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REVIEW

Resilience and Other Possible Outcomes After Mild Traumatic Brain Injury: a Systematic Review

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Abstract The relation between resilience and mild traumatic brain injury (TBI) outcome has been theorized but empirical studies have been scarce. This systematic review aimed to describe the research in this area. Electronic databases (Medline, CINAHL, PsychINFO, SPORTdiscus, and PILOTS) were searched from inception to August 2015 for studies in which resilience was measured following TBI. The search terms included 'TBI' 'concussion' 'postconcussion' 'resilience' and 'hardiness'. Inclusion criteria were peer reviewed original research reports published in English, human participants aged 18 years and over with brain injury, and an accepted definition of mild TBI. Hand searching of identified articles was also undertaken. Of the 71 studies identified, five studies were accepted for review. These studies were formally assessed for risk of bias by two independent reviewers. Each study carried a risk of bias, most commonly a detection bias, but none were excluded on this basis. A narrative interpretation of the findings was used because the studies reflected fundamental differences in the conceptualization of resilience. No studies employed a trajectory based approach to measure a resilient outcome. In most cases, the eligible studies assessed trait resilience with a scale and used it as a predictor of outcome (postconcussion symptoms). Three of these studies showed that greater trait resilience was associated with better mild TBI outcomes (fewer symptoms). Future research of the adult mild TBI response that predicts a resilient outcome is encouraged. These studies could yield *empirical* evidence for a resilient, and other possible mild TBI outcomes.

Keywords Mild traumatic brain injury · Resilience · Concussion · Persistent postconcussion symptoms

Traumatic brain injury (TBI) is a major cause of death and disability (Coronado et al. 2015). Mild TBI accounts for approximately three quarters of all TBIs (Ruff et al. 2009), and it is one of the most common neurological injuries (Hirtz et al. 2007). Mild TBI is estimated to affect approximately 600/100,000 people annually (Cassidy et al. 2004). The true extent of the problem of mild TBI is probably greater than these numbers suggest. The epidemiology of mild TBI and its natural history are understudied (Diaz-Arrastia and Kenney 2014; Barker-Collo and Feigin 2008; Hyder et al. 2007) and selection biases are common (Luoto et al. 2013). Unfortunately, the outcome from this common injury remains poorly understood.

A mild TBI can occur if the head receives mechanical energy from an external physical force. This force can occur as a result of accidental, incidental or deliberate acts, including acts of violence. Because of the myriad of ways this injury can be sustained, mild TBI can affect people of all ages and backgrounds. This particular characteristic of mild TBI makes it challenging to study (Rabinowitz et al. 2014). Another challenging aspect of mild TBI research is the significant variation in the definition of this injury and its outcome.

Outcome after mild TBI is often presented as a clinically defined dichotomy. It is commonly stated that most people will make a full recovery within days to weeks of injury

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(McCrea et al. 2009). A less common or *atypical* response is also described, that is, the cognitive, emotional, vestibular, and somatic symptoms that are experienced acutely after mild TBI do not resolve as expected. In such situations the mild TBI injury response is described as "poor" and the injured person may receive a new diagnosis (e.g., Postconcussional Disorder).

Existing models of outcome after mild TBI have typically focussed on poor outcome following mild TBI. These models posit that pre, peri or postinjury factors contribute to the prolonged, negative outcome that some individuals experience. The specific symptoms that characterize a poor mild TBI outcome – such as difficulty concentrating, fatigue, physical coordination problems, and irritability – persist beyond the period during which they are expected to resolve. They may also fluctuate (Lange et al. 2013), and are experienced as disabling (Broshek et al. 2015). The potential for such an outcome has led some authors to question if the term "mild" is in fact a misnomer (Diaz-Arrastia and Kenney 2014; McMahon et al. 2014), and this prospect has fuelled much research into the variability of the mild TBI injury response.

Despite intensive research effort, it is unknown why the injury response after mild TBI is variable. The need to uncover the reason for the variability in mild TBI outcome continues to be articulated (McCrea et al. 2015), and finding new ways to respond to mild TBI is recognized as one of the six priorities by leading neurotrauma authorities (Diaz-Arrastia and Kenney 2014). Several factors have been identified as contributing to a poor outcome after mild TBI, including low "resilience" (e.g., Iverson 2012). This review interrogates the mild TBI literature to determine how the notion of resilience has been used in empirical studies of mild TBI outcome.

Conceptualizing the Broad Construct of Resilience

It has been argued that the concept of resilience is often poorly specified and that it is the subject of "serious conceptual misunderstandings" (Bonanno 2012). Many have argued that a consensus definition of resilience is sorely lacking. The term *resilience* has colloquial meaning (Bonanno 2012) and this concept is often spoken of in loose or ambiguous terms, even in scholarly references (see Southwick et al. 2014). Some examples of how resilience has been defined include as a "dynamic process encompassing positive adaptation within the context of significant adversity" (Luthar et al. 2000), as the ability to "maintain relatively stable, healthy levels of psychological and physical functioning" (Bonanno 2004), and as the "ability to bounce back" from adversity (Smith et al. 2008).

