10 (-0.37, 0.18)	0.14	-.17	.47
DASS Stress	0.16 (-0.11, 0.43)	0.13	.32	.23
Spot-the-Word*	0.38 (0.05, 0.72)	0.16	.40	.03

Note: R^2=.251, *n*=49

*Significant at the *p*<.05 level

Table 25 demonstrates that no predictors were significantly associated with performance on the Delayed Recall task of the CVLT, except premorbid function.

Table 25.

Linear Regression of CVLT – Delayed Recall with TBI History

	B (95% C.I)	*SE B*	β	*p*
Constant	5.78 (2.04, 9.53)	1.85		<.01
Number of TBI	0.17 (-0.26, 0.59)	0.21	.13	.43
Most Severe TBI	0.39 (-0.73, 1.51)	0.55	.11	.49
Any Period of TBI Pervasiveness	-0.35 (-1.99, 1.29)	0.08	-.06	.67
Ethnicity	-1.17 (-2.91, 0.56)	0.86	-.22	.18
ASSIST	0.12 (-0.11, 0.35)	0.11	.16	.30
DASS Depression	-0.08 (-0.29, 0.12)	0.10	-.17	.42
DASS Anxiety	-0.07 (-0.33, 0.20)	0.13	-.12	.62
DASS Stress	0.10 (-0.15, 0.36)	0.13	.21	.42
Spot-the-Word*	0.40 (0.07, 0.72)	0.16	.42	.02

Note: R^2=.282, *n*=48

*Significant at the *p*<.05 level

Table 26 demonstrates no predictors were associated with performance on Maze completion.

Table 26.

Linear Regression of NAB - Mazes with TBI History

	B (95% C.I)	*SE B*	β	*p*
Constant	10.21 (6.11, 14.30)	2.03		<.01
Number of TBI	0.08 (-0.39, 0.54)	0.23	.06	.74
Most Severe TBI	0.68 (-0.51, 1.86)	0.59	.20	.26
Any Period of TBI Pervasiveness	0.19 (-1.60, 1.97)	0.88	.03	.84
Ethnicity	-0.27 (-2.17, 1.63)	0.94	-.05	.77
ASSIST	-0.11 (-0.36, 0.14)	0.12	-.15	.38
DASS Depression	0.01 (-0.22, 0.23)	0.11	.02	.95
DASS Anxiety	-0.12 (-0.40, 0.17)	0.14	-.21	.41
DASS Stress	0.04 (-0.24, 0.31)	0.14	.07	.80
Spot-the-Word	0.15 (-0.20, 0.49)	0.17	.16	.39

Note: R^2=.139, *n*=49

*Significant at the *p*<.05 level

Table 27 found no associations between TBI history or the measured predictors with Colour Trail 2 performance.

Table 27.

Linear Regression of Colour Trails 2 with TBI History

	B (95% C.I)	*SE B*	β	*p*
Constant	8.77 (5.46, 12.09)	1.64		<.01
Number of TBI	0.13 (-0.24, 0.51)	0.19	.13	.48
Most Severe TBI	0.56 (-0.40, 1.52)	0.47	.20	.25
Any Period of TBI Pervasiveness	-0.01 (-1.45, 1.44)	0.71	-.002	.99
Ethnicity	-0.26 (-1.79, 1.28)	0.76	-.06	.74
ASSIST	0.04 (-0.17, 0.24)	0.10	.06	.73
DASS Depression	0.03 (-0.16, 0.21)	0.09	.06	.77
DASS Anxiety	-0.01 (-0.24, 0.22)	0.11	-.01	.95
DASS Stress	-0.08 (-0.30, 0.14)	0.11	-.19	.48
Spot-the-Word	0.27 (-0.01, 0.55)	0.14	.34	.06

Note: R^2=.203, *n*=49

*Significant at the *p*<.05 level

Table 28 demonstrates that an increased number of reported TBI was associated with higher performance on the Working Memory component of the Digit Span subtest, as was premorbid functioning.

Table 28.

Linear Regression of Digit Span (Backwards and Sequencing) with TBI History

	B (95% C.I)	*SE B*	β	*p*
Constant	12.50 (7.94, 17.05)	2.25		<.01
Number of TBI*	0.79 (0.27, 1.30)	0.25	.42	<.01
Most Severe TBI	-0.76 (-2.08, 0.56)	0.65	-.15	.25
Any Period of TBI Pervasiveness	-0.14 (-2.13, 1.84)	0.98	-.02	.89
Ethnicity	-1.35 (-3.46, 0.76)	1.04	-.17	.20
ASSIST	-0.14 (-0.41, 0.14)	0.14	-.12	.33
DASS Depression	-0.05 (-0.30, 0.20)	0.12	-.07	.70
DASS Anxiety	0.11 (-0.21, 0.43)	0.16	.13	.49
DASS Stress	-0.16 (-0.47, 0.14)	0.15	-.23	.29
Spot-the-Word*	1.00 (0.61, 1.38)	0.19	.71	<.01

Note: R^2=.520, *n*=49

*Significant at the *p*<.05 level

Table 29 demonstrates that anxiety was positively associated with performance on the Matrix Reasoning subtest, and stress was negatively associated with performance on the Matrix Reasoning subtest. Premorbid functioning was also associated.

Table 29.

Linear Regression of Matrix Reasoning with TBI History

	B (95% C.I)	*SE B*	β	*p*
Constant	2.06(-2.39, 6.50)	2.20		.36
Number of TBI	0.05(-0.45, 0.56)	0.25	.03	.83
Most Severe TBI	0.64(-0.65, 1.93)	0.64	.14	.32
Any Period of TBI Pervasiveness	1.04(-0.90, 2.98)	0.96	.14	.28
Ethnicity	1.30(-0.76, 3.36)	1.02	.18	.21
ASSIST	0.10(-0.18, 0.37)	0.13	.10	.48
DASS Depression	-0.07(-0.31, 0.18)	0.12	-.10	.59
DASS Anxiety*	0.34(0.03, 0.65)	0.15	.44	.03
DASS Stress*	-0.37(-0.67, -0.07)	0.15	-.56	.02
Spot-the-Word*	0.56(0.18, 0.93)	0.19	.44	<.01

Note: R^2=.441, *n*=49

*Significant at the *p*<.05 level

Table 30 demonstrates that only ethnicity was associated with performance on the Picture Completion subtest.

Table 30.

Linear Regression of Picture Completion with TBI History

	B (95% C.I)	*SE B*	β	*p*
Constant	3.20(-1.74, 8.15)	2.44		.20
Number of TBI	-0.16(-0.72, 0.40)	0.28	-.10	.56
Most Severe TBI	0.24(-1.19, 1.67)	0.71	.06	.74
Any Period of TBI Pervasiveness	0.38(-1.78, 2.53)	1.07	.05	.73
Ethnicity*	3.01(0.72, 5.30)	1.13	.42	.01
ASSIST	0.07(-0.23, 0.37)	0.15	.07	.65
DASS Depression	-0.10(-0.37, 0.17)	0.13	-.16	.45
DASS Anxiety	0.04(-0.31, 0.38)	0.17	.05	.83
DASS Stress	0.07(-0.26, 0.40)	0.17	.11	.67
Spot-the-Word	0.18(-0.24, 0.59)	0.21	.14	.40

Note: R^2=.255, *n*=49

*Significant at the *p*<.05 level

Table 31 demonstrates that only premorbid function was associated with Judgement task performance.

Table 31.

Linear Regression of Judgement with TBI History

	B (95% C.I)	*SE B*	β	*p*
Constant	4.80 (0.54, 9.05)	2.10		.03
Number of TBI	0.37 (-0.11, 0.85)	0.24	.24	.13
Most Severe TBI	0.13 (-1.10, 1.36)	0.61	.03	.83
Any Period of TBI Pervasiveness	-0.17 (-2.02, 1.69)	0.92	-.02	.86
Ethnicity	-0.91 (-2.88, 1.07)	0.98	-.13	.36
ASSIST	-0.20 (-0.46, 0.06)	0.13	-.22	.12
DASS Depression	-0.05 (-0.29, 0.18)	0.12	-.09	.66
DASS Anxiety	0.02 (-0.28, 0.31)	0.15	.02	.92
DASS Stress	0.01 (-0.27, 0.30)	0.14	.02	.93
Spot-the-Word*	0.68 (0.32, 1.04)	0.18	.59	<.01

Note: R^2=.396, *n*=49

*Significant at the *p*<.05 level

Table 32 demonstrates that experiencing a period of pervasive TBI was associated with reduced performance on the adjusted Inhibition task of the CWIT when compared to participants without pervasive injury history, and that European ethnicities completed the task faster than Māori and Pasifika participants.

Table 32.

Linear Regression of CWIT – Stroop effect with TBI History

	B (95% C.I)	*SE B*	β	*p*
Constant	10.15(7.24, 13.06)	1.44		<.01
Number of TBI	0.01(-0.33, 0.35)	0.17	.01	.95
Most Severe TBI	-0.38(-1.26, 0.49)	0.43	-.12	.38
Any Period of TBI Pervasiveness*	-2.81(-4.07, -1.56)	0.62	-.57	<.01
Ethnicity*	2.05(0.70, 3.40)	0.67	.41	<.01
ASSIST	0.02(-0.16, 0.20)	0.09	.03	.82
DASS Depression	-0.01(-0.17, 0.16)	0.08	-.02	.94
DASS Anxiety	0.19(-0.02, 0.39)	0.10	.36	.07
DASS Stress	-0.05(-0.25, 0.15)	0.10	-.12	.60
Spot-the-Word	-0.14(-0.39, 0.10)	0.12	-.17	.24

Note: R^2=.489, *n*=48

*Significant at the *p*<.05 level

Within the linear regressions, the components of TBI history that were significantly associated were pervasive TBI history with the CWIT (Stroop effect) and the Working Memory Digit Spans with number of TBI. Notably, increased reported frequency of TBI was associated with higher Digit Span performance, while the relationship between Pervasive TBI history and the CWIT (Stroop effect) was as hypothesised.

Regression Model Coefficients

In considering the clinical significance of these regression analyses it is important to assess both the statistical significance of the relationships, and the overall strength of the regression models. The only model that produced an R^2>.500 was with performance on the Digit Span – Backwards and Sequencing (.520), two further models produced R^2>.400, regressing for Matrix Reasoning (.441) and for CWIT (Stroop effect) (.489). Both Digit Span and the CWIT outcomes were associated with TBI history, with pervasive TBI being associated with poorer CWIT performance and TBI frequency being associated with improved Digit Span performance. It is therefore notable that Digit Span performance without TBI history within the model is only somewhat less effective as a model (R^2=.401). Additionally, the regression model of CWIT (Stroop effect) performance found pervasive TBI history to be associated with worse outcomes and the model is dramatically less effective (R^2=.145) with TBI history variables removed. This indicates that TBI history is more important to performance on the CWIT (Stroop effect) task than Digit Span performance, wherein the strength of the regression model appears attributable

to the other components of the model i.e., mood, anxiety, ethnicity, and substance misuse. This suggests that the peculiar outcome of increased performance with increased TBI frequency may not be a substantial clinical finding.

Discussion

This study hypothesised that increased exposure to more frequent, severe, and pervasive TBI would be associated with lower cognitive performance in a prison population, particularly on tasks assessing aspects of EF. The study identified that there was a link between experiencing a period of pervasive TBI and the CWIT (Stroop effect) measuring inhibition as a component of EF, as hypothesised. However, the results from this study did not support the hypotheses that TBI frequency or severity would also impact negatively on cognitive performance. Indeed, individuals with greater TBI exposure also performed better on one cognitive task, as TBI frequency was associated with improved performance on the Digit Span task, an assessment of working memory. Although the model for improved Digit Span performance by increased exposure was weaker than the model for decreased performance on the CWIT (Stroop effect). These findings suggest that experiencing a period of pervasive TBI is an important component of TBI history that needs to be assessed when working with prison populations. The importance of TBI pervasiveness is demonstrated in an identified association with an assessment of inhibition, the CWIT (Stroop effect). Further research is needed to validate this association within other prison populations.

