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CRITICAL REVIEW

Systematic Review and Meta-analysis of Outcome after Mild Traumatic Brain Injury in Older People

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Abstract

Objective: Older age is often identified as a risk factor for poor outcome from traumatic brain injury (TBI). However, this relates predominantly to mortality following moderate–severe TBI. It remains unclear whether increasing age exerts risk on the expected recovery from mild TBI (mTBI). In this systematic review of mTBI in older age (60+ years), a focus was to identify outcome through several domains – cognition, psychological health, and life participation. **Methods:** Fourteen studies were identified for review, using PRISMA guidelines. Narrative synthesis is provided for all outcomes, from acute to long-term time points, and a meta-analysis was conducted for data investigating life participation. **Results:** By 3-month follow-up, preliminary findings indicate that older adults continue to experience selective cognitive difficulties, but given the data it is possible these difficulties are due to generalised trauma or preexisting cognitive impairment. In contrast, there is stronger evidence across time points that older adults do not experience elevated levels of psychological distress following injury and endorse fewer psychological symptoms than younger adults. Meta-analysis, based on the Glasgow Outcome Scale at 6 months+ post-injury, indicates that a large proportion (67%; 95% CI 0.569, 0.761) of older adults can achieve good functional recovery, similar to younger adults. Nevertheless, individual studies using alternative life participation measures suggest more mixed rates of recovery. **Conclusions:** Although our initial review suggests some optimism in recovery from mTBI in older age, there is an urgent need for more investigations in this under-researched but growing demographic. This is critical for ensuring adequate health service provision, if needed.

Keywords: Brain concussion (MeSH), mTBI, Aged (MeSH), Older age, Cognition (MeSH), Mental health (MeSH), Social participation (MeSH), Activities of daily living (MeSH)

Traumatic brain injury (TBI) is a significant cause of disease burden worldwide (James et al., 2019) and has both economic impact due to direct medical and rehabilitation costs as well as indirect social impacts related to disability and loss of function (Nguyen et al., 2016). Mild traumatic brain injury (mTBI) is the most common form of TBI and accounts for as much as 80% of all head-related injuries seen at Emergency Departments (Dewan et al. 2019; Faul, Xu, Wald & Coronado, 2010). This has led to extensive research in various populations, including paediatric mTBI and associated outcomes in adulthood (Crowe, Babl, Anderson & Catroppa, 2009; Emery et al., 2016), blast-related mTBI in military settings (Hoge et al., 2008; Schneiderman, Braver & Kang, 2008), chronic traumatic encephalopathy after repetitive sports-related concussion (Baugh et al., 2012), and long-term risk of dementia after mid-life TBI (Godbolt et al., 2014; Livingston et al., 2020). When specifically considering aging populations, previous research has predominantly focused on outcome following moderate–severe head trauma, noting an increasing risk of mortality with increasing age (Hashmi et al., 2014; McIntyre, Mehta, Aubut, Dijkers & Teasell, 2013a). However, to date, there has been less focus on outcome associated with milder injury sustained in older age. Therefore, it is timely to evaluate the existing literature to understand the overall impact of mTBI in older age and to identify current gaps in research for this population.

The global trend towards aging communities (World Health Organisation, 2011) and noted increase in older age

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demographics presenting at Emergency Departments following traumatic injury (Mitra & Cameron, 2012) highlight the need to focus on older age patients. Compared with younger cohorts, older people are at higher risk of mortality following moderate–severe TBI (Cheng et al., 2014; Dams-O'Connor et al., 2013; Gardner, Dams-O'Connor, Morrissey & Manley, 2018; Hukkelhoven et al., 2003) and also possibly following mTBI (Susman et al., 2002). Explanations for this increased vulnerability may include age-related structural changes to the brain, such as brain volume shrinkage (Fjell & Walhovd, 2010) and the dura adhering more closely to the skull leading to stretching and weakening of bridging veins (Flanagan, Hibbard & Gordon, 2005; Karibe et al., 2017; Thompson, McCormick & Kagan, 2006). Older age is also related to an increased risk of frailty or having at least one chronic health condition (Thompson, Dikeman & Temkin, 2012; Vogeli et al., 2007) which can produce symptoms, such as balance instability or visual deficits. These impairments can increase the risk of injury (Ambrose, Paul & Hausdorff, 2013; Rubenstein, 2006) and also the rate of recovery (Abdulle et al., 2018; Rapoport, McCullagh, Streiner & Feinstein, 2003). Comorbidities seen in older adults often require pharmacological intervention that can interact with trauma effects and subsequent management. For example, anticoagulants commonly prescribed to manage heart conditions in older adults may also increase the risk of a brain bleed if blunt trauma is applied to the head (Peck et al., 2014). This potential vulnerability to more problematic trauma outcome after mTBI has resulted in calls for more targeted research in older age populations (Kristman et al., 2014; Peters & Gardner, 2018).

Although there is some debate about the time course of recovery from mTBI, the general consensus remains that recovery on standard neuropsychological testing is expected within the first 3 months of injury for working-age adults, who present with no additional risk factors (Carroll et al., 2004; Frencham, Fox & Maybery, 2005; Karr, Areshenkoff & Garcia-Berrera, 2014; Rohling et al., 2011). Nevertheless, in older people, differences in pre-injury cognitive reserve and presence of comorbidities may play an important role in outcome post-injury (Kumar et al., 2018; Schneider et al., 2014), and it remains unclear whether the 90-day timeline for cognitive recovery holds true for older populations (Kinsella, Olver, Ong, Hammersley & Plowright, 2014a). Therefore, in older age cohorts, it is important to consider slower rates of recovery through extended follow-up of trauma outcomes.

Additionally, although cognition is an important measure of TBI outcome, those who are often considered to be cognitively "recovered" (i.e., demonstrate no deficits on objective neuropsychological assessment) may continue to report difficulties related to daily activities and low mood (Cassidy et al., 2014). Indeed, cognitive recovery may not always be indicative of functional recovery, as it has been consistently shown that at least a small proportion of working-age adults show incomplete functional recovery from mTBI up to 12-month post-injury (De Koning et al., 2017; Korley et al., 2017; McMahon et al., 2014; Nelson et al., 2019; Scheenen et al., 2017; van der Horn, Spikman, Jacobs & van der Naalt, 2013).

To address this, Silverberg et al. (2017) propose a more global endpoint for recovery that includes other domains of outcome in addition to cognition, such as psychological health (e.g., anxiety, depression, post-concussion symptoms (PCSs), and posttraumatic stress) and life participation (e.g., recreational activities, community integration, quality of life, etc.). This more global approach in outcome measurement does start to address the potentially complex interactions between cognition, psychological status, and functional capacity. Although the most commonly used measure of functional recovery from injury remains the Glasgow Outcome Scale (original and extended versions; GOS/GOSE), some concerns have been raised about its use in determining outcome in older populations, where premorbid functioning and comorbidities may be misattributed to mTBI effects (Gardner et al., 2018). Nevertheless, at this stage, the GOS/GOSE provides the most extensive data on functional outcome.

The purpose of this review was to provide a systematic evaluation of the literature on mTBI sustained in older adulthood (i.e., ≥60 years of age). Outcome domains included cognition, psychological health, and life participation (including functional recovery based on the GOS/GOSE). Recovery was considered at various time points post-injury.

METHODS

This systematic review was conducted in accordance with the established PRISMA guidelines (Moher et al., 2009) and a search protocol was created and registered with PROSPERO (registration number: CRD42020139113).

Definition of mTBI

A problem that often pervades mTBI research is the inconsistency in both the reporting and operationalisation of mTBI (Kristman et al., 2014). The American Congress of Rehabilitation Medicine (ACRM) and the International Collaboration on mTBI Prognosis (National Center for Injury Prevention and Control, 2003; Kristman et al., 2014; Menon, Schwab, Wright & Maas, 2010) have proposed largely consistent guidelines to identify mTBI using four main criteria: (1) loss of consciousness and Glasgow Coma Scale (GCS) score; (2) posttraumatic amnesia; (3) alteration in mental state; and (4) focal neurological deficits or abnormalities. The International Collaboration on mTBI taskforce states that "mild TBI is an acute injury resulting from mechanical energy to the head from external physical forces" (Kristman et al. 2014, p. S266) and provides specific criteria to determine the presence or absence of injury (see Table 1).