Trait Versus Trajectory Resilience

Common to traditional trait definitions of resilience are the two core concepts of personal adaptation and adversity (Fletcher and Sarkar 2013). This concept of personal adaptation allows that resilience is a dynamic process, reflecting a shift away from earlier research that conceptualized resilience as an inherent characteristic. This distinction is important. Defining resilience as a personality characteristic necessarily suggests that resilience is stable across the lifespan, whereas if resilience is an adaptive *process*, it follows that resilience may fluctuate, and thus be modifiable. In this review, we use the umbrella term "trait resilience" to refer to such notions. An alternate view of resilience is that it is not a trait or process per se, but that it is a term that describes a specific temporal pattern of physical or psychological health that follows after an adverse event (i.e., a trajectory of stable, low, non-impactful symptoms). For this idea we use the term "trajectory resilience". [1]

Trait Resilience as a Predictor of "Poor" Mild TBI Outcome

To explain the variability in mild TBI outcome and in particular, to further understanding of a "poor" outcome, several conceptual models have been devised (Vanderploeg et al. 2006; Iverson 2012; McCauley et al. 2013; Belanger et al. in press). In these mild TBI models, trait resilience is linked with a specific clinically defined outcome (e.g., persistent postconcussion symptoms). For example, in Iverson's (2012) model, the concept of "*biopsychosocial resilience/hardiness*" (p. 39) is one of several factors that is linked to poor outcome, although it has been acknowledged that this relation does not yet have a strong evidence base. In Iverson's model, this concept is described as a *set* of diverse pre-injury factors that includes positive coping style, high efficacy, optimism, genetics, dopaminergic brain reward systems, and cortisol and other stress hormones. In the McCauley et al. model, resilience is defined as a psychological pre-injury "host" factor that can affect emotional outcome following mild TBI (McCauley et al. 2013, p. 643). The third model does not refer to resilience per se, but it does include "coping abilities" (p. 298) as a pertinent predisposing factor to a "poorer" mild TBI outcome (Belanger et al. in press). These models invoke a notion of trait resilience (variously defined) as a *predictor* of a clinically defined outcome.

[1] We also use the phrases "resilient outcome" and "resilient response" for this idea.

The Trajectory Approach

Another way of thinking about resilience and mild TBI is that this term describes a possible outcome from the injury. In other words, a resilient mTBI response (trajectory resilience) would be *predicted by* other factors, potentially including those identified in the mild TBI outcome models (e.g., gender, age, psychopathology). Trajectory resilience has been reliably demonstrated following potentially traumatic events such as bereavement and job loss (Galatzer-Levy et al. 2010; Galatzer-Levy and Bonanno 2012), whiplash (Sterling et al. 2010), spinal cord injury (Bonanno et al. 2012), and pediatric mild TBI (Yeates et al. 2009). This trajectory is illustrated in Fig. 1. Figure 1 also shows three *other* trajectories (or outcomes) that have been identified after a potentially traumatic event. The alternative trajectories could occur after adult mild TBI. These four "prototypical" trajectories are formally defined as follows: the continuation of preinjury-level symptoms that are at a low or non-impactful level (termed *trajectory resilience* or a *minimal-impact resilient response* Bonanno and Diminich 2013); an initial elevation over preinjury-level symptoms that gradually returns to the preinjury-level (*recovery*); a moderate increase in symptoms that gradually worsen overtime (*delayed*), and; symptoms above the preinjury-level that remain elevated over time (*chronic*).

Purpose of this Review

In 2002, studies of resilience in adults were described as uncommon (Luthar and Cushing 2002). In the year 2015 alone, several studies on the specific topic of resilience and mild TBI were published. A review of this research is therefore timely. The purpose of this review was to determine how the term resilience has been used in adult mild TBI research. As previously indicated, it is possible that it has been used as a predictor of a predefined clinical outcome (i.e., a trait resilience study), or that it has been used to describe an outcome type (i.e., a study of a resilient trajectory / outcome).

Method

Search for Studies

The review was registered on the PROSPERO database in August, 2015 (Reference number: CRD42015025233). A search strategy was devised to identify empirical studies of the relation between resilience and TBI, as too few studies were identified when the specifier "mild" was added as a required search term. Five databases (Medline, CINAHL,