Interview Process

The Tongariro Prison study participants appeared to be a highly motivated group. Upon initial introductions, many participants would readily describe instances of TBI in their past and how recent reporting on TBI in news media has spurned them to consider whether these may play a role in their mental wellbeing, personality, and offending history. This is reflected in a volunteer group of 87 in response to an initial flyer Appendix A – Study Flyer, this amount of interest was surprising and contributed to many participants waiting longer than was preferable (occasionally months) from expression of interest to interview date. Due to the limitations on being able to provide tangible incentives for research participation in this prison context, it is encouraging for future research that interest was so high. Whether this enthusiasm to report TBI history and symptomology results in any issues of performance validity is an important consideration for future research. Interviews were conducted on-site, at Tongariro Prison, in unit meeting rooms. This may have resulted in a degree of volunteer bias, particularly given the high proportion of the sample reporting a TBI, i.e., those taking part may have been more concerned about the impact of their TBI history on cognition.

The rooms where the assessments were conducted differed in their level of privacy offered, some were completely unobserved except for a small window through which custodial staff could periodically confirm the safety of the interviewer, while others were more public and staff or other prisoners returning from other sites may have briefly observed the participant while travelling into or out of the unit. This inability to provide a traditional clinical environment in which to conduct the interview is an unfortunate limitation of working in the secure prison environment which may have affected cognitive performance of the sample.

Engagement with the selected assessments was high and the order of delivery was chosen to intersperse tasks that were more engaging and stimulating with those that were more challenging or were otherwise suspected to be less well received. One learning from the study would be to refine the assessment order in the future to avoid beginning the interview with both the SCOLP STW and the CVLT, as both tasks are reliant on language skills and several participants commented on their specific difficulties in this area, this is supported by existing evidence of participant distaste for the STW as a measure (Barker-Collo et al., 2008).

Participants were receptive to the purpose of this research, with the vast majority having TBI history and having some understanding or experience of the cognitive effects that may follow. Anecdotally, there were several instances of participants struggling to identify a lower threshold for what might constitute TBI, particularly for those with history of experiencing DV, assaults, or contact sport injury. An additional difficulty appeared to be understanding the scope of TBI, such as conflating TBI with hypoxic brain injury. The OSU TBI-ID attempts to provide a rigid interview structure to generate reliable measures of TBI exposure but some issues remain; for example, one participant could not recall any specific instance of TBI, however they did report a period in which they were regularly fighting and therefore were categorised as experiencing a period of pervasive TBI, this period is considered one TBI within the OSU TBI-ID indices. That an individual can be simultaneously categorised as exposed to pervasive or repetitive TBI but considered to have experienced one instance of TBI is a concern with this assessment tool. Additional research into perceptions of TBI and their effects with offending populations may elucidate some of these issues and provide guidance for improved validation of self-reported TBI histories.

TBI Severity

In this study 25.4% of men reported experiencing at least one moderate or severe TBI in their lifetime. This is higher than is observed in the general population but is lower than the previous study conducted by Glover et al. (2018) who found 59.4% reported a moderate-severe TBI, and also used the OSU TBI-ID in a male US population (*N*=160) across programs in county jails, juvenile probation, Veteran's Court, and a problem-solving court. In the NZ context, Mitchell et al. (2017) found 14.9% of most recent TBI were in the moderate-severe range, while 15.8% of first TBI were in the moderate-severe range in an Auckland, NZ male prison population, which further demonstrates the elevated TBI severity experienced by offending populations. Another NZ prison population reported 20.3% of their population reported at least one moderate-severe TBI (Barnfield & Leathem, 1998a). These differences in moderate-severe TBI prevalence may be attributable to differences between the populations in age, ethnicity, and offending profile, as Tongariro is older, with a high rate of sexual offending, and a high proportion of indigenous Māori participants when compared to other New Zealand prisons (Department of Corrections, Personal Correspondence, January 31st, 2024).

The finding that there was no link between TBI severity and cognitive performance on any of the tests used, contrasts with a previous study conducted in a USA prison population (*N*=95) from 2014-2015 (Monaghan, 2021). In the study by Monaghan (2021), it was found that experiencing a moderate or severe TBI as assessed by the OSU TBI-ID was associated with poorer performance on conditions 3 and 4 of the CWIT, which assess inhibition (Monaghan, 2021). However, like the present study, no links were identified between TBI severity and the TMT which assesses processing speed and the executive function of sequencing (Bowie & Harvey, 2006). The difference in findings may reflect that only 16 participants reported having experienced a moderate-severe TBI in this sample, affecting the ability of the study to detect an effect.

Due to the high level of TBI exposure in the Tongariro study population, no meaningful analysis could occur comparing a group without TBI to those with mTBI or moderate-severe TBI. This is distinct from much of the literature on the cognitive effects of TBI in offenders, wherein many studies compared a no TBI group to those with any TBI (Cohen et al., 2003; Cohen et al., 1999; Fitzsimons, 2017; Gorgens et al., 2021; Katzin et al., 2020; Marsh & Martinovich, 2006; McMillan et al., 2021; Pitman et al., 2015; Shiroma, Pickelsimer, et al., 2010; Smith, 2016). This is notable as much of the community focussed literature demonstrates chronic cognitive differences in those with moderate-severe TBI, but much less evidence for a relationship with mTBI, meaning many of these studies may be underreporting the cognitive effect of more severe

injuries by incorporating mTBI into their exposure category (Königs et al., 2016; McInnes et al., 2017; Skandsen et al., 2010). The current study therefore presents novel evidence for the effect of moderate-severe TBI in a prison population.

TBI Pervasiveness

As the sole hypothesised difference that emerged from this study was associated with TBI pervasiveness, it is worthwhile to further investigate the existing evidence of cognitive effects associated with periods of pervasive/repetitive TBI exposure. Within the OSU-TBI ID, several summary indices have been identified but experiences of pervasive/repetitive TBI are not one of these (Bogner & Corrigan, 2009). Periods of pervasive TBI are categorised as singular injuries that fall under other indices, such as number of TBI (Bogner & Corrigan, 2009). That pervasiveness, as measured by the OSU TBI-ID, has shown a unique sensitivity to cognitive outcome is worth future consideration in studies that use this tool.

In a community-based sample (*N*=13,323) of middle-aged and older participants (mean age=61.95), a period of pervasive head injury was associated with lower performance on the Cogstate Brief Battery one-back test of reaction speed (Alosco et al., 2020). The same study also reported an interaction of pervasive injury with TBI with LOC associated with lower performance on the reverse memory span and TMT-B, tests of EF (Alosco et al., 2020). Most of the investigation into the effects of repetitive TBI exposure is based in sporting populations, wherein cognitive effects of pervasive or repetitive TBI have been inconsistent (Belanger et al., 2010; McAllister & McCrea, 2017). Several studies have found no long-term cognitive effects associated with repetitive or pervasive TBI exposure (Belanger et al., 2010; Broglio et al., 2006; Bruce & Echemendia, 2009), while others have found lower cognitive performance (Alosco et al., 2020; Moser & Schatz, 2002; Nolan et al., 2018; Pearce et al., 2018).

It is also important to acknowledge that 19 participants reported multiple periods of pervasive injury, and the effect of this was not able to be explored within the current analysis. Tools are needed that enable measurements of periods of pervasive injury. Participants often reported distinct periods of pervasive TBI attributable to DV, frequent fighting, or sporting injury. Future studies should consider the potential effect of multiple periods of TBI pervasiveness and whether the age, or cause, of pervasive TBI mediates post-TBI symptoms and recovery.

The CWIT is an adaptation of the Stroop test for the D-KEFS, and primarily serves as a test of response inhibition, an executive function, but is informed by several other cognitive factors including processing speed and fatigability (Delis et al., 2001; Lippa & Davis, 2010). Given the relationship identified within this study, and the existing evidence of TBI affecting

performance on the CWIT (Anderson et al., 2017; Monaghan, 2021), it may be worthwhile to investigate the combination of abilities at play and whether the CWIT is uniquely effective at identifying TBI-related cognitive effects in this population or whether other factors are at play. The current study was an exploratory study to determine if aspects of TBI history were related to cognitive performance. A study specifically powered to validate the association between experiencing a period of pervasive TBI on inhibition is needed.

That the CWIT, as an adaptation of the Stroop test, has uniquely identified disparities by TBI history is notable considering that the Stroop has been found to have a small effect size in a meta-analysis of TBI-affected populations (Morgan & Lilienfeld, 2000). Whether this is indicative of improved TBI reporting since the Morgan and Lilienfeld (2000) paper, the CWIT being effective in assessing cognitive sequelae of TBI in offending populations specifically, or that the CWIT has utility over the traditional Stroop is unclear. Future assessment might target this combination of inhibition, processing speed, and fatigability as a priority.

TBI Frequency

That no cognitive outcomes were statistically significantly associated with number of TBI is worth further investigation. While the OSU TBI-ID can produce distinct frequency and pervasiveness variables, it is presumed these are identifying a similar underlying exposure to multiple TBI (Bogner & Corrigan, 2009). This finding suggests that these periods of repetitive trauma are more strongly associated with cognitive impacts following injury than the number of distinct recollected injuries. This finding may be reflective of the comparatively high rate (14.3%) in this population of experiencing multiple periods of repetitive TBI and indicates that recording this aspect of TBI history may be of particular importance, especially in these highly exposed groups.

Implications of Inhibition Finding

Performance on the CWIT (Stroop effect) trial has been shown to be lower in violent offenders than controls, which aligns with the task as an assessment of disinhibition (Hancock et al., 2010; Shumlich et al., 2019). Furthermore the CWIT has shown sensitivity between forensic psychiatric patients compared to general offenders (Shumlich et al., 2019). More broadly, offending populations have shown to perform more poorly on tests of inhibition than controls (Ogilvie et al., 2011). Furthermore, EF deficits distinguish violent from non-violent offenders (Meijers et al., 2015; Meijers et al., 2017), and sexual offenders form non-sexual offenders (Cohen et al., 2010; Eastvold et al., 2011; Gillespie & McKenzie, 2000; Rodriguez et al., 2017). This suggests that the unique offending profile of the Tongariro prison population may play a part in why the CWIT was sensitive to pervasive TBI in this group.

This relationship also raises some additional questions regarding the issue of directionality of disinhibition, TBI, and offending behaviour. While it might be reasonable to suggest disinhibition might be associated with getting into fights, it is unlikely to play a role in whether an individual experiences DV, which accounts for many causes of pervasive TBI reported. Additional investigation is needed that accounts for differences in causes of pervasive TBI to further demonstrate directionality.

OSU TBI-ID Measures of TBI History

One of the challenges in determining TBI history is the use of self-report measures. It can be difficult for a person to accurately recall whether they have experienced an injury or not. Evidence has shown that the way people are asked about whether they have experienced a TBI or not can significantly affect how people report their TBI history (Ilie et al., 2018; Paul et al., 1997; Ramos et al., 2020; Schofield et al., 2011). The OSU-TBI tool was developed to provide a reliable and valid method for reporting TBI history in retrospective studies of TBI (Corrigan & Bogner, 2007a). While existing research has shown prison populations accurately report TBI that exist within the clinical record, it is possible that these populations are also prone to misrepresenting injury history that does not exist within the clinical record (Schofield et al., 2011). This possible misrepresentation of TBI history could be attributed to several possible causes and is not necessarily intentional falsification from respondents (Mah et al., 2018; Merz et al., 2017).

TBI is a poorly understood condition within clinical fields, let alone lay populations, and it may not be reasonable to expect a highly exposed prison population to accurately recall their injury history in clinical terms (Mah et al., 2018; Merz et al., 2017). The OSU TBI-ID asks participants to recall the length of LOC associated with each TBI experienced – which itself relies on third party witnessing of the event, and if not, to accurately recall if they felt dazed or had a period of PTA – a difficult task in a population often reporting repeated experiences of DV, assaults, and substance misuse, all of which could complicate the reporting of post-TBI sequelae. This study has revealed that the OSU-TBI ID has helped to determine components of TBI history that are linked to aspects of cognition in later life more than others e.g. that experiencing a period of repetitive TBI was associated with difficulties with inhibition but no other domains of cognitive functioning. Further refinement may be needed to explore other potential aspects of TBI history that may be linked to longer term outcomes that are yet unidentified.

Cognitive Domains

Premorbid Functioning

The primary measure of premorbid function within this battery was the SCOLP STW task. This was chosen over a more typical measure such as the Test of Premorbid Functioning (TOPF), or National Adult Reading Test (NART), because of issues of validity when using these tools with New Zealand Māori populations (Barker-Collo et al., 2008; Dudley et al., 2017). This reflects a fundamental issue when applying measures of premorbid function across cultural contexts. "Hold" tests of crystallised intelligence are often measures of literacy skills that are less affected by a breadth of neuropsychological trauma and can therefore be prone to issues of inappropriate standardisation across cultures (Marks, 2010). Within the New Zealand context, the TOPF and the NART have both been found to show poor associations with WAIS outcomes in Māori populations (Barker-Collo et al., 2008; Dudley et al., 2017). Alternatively, the STW has shown good association with WAIS performance in NZ Māori populations, albeit in small study samples (Barker-Collo et al., 2008).