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Table 1. International Collaboration on mTBI prognosis case definition criteria for mild traumatic brain injury

a) One or more of the following symptoms:
(i) Confusion or disorientation
(ii) Loss of consciousness (LOC) < 30 min
(iii) Posttraumatic amnesia for < 24 hr
(iv) Other transient neurological abnormalities (e.g., focal signs, seizure, and intracranial lesion not requiring surgery)
b) GCS score of 13–15 by 30-min post-injury or later upon presentation for health care
c) Symptoms are not due to drugs, alcohol, medications, caused by other injuries or treatment for other injuries, caused by other problems (e.g., psychological trauma, language barrier, co-existing medical condition), or caused by penetrating craniocerebral injury

For the purpose of this review, only articles that are consistent with (but not necessarily identical to) this definition of mTBI were included. As posttraumatic amnesia duration is often not reported in mTBI cases due to the transient nature of injury, this criterion was used as an indication of injury severity when reported, however, was not required for inclusion for review.

Search Strategy

In collaboration with search experts and researchers within the field of mTBI, a comprehensive search strategy for studies of mTBI outcomes was developed, focusing particularly on the outcome domains: (1) cognition; (2) psychological health; and (3) life participation (see Tables 2 and 3).

The electronic databases MEDLINE (OVID), Embase (OVID), CINAHL (EBSCO), and PsychINFO (OVID) were systematically searched up to March 23, 2020. There was no date restriction applied to database searches, as the aim was to achieve a comprehensive review of all literature within the field. However, it was noted that early research investigating mTBI was often prone to incomplete documentation of mTBI classification. To ensure consistency of injury type and severity, we used the current widely accepted diagnostic criteria to determine the presence of mTBI which resulted in the loss of some early research studies (see Figure 1).

Study Selection

Two independent reviewers were involved in screening studies for inclusion using a web-based software tool (Covidence; Veritas Health Innovation, www.covidence.org) which allowed reviewers to organise search results, efficiently manage the screening of titles and abstracts, and identify and locate full texts for inclusion. This software program is designed to follow the PRISMA guidelines for article screening, risk of bias assessment, and data extraction.

First, titles of all citations were retrieved from database searches and duplicates were removed. From 1503 titles identified, 429 duplicates were removed. Next, 1074 abstracts and titles were screened; those that were clearly not related to mTBI (e.g., severe TBI) or older adult populations (e.g., paediatric samples) were removed. Additionally, any titles and abstracts that violated the exclusion criteria listed below were also removed.

- Samples representing populations <60 years (e.g., collegiate athletes), or adult samples not distinctly stratified into an older adult age group, or articles with no separate analysis of older adult cohorts
- Samples that included injury severity greater than "mild" TBI (i.e., moderate–severe brain injury) or that combined different severities of TBI
- Long-term outcome of mTBI sustained in younger adult (i.e., remote mTBI) in older populations

Table 2. General MeSH terms and key search terms related to mTBI and older adults that were used for the systematic search in MEDLINE (OVID)

General search terms	
Neurotrauma	Brain concussion (MeSH), head injuries, closed (MeSH), "mild traumatic brain injur*," "mild head injur*," minor head injur*, mTBI, concuss*
Age*	Aged, 80 and over (MeSH), aged (MeSH), geriatrics (MeSH), elder*, geriatric*, "older adult*", "over 60"

*As age range included the younger age bracket of 60–65 years, the MeSH term "Aged" (referring to 65–79 years olds) as well as the key search word "Over 60" was included to ensure all participants 60+ years were captured.

Table 3. Additional MeSH terms and key search terms related to specific domains of function that were used for the systematic search in MEDLINE (OVID)

Specific search terms for outcome domains	
Cognition	Cognition (MeSH), neuropsychological tests (MeSH), neuropsychology*, cogniti*
Psychological health	Mental health (MeSH), depression (MeSH), stress, psychological (MeSH), anxiety (MeSH), anxiety disorders (MeSH), adaptation, psychological (MeSH), "stress, psychological," stress, anxiety*, resilience, psychological (MeSH), resilience, stress disorders, post-traumatic (MeSH), depress*, "mood changes," affective disorders (MeSH), "mood disorder*," "affect* disorder*," wellbeing
Life participation	Social participation (MeSH), participat*, "community involvement," "community integration," social*, activities of daily living (MeSH), ADLs, "daily living activities," quality of life (MeSH), QoL, recreational activities, "recreation* participat*," living activities

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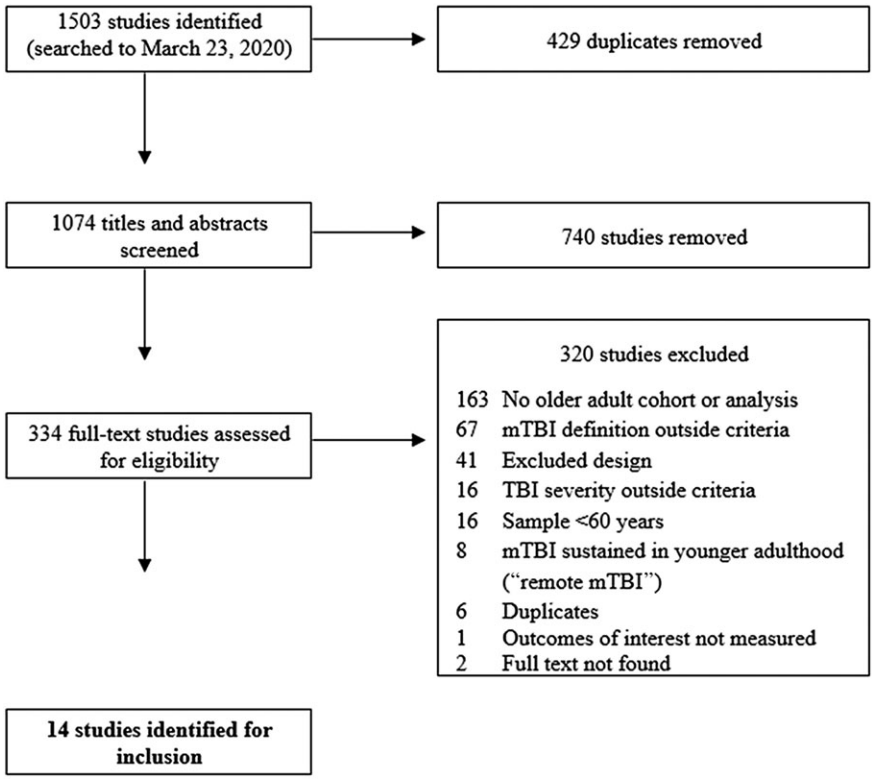

Fig. 1. *Flowchart of study selection process.*

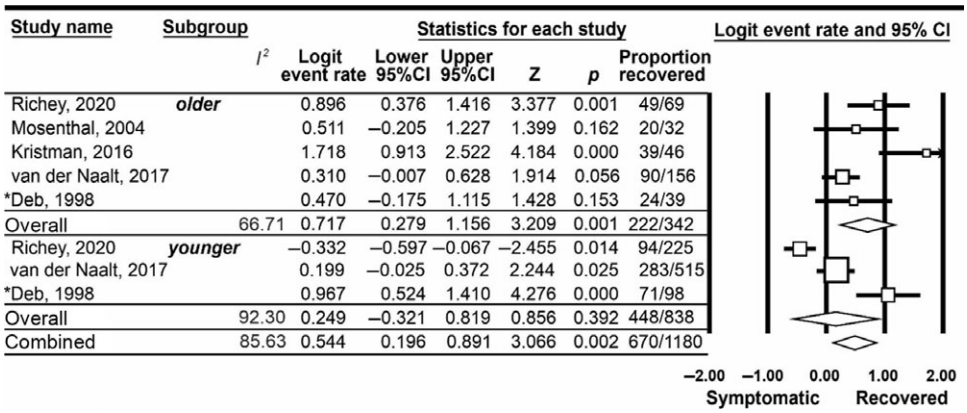

Fig. 2. *Forest plot depicting the proportion of older and younger adults recovered from mTBI at 6–12 months, based on GOS score. Note.* * = 12-month follow-up.