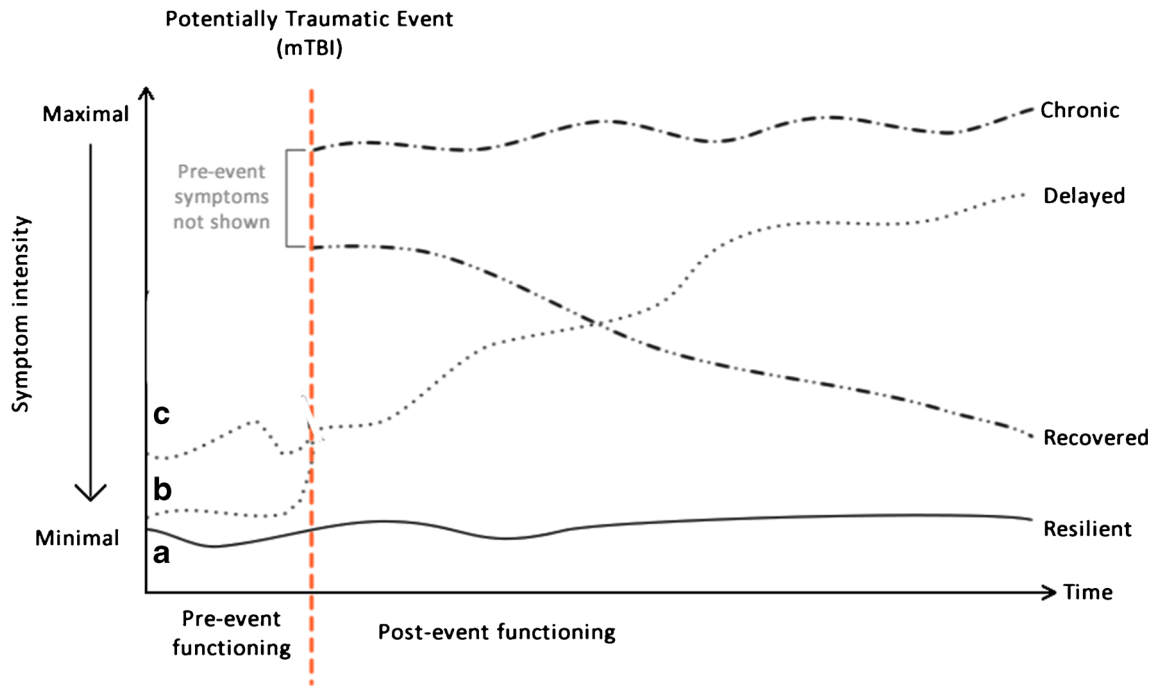

Fig. 1 Hypothetical response trajectories after adult mild TBI. The injury is depicted as an isolated potentially traumatic event (*red dashed line*). The Y-axis shows symptom intensity (for example, neurobehavioral symptom intensity). The X-axis shows time, and it includes two periods, pre- and post-event. The model depicts pre-event functioning (left of the potentially traumatic event line) for the resilient trajectory (labelled **a**). Pre-event variation (two scenarios, labelled **b** and **c**) is shown for the delayed trajectory. In scenario **b**, pre-event functioning is at a low level, and it increases sharply when the event occurs. To simplify the illustration the pre-event variation for all trajectories is not shown. The selected patterns of pre-event variation are included for illustrative purposes only. Four potential post-event response trajectories are shown: chronic, delayed, recovered, and resilient (right of the line denoting the potentially traumatic event)

PsychINFO, SPORTdiscus, and PILOTS) were searched from inception to August, 2015. Table 1 shows the terms that were used to search the databases.

Peer-reviewed, English-only records were included. Records that were identified in the search were excluded hierarchically from the review as follows. Records were excluded if they were not related to the topic of this review, for example, if resilience was not a primary focus or if no brain injury was studied. Studies that examined *resilience promoting* factors, such as family functioning or social support, were deemed to examine factors *related* to resilience and thus were excluded based on resilience not being the primary focus. Studies that did not *empirically* test the relationship between resilience and mild TBI outcome or the resiliency of the response to the injury were also excluded. To ensure a focused review, studies were excluded if the study population was not persons 18 years and over with a brain injury (e.g., children, adolescent and family member or carer studies were excluded). Studies were also excluded if the definition of mild TBI did not fall within the definitions provided by the WHO Collaborating Centre for Neurotrauma Task Force on Mild Traumatic Brain Injury (Cassidy et al. 2004) or the American Congress of Rehabilitation Medicine Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group (ACRM; American Congress of Rehabilitation Medicine 1993). Further, given the focus on mild TBI outcome, studies that included mild TBI among other TBI severities (i.e., moderate to severe brain injuries) were excluded if the results were not stratified according to injury severity, or if a standardised measure of postconcussion symptoms was not used. This allowed for investigation of resilience in relation to mild TBI without confounding results by including studies that examined more severe forms of brain injury.

Search Outcome

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used to inform the reporting of the results (Moher et al. 2009). The selection of studies is outlined in Fig. 2. The initial search yielded 68 articles and three dissertations. After nine duplicates were removed, 62 records were available for screening. Titles and abstracts were screened, and the exclusion criteria applied, leaving 32 records for full-text review. After full-text records were assessed, 27 were excluded. Eleven new articles were found on hand searching of included records, however after they were reviewed none could be included. The two studies led by Losoi et al. were inspected to determine if they were duplicates. These studies were from the same parent study. The study by Losoi, Waljas et al. was excluded for this reason and because it was not focussed on postconcussion symptoms. The study by Graham et al. (2013) predicted trait resilience in Veterans with and without a history of prior mild TBI and, despite a primary focus on genetic factors, this study was retained. Thus, five studies were included in the review. Primary data extraction was carried out by C.B.K. The following data were extracted: study characteristics, the definition of resilience given by the study authors, the measure of resilience used (if applicable), the outcome measure, and the study findings. The study findings were summarized in terms of direction, effect size, and statistical significance. A second reviewer, K.A.S., was consulted on any data interpretations that required review. A risk of bias assessment of each study was independently performed by C.B.K and S.L.E. Discrepancies were resolved through discussion by the raters, and as necessary, consultation with K.A.S. The risk of bias evaluation was performed using the method proposed by Viswanathan et al. (2013). This method was not used to score the risk of bias, rather each article was assessed to determine if there was a threat to validity (e.g., selection bias). The following a priori risks were identified by K.A.S and C.B.K. and these risks were explicitly considered during the interpretation of the data: selection or attrition bias (e.g., the tendency for studies to recruit treatment-seeking individuals and retain either those individuals who feel well enough to participate or those individuals who have remained symptomatic), and detection bias (e.g., the failure to follow individuals for a sufficient duration or on a sufficient number of occasions or at a reasonable period post injury, such that the outcome can not properly be assessed or a failure in the nature and timing of the preinjury [or proxy] assessments that provide the standard against which the postinjury outcomes are evaluated).

Table 1 Search terms used in this review

Subject Terms	postconcussion OR postconcussional OR postconcussive OR post-concussion OR post-concussive OR concussion OR concussive OR MILD TBI OR TBI OR "brain injury" OR "brain injuries" OR "brain concussion" OR "head injury" OR "head injuries" OR "brain contusion" OR "brain damage" OR "head injury"
	Thesaurus term: "postconcussion syndrome", "brain injuries"
Subject Terms	resilience OR resilient OR resiliency OR hardiness
	Thesaurus term: hardiness

Given the range and differences in the conceptualization of resilience across the studies included for review, a narrative interpretation of the findings was employed (Fig. 2).

Results

Summary of Study Characteristics Two studies were conducted in the United States of America (Graham et al. 2013; McCauley et al. 2013), one in Finland (Losoi et al. 2015), and one in Australia (Sullivan et al. 2015). These studies are summarized in Table 2.

