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UPDATE

Reframing postconcussional syndrome as an interface disorder of neurology, psychiatry and psychology

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Persistent symptoms following a minor head injury can cause significant morbidity, yet the underlying mechanisms for this are poorly understood. The shortcomings of the current terminology that refer to non-specific symptom clusters is discussed. This update considers the need for a multi-dimensional approach for the heterogenous mechanisms driving persistent symptoms after mild traumatic brain injury. Relevant pathophysiology is discussed to make the case for mild traumatic brain injury to be conceptualized as an interface disorder spanning neurology, psychiatry and psychology. The relevance of pre-injury factors, psychological co-morbidities and their interaction with the injury to produce persistent symptoms are reviewed. The interplay with psychiatric diagnoses, functional and somatic symptom disorder presentations and the influence of the medicolegal process is considered. The judicious use and interpretation of investigations given the above complexity is discussed, with suggestions of how the explanation of the diagnostic formulation to the patient can be tailored, including insight into the above processes, to aid recovery. Moving beyond the one-dimensional concept of 'postconcussional syndrome' and reframing the cause of persistent symptoms following mild traumatic brain injury in a bio-psycho-socio-ecological model will hopefully improve understanding of the underlying contributory mechanistic interactions and facilitate treatment.

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Abbreviations: mTBI = mild traumatic brain injury; PCS = postconcussional syndrome

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Traumatic brain injury (TBI) is common. Fortunately, the vast majority of injuries are mild, typically causing transient, self-limiting symptoms and no long-term sequelae. However, approximately 20% of people report persistent symptoms at 3 months post-injury following mild TBI (mTBI). For these people, the long-term outlook is poor, with many experiencing ongoing negative impact on work and social function.[1,2] Given how common mTBI is, this represents a huge number of affected individuals.

Persistent symptoms that occur after mTBI are likely to be due to a range of identifiable disorders, many of which have evidence-based treatments. However, we argue that clinical and research practice has been held back by the use of syndromic terms such as postconcussional syndrome (PCS) to categorize patients. Clinically, it produces bias away from considering treatable underlying causes of symptoms. From a research perspective, it fosters an assumption that people with such symptoms are a single group pathophysiologically. However, we would argue that the diagnostic heterogeneity here means that group data from, for example functional MRI studies, are unlikely to provide a valid source of information to make inferences about mechanisms of symptoms, nor to extrapolate from, in order to determine new avenues for treatment development.

Current terminology and its weaknesses

Numerous definitions for mTBI have been published (Table 1).[3–13] The definitions extrapolate the presumed presence and severity of an underlying TBI from clinical markers. Alteration of mental state is considered a fundamental marker of TBI, with classifications agreeing, for example, that loss of consciousness is sufficient (but not necessary) to diagnose a mTBI. However, debate remains regarding the degree of alteration in mental state required, whether evidence of structural injury constitutes a more severe injury and whether the presence of subjective post-injury symptoms (e.g. headache, dizziness, cognitive impairment) is sufficient to diagnose a TBI.

A recent survey of mTBI experts found agreement amongst the panel that individuals with an mTBI can present with isolated subjective symptoms such as headache, dizziness and cognitive impairments.[4] However, such symptoms are not specific to head injury, occurring at the same rate in those with extracranial injury and in up to three quarters of otherwise healthy adults.[14–16] This perhaps explains the finding that 59% of the general population who report having been 'concussed' deny ever having had a brain/head injury.[17]

Despite the lack of specificity of these symptoms to brain injury, the term 'PCS' is widely used to describe the persistence of these symptoms beyond 3 months following mTBI. Perhaps in recognition of this lack of specificity [there was only 40% agreement between the 4th edition of the Diagnostic and Statistical Manual (DSM-4) and 10th edition of the International Classification of Disease (ICD-10) diagnostic criteria for PCS when applied to a large cohort[18]], the latest iterations of the DSM and ICD have removed the category of PCS and subsumed it under 'neurocognitive disorders due to traumatic brain injury' and 'mild neurocognitive disorder' (which can be secondary to trauma), respectively (Table 2).

Unfortunately, the criteria for neurocognitive disorder continue to lack diagnostic precision and focus on non-specific symptoms. The aim should be objective diagnostic measures to help categorize the symptoms within specific diagnoses, that in turn might link to specific treatments. In the differential diagnosis section of neurocognitive disorders due to TBI in DSM-5, the practitioner is advised specifically to consider alternative diagnoses of somatic symptom disorder or factitious disorder to explain the persistent neurocognitive impairment. The Scottish Intercollegiate Guidelines Network (SIGN) for brain injury rehabilitation states: 'In a small minority of mTBI patients, symptoms may be more prolonged, but in such cases the determinants of disability appear to be personal and social factors and not related to the brain injury.[19] This approach results in a clear dualistic split between an (unspecified) physical damage-related mechanism for persistent symptoms and an (unspecified) psychological mechanism. However, as detailed below, a variety of interacting mechanisms for symptoms may exist which span the false divide between 'physical' and 'psychological'.