- Insufficient detail to identify mTBI according to the operationalised criteria (Table 1)
- Animal studies
- Study designs and formats including letters, narrative reviews, reviews without data, theses, government reports, books and book chapters, case reports, and case series

From this, 334 full-text articles were obtained to assess full-text eligibility based on selection criteria below:

- Full-text access and published in the English language
- Identified acute mTBI in accordance with our criteria, including complicated mTBI but not those requiring neurosurgery
- Sample or cohort analysis ≥60 years
- Study designs and formats including meta-analyses, systematic reviews, randomised controlled trials, cohort studies, case–control studies, and cross-sectional studies

Any disagreement about inclusion of full-text articles was discussed by both reviewers and consensus was reached for all conflicts, without need for a third reviewer. Fourteen studies were identified for final inclusion (see Figure 1).

All identified papers were evaluated using an appropriate quality assessment tool based on research design

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(Quigley, Thompson, Halfpenny & Scott, 2019). The Quality Assessment Tool for Observational Cohort and Cross-sectional Studies (National Heart Lung and Blood Institute, 2017) comprises of 14 items, assessed as present or absent from study design. All 14 identified studies were evaluated as being of "fair" or "good" quality (see Supplementary Table 1). Four of the 14 studies were identified as having overlapping samples and therefore the effect sizes were selected only from studies that provided relevant information, or the most recent information (see Tables 4–7 for details). All data included in this manuscript were obtained in compliance with institutional/national research standards for human research and the Helsinki Declaration.

Data Extraction and Analysis

A narrative synthesis was undertaken for all studies within the cognitive, psychological health, and life participation domains. A further meta-analysis was undertaken but only for studies using the GOS/GOSE at 6+ months post-injury. This narrower focus was necessary due to the large variety of outcome measures and comparison groups used between studies and at various time points, which prevented further quantitative analysis.

For quantitative analysis, the same two independent reviewers extracted effect size data from the papers with consensus reached on all included effects. Comprehensive Meta-Analysis software (Version 3; Borenstein, Hedges, Higgins & Rothstein, 2005) was used to calculate the estimated proportion of "complete" functional recovery, as shown by the GOS/GOSE 6+ months post-mTBI. Proportions from individual studies were then combined using random-effects models. Groups were split into subgroups of older adults (≥65 years) and younger adults (<65 years). The I^2 statistic was used to determine heterogeneity of subgroups, with scores of .25, .50, and .75 corresponding with low, moderate, and high levels of heterogeneity, respectively (Higgins, Thompson, Deeks & Altman, 2003). As we did not have more than five studies in any subgroup, we did not conduct meta-regression moderation analysis to assess for differences on demographic information.

RESULTS

Cognition

Only two studies were identified, at any time points, that investigated cognition following mTBI in older adults using neuropsychological assessment or cognitive screening tools.

Acute outcome (≤1 month)

No studies meeting criteria were identified.

Short-term outcome (1–3 months)

Kinsella, Olver, Ong, Gruen, and Hammersley (2014b) assessed neuropsychological outcome 3 months following mTBI injury and compared test performances to a trauma (orthopaedic) and community control group. The mTBI group displayed deficits on tasks related to prospective memory and control of attention allocation (executive function) when compared to community controls. However, both trauma groups (mTBI, orthopaedic) were impaired on these tests when compared to community controls. This raises the issue of whether the noted cognitive deficits in the mTBI group were related to general trauma effects (e.g., posttraumatic stress) rather than specific brain injury effects. Potential for a mediating role of psychological distress in cognitive outcome was not addressed in this study and will be important to further explore. However, both trauma and community groups reported similar levels of mental well-being on the 12-item Short-Form Survey Version 2 (SF-12v2) suggesting that psychological health, as measured by a quality-of-life scale, was not associated with differences seen on neuropsychological testing. Although the severity of brain injury (presence of intracranial injury, i.e., complicated mTBI) and increasing age were identified in further analyses as significant predictors of cognitive outcome, it could be that some of the observed cognitive differences predated the traumatic injury for both trauma groups.

Long-term outcome (≥6 months)

Deb, Lyons, and Koutzoukis (1998) rated older adult cognitive performance 1-year post-injury in comparison to a younger adult group, by using a cognitive screening tool (Mini Mental Status Examination; MMSE). Results suggested that 62% of older adults presented with "cognitive disability" (based on MMSE score <24) 1 year after sustaining a mTBI, compared to 8% of younger adults. The MMSE is a cognitive screening tool often used as the first step in further evaluation of cognitive status in older patients; as no further analysis was done to screen or control for an evolving comorbidity (e.g., dementia), it is possible that observed age differences on the MMSE identified premorbid and/or subsequent cognitive decline, rather than cognitive change related to mTBI.

Psychological Health

Acute outcome (≤1 month)

Karr et al. (2020) examined PCSs 1-week post-mTBI, using the Rivermead Post-concussion Symptoms Questionnaire (RPQ). Participants were dichotomised into older (≥65 years) and younger (<65 years) age groups and included adults with premorbid functional impairment, neurological impairment, and/or dementia diagnosis, which were more likely to be present in older adults. Despite this, no group differences were found for PCS severity or total number of symptoms endorsed, indicating similar levels of PCS across age groups. However, younger adults were more likely to endorse particular PCS (i.e., headaches, noise and light sensitivity, irritability, frustration and impatience) and from a subset of

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Table 4. Characteristics of identified studies

Study	Design	Site	mTBI n for older cohort	Age	mTBI definition	Time since injury	Outcome measures
Abdulle et al. 2018[1]	Observational cohort (UPFRONT)	The Netherlands, multi-centre	161	≥60 years	LOC ≤ 30 min PTA < 24 hrs GCS ≥ 13	2 weeks 1–3 years	Psychological health Life participation
Abdulle et al. 2020[1]			162			2 weeks 6 months	
van der Naalt, et al. 2017[1]			156	≥65 years		2 weeks 6 months	
Deb et al. 1998	Cross-sectional	United Kingdom, single centre	40	>65 years	GCS ≥ 13 LOC or radiological evidence (skull fracture or cerebral haemhorrage) or focal neurological signs	1 year	Cognition Psychological health Life participation
Hu et al. 2017	Cross-sectional	Canada, single centre	14	>65 years	LOC ≤ 30 min PTA < 24 hrs GCS ≥ 13 Confusion, disorientation, or focal neurological deficits	317 days	Psychological health
Karr et al. 2020	Cross-sectional	Finland, single centre	101	≥65 years	GCS ≥ 13 No neurosurgery following injury	1 week	Psychological health Life participation
Kinsella et al. 2014	Cross-sectional	Australia, single centre	50	≥65 years	Cognitive confusion or disorientation LOC ≤ 30 min PTA < 24 hrs GCS ≥ 13 (including CT abnormality)	3 months	Cognition Life participation
Kristman et al. 2016[2]	Prospective cohort	Canada, multi-centre	46	≥65 years	Confusion or disorientation LOC ≤ 30 min PTA < 24 hrs GCS ≥ 13 Transient neurological abnormalities	Discharge 6 months	Psychological health Life participation Psychological health Life participation
Asselstine et al. 2020[2]							
Mosenthal et al. 2004	Prospective cohort	New Jersey, USA, multi-centre	44	≥65 years	GCS ≥ 13	6 months	Life participation
Rapoport & Feinstein 2001	Cross-sectional	Canada, single centre	26	≥60 years	LOC ≤ 30 min PTA < 24 hrs GCS ≥ 13	19 days	Psychological health Life participation
Rapoport et al. 2003	Cross-sectional	Canada, single centre	64	≥60 years	LOC ≤ 30 min PTA < 24 hrs GCS ≥ 13	49 days	Psychological health
Richey et al. 2020[3]	Prospective cohort (HeadSMART)	Maryland, USA, multi-centre	88	≥65 years	Alteration of consciousness/mental state < 24 hrs LOC ≤ 30 min PTS < 24 hrs	1 month 3 months 6 months	Psychological health Life participation
Peters et al. 2018[3]			56		GCS ≥ 13	1 month	

Note: "Cognition" refers to performance on standardized cognitive assessment; "Psychological Health" outcomes refer to self-reported depressive and anxiety symptoms, post-concussion symptoms (psychological and/or physical), or general mental wellbeing; "Life Participation" outcomes refer to self-reported health and general quality of life, functional status, and/or recovery from injury.
LOC = loss of consciousness; PTA = posttraumatic amnesia; GCS = Glasgow Coma Scale; PCS = post-concussion symptoms.
[1]Sample from the UPFRONT observational study, the Netherlands.
[2]Same sample used.
[3]Sample from the HeadSMART prospective cohort study, USA.