Three of the included studies were cross-sectional and two studies employed a cohort design. Four of the five studies (Graham et al. 2013; McCauley et al. 2013; Losoi et al. 2015; Sullivan et al. 2015) included a control or comparison group. These groups were comprised of people with orthopaedic nonbrain injury (Losoi et al. 2015; McCauley et al. 2013) or uninjured people with no history of mild TBI (Graham et al.; Sullivan et al.). Two studies assessed mild TBI in a military sample (service members who served in Afghanistan or Iraq; Graham et al.; Merritt et al. 2015), one study employed a civilian sample (Sullivan et al.), and two studies prospectively enrolled consecutive admissions for mild TBI at a hospital (Losoi et al. 2015; McCauley et al. 2013). The number of participants with a positive mild TBI history in each of the studies ranged from 35 to 142. The average age of these participants ranged from 22 to 37 years. Overall, 388 participants with mild TBI were enrolled across the included studies. Follow-up periods ranged from less than 24 h through to 12 months post injury. All but one study (Sullivan et al.) had a greater proportion of male compared to female participants. Of the three studies that reported ethnicity, two had a predominantly Caucasian sample (Sullivan et al.; Graham et al.). Ninety-five percent of the sample in one study of military service members (Graham et al.) experienced a blast-related injury. In the other study that assessed a military sample (Merritt et al. 2015), 73.9 % of the mild TBIs were experienced during combat, with 57.7 % of those combat injuries being blast-related. In the civilian sample (Sullivan et al. 2015), the major cause of the mild TBI was sport (71.45 % of injuries). The study in which

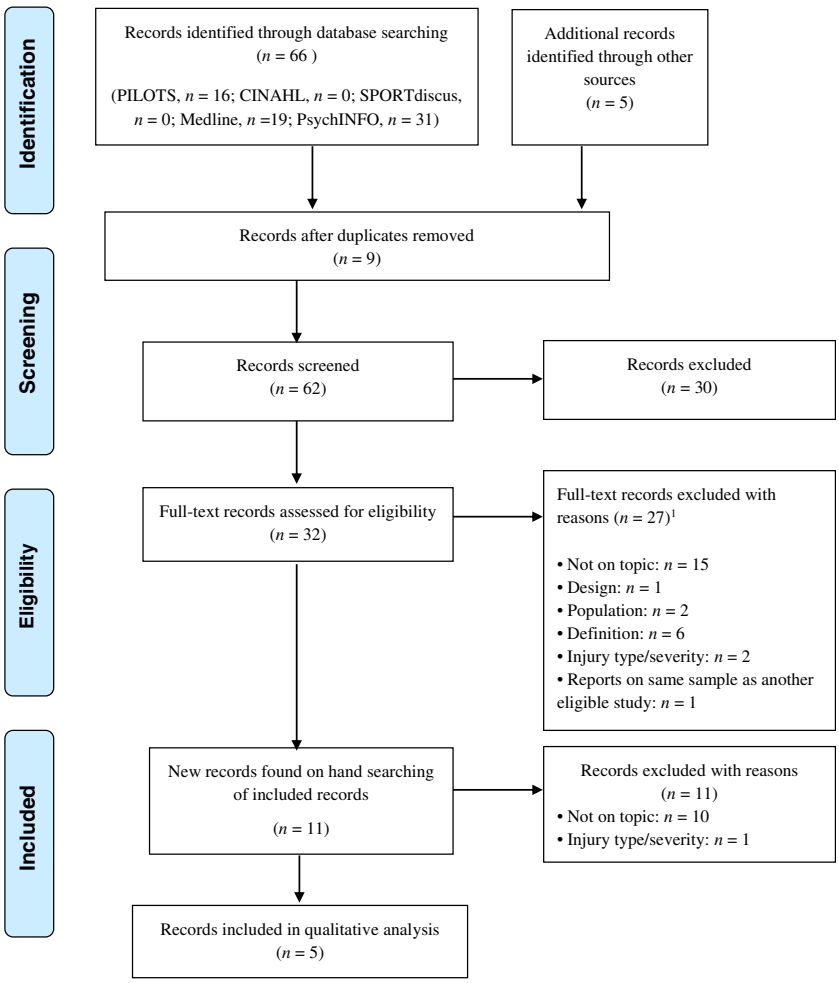

Fig. 2 PRISMA flow diagram showing the study selection process. [1] The three dissertations were among those that were excluded at this stage because of poor TBI definition ($n = 2$) or the population (adult caregivers)

Table 2 Chronological list of empirical studies of 'resilience' and mild traumatic brain injury, showing variation in the conceptualisation of resilience, its measurement and findings