Utilising the STW was not without challenges, three participants chose not to complete the task due to issues with dyslexia or general literacy, while others appeared demotivated by the content, seemingly due to literacy issues. This represents an underlying issue of the STW, the level of dissatisfaction that New Zealanders – and Māori in particular – report with STW as a measure; 56% of NZ Europeans and 78% of Māori report a dislike of the tool (Barker-Collo et al., 2008). Ten further participants were lost due to the STW being validated up to age 64 only and the study sample being notably older than expected. Concerns around age should have been accounted for in the battery design process, but because of a late-stage change of prison-site, the battery was not altered with the atypically older Tongariro prison population in mind.

Processing Speed

Performance on tests of processing speed were in the average range and no differences were found in performance on tests of processing speed by TBI history, a result that does not align with the existing body of research in general populations, but does align with the results reported in offending populations (Barnfield & Leathem, 1998b; Bogner & Corrigan, 2009; McMillan et al., 2021; Suchy, Euler, et al., 2014). Large and statistically significant deficits in attention and processing speed have been found in meta-analysis of studies of individuals with history of severe TBI, and given the high rates of severe TBI being reported in both the current study and prior studies in prison populations, it is notable that this trend does not emerge in offending populations in the same way (Mathias & Wheaton, 2007).

When targeting mTBI populations specifically, processing speed deficits are less pronounced than those with severe TBI history; however, individuals with mTBI-associated mental fatigue experience higher levels of processing speed deficit (Johansson et al., 2009) and post-acute mTBI (1-month post-injury) study populations perform significantly lower than

healthy controls on tests of processing speed (Mathias et al., 2004). There is also increasing evidence of neurophysiological mechanism underpinning these deficits, with fractional anisotropy trends in mTBI patients showing correlation with processing speed deficits (Bai et al., 2020). With this evidence in mind, it appears there are underlying factors unaccounted for that may be affecting the relationship between processing speed outcomes and TBI in offending populations.

Perceptual Reasoning

No differences were found in performance on tests of perceptual reasoning by TBI history, which broadly aligns with the existing literature. Perceptual reasoning is a domain of cognitive functioning that seems to be less affected by TBI within the existing body of research (Calvillo & Irimia, 2020; Miotto et al., 2010; Rackley et al., 2012). It is for this reason that a perceptual reasoning subtest such as Matrix Reasoning may serve as an alternative test of premorbid cognitive ability, with populations for whom a language-based measure of premorbid function may be inappropriate (Holdnack et al., 2013). That this study population performed better on tests of perceptual reasoning (Matrix Reasoning Scaled Score = 8.98; Picture Completion Scaled Score = 9.48) than the STW (Scaled Score = 8.24), is further supportive of this conclusion and therefore future research may incorporate Matrix Reasoning as a test of premorbid function.

Verbal Learning

This study identified verbal learning as an area of relative weakness for the study sample but reported no associations by any measure of TBI history. The lack of association between TBI and performance on the CVLT-3 as a measure of immediate and delayed recall is in alignment with existing research in New Zealand prison populations. Barnfield and Leathem (1998b) utilised the similar RAVLT with a NZ prison population and found relative weakness in the domains of immediate and delayed verbal learning, but that performance was not mediated by TBI history or substance misuse. This relative weakness of verbal learning has borne out in other offending populations using comparative assessment tools such as the Hopkins Verbal Learning Test (Bernett, 2013) and Selective Reminding Verbal Learning Test (Cohen et al., 1999) in USA offending samples. These results further reinforce the insensitivity of the verbal learning measures to TBI and the underlying issue of poor verbal learning skills in offending populations.

Performance Validity

By taking a liberal approach to performance validity, it is possible this study's results are being influenced by pervasive issues of performance invalidity. Inclusion required only meeting the cut score on one of the two PVTs used, the RDS-R and the CVLT-3 Forced Choice. If instead failing to meet the performance validity cut-off for either test was an exclusion criterion, a

further 11 participants would be excluded. Given the final sample of 63, that 11 (17.5%) of these participants did not meet performance validity on one of the tests conducted raises questions regarding the validity of their results. Due to time constraints in the prison environment, and the already lengthy interview battery (75-120 minutes), it was decided that embedded measures of performance validity would be most appropriate.

Given that participants were volunteers with little secondary gain to consider, it was thought that intentional performance invalidity was of low to moderate risk. Regarding secondary gain, participants were instructed that the study was independent from the Department of Corrections and that the content of the assessment would not be considered valid for clinical purposes, further detail in Appendix C – Participant Information Sheet. The final performance validity strategy was chosen to ensure specificity in including all likely valid data - given the study population was expected to experience a multitude of sociocultural risk factors likely impacting their engagement with the assessment battery such as education, acculturation, and income, which has shown to mediate cognitive performance in minority ethnicity groups in particular (Dudley et al., 2019). Even with this liberal performance validity strategy six participants were lost to performance invalidity, demonstrating the strategy maintained a degree of sensitivity. Future studies may explore the issue of performance validity in these populations further, ideally with a large enough sample to run effective sensitivity analysis to better understand the effect the performance invalidity might have on cognitive assessment.

Strengths and Limitations

This study has several areas of strength and some meaningful limitations. A major strength of this study is the breadth of TBI history considered in relation to cognitive outcomes. While most studies have assessed populations in a dichotomous manner i.e., any TBI vs no TBI (Cohen et al., 2003; Cohen et al., 1999; Fitzsimons, 2017; Gorgens et al., 2021; Katzin et al., 2020; Marsh & Martinovich, 2006; McMillan et al., 2021; Pitman et al., 2015; Shiroma, Pickelsimer, et al., 2010; Smith, 2016), this study provides analysis of outcomes by most severe injury, number of injuries, and experience of pervasive injury. This study also used a thorough battery of assessments, which provide an improved understanding of the cognitive profile of the study population.

When possible, this study also applied Māori norms on cognitive assessments (Dudley et al., 2022), which is an important consideration in prison populations where Māori are disproportionately represented (Department of Corrections, 2024a). As use of appropriate norms increases, the current study's results will become better contextualised. Participants of this study were provided with a simplified report of their test performance, alongside a lay explanation of what areas of relative strength or weakness may mean. This returns some

ownership of this information back to the participant and was passed along to relevant healthcare providers as requested, to inform better care for individuals.

Several limitations of this study should also be considered in interpreting these results. Given the existing underrepresentation of women offenders in existing literature (Allely, 2016; Durand et al., 2017; Moynan & McMillan, 2018; O'Rourke et al., 2016), it was especially disappointing that a women's prison population was not available and accessible at the time of this study. Unfortunately, in the process of coordinating this study, COVID-19 restrictions necessitated a relocation from a planned Auckland-based prison site, where a women's prison study may have been possible, to Tongariro Prison, where no such women's prison population is accessible. This continues to be an important avenue for future investigation, particularly given the heterogenous study outcomes being seen across offending groups in men's populations alone (Adjorlolo & Egbenya, 2016; Cohen et al., 2010; Eastvold et al., 2011; Gillespie & McKenzie, 2000; Rodriguez et al., 2017).

Although this analysis has endeavoured to account for the key variables that mediate the relationship between cognition and TBI history in this prison population, these results likely indicate that there are significant variables unaccounted for that are mediating these relationships. As mentioned, Tongariro prison has a distinct population for whom generalisation to the overall NZ prison population is likely inappropriate as their demography and nature of their offending is materially different from most NZ men's prisons. This, however, does not account for the unexpected relationship between increased TBI exposure and increased cognitive performance; that these results have been replicated in existing studies (Katzin et al., 2020) demonstrates that there may be underlying confounders between experiencing TBI and cognition, for offending populations.

Conclusion

This study assessed the relationship between TBI history and cognitive outcomes for a NZ men's prison population. Most assessments did not detect a difference in cognitive performance by TBI history, however the CWIT (Stroop effect) task assessing inhibition by pervasive TBI history did detect a statistically significant relationship. This suggests investigating TBI pervasiveness as an outcome is worthwhile in future investigations and raises further questions around the role of TBI in disinhibition and resulting offending behaviours.

Chapter Eight: Thesis Summary

This thesis aimed to improve the understanding of the relationship between cognition and TBI in offending populations. Three original studies contributed to this goal and comprise this thesis; study one (Chapter Five: A Systematic Review of TBI History and Cognitive Functioning in Criminal Offenders) was a systematic literature review of prior studies that had psychometrically assessed cognitive performance in an offending population and reported these outcomes by some aspect of TBI history; study two (Chapter Six: Assessing Cognitive Functioning Following Acute mTBI as a Predictor of Long-Term Offending Behaviour) was an analysis of existing data from a 10-year follow-up of TBI-affected individuals in the Waikato region of New Zealand which assessed the role of post-acute cognition in offending behaviour in the 10 years following mTBI; study three (Chapter Seven: Assessing the Relationship between TBI History and cognition in an Aotearoa New Zealand Men's Prison Population) was a study of cognitive performance by TBI status in a unique New Zealand prison sample. These three studies illustrate a field of investigation that is rife with challenges, study one demonstrated a body of literature defined by heterogeneity, in methods and in quality, study two provided a rare example of prospective research despite the difficulties of sound longitudinal investigation in an often-transient population, and study three showed the unique profile of a local prison population and how cognitive performance in this group is being influenced by a multitude of factors, this study also demonstrated potential concerns and considerations around existing measures of TBI history when working with high TBI exposure populations. While these studies were not able to completely elucidate the relationship between TBI and cognition in offenders, they provide further direction and understanding of the multitude of factors to consider in any such complex and comorbid population.

These studies hypothesised that greater TBI history would be associated with greater chronic cognitive symptoms in offenders. This was based on the existing body of research that has identified that offending populations experience TBI at a higher rate than community populations, while experiencing many risk factors for poor neurocognitive outcomes (Allely, 2016; Durand et al., 2017; Fraser et al., 2019; Moynan & McMillan, 2018). Relevant risk factors include drug and alcohol misuse (Kuhns et al., 2022; Morin et al., 2019; Potvin et al., 2018), poor emotional wellbeing (Ashman et al., 2004; Deb et al., 1999; Whelan-Goodinson et al., 2010), low socio-economic status (Haines et al., 2019; Humphries et al., 2020), and low cognitive reserve (Fraser et al., 2019; Mathias & Wheaton, 2015). These factors suggested that offending populations may be more vulnerable to the cognitive effects of TBI, which could contribute to greater issues in EF, leading to anti-social and offending behaviour.

One hypothesised outcome did emerge from the cross-sectional study of the Tongariro prison population. Experiencing a period of pervasive, repetitive TBI was associated with reduced performance on the CWIT assessment of inhibition (Stroop effect). That the only association found with cognition was by pervasive TBI history is a unique finding, particularly as much of the literature does not operationalise TBI exposure in this way. This is notable as an increasing body of literature is interested in the long-term effects of repetitive injuries in sporting populations, and findings do suggest some neurodegenerative effects of repetitive TBI in this group (Alosco et al., 2020; Saigal & Berger, 2014; Wright et al., 2020).

Cognitive Performance by TBI History in Offenders

The existing literature reveals interesting trends in studies of cognition, offending, and TBI. Of particular importance is the lack of consistency shown in method and outcome in studies investigating the relationship between TBI and cognition in offending populations. A few studies were identified in the systematic review which report a relationship between TBI and cognitive performance in offenders (Barnfield & Leathem, 1998b; Gorgens et al., 2021; Marsh & Martinovich, 2006), and conversely many studies did not. This can in part be attributed to a lack of uniformity in how TBI is measured and analysed. The prevailing strategies in existing research is to compare populations by their most severe TBI experienced (Bernett, 2013; Chitsabesan et al., 2015; La Point, 2014), or to compare those with any TBI to those without (Cohen et al., 2003; Cohen et al., 1999; Fitzsimons, 2017; Gorgens et al., 2021; Katzin et al., 2020; Marsh & Martinovich, 2006; McMillan et al., 2021; Pitman et al., 2015; Shiroma, Pickelsimer, et al., 2010; Smith, 2016). This may be a sound methodology when working with a population with few instances of TBI, however it may not be the most appropriate when working with a population like offenders who report very high rates of repetitive TBI.