Table 5. Cognitive outcomes

Study	Comparison group	Time since injury	Measures	Outcomes
Kinsella et al. 2014	Older adults ≥65 years mTBI ($n = 50$) Orthopaedic control ($n = 58$) Community control ($n = 123$)	3 months	Symbol Search (WAIS-III) Hopkins Verbal Learning Task (HVLT) Trail Making Test Verbal fluency Letter fluency Colour-word interference (DKEFS)	mTBI group performed significantly worse than CCs on prospective memory tasks (p <.01, d = 0.82–1.18). Significant contributors to differences were age, gender, and education (20.4%) and presence of intracranial abnormalities (5.0%) mTBI and OCs were significantly slower to shift attention than CCs (p <.01; CC *vs.* OC d = -0.69, CC *vs.* mTBI d = -0.61), but there were no significant difference between the two trauma groups. Nonsignificant but moderate effects for mTBI group compared to CCs in attention inhibition (D-KEFS Color-Word) (d = 0.49), attention monitoring (D-KEFS letter fluency) (d = 0.38), verbal memory (HVLT-R) (d = 0.39), and speed of processing (WAIS-III SS) (d = 0.38).
Deb et al. 1998	Older adults >65 years ($n = 37$) Middle-age adults 41–65 years ($n = 27$) Younger adults 18–40 years ($n = 70$)	1 year	Mini Mental Status Examination (MMSE)	62.2% (23/37) of older adults had MMSE score ≤23, compared with 14.8% (4/27) of middle-aged adults and 5.7% (4/70) of younger adults.

participants reporting "new" onset of functional impairment after injury, younger adults reported greater PCS severity compared to older adults. This suggests that older adults report similar or fewer PCS soon after injury, although this does not necessarily translate to better functional outcome post-injury.

In a single-age cohort study of hospital admissions of older adults (≥60 years) following mTBI, Abdulle et al. (2018) examined the proportion of older people endorsing "high" levels of anxiety and depressive symptoms (scores >8 on the Hospital Anxiety and Depression Scale; HADS) 2 weeks post-injury. Overall, only 16% endorsed anxiety symptoms and 14% endorsed high levels of depressive symptoms post-mTBI, which are slightly less or similar to normative levels for HADS anxiety and depression in a general nonclinical population (normative anxiety symptoms 33%, normative depressive symptoms 11%; Crawford, Henry, Crombie & Taylor, 2001). Nevertheless, when the older adults were dichotomised into "frail" or "non-frail" groups, a higher proportion of depressive symptoms were identified in "frail" compared to "non-frail" older people (26% and 7%, respectively, $p = .001$). The researchers suggest that although in the acute phase of recovery many older adults will not report elevated levels of anxiety or depression compared to general populations, the presence of comorbidities resulting in frailty will negatively impact psychological health post-injury.

PCS for this same sample was also examined (Abdulle et al., 2020) using the Head Injury Symptoms Checklist (HISC) and measures of posttraumatic stress and coping. Results indicated that 73% of older people endorsed at least one PCS 2 weeks after injury, with the most frequent complaints being dizziness, fatigue, and headache. Further analysis also revealed that endorsing higher levels of depressive symptoms and PCS were associated with slightly decreased odds of complete recovery, whereas coping style, posttraumatic stress, and other demographic variables were not. This suggests that greater PCS severity and depression may impede recovery from injury, rather than other personal or injury-related factors.

Using a referral clinic for trauma patients, Rapoport & Feinstein (2001) recruited a sample of older (≥60 years) and younger (18–59 years) participants. At the acute assessment stage (mean 19-day post-injury), using the General Health Questionnaire, older patients reported significantly less psychological impairment and distress than the younger patients. Older adults also reported significantly fewer psychosocial difficulties (as rated on the Rivermead Head injury Follow-up Questionnaire) and PCS (measured on

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Table 6. Psychological health outcomes

Study	Comparison group (*n*)	Time since injury	Measures	Outcomes
Karr et al. 2020	Older adults ≥65 years ($n = 101$) Younger adults 18–64 years ($n = 120$)	1 week	Rivermead Post-concussion Symptom Questionnaire (RPQ)	No age differences on total number of PCS or total symptom severity. Younger adults were significantly more likely to endorse certain symptoms; headaches (35.0% *vs*. 20.8%, $p = .020$), noise sensitivity (13.3% *vs*. 4.0%, $p = .016$), irritability (15.0% *vs*. 3.0%, $p = .002$), frustration/impatience (13.3% *vs*. 4.0%, $p = .016$), and light sensitivity than older adults (15.0% *vs*. 4.0%, $p = .006$). Of those who transitioned from no functional impairment prior to injury to functional impairment after mTBI ($n = 122$), older adults had lower PCS severity (median = 2, IQR = 0–2) than younger adults (median = 7, IQR = 1–16). There were no differences in PCS among older and younger adults that did not transition to functional impairment after injury.
Abdulle et al. 2018[1]	Older adults ≥60 years Dichotomized into frail ($n = 59$) and nonfrail ($n = 102$)	2 weeks	Hospital Anxiety Depression Scale (HADS)	14% of older adults experienced depression (26% frail *vs*. 7% non-frail, $p = .001$) and 16% experienced anxiety (24% frail *vs*. 13% nonfrail, $p = .06$).
Abdulle et al. 2020[1]	Older adults ≥60 years Dichotomized into complete recovery ($n = 59$) and incomplete recovery ($n = 102$)	2 weeks	RPQ	73% of older adults reported 1 + PCS; most frequent symptoms were dizziness, fatigue, and headache. A higher percentage (85%) of older adults not completely recovered by 6 months (GOSE score <8) reported PCS at 2 weeks, compared to of those fully recovered (GOSE = 8) at 6-month post injury (65%; $p < .001$).
Rapoport & Feinstein 2001	Older adults ≥60 years ($n = 26$) Younger adults 18–59 years ($n = 30$)	19 days	General Health Questionnaire (GHQ) RPQ Rivermead Head Injury Follow-up Questionnaire (RFQ)	Older adults reported less psychological distress (M = 6.65, SD = 7.2) than younger adults (M = 12.97, SD = 7.5, p = 0.002). They also reported less psychosocial dysfunctional (M = 10.48, SD = 8.5) than younger adults (M = 22.00, SD = 10.6, $p < .0001$), and less PCS (M = 12.88, SD = 15.7) than younger adults (M = 30.46, SD = 20.0, $p = .005$). Group differences became nonsignificant once employment status was controlled for ($p = .035$).
Richey et al. 2020	Older adults ≥65 years ($n = 74$)* Younger adults 18–64 years ($n = 258$)* *Some attrition across time points	1 month 3 months 6 months	Patient Health Questionnaire-9 (PHQ-9) RPQ	Depressive and PCS symptoms were reported at 1-, 3- and 6-month post-mTBI. Depressive symptoms were calculated as >5 on the PHQ-9, and unfavourable PCS was calculated as mild/moderate/severe problems in 2+ domains, using the RPQ. ○ 1-month depressive symptoms were reported by 18.9% (14/74) older adults compared to 43.7% (113/258) younger adults. PCS was reported by 14.8% (11/74) older adults compared to 51.0% (132/259) younger adults. ○ 3-month depressive symptoms were reported by 23.1% (15/65) older adults compared to 37.7% (90/239) younger adults. PCS was reported by 21.1% (14/66) older adults compared to 50.20% (120/239) younger adults. ○ 6-month depressive symptoms were reported by 24.1% (14/58) older adults compared to 38.1% younger adults. PCS was reported by 18.6% (11/59) older adults compared to 48.8% (107/221) younger adults. Risk of depression for older adults did not significantly decrease over time (OR = 1.09; 95% CI 0.86–1.37, p = 0.47) but did for younger adults (OR = 0.870; 95% CI 0.777–0.974, p = 0.016). Rate of change over time in odds of depressive symptoms was not significantly different between age groups ($p = .088$).