Study	Design	Participants	Definition of resilience[1]	Resilience measure with or without retrospective reporting	Mild TBI outcome measures	Findings
Graham et al. (2013)	Cross sectional	67 OEF/OIF/OND[1] veterans with mild TBI =41 or no mild TBI (controls) = 26	Uses Luthar et al. (2000)'s definition: "a dynamic process encompassing positive adaptation within the context of significant adversity" (p.835); implies personal adaptation.	CD-RISC, not retrospectively assessed[2]	Postconcussion symptomatology (NSI); Perceived limitations (CRIS subscale)[3]; Posttraumatic stress disorder (PCL-C); Depression (CES-D)	Veterans with mild TBI had significantly lower resilience ($d = -0.78$), more perceived limitations, higher PCS symptomatology, posttraumatic stress symptoms, and depression compared to veterans without mild TBI. S'S'carrier 5-HTTLPR gene was significantly associated with greater resilience and fewer perceived limitations compared to L' carrier. Both TBI status and 5-HTTLPR genotype had very mild moderating effects on the relationship between resilience and perceived limitations (standardized β for genotype = .298 and for TBI = −.297) however no significant interaction was found.
McCauley et al. (2013)	Cohort	mild TBI = 46, orthopaedic injury = 29	"…ability to maintain sufficient psychological balance to maintain mental and physical functioning following exposure to aversive stress and/or trauma" (p. 643); implies personal adaptation and adversity.	CD-RISC	Postconcussion symptomatology (RPQ), retrospectively reported (for the period "in the previous month as a proxy for …preinjury status" (p. 644); Anxiety (ASDS); Posttraumatic stress disorder (PCL-C)	Greater preinjury resilience was significantly associated with greater PCS, depression, anxiety, and posttraumatic stress symptom severity. Preinjury resilience was a significant predictor of postconcussion symptoms, such that greater resilience was associated with greater symptom severity (Adjusted r^2 at preinjury/baseline = 0.33; at 1 week = .37; and at 1 months = .22). Preinjury resilience was also a significant predictor of anxiety (Adjusted r^2 at preinjury/baseline = 0.42; at 1 week = .33; and at 1 months = .37).
Losoi et al. (2015)	Cohort	74 mild TBI 39 orthopaedic controls	"…is an ability to recover from adversity…resilient individuals… have the tendency to manifest adaptive behaviour" (p.E24-5); implies personal adaptation.	RS and RS short form, neither were reported retrospectively	Postconcussion symptomatology (RPQ); Fatigue (BNI-FS); Insomnia Severity Index (ISI); Pain (RNBI); Posttraumatic stress disorder (PCL-C); Depressive symptoms (BDI-II); Quality of Life (QOLIBRI); Return to Work (RTW)	Patients with mild TBI and moderate-high resilience (measured 1 month post injury) reported significantly fewer postconcussion ($d = .58$), fatigue ($d = .46$), insomnia ($d = .37$), traumatic stress ($d = .55$), and depressive symptoms ($d = 1.01$) and better quality of life ($d = .74$) than mild TBI patients with relatively low resilience at 1 month follow up ($n = 74$). Patients with mild TBI and moderate-high resilience (measured 1 month post injury) reported significantly fewer postconcussion ($d = .80$), fatigue ($d = .79$), insomnia ($d = .58$), traumatic stress ($d = .70$), and depressive symptoms ($d = .82$) and better quality of life ($d = 1.11$) than mild TBI patients with relatively low resilience at 6 month follow up ($n = 70$). No significant difference in PCS symptomatology between moderate-high and low resilience groups at 12 month follow up ($n = 60$; $d = .42$) but moderate-high group did report significantly fewer fatigue ($d = .41$) and traumatic stress symptoms ($d = .60$), and better quality of life ($d = 1.07$) than the low resilience group.

Table 2 (continued)

Study	Design	Participants	Definition of resilience[1]	Resilience measure with or without retrospective reporting	Mild TBI outcome measures	Findings
Merritt et al. 2015	Cross-sectional	142 military service members divided into 3 resilience groups based on responses to "Response to stressful experiences" scale Moderate = 42 High = 51 Very High = 49	"a multi-dimensional construct reflecting a person's ability to bounce back after facing adversity or trauma or being able to adapt well, despite experiencing significant adversity, trauma, or stress….[with the central concept being]…ability to preserve despite adversity" (p.1).	RSES, not reported retrospectively	Postconcussion symptomatology (NSI); Posttraumatic stress disorder (PCL-C)	No association between resilience and RTW (r = .094 for the total score and r = .115 for the short form) Moderate resilience group reported significantly greater number of NSI symptoms compared to very high resilience group (d = .59). Moderate resilience group reported significantly greater no. of NSI cognitive symptoms than the very high resilience group (d = .81) and significantly greater no. of NSI affective symptoms than the high resilience group (d = .45) and the very high resilience group (d = .58). Moderate resilience group reported significantly greater number of posttraumatic stress symptoms compared to the very high resilience group (d = .50) and a greater number of avoidance (d = .49) and hyperarousal symptoms (d = .50) compared to the very high resilience group. Resilience significantly predicted PCD present and absent groups, over and above demographic variables, with overall model explaining 18 % of the variance when PCD endorsed at mild or higher level, and 20 % when PCD endorsed at moderate or higher level. Resilience significantly predicted PTSD present and absent groups, over and above demographic variables, when symptoms were endorsed at moderate or higher level, overall model explaining 14 % of the variance.
Sullivan et al. (2015)	Cross-sectional	mild TBI = 35 community-dwelling no mild TBI = 198	"a flexible, dynamic process-oriented psychological construct or the ability to bounce back" (p.148); implies adversity and personal adaptation	BRS, not retrospectively reported	Postconcussion symptomatology (NSI)	Lower perceived psychological resilience predicted greater self-reported postconcussion-like symptomology (Pearson's r = −0.330 to −0.364)