A body of evidence is developing that demonstrates the importance of repetitive TBI. Therefore, studies of populations such as offenders, contact sportspeople, and victims of DV need to consider not only singular instances of severe injury, but the impact of a history of repeated trauma (Alosco et al., 2020; Saigal & Berger, 2014; Wright et al., 2020). It is also notable that many of these studies do not account for earliest TBI experienced, a variable that has been found to show distinct relationships with TBI sequelae but appears under-investigated in a population reporting high rates of childhood TBI and other experiences of physical violence (Königs et al., 2016; Séguin et al., 2022; Taylor et al., 2015).

Complexity of Self-Reported TBI

Due to the high rate of medically unreported mTBI, any retrospective investigation into the effects of TBI exposure necessarily relies upon self-report to determine injury history.

Research is still ongoing to design methods for recording TBI history in the most appropriate manner, and there are several underlying difficulties in doing so.

One issue of self-report is the degree of misinformation in the public consciousness regarding TBI. Individuals with elite sport participation and specialised concussion training demonstrate higher levels of misconception around TBI than others (Merz et al., 2017). This trend also appears to be worsening with knowledge accuracy rates decreasing across several metrics in recent decades (Hux et al., 2006; Merz et al., 2017). If individuals with high rates of TBI exposure, such as offenders, are also receiving misinformation and hold inaccurate beliefs of TBI, self-report TBI history tools need to be interrogated to determine whether experiences of TBI are being reliably measured, or whether outcomes are being influenced by a preponderance of TBI misinformation.

Study three identified an instance of a positive cognitive effect associated with increased TBI exposure, and although counterintuitive, this is a not unprecedented outcome within the existing literature (Bogner & Corrigan, 2009; Katzin et al., 2020). This invites investigation of the validity of measures of self-reported TBI history with offending populations. The most relevant component of validity in this regard is construct validity, which refers to how well the concept being measured, in this case TBI, is operationalised by the tool being used. The point of concern with measures of TBI history is convergent construct validity, which is the tool's ability to maintain association between constructs that are truly related i.e., there is substantial evidence of the long-term cognitive effects of severe TBI, therefore if a tool proposes that a population with a history of severe TBI performs better on well validated tests of cognition, it is showing poor convergent construct validity. That multiple instances have occurred in which studies have found high rates of moderate and severe TBI, and not an association with cognitive effects is concerning for this reason (Katzin et al., 2020; Monaghan, 2021).

Another significant concern in assessing TBI history is the evolving understanding of what constitutes a TBI. Existing tools achieve content validity by relying upon expert consensus of the integral components of a diagnosis (Taherdoost, 2016). An example would be the OSU TBI-ID, which was designed to align with the conceptual definition of TBI as recommended by the Center for Disease Control and Prevention for TBI surveillance (Centers for Disease Control & Prevention, 2003; Ohio Valley Center for Brain Injury Prevention and Rehabilitation). Although this reflects the diagnostic criteria of TBI as it stood at the time of the instrument design, specific diagnostic criteria are continuing to change in reflection of evolving understandings in the field. As recently as 2023, the American Congress of Rehabilitation Medicine has proposed alternative and updated criteria for diagnosis of TBI, and preexisting assessment methods do not reflect

these shifting definitions (Silverberg et al., 2023). Any questionnaire of historical TBI will be affected by the evolving understandings of TBI.

It is also worth considering whether the metrics used for categorising severe TBI are being appropriately applied with the milder majority of injuries. There is a substantial body of literature indicating the dose-response relationship acute symptoms of LOC and PTA have with long-term rehabilitative outcomes – but only in moderate and severe instances of TBI. In many instances of mTBI, patients will record a GCS score of or near 15, indicating no symptoms, and this creates a ceiling effect when using these tools with mTBI-affected populations (Reith et al., 2017). That many individuals with complicated mTBI would score highly on the GCS but experience chronic symptoms demonstrates the limitation of these approaches (Drake et al., 2006; Reith et al., 2017). The ceiling effect limits existing assessment tools by providing no ability to distinguish between most instances of mTBI, which themselves make up the vast majority of all TBI. Tools therefore need to be developed that identify the variables that differentiate important variables for more severe TBI, but also those variables that distinguish mTBI.

Future Research

The effects of TBI in offending populations remains an area with many important avenues for future research. One study that was unable to be completed within this thesis due to COVID-19 limitations was to explore whether subjective experiences of cognitive difficulty are aligning with performance-based testing of cognitive performance, in offenders with TBI history. This was intended to provide insight into how disabling, if at all, these individuals felt their TBI history was. This would also improve our understanding of the lived experience of post-TBI cognitive symptoms, and whether domains of cognitive concern align with domains of comparative cognitive deficit in this group. Based upon the anecdotes shared by Tongariro study participants throughout their interview, there appeared to be a high level of awareness of TBI and concern for the effects of TBI within this study population. A future study of mixed-methods design in a highly TBI-exposed population would be worthwhile to explore these issues.

Future investigation is also needed into how self-reported measures of TBI history can be improved. The finding from the Tongariro prison study suggests pervasive TBI exposure is an aspect of TBI history that should be considered in future studies. Additional research is needed that explores the validity of the pervasiveness variable of the OSU TBI-ID, and that considers how different aspects of experiencing a period of repetitive TBI might affect recovery outcomes, relevant variables include source of injury, age of exposure, and multiple sources of pervasive TBI. The Tongariro prison study population was notable in that they not only report periods of pervasive TBI, but pervasive TBI at multiple points in time and due to multiple causes, such as DV, sports, and fighting.

There are several other factors that may play a role in the relationship between TBI and cognition in offenders that could not be explored in detail within the studies of this thesis. Some of these factors are explored below.

Cognitive Rehabilitation Strategies

One potential component of TBI recovery that could be explored in future research is rehabilitative services. Rehabilitative services are an important component of TBI recovery for many and therefore the efficacy and accessibility of cognitive rehabilitation services are an important factor contributing to long-term cognitive outcomes. A 2019 systematic review (Cicerone et al., 2019) of cognitive rehabilitation strategies following TBI found evidence that rehabilitation treatment following TBI could assist with attention deficits, memory impairment, social communication issues, and executive functions. A growing body of evidence has also investigated computerised and virtual-reality cognitive rehabilitation techniques, however more high-quality research is needed to determine the efficacy of these approaches (Alashram et al., 2019; Brassel et al., 2021; Fetta et al., 2017; Maggio et al., 2019).

A component of long-term cognitive outcomes following TBI is therefore access to and utilisation of rehabilitative healthcare. In the American context, accessing these services is associated significantly with race and ethnicity, as well as insurance status (Gao et al., 2018; Odonkor et al., 2021). Within Denmark, older and female individuals with severe TBI report lower access to specialised rehabilitation services (Odgaard et al., 2015). Qualitative research has found that in both private and public healthcare systems there is significant impediment to access, and ongoing social support determines whether these services can be used (Dams-O'Connor et al., 2018; Graff et al., 2018). It is important to consider that studies of access are typically not targeted to cognitive outcomes alone, and additional research is needed to understand what factors are influencing engagement with these cognitive rehabilitation services specifically (Gao et al., 2018).

TBI and Mental Health

Mental health history is an important variable both before and after instances of TBI. TBI can contribute to chronic issues with emotional disturbances (Emery et al., 2016; Grandhi et al., 2017; Howlett et al., 2022; Juengst et al., 2017). TBI is associated with a higher incidence of mood, anxiety, personality disorders, and conduct disorders in children (Juengst et al., 2017; McKinlay, 2014; Vasterling et al., 2018). The most common psychological disorders diagnosed post-injury are depression and anxiety, which present comorbidly in 75% of cases with moderate-severe TBI, and can produce significant effects on cognitive performance (Gould et al., 2011; LeMoult & Gotlib, 2019; McMillan & Wood, 2013; Moran, 2016; Perini et al., 2019). Patients with any TBI have been found to be twice as likely as controls to exhibit any mental

health condition, with rates increasing to four times where the person had any pre-injury history of mental illness (Gould et al., 2011; Schofield et al., 2015). These rates worsen for those experiencing a moderate-severe TBI, 61.0% of whom receive a psychiatric diagnosis within the first year post-injury (Gould et al., 2011).

Relative to the general population, the TBI population is disproportionately affected by onset of mental health concerns which have been shown to continue until two-three years post-injury and elevated rates of depression in the TBI population have been found to continue for as many as 30 years post-injury (Ashman et al., 2004; Emery et al., 2016; Howlett et al., 2022; Koponen et al., 2002). Several factors may contribute to the onset and recovery of mental illness following TBI, including the nature of the injury, strength of support network, and severity of co-occurring disability that may affect the patient's independence and ability to perform their daily activities (Emery et al., 2016; McMillan & Wood, 2013).

It is important to consider that while the tissue damage resulting from a TBI may increase susceptibility to any number of mental health conditions, the psychological trauma that can accompany these injuries can be debilitating in and of itself (Iverson et al., 2017; Vasterling et al., 2018). Many TBI are attributable to events that can be emotionally traumatising, such as IPV, other domestic abuse, armed conflict, or massive polytrauma (Iverson et al., 2017; Ropacki et al., 2018; Vasterling et al., 2018; Yue et al., 2020). Therefore, a possibility of post-traumatic stress disorder (PTSD) might be considered when evaluating cognitive outcomes following TBI, as PTSD can present similar cognitive issues to TBI (Scott et al., 2015; Vasterling et al., 2018). A 2019 meta-analysis of civilian TBI populations determined a risk ratio of 1.73 for PTSD when compared to TBI unaffected controls (Van Praag et al., 2019). Studies of military populations provide insight into this interaction between PTSD, TBI, and cognitive rehabilitation outcomes, showing that in mTBI-affected veterans severity of PTSD mediates cognitive performance (Mattson et al., 2019).

It is an unfortunate limitation of the current studies that historic mental health conditions could not be considered in more depth. Particularly as the vulnerable mental health of those with TBI is a potentially significant component of the disability burden attributable to their injury.

Physiological Symptoms and Post-TBI Cognition

Those with a TBI are often experiencing a double burden of fatigue, both mental and physical, as TBI negatively affects energy levels during an often already exhausting TBI recovery process, and this can have meaningful effects on cognitive performance (Baumann et al., 2007; Bushnik et al., 2008; McMillan & Wood, 2013). Many of the most noticeable effects for those

living with TBI are physical disturbances such as chronic fatigue, headaches, light and noise sensitivity, sleep disturbance, nausea, imbalance and dizziness (Van Gils et al., 2020). This fatigue and general emotional distress often creates or exacerbates sleep disturbances, with approximately half of those in the post-acute phase of TBI recovery having exhibited sleep-wake disturbances (Baumann et al., 2007; Ponsford & Sinclair, 2014). These physiological symptoms can create a feedback loop with the cognitive sequelae of TBI, as cognitive issues of processing speed, attention, and memory may make previously superficial tasks more challenging, creating further fatigue and sleep disturbance, and as the individual faces more cognitive fatigue, they will find these tasks more challenging (Ashman et al., 2008; Cantor et al., 2008).

Chronic pain and headaches are another common complication of TBI. In a 2008 systematic review 57.8% of those with a history of TBI were reporting chronic headaches, while 43.1% reported other chronic pain syndromes (Nampiaparampil, 2008). Sleep disturbance and anxiety following a TBI may also be playing a role in worsening the impact of TBI on chronic pain and headaches (Van Gils et al., 2020). Headaches following TBI may also present as vestibular migraines, which cause dizziness that can be an especially disturbing symptom in the acute and post-acute stages of recovery when a patient may consider this evidence of more severe neurological injury (Van Gils et al., 2020). Photosensitivity and phonosensitivity are also common symptoms of TBI that are intertwined with chronic headaches (Mares et al., 2019; Truong et al., 2014). The issue of photosensitivity can be especially impactful on quality of life and ability to work, as many people report computer and phone screens as triggers for photosensitive migraines (Mares et al., 2019). Furthermore, these post-acute symptoms have been demonstrated to be worse in those suffering from recurrent TBI (Theadom et al., 2015). Combined, chronic TBI symptoms can lead to severe impacts on performance in activities of living and quality of life (Cantor et al., 2008). The role of physiological symptoms in the cognitive performance of individuals recovering from TBI is therefore an important consideration when assessing these affected populations.

Conclusion

This thesis contributes several new findings to the existing corpus on the relationship between cognition and TBI in offending populations. The foremost finding is that performance on a test of inhibition was associated with experiencing a period of pervasive, repetitive TBI in a prison population. Given the existing understanding of the relationship between disinhibition and anti-social behaviour, this suggests measures of TBI exposure should consider pervasive TBI a unique risk factor for cognitive symptoms.