(*Continued*)

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Table 6. (*Continued*)

Study	Comparison group (*n*)	Time since injury	Measures	Outcomes
				Risk of PCS for older adults did not significantly decrease over time for either older (OR = 1.05; 95% CI 0.820–1.34, $p = .70$) or younger adults (OR = 0.931; 95% CI 0.831–1.042, $p = .212$). Rate of change over time in odds of PCS was also not significantly different between age groups ($p = .385$).
Rapoport et al. 2003	Older adults ≥60 years ($n = 64$) Younger adults 18–59 years ($n = 146$)	49 days	Structured Clinical Interview from DSM-IV (SCID)	6.3% (4/64) older adults had diagnosis of major depressive disorder (MDD) compared to 21.2% (31/146) of younger adults ($p < .001$, OR = 4.04, 95% CI 1.36–11.99), despite higher previous history of depression (25.0% *vs.* 9.9 %, $p = .01$) and family history of mood disorder (21.9% *vs.* 6.1%, $p = .001$). Differences in MDD remained after excluding for history of substance abuse ($p < .05$)
Asselstine et al. 2020	Older adults ≥65 years ($n = 46$) None; repeated measures design	Discharge (approx. 10 days) 6 months	RPQ Centre for Epidemiological studies-Depression scale (CES-D)	Older adults had an average of 3 PCS at baseline (M = 3.20; 95% CI 2.21–4.18) which decreased by 6-month post-injury (M = 1.17; 95% CI 0.47–1.87). After controlling for three previously determined confounders, (1) health 1 year prior to injury, (2) "sub-clinical depression," and (3) LOC, the adjusted relative risk for the association between baseline RPQ scores and GOSE at 6-month post-injury was 2.13 (95% CI 1.51–6.07). Similarly the adjusted relative risk for the association between RPQ scores at baseline and self-reported recovery at 6 months was 2.64 (95% CI 1.3–8.98). Depressive symptoms based on the CES-D at discharge (M = 7.57) was similar to 6-month follow-up (M = 6.41) for older adults and similar to normative data for community-dwelling older adults (M = 8.33, SD = 6.84; Lewinsohn et al., 1997).
Hu et al. 2017	Older adults >65 years ($n = 14$) Middle-aged adults (36–45 years, $n = 29$; 46–55 years, $n = 42$; 46–55 years, $n = 24$) Younger adults (16–25 years, $n = 27$; 26–35 years, $n = 31$)	317 days	RPQ	Compared to oldest adults (>65 years): ○ Middle-aged adults (36–45 years and 46–55 years) reported greater symptom severity for headaches (OR = 5.56; 95% CI 1.51–20.44, $p = .01$), nausea or vomiting (OR = 25.15; 95% CI 2.72–233, $p = .01$), irritability (OR = 5.65; 95% CI 1.57–20.31, $p = .01$), poor concentration (OR = 4.93; 95% CI 1.36–17.81, $p = .02$), and taking longer to think (OR = 4.74; 95% CI 1.30–17.20, $p = .02$). ○ Adults aged 46–55 years reported greater severity of sleep disturbance (OR = 3.85; 95% CI 1.09–13.60, $p = .04$), blurry vision (OR = 4.10; 95% CI 1.16–14.4, $p = .03$), and light sensitivity (OR = 3.80; 95% CI 1.09–13.19, $p = .04$). ○ Adults aged 56–65 years reported more severe concentration issues (OR = 5.01; 95% CI 1.33–18.91, $p = .02$).
Deb et al. 1998	Older adults >65 years ($n = 37$) Middle-aged adults 41–65 years ($n = 27$) Younger adults 18–40 years ($n = 70$)	1 year	Clinical Interview Schedule-Revised (CIS-R)	Presence of psychiatric symptoms were identified as CIS-R > 11. Psychiatric symptoms were reported in 5.4% (2/37) older adults, compared to 22.2% (6/27) middle-aged adults and 21.4% (15/70) younger adults.

[1]sample from the UPFRONT observational study, Netherlands

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Table 7. Life participation outcomes

Study	Comparison group (age, n)	Time since injury	Measures	Outcomes
Karr et al. 2020	Older adults ≥65 years ($n = 101$) Younger adults 18–64 years ($n = 120$)	1 week	Modified Rankin Scale (MRI)	65.3% of older adults compared to 46.7% of younger adults, transitioned from no functional impairment to functional impairment 1 week after injury.
Rapoport & Feinstein 2001	Older adults ≥60 years ($n = 26$) Younger adults 18–59 years ($n = 30$)	19 days	Glasgow Outcome Scale (GOS)	Functional status based on GOS mean score. Older adults showed slightly better functional recovery (M = 4.67) compared to younger adults (M = 4.03; $p = .002$). Group differences became nonsignificant once employment status was controlled for ($p = .030$).
Richey et al. 2020	Older adults >65 years ($n = 76$)* Younger adults 18–65 years ($n = 258$)* *Some attrition across time points	1 month 3 months 6 months	Glasgow Outcome Scale-Extended (GOSE)	Complete functional recovery was reported at 1-, 3- and 6-month post-mTBI. Older adults >65 years were compared to younger adults 18–65 years. Complete functional recovery was calculated as GOSE = 8. ○ 1-month complete recovery seen in 65.8% (50/76) compared to 38.0% (98/258) younger adults. ○ 3-month complete recovery seen in 71.0% (49/69) older adults compared to 37.7% (94/240) younger adults. ○ 6-month complete recovery seen in 78.8% (52/66) older adults compared to 41.7% (94/225) younger adults. Risk of incomplete functional recovery decreased significant over time for older and younger adults. Rate of change over time in odds of functional recovery was not significantly different between age groups ($p = .200$).
Kinsella et al. 2014	Older adults ≥65 years mTBI ($n = 50$) Orthopaedic control ($n = 58$) Community control ($n = 123$)	3 months	SF-12 Health Survey (SF-12v2) Community integration Questionnaire (CIQ)	For physical quality of life on SF-12v2 was significantly lower for both trauma groups compared to CCs (CC *vs.* OC d = 0.84, CC *vs.* mTBI d = 0.67). No significant differences between groups on mental quality of life on SF-12v2 although effects were medium for CC *vs.* mTBI groups (d = 0.54). No significant differences between groups in community integration.
Kristman et al. 2016	Older adults ≥65 years ($n = 46$) None; repeated measures design	6 months	SF-12 Health Survey (SF-12v2) Self-reported Recovery (single item)	Mental quality of life significantly improved from baseline (M = 71.5, SD = 21.1) to 6-month post-injury (M = 84.1, SD = 15.4, $p = .0001$). Physical quality of life also significantly improved from baseline (M = 46.9, SD = 28.9) to 6-month post-injury (M = 74.3, SD = 25.0, $p < .0001$). 20.4% of older adults self-reported global recovery at discharge which significantly increased to 73.5% at 6-month post-injury ($p < .0001$). Only baseline factor associated with lower physical quality of life at 6 months was poor health 1 year prior to injury. Poor health 1 year prior to injury was also associated with poorer self-reported recovery at 6 months (RR = 2.71).
Mosenthal et al. 2004	Older adults ≥65 years ($n = 40$) Younger adults 18–64 years ($n = 142$)	Discharge 6 months	Glasgow Outcomes Scale (GOS) Functional Independence Measure-Modified (FIM)	At discharge, older adults reported greater disability (M = 10.4) compared to younger adults (M = 11.4; $p = .001$). "Good functional outcome" was measured as 11–12 on FIM. At discharge, 68% of older adults had good functional outcome compared to 89% of younger adults. 6-month post-injury older adults showed greater disability (M = 11.0) compared to younger adults (M = 11.7, $p = .001$). When change in function was measured using preinjury FIM as the baseline, 34% of older adults reported decreased functional outcome compared to 11% of younger adults.

(*Continued*)

Table 7. (*Continued*)

Study	Comparison group (age, n)	Time since injury	Measures	Outcomes
Deb et al. 1998	Older adults >65 years ($n = 40$) Middle-aged adults 41–65 years ($n = 28$) Younger adults 18–40 years ($n = 72$)	1 year	Edinburgh Rehabilitation Status Scale (ERSS)	ERSS subscales (rated between 0 and 7) included "support," "inactivity," "social integration," and "effects of current symptoms." Scores >2 on subscales and total ERSS used to indicate "disability." ◦ 47.4% of older adults showed disability (based on ERSS total score) compared to 33.3% of middle-aged adults and 25.7% of younger adults. Using regression analyses, only MMSE score was the significantly negatively associated with ERSS total score ($p < .001$). When MMSE was controlled for, there was a significant positive association between age and ERSS score ($p < .001$).
Abdulle et al. 2018	Older adults ≥60 years Dichotomized into frail ($n = 59$) and nonfrail ($n = 102$)	1–3 years	Glasgow Outcome Scale-Extended (GOSE)	1–3 years post-injury 54% older adults were completely recovered (GOSE = 8). 72% of nonfrail older adults reported complete recovery compared to 24% of frail older adults ($p < .01$). Frailty (OR = 2.1, $p < .001$) and presence of post-concussive complaints (OR = 1.13, $p = .04$) were significant predictors of function for total sample, with estimated explained variance of 46%. Age and early anxiety and depression were not significant predictors of long-term functional outcome.

the RPQ) than younger adults. However, after controlling for employment status, group differences were smaller (and mostly nonsignificant) across these outcome measures, leading to the suggestion that age differences in psychological health and PCS can be moderated by psychosocial variables, such as the stress related to early return to work as often experienced by younger patients.