Notes: 1 = Definitions of resilience that included the key components of personal adaptation and adversity have those terms underlined. 2 = used as an outcome; 3 = used as a predictor; CD-RISC = 25-item Connor Davidson RISC scale (Connor and Davidson 2003); NSI = Neurobehavioral Symptom Inventory (Cicerone and Kalmar 1995); CRIS = Community Reintegration of Service Members Instrument (CRIS), perceived limitation subscale (Resnik et al. 2009); RPQ = Rivermead Post Concussion Symptom Questionnaire; RS = Resilience Scale (Wagnild 2009); BRS = Brief Resilience Scale (Smith et al. 2008). BNI-FS = Barrow Neurological Institute Fatigue Scale (Borgaro et al. 2004); RTW = return to work measured in days and defined as duration of sick leave or in case of students and unemployed, time before returning to normal activities; RSES = Response to Stressful Experiences Scale (Johnson et al. 2011); QoLBRI = Quality of life after brain injury (von Steinbuechel et al. 2012); RNBI = Ruff Neurobehavioural Inventory (Ruff and Hibbard 2003); PCLC = Posttraumatic Stress Disorder (PTSD) Checklist-Civilian Version, (Weathers et al. 1993); ASDS = Acute Stress Disorder Scale (Bryant et al. 2000); BDI-II = Beck Depression Inventory-Second Edition, (Beck et al. 1996); CES-D = Center for Epidemiological Studies (Radloff 1977). PCD = Postconcussional Disorder. Retrospective reporting = the measure was used with an instruction to participants to respond to the questions as if before the injury. Study design identification was determined using the method described by Viswanathan et al. (2013). OEF = Operation Enduring Freedom; OIF = Operation Iraqi Freedom; OND = Operation New Dawn. OEF, OIF and OND are the names of military missions led by the United States of America. d = Cohen's d; r = Pearson's r. Values for small, medium, and large effects, respectively, are: d = .2, .5, and .8, and; r = .1, .3, and .5 (Rice and Harris 2005). The Cohen's d value for the study by Graham et al. (2013) was calculated by us for this table

patients were drawn from an Emergency Department did not report the cause of injury (Losoi et al. 2015).

Resilience Definitions Each of the five studies provided a theoretical definition of resilience (see Table 2), all of which we classified as trait resilience and none of which assessed trajectory-resilience. Common to these trait resilience definitions was the concept of adversity (Merritt et al. 2015; Graham et al. 2013; Losoi et al. 2015), and the as the idea of a dynamic process (Sullivan et al. 2015; Graham et al. 2013). One study explicitly recognized the concept of personal adaptation (Merritt et al. 2015) and another used the term "positive" adaptation (Graham et al.). Personal adaptation was *implied* in the definition of resilience in the other studies (these definitions indicated that individuals would change or adapt in response to adversity). For example, in Losoi and colleagues' study (2015), resilience was defined as "the ability to recover from adversity", implying a process of individual adjustment, or personal adaptation, following a traumatic event. None of the studies defined resilience as a trajectory, in which the pattern of postconcussion symptoms over time remains at a low and non-impactful level despite the injury.

Trait Resilience Measures All of the reviewed studies assessed trait resilience using a standardized self-report measure (see Table 2). Four of the studies (Graham et al. 2013; McCauley et al. 2013; Sullivan et al. 2015; Losoi et al. 2015) analyzed trait resilience as a continuous variable, with higher scores indicating greater resilience. One study analyzed trait resilience as a categorical variable (Merritt et al. 2015). Merritt and colleagues used the Responses to Stressful Experiences Scale (Johnson et al. 2011) which aims to assess behavioural, cognitive and emotional responses to stressful experiences. Using a mean item score from the RSES, Merritt and colleagues divided the participants into three resilience categories: *moderate*, *high*, and *very high*. The Connors-Davidson RISC (Connor and Davidson 2003) was used by Graham et al. (2013) and McCauley et al. (2013). The Brief Resilience Scale (Smith et al. 2008) was used by Sullivan et al. (2015) and a short form of the Resilience Scale was used by Losoi et al. (2015).

Outcome Assessment The most common outcome was postconcussion symptoms, measured using established self-report measures and operationalized as the presence or absence of Postconcussion Syndrome (PCS) or as a continuous variable. The use of a research design that favours binary, clinically-defined outcome (such as recovered or not) is not uncommon in the broader mild TBI research. None of the reviewed studies used the symptom trajectory as an outcome.

As Table 2 shows, four of the five studies used one of two postconcussion symptom questionnaires. The Neurobehavioral Symptom Inventory (NSI, Cicerone and Kalmar 1995) was used by Graham et al. (2013), Merritt et al. (2015) and Sullivan et al. (2015). The Rivermead Postconcussion Symptom Questionnaire (King et al. 1995) was used by McCauley et al. (2013) and Losoi et al. (2015). Of those studies that used the NSI, one of them reported the total and subscale data (Merritt et al. 2015). Three of the studies that assessed postconcussion symptoms used continuous measurement (McCauley et al. 2013; Graham et al. 2013; Losoi et al. 2015), two studies used a combination of continuous measurement and a clinical cut score (Sullivan et al. 2015; Merritt et al. 2015). The study led by Losoi et al. examined multiple outcomes. In addition to postconcussive symptoms, Losoi et al. investigated posttraumatic stress disorder symptoms, return to work, quality of life, pain, fatigue, depressive symptoms, and insomnia symptoms (Losoi et al. 2015).

Association Between Trait Resilience and Mild TBI Higher trait resilience was associated with a "better" mild TBI outcome albeit with some very important caveats. As shown in Table 2, after mild TBI higher resilience was associated with better quality of life, and less fatigue, insomnia, depressive symptoms, and traumatic stress (Losoi et al. 2015; Merritt et al. 2015). There was no association between trait resilience and the number of days between the mild TBI and return to work (Losoi et al. 2015). Greater trait resilience was associated with fewer postconcussion symptoms (Losoi et al. 2015) in all but one of the studies that examined this relation (McCauley et al. 2013). Lower trait resilience was a significant predictor of higher PCS symptomatology (Sullivan et al. 2015; Merritt et al. 2015) and of posttraumatic stress disorder (Merritt et al. 2015). Merritt and colleagues found that greater trait resilience was associated with a decrease in the NSI postconcussion symptom total score *as well as* a decrease in affective and cognitive symptoms on the NSI subscales (the relation with NSI somatic/sensory symptoms was unclear). McCauley et al. (2013), contrary to their expectations and the theorized relation, found a positive relationship, such that greater trait resilience was associated with *higher* postconcussion symptom severity as well as higher anxiety symptom severity. McCauley et al. suggested the timing of trait resilience measurement, at one week (the proxy pre-injury assessment) and at 1 month post mild TBI, may have provided insufficient time to bounce back from injury thus leading to an unexpected positive relationship between trait resilience and PCS symptomatology.