By reviewing the existing literature, this thesis also identified several underlying issues that can be accounted for in future research. Self-reporting of TBI history remains a challenging but necessary component of retrospective research, and tools need to be used that are valid and reliable with their study population. It is also clear that reporting TBI history needs to be done in a clear and uniform manner, while several studies make claims as to the cognitive effects of TBI exposure, the metric in use is often unclear. Clarity is needed as there is reason to believe similar but distinct exposures such as medically attended TBI, complicated TBI, and self-reported history of TBI will differ in cognitive outcome, and studies should ensure they are understood distinctly.

There remains an opportunity for qualitative investigation into how TBI and TBI recovery is perceived and experienced in populations such as offenders, whose experience of TBI often begins in early childhood and can continue throughout their life course. Unfortunately, this thesis also contributed to the underrepresentation of female populations in studies of cognition and TBI in offenders, and this relative research gap needs to be considered. Given the demonstrated importance of experiencing a period of pervasive, repetitive period of TBI, and the high levels of experiencing DV in female offending populations, this area of research has become even more pertinent.

He manu aute,

e taea te whakahoro.

Appendices

Appendix A – Study Flyer

AUT TRAUMATIC BRAIN INJURY NETWORK

RESEARCH OPPORTUNITY

We are looking for people in Tongariro to help us with a research study. We will be looking to see if past injuries to the head affect the way people think in the longer term.

We would like to talk with both people who have experienced a hit to the head and those who have not.

You will be asked to complete some tasks to see how you think and how you cope with different situations.

It will take about 2 hours in total.

We will share our findings with you after the study, so people can learn from each other's experiences, and staff can provide better support.

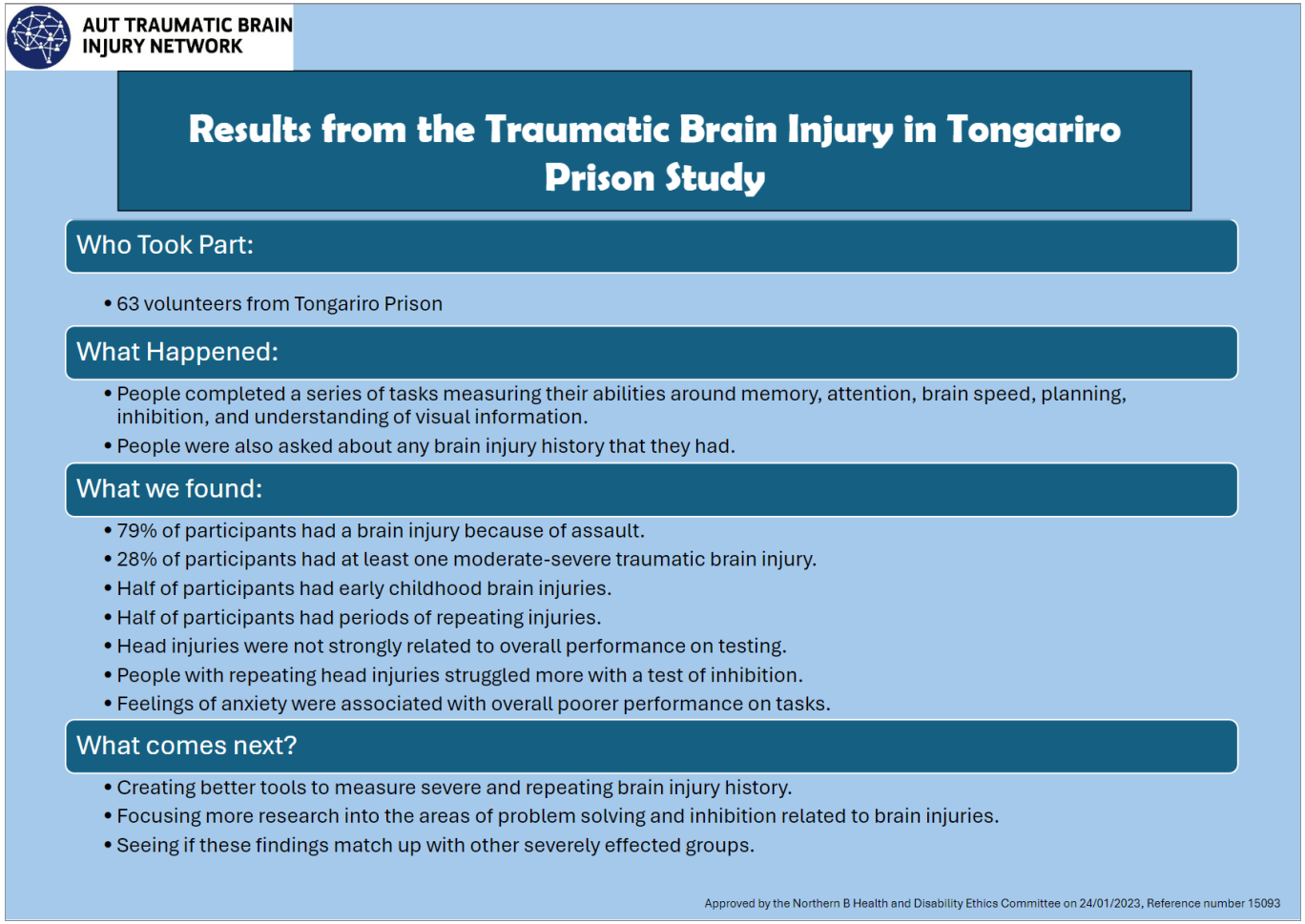
If you would like to find out more, please write your name below and send this form to the health team.

Name:

He waka kōtuia, e kore e tukua ngā mimira.
A waka that is expertly lashed together will not come undone in rough seas.
We are keen to learn from your experience to help us support our future generations better

Approved by the Northern B Health and Disability Ethics Committee on 24/01/2023, Reference number 15093

Appendix B – Tongariro Study Results Summary



Appendix C – Participant Information Sheet

AUT TRAUMATIC BRAIN INJURY NETWORK

Participant Information Sheet

Lead Researcher: Sam Guy

Study Site: Tongariro Prison

Contact person: Michael Wei - Health Centre Manager

Ethics committee ref.: 15093

Do injuries to the brain affect how people think in the longer term?

A study of people who have and have not experienced injuries to the brain in corrections

You are invited to take part in a study on injuries to brain, such as concussion and whether it affects how people think. Whether or not you take part is your choice. If you don't want to take part, you don't have to give a reason, and it won't affect the care you receive. If you do want to take part now, but change your mind later, you can pull out of the study at any time.

This Participant Information Sheet will help you decide if you'd like to take part. It sets out why we are doing the study, what your participation would involve, what the benefits and risks to you might be, and what would happen after the study ends. We will go through this information with you and answer any questions you may have. You do not have to decide today whether or not you will participate in this study. Before you decide you may want to talk about the study with other people, such as family, whānau, friends, or healthcare staff. Feel free to do this.

If you agree to take part in this study, you will be asked to sign the Consent Form on the last page of this document. You will be given a copy of both the Participant Information Sheet and the Consent Form to keep.

This document is 7 pages long, including the Consent Form. Please make sure you have read and understood all the pages.

Is the study voluntary?

You can choose whether you want to take part in this research or not. If you decide not to take part this will not affect the healthcare you receive. You can also start the interview and then decide that you no longer want to take part later.

What is the purpose of the study?

This study aims to find out whether injuries to the brain experienced earlier in life can affect how people think. We would like to talk with you whether or not you have experienced an injury to your head or not. If we learn that people have trouble with how they think, we can suggest ways that staff may be able to support people better.

How is the study designed?

We will be talking with about 65 people in Tongariro prison. These interviews will take between 90 minutes and 2 hours in the same rooms you might talk to your doctor in. They can be done in one session or in two shorter sessions.

You will be asked about any injuries to the brain that you may have had in the past and then be asked to complete some tasks that look at your memory and attention. We will also ask how you are feeling and about alcohol and substance use. We are asking about these things as they can also affect how you think. We will also ask you about how you cope with difficult situations. We will then look at the strategies people use and then share these with other people in Corrections at the end of the study.

We will then see if there are any differences in how people did on the cognitive tasks between people who have had injury to the head with those who have not.

Who can take part in the study?

Anyone in Tongariro prison can take part if they are over 18 years old, can hold a pencil, feel well enough to participate, and will be staying at Tongariro prison long enough to organize the meeting.

What are the possible risks of this study?

You might find some of the tasks difficult, tiring, or stressful. You will also be asked about medical conditions and injuries that you have had which you may find upsetting.

There will be chances to take a break if you need to. You do not have to answer any questions you do not wish to.

What are the possible benefits of this study?

This study will help us understand what sort of cognitive tasks and situations people in Ara Poutama find easier, and which they struggle with. We hope we can use this study to help Ara Poutama staff support people who experience cognitive difficulties, possibly because of head injury(ies), better.

WILL ANY COSTS BE REIMBURSED?

There is no cost to take part. This research will take two hours of your time. We will send you a thank you note and a summary of the study results. Your tests results can be made available to your health care practitioner or the corrections health care team if you would like them to.

WHAT IF SOMETHING GOES WRONG?

If you were injured in this study, you would be eligible **to apply** for compensation from ACC just as you would be if you were injured in an accident at work or at home. This does not mean that your claim will automatically be accepted. You will have to lodge a claim with ACC, which may take some time to assess. If your claim is accepted, you will receive funding to assist in your recovery.

If you have private health or life insurance, you may wish to check with your insurer that taking part in this study won't affect your cover.

WHAT WILL HAPPEN TO MY INFORMATION?

During the meeting the researcher will record information about you. However, they will not write down your name on any of the study sheets.

Your name will only be recorded on the consent form which will be stored separately from your health information and test results.

To make sure your personal information is kept private, you will only be identified by a study specific number. The researcher will keep a list linking your study number with your name which will be password protected, so that you can be identified your data if needed. Your name will not be included in any report generated by the researcher.

Your information will only be used for this study.

Security and Storage of Your Information.

On completion of the assessment your information will be stored at Auckland University of Technology. Your information will be held for at least 10 years, then destroyed. All storage will comply with local and/or international data security guidelines.

Risks.

Although efforts will be made to protect your privacy, absolute confidentiality of your information cannot be guaranteed. Even with coded and anonymised information, there is no guarantee that you cannot be identified. The risk of people accessing and misusing your information (e.g., making it harder for you to get or keep a job or health insurance) is currently very small, but may increase in the future as people find new ways of tracing information.

This research includes basic information such as your ethnic group, age range, and sex. It is possible that this research could one day help people in the same groups as you. However, it is also possible that research findings could be used inappropriately to

support negative stereotypes, stigmatize, or discriminate against members of the same groups as you.

Rights to Access Your Information.

You have the right to request access to your information held by the research team. You also have the right to request that any information you disagree with is corrected.

We will need to spend time looking at your data at the end of the assessment. If you would like us to share your results with your GP or health care practitioner or with the Corrections health care team please let us know. We will only share your data with others if you give us permission.

If you have any questions about the collection and use of information about you, you should ask the researcher.

Rights to Withdraw Your Information.

You may withdraw your consent for the collection and use of your information at any time, by informing the researcher.

If you withdraw your consent, your study participation will end, and the study team will stop collecting information from you.

We will not be able to remove your data if you choose to withdraw after analysis has started.

Māori Data Sovereignty

Māori data sovereignty is about protecting information or knowledge that is about (or comes from) Māori people. We recognise the taonga of the data collected for this study. To help protect this taonga:

- We have consulted with Māori research advisors from the University of Auckland and Ara Poutama about the collection, ownership, and use of study data.
- The design of the study has also been informed through advice and consultation with Māori research specialist Dr Makarena Dudley.

CAN I FIND OUT THE RESULTS OF THE STUDY?

Yes, you can be provided with a summary of the overall results of the study if you would like. These will also be provided on the Traumatic Brain Injury Network website https://tbin.aut.ac.nz

WHO IS FUNDING THE STUDY?

This research will be part of a PhD for Sam Guy (Ngāti Maru) at AUT, funded through a PhD stipend and scholarship from the Traumatic Brain Injury Network.

WHO HAS APPROVED THE STUDY?

This study has been approved by an independent group of people called a Health and Disability Ethics Committee (HDEC), who check that studies meet established ethical standards. The [insert Committee name] has approved this study.

WHO DO I CONTACT FOR MORE INFORMATION OR IF I HAVE CONCERNS?