A more recent large study (Richey et al., 2020), based on Emergency Department admissions, used a prospective cohort design to examine age differences in recovery from mTBI at 1-, 3- and 6-month post-injury. Depressive symptoms were monitored using the Patient Health Questionnaire-9 (PHQ-9), where scores of >5 identified people with mild depressive symptomatology. This cutoff is lower than the recently recommended cutoff of ≥10 (Levis, Benedetti & Thombs, 2019); however, it appears to have acceptable sensitivity and specificity for TBI patients (Fann et al., 2005). PCS were measured using the RPQ, whereby scores were dichotomised into "favourable" and "unfavourable" outcome based on the severity and number of symptoms endorsed. At the 1-month assessment, only 18.9% of older adults (65+ years) endorsed depressive symptoms and 14.8% endorsed PCS symptoms, compared with 43.8% and 51.0% of younger adults, respectively (18–59 years). In this study, sample size was substantially larger for the younger adult cohort, ($n = 259$ compared with $n = 74$ for older adults) and psychosocial variables, including employment status, differed significantly between age groups (and were not statistically controlled in analyses).

Short-term outcome (1–3 months)

In a further evaluation of patients attending a trauma clinic (see study description in acute findings above), Rapoport et al. (2003) used the structured clinical interview (SCID-DSM-IV) to report that older adults had lower rates of major depression than younger adults (6.3% *vs*. 21.2%, respectively) at 1–3 months post-injury. They also had a lower relative risk of post-injury depression, even after accounting for history of substance abuse and previous/family history of depression.

As part of their cohort study (described in acute findings above), Richey et al. (2020) reported that older adults continued to endorse fewer depressive symptoms (23.1%) and PCS (21.2%) than younger adults (37.6% and 50.2%, respectively) 3-month post-mTBI.

Long-term outcome (≥6 months)

Six months following injury, in the same sample described above (Richey et al., 2020), older adults continued to endorse lower levels of depressive symptoms (24.1%) and fewer PCS symptoms (18.6%) in comparison to younger adults (38.1% and 48.4%, respectively); at this time point, the younger adult group was almost twice as likely to endorse high levels of depressive symptoms and unfavourable PCS outcome

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compared to older adults. The researchers reported no change in depressive symptoms or PCS outcome for older adults across acute, short-term and longer-term time points.

A similar study (Asselstine, Kristman, Armstrong & Dewan, 2020) used a prospective cohort of older adults (≥65 years) to examine PCS and depressive symptoms (using the Centre for Epidemiological Studies-Depression Scale; CES-D) at baseline (i.e., 10-day post-injury) and 6-month post-injury. By 6 months, older adults endorsed fewer symptoms of post-concussion (baseline $M = 3.20$ *vs.* 6 months $M = 1.17$), indicating some resolution of symptoms over time. Although no statistical group analysis was completed for depressive symptoms, results also indicated only small changes in mean scores across time (baseline $M = 7.57$ *vs.* 6 months $M = 6.41$) which are similar to normative levels for community-dwelling older adults ($n = 1{,}005$; $M = 8.33$; $SD = 6.84$; Lewinsohn, Seeley, Roberts & Allen, 1997). Further predictive analysis indicated that older people with higher endorsement of PCS at baseline were twice as likely to have incomplete functional recovery ($RR = 2.13$; 95% CI 1.51, 6.07), and incomplete self-reported recovery ($RR = 2.64$; 95% CI 1.31, 8.98) 6-month post-mTBI. Although the attrition rate appeared adequate (17% of the sample), participants that were removed or lost to follow-up endorsed significantly higher levels of PCS ($M = 14.4$) at baseline compared to those who were included in final analysis ($M = 3.2$). Therefore, findings are likely to be an underrepresentation of PCS outcome in older people, but remain in line with results from other identified studies.

Another study (Hu, Hunt & Ouchterlony, 2017) examined PCS as measured by the RPQ in patients attending a head injury clinic, approximately 1-year post-injury. Participants were grouped by age, and similar to findings from previous time points, total PCS severity was significantly lower in the oldest participants (>65 years) compared to middle-aged groups (36–65 years). Additionally, several age differences for individual symptoms were identified, whereby middle-aged participants (aged 36–55 years) were significantly more likley to report greater severity of headaches, nausea and vomiting, irritability, poor concentration, and taking longer to think, compared to adults >65 years. Adults 46–55 years were also more likely to report greater sleep disturbance, blurry vision, and light sensitivity than older adults, and the 56–65 age group endorsed greater concentration issues compared with adults >65 years.

Finally, Deb et al. (1998) used the Clinical Interview Schedule-Revised (CIS-R) to determine mental health in a sample of younger (18–65 years) and older adults (>65 years) 1 year following mTBI. Consistent with other time points, older adults were four times less likely to report significant psychological symptoms (scores >12 on the CIS-R) than younger adults (5.2% *vs.* 21%, respectively). This provides some evidence that older adults may continue to report lower levels of psychological distress up to 1 year following mTBI compared to younger adults.

Life Participation

Meta-analysis of long-term functional recovery using the GOS

From the identified studies, the GOS/GOSE was the only consistently used outcome measure that allowed for meta-analytic evaluation of functional outcome following mTBI. The GOS/GOSE measures global functional outcome following injury (or worsening of preexisting disability) using a 5- or 8-point rating system, whereby lower scores indicate greater disability or "incomplete" recovery, and a perfect score indicates "complete" or full recovery. Although there are limitations to the GOS/GOSE, this is currently the most widely used outcome measure following TBI and provides the most extensive data on functional outcome to date.

Five studies reported the proportion of "complete" recovery for older adults using the GOS/GOSE; four examined outcome at 6-month post-injury, whereas one study (Deb et al., 1998) observed outcome at 1-year post-injury. The paper by Abdulle & van der Naalt (2020) was initially identified for inclusion; however, as this study dichotomised older age as ≥60 years and all other studies defined older age as ≥65 years, the van der Naalt et al. (2017) data, which shared the same sample as Abdulle et al. (2018, 2020) and reported proportion of recovery based on age ≥65 years, was used in preference. This also provided data for a further subgroup analysis (old *vs.* young), as two other studies reported proportion of recovery for younger adults aged between 18 and 64 years as well as their older age samples.

An examination of the data indicates that 6+ months after mTBI, 67.2% of older adults were considered functionally recovered, which represented a significant logit event rate of recovery, 95% CI 0.569, 0.761, $p = .001$ (See Figure 2). For younger adults, by comparison, a nonsignificant 56.2% of people had recovered from injury, 95% CI 0.420, 0.694, $p = .392$. However, subgroup analysis revealed that the proportion of recovered individuals did not differ between older and younger populations, $Q = 1.629$, $p = .202$. Heterogeneity of event rates was calculated using I^2 and suggested moderate heterogeneity for the older adult subgroup but high heterogeneity for the younger adult subgroup which may partially explain nonsignificant findings in terms of recovery for the younger age group.

The result from Egger's regression (p (two-tailed) = .179) confirmed that these findings were not significantly asymmetric and Duval and Tweedie's trim and fill method indicated it was unlikely there were missing studies, which collectively suggests a low risk of publication bias. The finding of a significant proportion of older adults achieving recovery post 6 months also appears robust, with the fail-safe N statistic suggesting that another 35 studies with a logit event rate of zero would be required to render the current finding nonsignificant.

Additional studies of life participation

Several studies could not be included for quantitative analysis due to variability in timing of assessment or outcome measures, and therefore they are reviewed individually.