Graham et al. (2013) investigated the association between the 5HTTLPR gene, a serotonin transporter, mild TBI and trait resilience. The S'S' carrier 5HTTLPR gene was positively and independently associated with trait resilience,

whereas mild TBI was negatively and independently associated with this outcome. Veterans with mild TBI were found to have lower trait resilience and more perceived limitations to community reintegration than veterans who had not experienced a mild TBI. The mild TBI group also had significantly higher PCS symptomatology, posttraumatic stress symptoms, and depression compared to veterans without mild TBI.

Risk of Bias The decision was made to report the risk of bias data descriptively rather than quantitatively. The results of the risk of bias analysis are shown in Table 3. This analysis showed that each of the reviewed studies carried a risk of bias, primarily because of selection and detection. The criteria that focus on group comparisons provide information about the nature and relevance of the potentially traumatic event. The enacted methodology was also compared to the proposed methodology in the registered protocol. The following variations were noted: the inclusion of one study that did not use a measure of postconcussion symptoms as the primary outcome, a widening of the scoping of the initial search (TBI as opposed to mild TBI), and the inclusion of studies irrespective of risk of bias.

Discussion

This review sought to determine how the notion of resilience has been used in mild TBI research. The key finding from this review is that there is significant variation in how trait resilience has been conceptualized and operationalized in adult mild TBI research and that the existing studies leave many questions unanswered. In effect, it is too early for strong conclusions based on this literature, but there is much to be gained from considering the approach. All of the reviewed studies operationalized resilience as trait resilience and although most of the reported definitions conveyed a notion of personal adaptation, none of them measured trajectory resilience. This distinction between trait resilience and trajectory resilience reflects a critical difference in the elements of resilience under study. This difference has important implications for how we interpret the reviewed research and it has shaped the recommendation for future studies.

Typically, the reviewed studies used cross-sectional measurement. They employed a standardized scale of trait resilience. This scale was used to predict a pre-defined outcome (e.g., whether the individual met the clinical criterion or not). The reviewed studies did not determine if there is a resilient trajectory response because they did not measure the unfolding of such a response after the TBI event. In other words, the reviewed studies did not determine if the observed outcome was in fact characteristic of a resilient outcome trajectory. This would be shown if, despite the event, the symptom profile demonstrated the prototypical pattern of stable, low, non-impactful symptoms. Considering that the existing studies have not shown whether the outcome after mild TBI might be described as resilient, it is questionable that these studies have actually measured 'resilience'. A more accurate evaluation might conclude, for example, that these studies had linked trait resilience to generally favourable adjustment.

In three of the five reviewed studies, a higher degree of trait resilience was associated with lower postconcussion symptoms, as the mild TBI models would predict. However, not all postconcussive symptoms (e.g., somatic/sensory) or outcomes (e.g., return to work) were similarly affected, and in one study a contrary finding emerged. In the reviewed studies, trait resilience was measured one to three times on separate occasions. The scales that were used to measure resilience were rarely used in the same postinjury period across studies. This period ranged from less than 24 h to 12 months post injury. In four of the five reviewed studies, a different standardized scale was used. This variability must be taken into account in the interpretation of the studies, it may contribute to inconsistencies in the findings, and it may pose a risk that the reported relations are biased or incomplete. On balance, a very tentative conclusion could be that there is limited support for the relation suggested in the mild TBI models. We understand this research as showing that trait resilience (or the various concepts measured by these scales) may be related to mild TBI outcome. However, this research does not address the notion of whether the outcome after mild TBI can be resilient.

None of the reviewed studies measured the postconcussion symptom trajectory in a way that would enable the modelling of a resilient outcome after mild TBI (trajectory resilience). Such a study would require a change of approach from that used in the reviewed research, although in practical terms the required change could be easily achieved. The symptom trajectory would be tracked using standard symptom measures such as the Neurobehavioral Symptom Inventory or the Rivermead Postconcussion Questionnaire. These would be given on at least three occasions (Norris et al. 2009), including to obtain a retrospective estimate of preinjury symptoms, and at time critical periods such as one, three or six months postinjury. If the postconcussive symptom trajectory displays the prototypical patterns identified after other potentially traumatic events, the lessons learned from this wider body of research could be applied in adult mild TBI. If these multiple trajectories are identified, their relative frequency and their predictors could be determined. We could glean information about the optimal timing for interventions or additional resources. If we could identify the characteristics of the groups who are the most likely to experience each of the trajectories, including a resilient trajectory, it could improve patient advice. Findings such as these could lead to a reconceptualization of the mTBI response as a specific example of a more general response to a potentially traumatic event, and the trialling of techniques from everyday stress and coping models to shape this response. Importantly, it could also prompt a