If you have any questions, concerns or complaints about the study at any stage, you can contact:

Alice Theadom, Professor at AUT
Alice.Theadom@aut.ac.nz

Sam Guy, PhD candidate at AUT
Sam.Guy@AUT.ac.nz

If you want to talk to someone who isn't involved with the study, you can contact an independent health and disability advocate on:

Phone: 0800 555 050
Fax: 0800 2 SUPPORT (0800 2787 7678)
Email: advocacy@advocacy.org.nz
Website: https://www.advocacy.org.nz/

You can also contact the health and disability ethics committee (HDEC) that approved this study on:

Phone: 0800 4 ETHIC
Email: hdecs@health.govt.nz

AUT TRAUMATIC BRAIN INJURY NETWORK

Short Information Sheet

Do injuries to the brain affect how people think in the longer term?

A study of people who have and have not experienced injuries to the brain in Corrections

Lead Researcher: Sam Guy

Study Site: Tongariro Prison

Contact person: Michael Wei from the Health Centre

Ethics committee ref.: 15093

You are invited to take part in a study on injuries to brain, such as concussion and whether it affects how people think. Whether or not you take part is your choice. If you don't want to take part, you don't have to give a reason, and it won't affect the care you receive. If you agree to take part now, you can change your mind later and stop at any time.

This Information Sheet will help you decide if you'd like to take part. It sets out why we are doing the study, what will happen, what the benefits and risks to you might be, and what will happen after the study ends. We will go through this information with you and answer any questions you may have. You may want to talk about the study with other people, such as family, whānau, friends, or your health care team before you decide to take part. Feel free to do this.

If you agree to take part in this study, you will be asked to sign the Consent Form on the last page of this form. You will be given a copy of both the Participant Information Sheet and the Consent Form to keep.

This information sheet is 3 pages long. Please make sure you have read and understood all the pages.

WHAT IS THE PURPOSE OF THE STUDY?

We know that experiencing repeated injuries to the brain from sport can affect how people think in the longer term. We also know that people in prison have often experienced injuries to the brain over their lives too. This study aims to find out if people in prison who have had past injuries to their brain are affected in the same way. For example, do people who have experienced injuries to the brain have more difficulties remembering and focusing on things compared to those who have not.

If we learn that people have trouble with certain ways of thinking, we can then suggest ways that people can be supported within the prison environment and on release better.

WHO IS DOING THE STUDY?

This study is being done by Sam Guy (Ngāti Maru) as part of his PhD. He is being supported by a team of researchers who work at the Auckland University of Technology (AUT), Waikato University and the University of Auckland and in Ara Poutama (Corrections).

Only Sam will know who you are. You will be given a study number and only Sam will be able to link your data to you. Your name will not appear on any answer sheets to protect your privacy. Your answer sheets will be stored in a locked cabinet and any electronic information will be password protected on the university secure system.

WHAT WILL HAPPEN?

We will be talking with about 65 people in Tongariro prison.

Sam will meet with you in one of the health care centre rooms in Tongariro. He will ask you about any potential brain injuries (concussions) you may have had. He will also ask how you are feeling, how you cope with difficult situations and about whether you have used of alcohol and other drugs (as these can affect how you think). We will then ask you to complete some tasks which look at how you think, and to see if you find some tasks easier than others.

It will take between 90 minutes and 2 hours to take part. This can be done all at once or we can split it up over two shorter sessions if you would prefer.

We will then compare everyone's results to see if there are any differences between people who have had an injury to the brain and those who have not.

We will then share the main learnings from this study with other people in Ara Poutama (Corrections) as well as staff, other scientists and the public. We will share people's suggestions about things that help them cope with difficult situations as well as techniques to help with things such as poor memory.

WHO CAN TAKE PART IN THE STUDY?

Anyone in Tongariro prison can take part if they are over 18 years old, can hold a pencil and feel well enough to participate. People will also need to be staying at Tongariro prison long enough to organize the meeting.

WHAT ARE THE POSSIBLE RISKS?

You might find some of the tasks hard or stressful. You will also be asked about your health and injuries that you have had which you may find upsetting.

There will be chances to take a break if you need to. You do not have to answer any questions you do not want to.

DOES IT COST ANYTHING AND WHAT DO I GET FOR IT?

There is no cost to take part. This interview will take up to two hours of your time. We will send you a thank you note and let you know what we learn from the study. We can share your tests results with your Doctor or the corrections health care team if you would like us to.

WHO HAS APPROVED THE STUDY?

This study has been approved by an independent group of people called a Health and Disability Ethics Committee (HDEC), who check that studies meet established ethical standards. The Northern B Health and Disability Ethics Committee has approved this study.

WHO DO I CONTACT FOR MORE INFORMATION OR IF I HAVE CONCERNS?

If you have any questions, concerns or complaints about the study at any stage, you can contact:

Sam Guy, PhD candidate at AUT
Sam.Guy@aut.ac.nz

Or his main supervisor
Alice Theadom, Professor at AUT
alice.theadom@aut.ac.nz

If you want to talk to someone who isn't involved with the study, you can contact an independent health and disability advocate on:

Phone: 0800 555 050
Fax: 0800 2 SUPPORT (0800 2787 7678)
Email: advocacy@advocacy.org.nz
Website: https://www.advocacy.org.nz/

You can also contact the health and disability ethics committee (HDEC) that approved this study on:

Phone: 0800 4 ETHIC
Email: hdecs@health.govt.nz

Appendix E – Consent Form

AUT TRAUMATIC BRAIN INJURY NETWORK

Consent Form

Do injuries to the brain affect how people think in the longer term?

Please tick to indicate you consent to the following

I have read the Participant Information Sheet or have had it read to me in a language I understand, and I fully comprehend what it says.		
I have been given sufficient time to consider whether or not to participate in this study.		
I have had the opportunity to use a legal representative, whanau/ family support or a friend to help me ask questions and understand the study.		
I am satisfied with the answers I have been given regarding the study and I have a copy of this consent form and information sheet.		
I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without this affecting my medical care.		
I consent to the research staff collecting and processing my information, including information about my health.		
If I decide to withdraw from the study, I agree that the information collected about me up to the point when I withdraw may continue to be processed.	Yes ☐	No ☐
I consent to my GP or current provider being informed about my participation in the study and of any significant abnormal results obtained during the study.	Yes ☐	No ☐
I consent to my GP or current provider being provided with a copy of my assessment results.	Yes ☐	No ☐
I consent to things I say during the interview being anonymously included with reports from this study.	Yes ☐	No ☐

I understand that my participation in this study is confidential and that no material, which could identify me personally, will be used in any reports on this study.	
I understand the compensation provisions in case of injury during the study.	
I know who to contact if I have any questions about the study in general.	
I understand my responsibilities as a study participant.	
I wish to receive a summary of the results from the study.	Yes ☐ No ☐

Declaration by participant:
I hereby consent to take part in this study.

Participant's name: _____

Signature: _____ Date: _____

Declaration by member of research team:

I have given a verbal explanation of the research project to the participant and have answered the participant's questions about it.

I believe that the participant understands the study and has given informed consent to participate.

Researcher's name: _____

Signature: _____ Date: _____

Appendix F - CASP Quality Checklists

Barnfield and Leathem (1998b) /9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Neuropsychological outcomes of TBI and substance use.
Did the authors use an appropriate method to answer their question?	Yes, given the exposure and outcome, cross-sectional research may be the most appropriate/feasible option.
Were the subjects recruited in an acceptable way?	Yes, volunteers were recruited appropriately for cross-sectional research in a prison population, with appropriate consent protocol
Were the measures accurately measured to reduce bias?	Possibly not. Method of determining TBI history was not validated and possibly difficult to accurately respond to. No PVT on cognitive measures.
Were the data collected in a way that addressed the research issue?	Yes, a battery of appropriate assessments was used.
Did the study have enough participants to minimise the play of chance?	Unlikely. Given the number of analyses performed, a lack of correction is concerning, no power calculation noted.
How are the results presented and what is the main result?	t-tests of difference. On RAVLT delayed recall the more severe TBI group performed at a significantly lower level than the less severe TBI group, $t(48) = 2.25$, $p = 0.03$.
Was the data analysis sufficiently rigorous?	No. A lack of multiple correction and low PVT cut-score. Further consideration of interaction between TBI and substance use is needed.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Yes. This is a NZ prison population, and although it is a somewhat older study, many of the same risk factors remain.
How valuable is the research?	Somewhat, this work provided a good starting point for work in the NZ specific population and several relevant covariates to consider.

Bernett (2013) 9/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes, this study clearly explains a hypothesis connecting TBI, executive functioning performance, and behavioural outcomes.
Did the authors use an appropriate method to answer their question?	Yes, given the exposure and outcome, cross-sectional research may be the most appropriate/feasible option.
Were the subjects recruited in an acceptable way?	Yes, data was used from prior study that was conducted appropriately
Were the measures accurately measured to reduce bias?	Yes, a standardised method of reporting TBI history was used. Appropriate cognitive measures used.
Were the data collected in a way that addressed the research issue?	Yes, data was collected prior to the current study, in an appropriate manner for cross-sectional research on a prison population.
Did the study have enough participants to minimise the play of chance?	Yes, a large sample was used, and power calculation was performed.
How are the results presented and what is the main result?	Appropriately, figures presented show no significant differences in EF performance by TBI status.
Was the data analysis sufficiently rigorous?	Yes, thorough analysis was performed across several variables to investigate the hypotheses.
Is there a clear statement of findings?	Yes, findings are explicitly stated, and results are contextualised to existing research with acknowledgement of limitations.
Can the results be applied to the local population?	Yes, the local prison population demonstrates a similar risk profile for outcomes following TBI
How valuable is the research?	This research has value in thorough methodology and analysis; however, limitations are noted and suggestions for future research are made.

Bogner and Corrigan (2009) 8/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes, this study is intended to assess psychometric properties of the OSU TBI-ID in prisoners.
Did the authors use an appropriate method to answer their question?	Yes, appropriate factor modelling was performed for the purposes of this study.
Were the subjects recruited in an acceptable way?	Yes, however there is a consideration of volunteer bias in this sort of study and the age limitation prevents a level of generalisability of result.
Were the measures accurately measured to reduce bias?	Yes, appropriate cognitive measures were used.
Were the data collected in a way that addressed the research issue?	Yes, data was collected in an appropriate manner for a cross-sectional study in this population.
Did the study have enough participants to minimise the play of chance?	Unclear, a comparatively large sample size for this literature, although it is unclear if any power calculation occurred or if multiple testing was accounted for.
How are the results presented and what is the main result?	The study presents 16 indices that were found reliable in the OSU TBI-ID.
Was the data analysis sufficiently rigorous?	Yes, appropriate factor analysis has occurred.
Is there a clear statement of findings?	Yes
Can the results be applied to the local population?	Yes, the risk profile of this population likely aligns with that of the local offending population.
How valuable is the research?	This research provides value in further developing a method for assessing TBI history in offenders. It is unclear how meaningful the cognitive outcomes shown are.

Cohen et al. (1999) 9/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes, neuropsychological functioning is explored and comparisons made between those with DV and those without.
Did the authors use an appropriate method to answer their question?	Yes, sound cognitive assessment tools were used, and appropriate controls were identified.
Were the subjects recruited in an acceptable way?	Yes, DV cases were recruited from outpatient treatment and controls were volunteers from the community. DV participants were incentivised through payment of treatment.
Were the measures accurately measured to reduce bias?	Yes, appropriate cognitive measures were used. Several appropriate measures of relevant confounders were also used. TBI exposure was identified systematically by interview.
Were the data collected in a way that addressed the research issue?	Yes, appropriate cross-sectional study methods were used. Medical history was recorded by an interviewer blinded to cognitive outcomes.
Did the study have enough participants to minimise the play of chance?	Possibly. Although no a priori analysis was reported. MANOVA were conducted with an alpha level of .01 and detected significant differences. Unclear if the study was statistically powered for between groups effect of TBI and DV.
How are the results presented and what is the main result?	Logistic regression analysis identified several significant differences between those with DV for those without. DV group reported more TBI. TBI-affected group performed lower on NVSRT, but no significant interaction detected between TBI and DV history.
Was the data analysis sufficiently rigorous?	Yes, appropriate regression techniques used, and the most relevant confounders were considered.
Is there a clear statement of findings?	Yes, several notable findings are reported in an appropriate manner.
Can the results be applied to the local population?	Yes, these results provide insight into several notable relationships. Some care will need to be take in applying results cross-culturally.
How valuable is the research?	Very. A comparatively early piece of research in this area that assessed TBI in an appropriate manner, in a specific offending subgroup. Many of the key confounders were also considered in an effective way.