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Karr et al. (2020) investigated changes in functional status in older and younger adults using the Modified Rankin Scale. Findings (and our analysis of the data) indicated that older adults were 1.4 times more likely than younger adults to transition from no functional impairment prior to injury to functional impairment 1 week after mTBI (65.3% of older adults *vs*. 46.7% younger adults). At 1-month post-mTBI, however, Rapoport & Feinstein (2001) reported that although older adults ≥60 years who had sustained a mTBI showed slightly better functional recovery (mean GOS = 4.67) than younger adults (mean GOS = 4.03), small differences between age groups became nonsignificant when employment status was controlled.

Kinsella et al. (2014b) examined community integration [using the Community integration Questionnaire (CIQ)] and mental and physical quality of life (using the SF-12v2) 3-month post-injury. Findings demonstrated no significant differences in community integration between older adults who sustained mTBI and orthopaedic injury or community control groups suggesting that community integration is normative by 3-month post-injury. In contrast, physical quality of life was significantly lower for both trauma groups (mTBI, orthopaedic) but not mental quality of life, although small effects were found between trauma groups and community controls. Kristman, Brison, Bedard, Reguly & Chisholm (2016) also investigated mental and physical quality of life in an older age cohort up to 6-month post-injury using the SF-12, as well as a single-item measure of recovery (labelled global self-reported recovery). Mean scores in both mental and physical quality of life significantly improved by 6-month post-injury from baseline levels. Self-reported recovery at hospital discharge was low (20.4%), however, also significantly increased to 73.5% by 6-month post-injury.

In comparison to younger adults, however, Mosenthal et al. (2004) suggested that a greater percentage of older adults (34%) reported decreased functional outcome (using a modified version of the Functional Independence Measure) at 6-month post-injury compared to younger adults (11%; $p = .02$) even after accounting for preexisting impairment. Nevertheless, both age groups did show higher levels of functional independence 6-month post-injury when compared to discharge from hospital.

Deb et al. (1998) also compared the rehabilitation status of older adults (>65 years) to younger adults (18–65 years), 1 year after mTBI to suggest that older adults were 1.7 times more likely to show disability as rated on the Edinburgh Rehabilitation Status Scale (ERSS) than their younger adult counterparts. Regression analysis indicated that cognitive function (based on MMSE score) was associated with ERSS scores, whereas age, gender, GCS score, estimated premorbid intelligence, and alcohol consumption were not. When cognition was controlled, increasing age became positively associated with increasing disability. However, the researchers note that some disability could have existed pre-injury which is an important consideration in ageing cohorts.

Finally, Abdulle et al. (2018) examined recovery 1–3 years after mTBI (mean time since injury = 30.1 months) to show that 54% of older adults fully recovered (based on GOSE scores of 8) and a significantly lower percentage of frail older adults reported complete recovery (24% frail *vs*. 72% nonfrail, $p < .01$). However, due to the variability in follow-up time since injury it remains unclear whether "incomplete recovery" on GOSE captured post-injury function, or a worsening of new or non-injury-related problems.

DISCUSSION

This review aimed to identify mTBI outcomes for older people using multiple domains – cognition, psychological health, and life participation (including functional recovery). Overall, the current evidence suggests cautious optimism for older adults following mTBI, at least in terms of psychological health and longer-term functional recovery from injury.

Surprisingly, only two studies examining cognitive outcome post-mTBI in older adults met inclusion criteria (Deb et al., 1998; Kinsella, et al., 2014b). From this, the limited evidence suggests that older adults may still display specific cognitive deficits 3-month post-injury. However, whether this outcome is due to compromised premorbid cognitive functioning leading to increased risk of injury, or a generalised effect of trauma, cannot be determined yet and requires further investigation. In addition, longer follow-up assessments (6-month+) will determine if cognitive difficulties persist or recovery is generally achieved, albeit at a slower rate than expected for younger age cohorts following mTBI.

In terms of psychological health, there is emerging evidence that older adults consistently report less psychological distress, endorse less symptoms of depression and anxiety, and report less severity of PCS than younger adults, regardless of time since injury (Deb et al., 1998; Rapoport & Feinstein, 2001; Rapoport et al., 2003; Richey et al., 2020; Hu et al., 2017). Possible explanations for these older age benefits in psychological outcome have not been systematically addressed, although there is limited evidence to suggest that increased psychosocial stressors associated with younger age (e.g., employment demands) may moderate age differences in outcome.

Other explanations could be that better psychological health prior to injury acts as a protective factor, allowing for better psychological adjustment, and ensuring a return to "baseline" mental well-being soon after injury. Results from this review revealed that, in comparison to normative data, older adults who sustained a mTBI reported similar levels of depression and anxiety compared to general population samples (Abdulle et al., 2018; Asselstine et al., 2020). More specifically, older adults reported generally low levels of psychological distress immediately following injury with little to no change over time (Kristman et al., 2016) and similar trajectories compared to younger adults (Richey et al., 2020). Nevertheless, frailty has been identified as a factor associated with poorer psychological outcome in older adults (Abdulle et al., 2018) and there is some evidence that greater

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severity of PCS and depressive symptoms immediately after injury may decrease the likelihood of recovery (Abdulle et al., 2020; Asselstine et al., 2020). In addition, recent research in younger adult cohorts (not part of this review) has emphasised the strong relationship between pre-injury characteristics and ongoing somatic post-mTBI complaints (Meares et al., 2011; Ponsford et al., 2019), highlighting the possible impact of premorbid psychological well-being on post-injury outcome. Although intuitively defensible, the evidence for these prognostic variables in older adult samples is generally based on single studies and requires further investigation and replication.

Alternative explanations for age effects on psychological well-being include generational differences surrounding perceived stigma of mental disorders (Conner et al., 2010), possibly resulting in an unwillingness to report (or even an inability to identify) symptoms of psychological distress (Wetherell et al., 2009; Andreas et al., 2017). Older adults may be more likely to endorse more somatic symptoms, anhedonia, and cognitive complaints compared to younger adults, suggesting a different experience of psychological distress that may not be fully captured on current psychological measures of distress (Wuthrich, Johnco & Wetherell, 2015; Fiske, Wetherell & Gatz, 2009). Therefore, future research will need to consider the appropriateness of psychological health measures for older adult samples.

Evidence related to functional outcome and life participation varied across time points and comparison groups; however, based on findings from our meta-analysis using the GOS/GOSE, a significant proportion (67%) of older adults aged ≥65 years show full functional long-term recovery from injury post-mTBI, and this proportion of recovered individuals does not significantly differ and may even surpass the rate from younger adults (56%). By contrast, previous research that has investigated outcome following moderate–severe TBI suggests older age negatively predicts outcome and mortality (Flaada et al., 2007; Gardner et al., 2018; Hashmi et al., 2014; McIntyre et al., 2013a). Our more positive age-related findings after mTBI align with a previous meta-analysis (McIntyre, Mehta, Janzen, Aubut & Teasell, 2013b) that reported 80% of older adults had a favourable outcome after mTBI, compared to 32% for moderate and 8% for severe TBI.

Although not the focus of this review, our finding that 56% of younger adults showed complete recovery as measured on the GOS appears low given the consistent evidence that neuropsychological recovery, by contrast, is expected within 90 days of injury (Carroll et al., 2004; Frencham et al., 2005; Karr et al., 2014; Rohling et al., 2011). Nevertheless, reports of incomplete or unfavourable recovery from mTBI are not unusual for a proportion of younger adults, ranging anywhere between 23% and 53% of adults (De Koning et al., 2017; Korley et al., 2017; McMahon et al., 2014; Nelson et al., 2019; Scheenen et al., 2017; van der Horn et al., 2013). Additionally, although the GOS is a commonly used measure of recovery from injury, there is some criticism about its use as a dichotomous measure (McMillan et al., 2016) and it may provide little information about current life participation or functional status compared to community-dwelling age-matched samples. To this end, we evaluated and described results from several identified studies that used outcome measures other than GOS rates of recovery, to determine outcome for life participation across several time points.

From these studies, the evidence was more mixed. One week after mTBI, older adults may show greater functional impairment than younger adults (Karr et al., 2020) and yet, it has been reported that within the first month following injury, older adults show similar functional recovery as compared to younger adults (Rapoport & Feinstein, 2001). Additionally, older adults report similar levels of community integration 3-month post-injury compared to non-injured older adults (Kinsella, et al., 2014b), even though physical quality of life remained lower; and many older adults have been reported to perceive themselves as "recovered" by 6-month post-injury (Kristman et al., 2016). In contrast, there is some evidence to suggest that older adults show greater long-term disability compared to younger adults 6- to 12-month post-injury (Deb et al., 1998; Mosenthal et al., 2004), but it should be noted that whether these disabilities were not related to the actual trauma and were additional comorbidities has not been determined. Therefore, the need for ongoing investigation of life participation post-injury remains a priority.