Approaching mild traumatic brain injury as an interface disorder

The syndrome of persistent symptoms following mTBI rests at the interface between neurology, neurosurgery, psychiatry and psychology. Far from being a 'one-size fits all' condition, mTBI is a complex condition with multiple potential underlying pathophysiological and psychopathological processes, requiring a range of interventions across numerous specialties. A novel approach focusing on pathology and impairment-based diagnostics would allow accurate and timely diagnosis of the often complex symptoms occurring after mTBI.[20]

Preinjury factors

Pre-injury depressive or anxiety disorder are the strongest predictors of persistent symptoms after mTBI.[21,22] Additional factors that influence recovery include pre-injury life events, social circumstances, personality traits including neuroticism and memory perfectionism, illness expectation and beliefs.[23–25] Expectations relevant for outcome include beliefs about symptom duration, the strength of identity and the emotional impact of the TBI.[26–28] Pre-existing anxiety and anxiety sensitivity are associated with more severe and prolonged symptom reporting, potentially related to negative illness beliefs.[29,30]

Pre-injury neurodegeneration or even healthy ageing affect the outcome of the injury regardless of its severity.[31,32] In addition, it is likely that pre-existing neurodevelopmental disorders would have an impact on outcome after mTBI. Premorbid psychiatric illnesses including attention deficit hyperactivity disorder are seen in a higher proportion of those with mTBI than would otherwise be expected.[33–35] This may relate to impulse control behaviours, including alcohol and substance misuse, which can predispose an individual to sustaining a TBI. These examples indicate that the neural substrate on which the injury occurs interacts with the effect of the injury itself.

The injury: to what extent has persistent damage occurred?

A TBI results from an external mechanical force which is hypothesized to cause a primary injury. However, the mTBI group comprises a huge range of injury severity. Within this same category might be a person who sustained a very minor blow to the head resulting in symptoms such as dizziness, headache and nausea and a person who, following a blow to the head, had 29 min of loss of consciousness, 23 h of post-traumatic amnesia and a non-displaced

Table 1 Key definitions of mTBI and concussion

Criteria (year)	Definition of head injury	Factors related to injury can include
Centers for Disease Control and Prevention (2003)[7]	Blunt trauma to head or acceleration/deceleration forces results in a brief alteration of mental status or brief loss of consciousness	GCS 13–15, LOC < 30 min; PTA ≤ 24 h; non-penetrating cranio-cerebral injury.
WHO (2005)[6]	Acute brain injury resulting from mechanical energy to the head from external physical forces.	GCS 13–15[a], LOC ≤ 30 min; PTA < 24 h; and/or other transient neurological abnormalities,[b,c] and intracranial lesion not requiring surgery.
Mayo (2007): mild (probable) TBI[12]	Traumatically induced injury that contributed to physiological disruption of brain function	GCS 13–15 (≥13 at 30 min); LOC momentary to 30 min; PTA momentary to 24 h; skull fracture with intact dura; EXCLUSION if death due to TBI, worst GCS in first 24 h < 13[c], abnormal head CT.
Mayo (2007): symptomatic (possible) TBI[12]	Traumatically induced injury that contributed to physiological disruption of brain function	Symptoms only[d]. Symptoms must not be attributable to pre-existing or co-morbid diagnoses. EXCLUSION if criteria met for mild probable TBI.
Department of Veterans Affairs/Department of Defense (2009)[8]	A traumatically induced structural injury and/or physiological disruption of brain function as a result of an external force	GCS 13–15[e]; LOC momentary to 30 min; alteration of consciousness/mental state (AOC) momentary up to 24 h; PTA < 24 h; neurological deficits[f] that may or may not be transient; normal structural imaging.
Ontario neurotrauma (2018)[11,g]	Concussion/mTBI denotes the acute neurophysiological event related to blunt impact or other mechanical energy applied to the head, neck or body (with transmitting forces to the brain), such as from sudden acceleration, deceleration or rotational forces	LOC < 30 min; any AOC at the time of the injury; PTA ≤ 24 h; physical symptoms[h]; normal standard imaging.
American congress of rehabilitation medicine (2021)[4]	A traumatically induced physiological disruption of brain function	Symptoms following a head impact, without associated observable signs (in some instances), Recommendation (i) consider a probabilistic framework that weighs observable signs more than subjective symptoms and (ii) incorporate objective cognitive, balance and vestibular-oculomotor test findings. 1993 criteria[c]: initial GCS 13–15; any LOC; any AOC at the time of the injury and focal neurologic deficit(s) that may or may not be transient; any PTA.
1st International conference of concussion in sport (2002)[13]	A complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces.	(i) Direct blow to the head, face, neck or elsewhere on the body with an 'impulsive' force transmitted to the head. (ii) Rapid onset of short-lived impairment of neurological function that resolves spontaneously. (iii) May result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance versus structural injury. (iv) Results in a graded set of clinical syndromes that may or may not involve LOC. Resolution of the clinical and cognitive symptoms typically follows a sequential course. (v) Typically grossly normal structural neuroimaging studies.
5th International conference of concussion in sport (2017)[5]	Sports-related concussion is a TBI induced by biomechanical forces	Modifications to the above: (i) In some cases, signs and symptoms evolve over a number of minutes to hours. (ii) No abnormality is seen on standard structural neuroimaging (iii) Sports-related concussion results in a range of clinical signs and symptoms.[c] In some cases symptoms may be prolonged.