Cohen et al. (2003) 8/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. The relationship of cognitive performance with DV.
Did the authors use an appropriate method to answer their question?	Yes, a sound cross-sectional approach was used with appropriate measures of cognitive performance and confounders.
Were the subjects recruited in an acceptable way?	Yes, community volunteers and referral from outpatient DV treatment.
Were the measures accurately measured to reduce bias?	Yes, appropriate tools were used, and relevant confounders were identified and adjusted for.
Were the data collected in a way that addressed the research issue?	Yes, appropriate cognitive assessment methods used. LOC used as measure of TBI severity.
Did the study have enough participants to minimise the play of chance?	Unclear, no a priori power calculation reported. Significant differences were detected ($p<.05$). Moderate sample size, N=61.
How are the results presented and what is the main result?	Results of MANOVA are reported and logistic regression by TBI status also discussed. Measures of verbal ability and inhibition both show statistically significant relationships with TBI and DV status.
Was the data analysis sufficiently rigorous?	Bonferroni adjustment performed for multiple testing.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Yes, these results provide insight into several notable relationships. Some care will need to be take in applying results cross-culturally.
How valuable is the research?	Very. A comparatively early piece of research in this area that assessed TBI in an appropriate manner, in a specific offending subgroup. Many of the key confounders were also considered in an effective way. Consideration of sample size is needed.

Fitzsimons (2017) 8/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. TBI and offending in a female prison population; including associations with cognitive performance.
Did the authors use an appropriate method to answer their question?	Yes. Sound cross-sectional approach. Appropriate measures of cognitive performance: WASI, BADS, and RBANS. Structured interview and BISI for TBI history.
Were the subjects recruited in an acceptable way?	Yes. Convenience sample from a women's prison population.
Were the measures accurately measured to reduce bias?	Yes. Appropriate assessment methods and several confounders accounted for.
Were the data collected in a way that addressed the research issue?	Yes. Appropriate cognitive assessment methods and standardised recording of TBI history.
Did the study have enough participants to minimise the play of chance?	Borderline. An a priori sample size was calculated and the study recruited for this, but 1 participant had to be transferred from non-TBI to TBI group after recruitment had been ceased.
How are the results presented and what is the main result?	No statistically significant differences in cognitive performance by TBI status on independent samples t-tests and Mann-Whitney U tests
Was the data analysis sufficiently rigorous?	Yes. Familywise corrections appropriately used due to many t-tests and Mann-Whitney U tests.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Yes, these results provide insight into several notable relationships. Some care will need to be take in applying results cross-culturally.
How valuable is the research?	Very. One of few papers exploring an offending female study population.

Gorgens et al. (2021) 7/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. TBI outcomes in community corrections populations
Did the authors use an appropriate method to answer their question?	Yes. Cross-sectional approach used. Several appropriate tools used for assessment of cognitive outcomes and standardised OSU-TBI ID for TBI history.
Were the subjects recruited in an acceptable way?	Yes. Appropriate consent protocol was followed to analyse data from community corrections settings.
Were the measures accurately measured to reduce bias?	Yes. Appropriate cognitive and retrospective TBI history methods were used.
Were the data collected in a way that addressed the research issue?	Yes. Although comparison was to norms, rather than a non-TBI control group.
Did the study have enough participants to minimise the play of chance?	Yes. 314 participants with TBI completed cognitive testing.
How are the results presented and what is the main result?	71% of TBI exposed participants performed 2 S.D. below mean norm on cognitive testing.
Was the data analysis sufficiently rigorous?	No. This was not the primary study outcome within this study and additional analysis comparing participants by the severity of their exposure and appropriate controls would be needed.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Unlikely. The scope of deficit in the study population is extreme and further study would be needed to understand how this came about.
How valuable is the research?	Somewhat. This is a comparatively large-scale community-based offending population, which is a rarity in this space. Further analysis and consideration of these outcomes is needed.

Johnson (2016) 4/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Cognitive effects of TBI in a forensic population.
Did the authors use an appropriate method to answer their question?	Somewhat. Appropriate tools of cognitive assessment and TBI history were used in this cross-sectional design. A comparatively brief cognitive assessment battery to other work in this space. Issues of using TBI frequency as measure of severity without deeper justification is odd.
Were the subjects recruited in an acceptable way?	Yes. Participants were volunteers from a drug court probation service.
Were the measures accurately measured to reduce bias?	Yes. Sound measures of TBI and cognition. No effort testing reported.
Were the data collected in a way that addressed the research issue?	No. Despite measuring LOC during interviews, the method of severity categorisation was by frequency and not by any sound metric.
Did the study have enough participants to minimise the play of chance?	Unlikely. No a priori power calculation. Comparatively small sample size (N=40).
How are the results presented and what is the main result?	Results from MANOVA are reported. No statistically significant associations found.
Was the data analysis sufficiently rigorous?	No. MANOVA was performed despite admission that sample size was insufficient, and no other methods of analysis were explored.
Is there a clear statement of findings?	Yes. A clear statement on results and limitations of findings is provided.
Can the results be applied to the local population?	No. This study was too statistically limited to draw generalisable conclusions.
How valuable is the research?	Not especially. Although there is limited research in this space, fundamental issues with this study limit its value.

Katzin et al. (2020) 9/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. TBI outcomes in young male offending population.
Did the authors use an appropriate method to answer their question?	Yes. Appropriate measures of cognitive performance were used, and TBI history was recorded to a relatively thorough degree.
Were the subjects recruited in an acceptable way?	Yes. This is a sound cross-sectional approach. Study population was evaluated for representativeness of general prison population.
Were the measures accurately measured to reduce bias?	Yes. Appropriate measures were used. However, no PVT was reported.
Were the data collected in a way that addressed the research issue?	Yes. Thorough assessment of TBI, cognitive performance, and anti-social and aggressive behaviour using appropriate measured.
Did the study have enough participants to minimise the play of chance?	Yes. Comparatively large sample size (N=269).
How are the results presented and what is the main result?	Offenders with any kind of TBI had statistically significant higher WAIS GAI scores than offenders without any kind of TBI. Statistically significant but clinically insignificant.
Was the data analysis sufficiently rigorous?	Yes. Appropriate student t-tests of difference, analysis of results provides additional clarity.
Is there a clear statement of findings?	Yes. Cognitive outcomes clearly articulated, and implications discussed.
Can the results be applied to the local population?	Yes, a large sample study from a young prison population. Care needed with cross-cultural application of results.
How valuable is the research?	Very. One of the few studies with large study population and focussed offending subgroup.

La Point (2014) 9/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Assessing neuropsychological outcomes of moderate-severe TBI and substance misuse in a prison population.
Did the authors use an appropriate method to answer their question?	Yes. Appropriate tools of cognition and TBI assessment were used in this cross-sectional approach.
Were the subjects recruited in an acceptable way?	Yes. Volunteers from a prison-based drug treatment centre were recruited.
Were the measures accurately measured to reduce bias?	Yes. Sound measures of TBI and cognition. Several relevant confounders were considered. No measure of PVT.
Were the data collected in a way that addressed the research issue?	Yes. Appropriate tools and methodology to address research issue.
Did the study have enough participants to minimise the play of chance?	Likely. No a priori calculation of power, but a relatively large sample size (N=213).
How are the results presented and what is the main result?	ANOVA found a history of moderate/severe TBI accounted for 3.4% of the variance on Part A of the TMT. Results indicated that offenders with moderate/severe TBI performed less well on TMT-A than offenders without moderate/severe TBI. There was no significant difference on TMT-B.
Was the data analysis sufficiently rigorous?	Yes. Appropriate and thorough data analysis was performed.
Is there a clear statement of findings?	Yes. Clear findings for each hypothesis are reported.
Can the results be applied to the local population?	Yes. A comparatively large study sample in a targeted subgroup of substance using offenders.
How valuable is the research?	Quite. This research targeted a specific study population with a distinct neuropsychological risk profile.

LeMay and Stinson (2021) 4/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes, outcomes of TBI in a sex offending population.
Did the authors use an appropriate method to answer their question?	Yes. Sound cross-sectional assessment of records from a forensic inpatient population.
Were the subjects recruited in an acceptable way?	Yes. Study is an exploratory analysis of existing records from a forensic inpatient population.
Were the measures accurately measured to reduce bias?	No. Cognitive measures were not available for many participants (13/25 w/TBI), and TBI exposure is limited to those present in the medical record.
Were the data collected in a way that addressed the research issue?	No. Due to the lack of cognitive data available for many participants, it is difficult to draw meaningful conclusions.
Did the study have enough participants to minimise the play of chance?	No. 25 participants with TBI, and only 12 of which had undergone cognitive testing.
How are the results presented and what is the main result?	Largely by means and chi-squares. Some reflection made on the differences in life experiences and ACEs between groups, but no meaningful conclusion to be drawn regarding the role of cognitive functioning.
Was the data analysis sufficiently rigorous?	No. The lack of cognitive testing in most TBI-exposed participants limited the ability to conduct rigorous statistical analysis.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	No. Lack of generalisability due to missing cognitive testing for most TBI participants.
How valuable is the research?	Only somewhat. Provides some insight into the backgrounds of a specific offending sub-group (sexual offenders), but few conclusions can be drawn regarding TBI from this exploratory analysis.

Marsh and Martinovich (2006) 8/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Executive functioning in DV men by TBI history.
Did the authors use an appropriate method to answer their question?	Yes. Several appropriate methods were used to assess TBI, EF, and several relevant covariates in this cross-sectional approach.
Were the subjects recruited in an acceptable way?	Yes. Volunteers from an abuse intervention programme with offending history.
Were the measures accurately measured to reduce bias?	Yes. A brief but appropriately targeted cognitive assessment battery and structured interview to elucidate TBI history, with consideration of possible desirability effects made.
Were the data collected in a way that addressed the research issue?	Yes. Appropriate tools and methodology were used.
Did the study have enough participants to minimise the play of chance?	Unclear. Some statistically significant differences ($p<.05$) were identified but a comparatively small sample size (N=38) may indicate some differences were not detected.
How are the results presented and what is the main result?	One-tailed t-tests found the TBI group had lower IQ, and Hayling and Brixton test performance.
Was the data analysis sufficiently rigorous?	Yes. Many of the most relevant confounders were considered and accounted for as matching variables.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Yes. This is an NZ based population, although a relatively small sample size.
How valuable is the research?	Very. This is locally based research using sound methodology in a particularly vulnerable population to TBI exposure.

McMillan et al. (2021) 9/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Outcomes of TBI in UK female prison populations.
Did the authors use an appropriate method to answer their question?	Yes. A brief but targeted cognitive assessment battery was used, and a validated measure of TBI history (OSU TBI-ID) was used in this cross-sectional study.
Were the subjects recruited in an acceptable way?	Yes. Volunteers across several UK women's prisons. Capturing much of the total national women's prison population.
Were the measures accurately measured to reduce bias?	Yes. Several appropriate tools were used for TBI and cognitive performance. PVT through the WMT.
Were the data collected in a way that addressed the research issue?	Yes. Appropriate and thorough recruitment and data collection.
Did the study have enough participants to minimise the play of chance?	Yes. 109 participants were recruited of a total prison population of approximately 400.
How are the results presented and what is the main result?	No significant cognitive differences by TBI status, whether or not covariates were adjusted for.
Was the data analysis sufficiently rigorous?	Yes. Several relevant covariates were accounted for.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Yes. Although consideration is needed for cross-cultural application.
How valuable is the research?	Very. A rare and comparatively large study of a female prison population, using thorough methods of assessment and analysis.

O'Sullivan et al. (2021) 6/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Cognitive outcomes of TBI in a women's prison population.
Did the authors use an appropriate method to answer their question?	Yes. Cross-sectional approach using a volunteer prison population. Sound assessment methods used for TBI and cognitive performance.
Were the subjects recruited in an acceptable way?	Yes. Prison-based volunteers.
Were the measures accurately measured to reduce bias?	Somewhat. Appropriate cognitive assessment tools were used, but the use of a LOC>10 mins as a cut-off for TBI exposure is somewhat arbitrary and likely contributing to underlying issues of statistical power. PVT and PMF are both accounted for, as well as several other relevant co-variates.
Were the data collected in a way that addressed the research issue?	Yes. Sound measures and recording of outcomes.
Did the study have enough participants to minimise the play of chance?	No. Only 10 participants were allocated to the TBI-exposed group, and no a priori power analysis is reported.
How are the results presented and what is the main result?	Mann-Whitney U-tests. No statistically significant differences in cognitive performance were detected.
Was the data analysis sufficiently rigorous?	Yes. Appropriate analysis and consideration of covariates. Some participants excluded due to low PVT scores.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	No. Due to small TBI sample and conservative categorisation of TBI, I would not generalise from this study.
How valuable is the research?	Somewhat. The statistical methods are sound but the underlying issues of TBI categorisation and power limit these findings.