Future Considerations for mTBI Research in Older People

Several limitations previously highlighted in mTBI research generally (Kristman et al., 2014) continue to pose unique challenges for mTBI research in older populations (Gardner et al., 2018; Peters & Gardner, 2018) and require consideration going forward. The first is that many mTBI studies use adult samples aged 18–90+ years to run prognostic analyses. Although useful, this requires large representative samples to allow for age comparisons and moderation analysis, as well as a need to account for potential age-related differences in psychosocial (e.g., return-to-work stress or carer responsibilities for younger adults) and biological (e.g., reduced cognitive reserve for older adults) factors. Thus, using a more focussed approach that specifically examines older cohorts may be more achievable and moves away from simply monitoring age (and ageist connotations) to allow for analysis of more targeted prognostic variables particularly relevant for older people (Romero-Ortuno & O'Shea, 2013). Promisingly, more recent research (e.g., Abdulle et al., 2018; Asselstine et al., 2020) has begun examining predictive factors (e.g., frailty, post-injury complaints, mood, PCS, etc.) that may impact outcome after injury in specifically older age cohorts.

Comparison Groups and Sample Recruitment

In this review, we focused on older adults as the primary population of interest and in doing so our results suggest that a

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large proportion of older adults do show functional recovery after mTBI and can expect similar (or even better) outcome in terms of psychological health and life participation as compared to younger adults. While it is useful to understand differences associated with age (younger *vs.* older age cohorts), appropriate age-matched control groups (e.g., orthopaedic trauma control groups, or healthy community control groups) and repeated measures designs with longer follow-up may provide more meaningful information and expectations about recovery specifically for older people.

Additionally, recruitment and sampling strategies used to select older adult participants following mTBI are important to consider. Clinical guidelines in many health settings recommend neuroimaging for all older people presenting with suspected head injury to manage risk of acute intracranial bleeding (National Institute for Health and Care Excellence, 2019). Therefore, older adults may be more likely to engage with health services following very mild injury which may inflate reported rates of recovery from injury. Additionally, stringent exclusion criteria often prohibit older adults with significant comorbidities (e.g., dementia diagnosis) from participating in major research trials. Although this may be necessary to control for confounding factors, recruited samples may risk being unrepresentative of older adult populations, thereby increasing the likelihood of a positive recovery. For example, a recent study examined mTBI functional outcome at discharge from hospital in a sample of older adults ≥75 years and reported that cancer or dementia diagnosis are significant predictors of outcome (Seno et al., 2019). The impact of culture may also emerge as a strong factor impacting prognostic models of outcome following TBI in older age. Often, there is an underrepresentation of ethnically diverse populations and samples (e.g., fluency in English language is commonly required for inclusion) and recommended interventions in response to TBI outcome (including mTBI) may depend on middle- to high-income country status (de Silva et al., 2009).

Given the complexities and multifactorial nature of aging and health, future studies of mTBI in older age will need to account for a range of confounding variables (pre- and post-injury), thereby requiring large datasets. These large and varied cohorts across different cultures and societies may provide a deeper understanding of the issues confronting older people following a traumatic injury.

Age-appropriate Outcome Measures

Most studies included in this review investigated multiple domains of outcome following mTBI, which indicates a positive shift towards a more holistic view of TBI outcome and recovery. However, as highlighted by this review, the variation in outcome measures makes direct comparisons of results difficult and often limits interpretation to single samples. Additionally, several studies reported arbitrary (and varied) cutoff scores to dichotomise outcomes and many used single-item or modified outcome measures without reporting psychometric evaluation. For older age cohorts, age-appropriate outcome measures that can adjust for the impact of premorbid physical and medical comorbidities and provide community norms for older cohorts is particularly important.

From the identified research, the only consistently used outcome measure was the GOS/GOSE, which allowed for quantitative analysis of longer-term functional recovery. However, even for this well-established measure, there was variation in reporting of outcome, with some studies presenting mean GOS scores and others using varied cutoff scores to represent "good recovery" from injury. Additionally, concerns have been raised that the GOS/GOSE may be particularly insensitive in older adult populations, where compromised premorbid functional abilities due to comorbidities may be inaccurately attributed to injury (Gardner et al., 2018). Therefore, using consistent and age-appropriate measures for older adult populations is essential to allow for further systematic evaluation of outcome post-injury.

Recommendations

- Although definitions of old age continue to vary across different cultures, it is recommended that age ≥65 years is used as a reference point for forming a sample of older adults, based on current global aging trends (World Health Organisation, 2011). This will allow for better comparison of research outcomes across studies. If the sample is sufficiently large, it is also recommended that diversity in old age is recognised by defining subgroups; for example, using youngest-old (65–74), middle-old (75–84), and oldest-old (85+) age ranges (see Lee, Oh, Park, Choi & Wee (2018) for an application of these subgroups).
- Include age-appropriate comparison groups, rather than relying on younger age comparisons. When possible, include both community and mild orthopaedic control groups as this may help to elucidate differences between pre-injury status or general trauma effects and mTBI-specific changes. This is especially relevant in older age where the impact of peripheral injuries resulting in chronic pain, medication use, or sleep disturbance may significantly impact cognition (Higgins, Martin, Baker, Vasterling & Risbrough, 2018; Ponsford, Hill, Karamitsios & Bahar-Fuchs, 2008; Vincent, Horodyski, Vincent, Brisbane & Sadasivan, 2015).
- It is recommended that research designs with older age populations include at least 6-month review, and preferably 12-month follow-up. In younger age cohorts, normative neuropsychological outcome is generally expected by 3-month post-injury. This has not been well established for older people and as neural recovery in older age maybe slower, at least a 6-month review is needed. Due to the higher risk of developing unrelated diseases and health conditions that frequently present in older age, high attrition rates in longitudinal studies may be expected and this should be factored into the initial design of the study.

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- Researchers should consider the appropriateness of outcome measures for older adults by adequately accounting for preexisting functional status and abilities. This will reduce the possibility of premorbid conditions being falsely attributed to brain injury. In relation to cognitive outcome, researchers should aim to use objective and detailed measures (e.g., reaction time, which is commonly measured using computerised tests) that go beyond limited screening tools and are based on age-appropriate normative data. Similarly, use psychological and functional outcome measures that have known validity for older age populations.

Limitations

This review used a stringent definition of mTBI based on widely accepted current criteria to best identify mTBI (Kristman et al., 2014; Menon-et al., 2010; National Center for Injury Prevention and Control, 2003). Given that the definition of mTBI has been historically contentious (Raskin, Lovejoy, Stevens, Zamrozieqicz & Oakes, 2014), it was considered important to adopt present guidelines for operationalising mTBI. Nevertheless, several early studies of mTBI did not use these criteria and, therefore, could not be included for systematic evaluation. A small number of studies were not reviewed due to including participants that required neurosurgery for injury and therefore were considered to have experienced a moderate TBI.

This review also used a cutoff age of ≥60 years. This resulted in some early studies being excluded as older age was identified as ≥50 years, which is inconsistent with the widely accepted chronological age used to consider health and older age (World Health Organisation, 2011).

All included studies were deemed as fair to good quality evidence for cohort or observational studies; however, only three studies were prospective studies with appropriate follow-up. Most were cross-sectional in nature and therefore findings should be interpreted with some caution. This review provides a summary of the current "state of the evidence" but acknowledges these design limitations in many of the included studies.

CONCLUSION

There is reason for cautious optimism for older adults following mTBI, as positive outcomes for psychological health and life participation are common for older adults. Nevertheless, similar to the investigation of younger adults, further research is also needed to identify predictive factors (including pre-injury health) for subpopulations of older adults who do not recover fully from injury or continue to show cognitive deficits following mild traumatic injury (whether related to brain injury or general trauma). Using a focused approach that specifically examines outcomes in older cohorts will allow for analysis of individual prognostic variables particularly relevant for older people. As the research field continues to expand, this review highlights the critical need for adopting appropriate measures and comparison groups to examine multi-domain outcome following mTBI in older adults, as well as the continued challenges associated with this.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/S1355617721000795

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CONFLICTS OF INTEREST

The authors have nothing to disclose.

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