Table 3 Risk of bias analysis of reviewed studies

	Graham et al. (2013)	McCauley et al. (2013)	Losoi et al. (2015)	Merritt et al. 2015	Sullivan et al. (2015)
Do the inclusion/exclusion criteria vary across the comparison groups of the study?	Cannot determine	No, does not vary	No, does not vary	N/A; no comparison group	Yes, varies[1]
Does the strategy for recruiting participants into the study differ across groups?	Cannot determine	No, does not differ	No, does not differ	N/A	No, does not differ
Is the selection of the comparison group inappropriate, after taking into account feasibility and ethical considerations?	Cannot determine	No, not inappropriate	No, not inappropriate	N/A	No, not inappropriate
Were valid and reliable measures, implemented consistently across all study participants…?	Yes	Yes	Yes, for primary measures.[3]	Yes	No (mild TBI status self reported)[2]
Was the length of follow-up different across study groups?	No	No	No	N/A	No
In cases of high loss to follow-up (or differential loss to follow-up), was the impact assessed?	N/A	N/A, no loss to follow-up	N/A, loss to follow up not considered to impact assessment	N/A	N/A
Are any important primary outcomes missing from the results?	Yes (PCS not an outcome)	No important outcome(s) missing	No important outcome(s) missing	No important outcome(s) missing	No important outcome(s) missing
Are results believable taking study limitations into consideration?	Yes	Yes, but unexpected	Yes	Yes	Yes
Any attempt to balance the allocation between the groups or match groups?	No	No	No	N/A	No
Were important confounding variables not taken into account in the design and/or analysis?	Yes, detection bias (insufficient number of ax)	Yes, detection bias (ax too soon) and selection bias (tx seeking)[4]	Yes, selection bias (recruited tx seeking)	Yes, detection bias (insufficient number of ax)	Yes, selection bias (recruitment might have encouraged symptomatic people) and detection bias (insufficient number of ax)

Notes 1. Prior history of mild TBI not used as exclusion for mild TBI group. The other studies also varied in the extent to which prior mTBI history was used as a criterion against which the groups were explicitly evaluated / matched. For example, Graham et al. (2013) did not indicate whether 'previous mTBI' was used as a criterion to match the groups. 2. Coded 'no' because the Sullivan et al. study employed a different, and potentially, unreliable measure of mild TBI compared to the other studies (i.e., self-report of the injury-characterizing severity elements of the WHO criteria only). The population used in this study (i.e., individuals from the community with mild TBI) necessitated the use of such self-report data as other data were not available. The authors identified this factor as a limitation. 3 = The reliability of the return to work measure was unknown; there was a differential method of survey completion for those who did not complete online. 4 = The authors suggest that possible moderator variables, such as social support, were omitted

reconsideration of the nomenclature and scope of mild TBI models (e.g., how should the term resilience be used in these models and should it predict outcome trajectories?).

Of note, the search for this study revealed three previous TBI studies that used group-based trajectory modelling as their method of studying resilience. Although these studies were not able to be included in the review, they are discussed to illustrate the approach. These studies examined long term posttraumatic stress symptoms in the *significant others* of patients with severe TBI (Pielmaier et al. 2011), the emotional distress symptoms five years after *mild to severe* TBI[2] (Sigurdardottir et al. 2014), or the injury response of children and adolescents aged eight to 15 years (Yeates et al. 2009). Sigurdardottir et al. (2014) found that the *resilience* trajectory was the most common trajectory following TBI (73.5 %). Using finite mixture modelling, Yeates et al. (2009) identified four postconcussion symptom trajectories post mild TBI that they labelled as follows (i) no postconcussion symptoms (the most common trajectory), (ii) moderate persistent postconcussion symptoms, (iii) symptom elevation acutely, followed by symptom decline (resolution), and (iv) acute symptom elevation and persistence. These studies indicate the viability of the trajectory approach and show how it could be applied in adult mild TBI. Future studies could attempt to model *a full range* of outcomes including sensory, cognitive, somatic, and affective neurobehavioral symptoms since existing studies suggest that these outcomes may respond differently.

The implications for clinical practice that can be drawn from this review are limited because of the nature of the underpinning research. However, we think that it is appropriate to acknowledge the relation between trait resilience (an umbrella term) and specific mild TBI outcomes. We regard it as a link that is not yet well supported by empirical research and we would view it as one of several factors that could contribute to how people fare after injury. Thus, it may be appropriate to discuss the idea of personal adaptation in response to adversity with clients. When discussing injury prognosis, it may be helpful to draw attention to the idea of a resilient response to adult mild TBI, although we can only speculate that it exists. The latter discussion could be seen as a reframing of current mild TBI postinjury advice, which stresses that a full recovery is the most likely injury outcome, but the response pathway could be viewed as a general pathway.

This review has a number of limitations. First, despite the use of a systematic search and review process, it is possible that this review missed or excluded relevant studies because: a) of the way in which they were reported, b) they were not written in English or, c) they were published after the search was undertaken. This review did not attempt to access unpublished results. There were minor variations in the enacted versus proposed review methodology as has been noted, and this could affect the interpretation. It is possible that the study by Graham et al. (2013) should have been excluded because their primary outcome was not postconcussion symptoms. Other studies may have been identified if the target outcome of the review was expanded (e.g., to include quality of life, or *specific* symptoms that are regarded as postconcussive, such as fatigue). An established process was used to assess the risk of bias of the reviewed studies, but these processes also have limitations (da Costa et al. 2014) and the use of other methods could have produced different results.

In summary, this review found that when the term "resilience" was used in adult mild TBI outcome studies, it was conceptualized as trait resilience and used as a predictor of a clinically defined outcome. It was not used as an outcome per se, even though this usage is recommended in the wider literature. The existing research does not address the notion of a resilient mild TBI outcome, or any other outcome that could be empirically shown by adopting a trajectory approach. Whilst further research is warranted, a fruitful way forward could involve a change of approach. We strongly encourage adult mild TBI research that uses a trajectory approach to empirically determine the range of responses that occur after this injury. We urge this further research because it could reveal new ways of understanding the variation in outcome after mild TBI; it allows for the disaggregation of theoretically and empirically distinct responses and their frequency; it could lead to improved conceptual models, and; if the predictors of the responses can be identified, it could stimulate a new direction for mild TBI interventions.

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Compliance with Ethical Standards

Conflict of Interest Sullivan, Kempe, Edmed and Bonanno declare that they have no conflict of interest.

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[2] The results were not stratified by injury severity.

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