Pitman et al. (2015) 9/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Cognitive effects of TBI in a male prison population.
Did the authors use an appropriate method to answer their question?	Yes. Sound cross-sectional approach was used with appropriate methods of cognitive and TBI assessment.
Were the subjects recruited in an acceptable way?	Yes. Volunteers recruited from a male prison population.
Were the measures accurately measured to reduce bias?	Yes. Appropriate reliable measures were used. An embedded measure of performance validity was included. A priori power calculation was conducted. Several appropriate covariates were measured.
Were the data collected in a way that addressed the research issue?	Yes. A thorough and reliable assessment battery that addressed the possible cognitive effects of TBI.
Did the study have enough participants to minimise the play of chance?	Yes. Appropriate a priori power analysis was conducted, and necessary sample size was successfully recruited.
How are the results presented and what is the main result?	Statistically significant differences on t-tests by TBI status in WASI, RBANS, and BADS.
Was the data analysis sufficiently rigorous?	Yes, appropriate analysis was performed, including adjustment for multiple testing.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Yes. A thorough analysis that provides good insight for the local offending population, although cross-cultural application of results should be considered.
How valuable is the research?	Very, this study used some novel methods of TBI exposure categorisation and a more rigorous statistical analysis than most research in this space.

Schofield et al. (2019) 7/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Correlates, including cognition, of TBI history in young offender population.
Did the authors use an appropriate method to answer their question?	Yes. A sound cross-sectional approach was used. However, the method of TBI history assessment was original and therefore reliability may be questioned, and cognitive assessment was brief (WASI).
Were the subjects recruited in an acceptable way?	Yes. A large proportion of young offenders on community orders were approached for volunteers.
Were the measures accurately measured to reduce bias?	Unclear. TBI assessment was likely sufficient however the brevity and lack of effort testing for cognitive measures is a potential source of bias.
Were the data collected in a way that addressed the research issue?	Yes. Although a more thorough cognitive assessment battery would be ideal.
Did the study have enough participants to minimise the play of chance?	Yes. This study had a comparatively large study sample of 788.
How are the results presented and what is the main result?	Results of chi-square and ANOVA presented. TBI exposed participants performed better than non-TBI exposed.
Was the data analysis sufficiently rigorous?	Yes. Relevant confounders were considered and adjusted for.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Unclear. The study sample is large but the results are contrary to hypothesis and would require additional exploration and validation.
How valuable is the research?	Quite. This is a large sample of a specific sub-group of offender that would be hypothesised to have differential outcomes. Consideration of the brevity of cognitive testing is needed.

Shiroma, Pickelsimer, et al. (2010) 9/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Relationship between TBI and in-prison behavioural infraction.
Did the authors use an appropriate method to answer their question?	Yes. Sound prospective cohort design of a large multiple prison population.
Were the subjects recruited in an acceptable way?	Yes. A large dataset was appropriately deidentified for research purposes.
Were the measures accurately measured to reduce bias?	Yes. As TBI had to be medically attended, there was no reliance on self-report. Cognitive testing was solely based upon the WRAT, is a brief but reliable measure that aligns moderately with IQ.
Were the data collected in a way that addressed the research issue?	Yes. A thorough dataset was used and evaluated for associations.
Did the study have enough participants to minimise the play of chance?	Yes. An extremely large dataset. N=21610. (n=1230 with TBI)
How are the results presented and what is the main result?	No statistically significant differences in WRAT performance on TBI history.
Was the data analysis sufficiently rigorous?	Yes. However, cognitive outcomes were not the primary outcome of interest in this study.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Yes. This is a very large sample but consideration is needed that TBI were medically attended and cross-cultural application of results.
How valuable is the research?	This is a very valuable study on behavioural outcomes, but does not provide great utility in understanding cognitive outcomes.

Slaughter et al. (2003) 6/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Determining neuropsychological correlates of recent TBI in a jail population.
Did the authors use an appropriate method to answer their question?	Yes. Sound cross-sectional approach with a coherent method of TBI self-report. Severity determined by LOC. A brief but targeted cognitive assessment battery was also used.
Were the subjects recruited in an acceptable way?	Yes. Randomly selected inmates of a local jail population. Some concern over the small subgroup of female participants.
Were the measures accurately measured to reduce bias?	Yes. Appropriate cognitive measures were included. Focussing on recent TBI reduces some bias.
Were the data collected in a way that addressed the research issue?	Yes. Sound methods of data collection, using appropriate tools.
Did the study have enough participants to minimise the play of chance?	Probably not. N=50 (TBI=25). Authors acknowledge low statistical power.
How are the results presented and what is the main result?	Two-tailed t-tests of difference found no statistical differences in cognitive performance by recent TBI status.
Was the data analysis sufficiently rigorous?	No. Due to the small study sample, a more thorough analysis may not have been possible. The use of a two-tailed rather than one-tailed approach likely hurt the possibility of identifying trends.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	No. The small sample size and need for more rigorous TBI history makes it difficult to apply these results locally, on top of the issues of cross-cultural appropriateness.
How valuable is the research?	Somewhat. Although underpowered, the focus on recent TBI is a unique approach in this area of study.

Smith (2016) 8/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. The effect of TBI history and methamphetamine use on delayed recall.
Did the authors use an appropriate method to answer their question?	Yes. Appropriate cross-sectional approach, using validated method of testing recall, and sound interview approach to identifying TBI history.
Were the subjects recruited in an acceptable way?	Yes. Volunteers from a local prison population.
Were the measures accurately measured to reduce bias?	Likely. Appropriate measures were used, but no PVT is a concern.
Were the data collected in a way that addressed the research issue?	Yes. Appropriate structured interview and testing conditions.
Did the study have enough participants to minimise the play of chance?	Yes. N=430.
How are the results presented and what is the main result?	Independent samples t-tests. No statistically significant differences in MoCA performance by TBI status.
Was the data analysis sufficiently rigorous?	Unlikely. A mixed-gender population without consideration of many confounding factors.
Is there a clear statement of findings?	Yes
Can the results be applied to the local population?	Yes. A comparatively large sample size. Results probably suggest MoCA is insufficient to detect possible differences and may not be appropriate for future research.
How valuable is the research?	Somewhat. A large study population but cognitive testing and statistical analysis could be more rigorous.

Suchy, Euler, et al. (2014) 8/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Exaggerated novelty effect following mTBI.
Did the authors use an appropriate method to answer their question?	Yes. Appropriate measures of cognition and novelty effect were assessed and TBI history was assessed with a consideration towards selection biases.
Were the subjects recruited in an acceptable way?	Yes. Volunteers from a population of offenders, consideration was made to avoid self-selection biases.
Were the measures accurately measured to reduce bias?	Yes. Appropriate measures of cognition, TBI history, and novelty effect.
Were the data collected in a way that addressed the research issue?	Yes.
Did the study have enough participants to minimise the play of chance?	No. A comparatively small study sample (N=38) with no a priori power calculation reported.
How are the results presented and what is the main result?	ANCOVA. No statistically significant differences on measures of cognition (EF, WM, PS)
Was the data analysis sufficiently rigorous?	Yes, appropriate covariates were considered. Despite small sample.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Yes. The novelty effect is notable and likely generalisable across offending populations, although validation is needed.
How valuable is the research?	Very. The size of the difference in novelty effect is very notable, particularly as cognitive differences were not significant.

Turner, Roszyk and Szumski (2020) 8/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Correlates of EF in sex offending populations.
Did the authors use an appropriate method to answer their question?	Yes. Sound cross-sectional approach including several relevant subgroup: CSO, SO, Non-Sexual Offender, Controls.
Were the subjects recruited in an acceptable way?	Yes. Volunteers from the general population and offenders from several prison populations.
Were the measures accurately measured to reduce bias?	Unclear method of determining TBI history, presumably self-report. An appropriate selection of cognitive measures was used and interview protocols appear sound.
Were the data collected in a way that addressed the research issue?	Yes.
Did the study have enough participants to minimise the play of chance?	Likely yes. N=243. With at least 49 participants in each offending sub-group.
How are the results presented and what is the main result?	Results of MANOVA and Latent Class Analysis. No statistically significant differences by TBI history after adjusting for multiple testing.
Was the data analysis sufficiently rigorous?	Yes. Appropriate methods used and adjustment for multiple testing reduces Type I error.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Yes. Analysis is rigorous enough to consider relevant locally, with consideration of cross-cultural validity.
How valuable is the research?	Very. The distinction of offender subtype is rare and provides significant value.

Umbrasas (2020) 7/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Working memory by TBI status in military justice.
Did the authors use an appropriate method to answer their question?	Yes. Sound cross sectional approach, although a small (n=16) sample of TBI-positive participants. Unclear methods of TBI history determination.
Were the subjects recruited in an acceptable way?	Yes. Data extracted from forensic reports on fitness to stand trial.
Were the measures accurately measured to reduce bias?	Likely. A sound cognitive tool was used, although method of determining and categorising TBI history could be clarified.
Were the data collected in a way that addressed the research issue?	Yes.
Did the study have enough participants to minimise the play of chance?	Unclear. N=80, but a only 16 participants that demonstrated TBI. No priori power calculation is provided.
How are the results presented and what is the main result?	t-tests of difference in mean on the WMI. No statistically significant differences by TBI status.
Was the data analysis sufficiently rigorous?	Yes. This is an appropriate statistical approach and PVT was considered.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	No. The specificity of a foreign forensic military sample that is categorising TBI in unclear ways is difficult to apply locally.
How valuable is the research?	Somewhat. The distinct population is interesting but the cognitive measures are brief and the outcomes can be hard to generalise from.

Warnick (2007) 8/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Understanding cognitive profiles and heterogeneity in murderers.
Did the authors use an appropriate method to answer their question?	Yes. Cluster analysis of cross-sectional data is fit for purpose.
Were the subjects recruited in an acceptable way?	Yes. Convenience sample (N=55) of deidentified data from a private practitioner working with convicted murderers.
Were the measures accurately measured to reduce bias?	Yes. Thorough evaluation of TBI history and cognitive profile would be expected within these evaluations. HRB and WAIS for cognition in this case.
Were the data collected in a way that addressed the research issue?	Yes. Evaluations were thorough and fit for purpose in clinical settings.
Did the study have enough participants to minimise the play of chance?	Unclear. 55 participants is a moderate sample size, but it is difficult to identify whether this is substantial enough for the cluster analysis in use.
How are the results presented and what is the main result?	Results are from Ward's cluster analysis and identified "Severely impaired" category had significantly more severe TBI history than "Neuropsychologically Normal" and 'Verbal Learning" clusters on ANOVA (p<.05)
Was the data analysis sufficiently rigorous?	Yes.
Is there a clear statement of findings?	Yes.
Can the results be applied to the local population?	Yes. Although a larger sample size would be ideal, with further validation these results can provide insight into local offenders.
How valuable is the research?	Very. This is a thorough assessment of a specific subgroup of offender from a rich dataset that is not available elsewhere.

Chitsabesan et al. (2015) 6/9 Quality Criteria Met	
Did the study address a clearly focused issue?	Yes. Describes neuropsychological profile of a juvenile offending population.
Did the authors use an appropriate method to answer their question?	Yes. Sound cross-sectional approach using a brief but validated cognitive assessment battery. CHAT used to evaluate TBI history.
Were the subjects recruited in an acceptable way?	Yes. Volunteers from a juvenile offenders secure site.
Were the measures accurately measured to reduce bias?	Yes. Appropriate measures used, however messing PVT.
Were the data collected in a way that addressed the research issue?	Yes. Appropriate sound data collection protocol is detailed.
Did the study have enough participants to minimise the play of chance?	No. Due to a lack of power, little data analysis was completed by TBI status.
How are the results presented and what is the main result?	Only frequency of low performance was reported by TBI status. *n*=33 no/mTBI were below average language score, *n*=8 mTBI below average IQ. *n*=5 moderate/severe TBI below average language score, *n*=1 below average IQ.
Was the data analysis sufficiently rigorous?	No.
Is there a clear statement of findings?	Yes
Can the results be applied to the local population?	No. Due to low power, and little relevant statistical analysis, it would be difficult to generalise from these findings.
How valuable is the research?	Not valuable to TBI based study. Some other neuropsychological findings will have value.

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