AOC = alteration of consciousness; GCS = Glasgow coma scale; LOC = loss or decrease of consciousness; PTA = post traumatic amnesia, any loss of memory for events immediately before or after the accident.

[a]Ideally at 30 min post injury or first opportunity presented to healthcare.

[b]Such as focal signs or seizure.

[c]The clinical signs and symptoms cannot be explained by alternate cause, e.g. drugs or other comorbidities (e.g. psychological factors or coexisting medical conditions).

[d]Blurred vision, confusion (mental state changes), dazed, dizziness, focal neurologic symptoms, headache or nausea.

[e]Best available score <24 h.

[f]Weakness, loss of balance, change in vision, praxis, paresis/plegia, sensory loss or aphasia, etc.

[g]Stratified into high and low risk mTBI.

[h]Vestibular, headache, weakness, loss of balance, change in vision, auditory sensitivity or dizziness.

Table 2 Current definitions of persistent symptoms post head injury

	Timing	Trigger	General	Physical	Emotional	Cognition
Postconcussional syndrome (ICD-10)	Chronic, permanent or late emerging.	Head injury usually with loss of consciousness.	Not explicitly specified.	Headache, dizziness, fatigue, insomnia.	Irritability, reduced tolerance to stress, emotional excitement and alcohol.	Difficulties with concentration, memory and mental tasks.[a]
Mild neurocognitive disorder (ICD-11)	<1 month between head injury and symptom onset.	Head injury with loss of consciousness or aetiology may be undetermined.	Not sufficiently severe to significantly interfere with independence or activities of daily living.	Headache, dizziness, fatigue, insomnia, noise intolerance.	Irritability, reduced alcohol tolerance, depression, anxiety, emotional lability, preoccupation with symptoms.	Subjective decline in concentration, memory, or intellectual difficulties.
Major/mild neurocognitive disorders due to TBI (DSM-5)	From injury or when consciousness recovers. Persists beyond acute period. Resolution: usually complete and <3 months.	Head injury.	Severe versus modest interference with ability to be independent in functions of daily living.	Headache, vertigo, sleep disorder, tinnitus, hyperacusis, photosensitivity, anosmia, hemiparesis, seizures, visual disturbance, orthopaedic injury, cranial nerve or neuromotor deficits.	Irritability, reduced tolerance to psychotropic medication, loss of emotional control (e.g. aggression), inappropriate affect, apathy, anxiety, depressed mood,[b] altered personality and/or social cognition.	Difficulty concentrating, learning and memory, executive function, slowed processing speed, reduced cognitive efficiency, decline in language, neglect, constructional dyspraxia.

[a]Persistent disorientation and confusion (compare post-traumatic stress disorder with specific triggers).
[b]Depressive and anxiety symptoms amplify cognitive complaints and worsen functional outcome.

skull fracture. It seems logical that the physical consequences to the brain are likely to differ across this spectrum.

Despite this complexity, there often appears to be an assumption in the literature that symptoms after mTBI are always caused by the same basic process of brain injury at a cellular and structural level and, therefore, that experimental studies at a group level are a reasonable way to investigate the nature of these injuries.[36] This fails to recognize the heterogeneity of likely physical injury within the broad mTBI category and also, crucially, that other disorders can cause persistent symptoms after mTBI (e.g. functional neurological disorder, depression, migraine) which are themselves associated with abnormalities on experimental measures such as functional MRI.[37–39]

Post-mortem studies of patients with a history of mTBI, but who died of other reasons, have found evidence in some of white matter injury and persistent inflammation months after the injury.[40,41] Secondary injury could therefore develop in minutes, hours or months, with possible long-term effects on symptoms and function.[42] However, caution must be applied, because these phenomena are likely to affect only a proportion of people with mTBI. There is also a tendency to extrapolate in an unrestrained way the results of animal studies to humans, even though the vast range of injury severities in humans with mTBI do not map well onto the carefully controlled experimentally-induced injuries in animal studies.

Use of brain imaging to define extent of brain damage after mild traumatic brain injury

Advances in brain imaging techniques have allowed the possibility of examining the presence of post-TBI pathophysiological changes *in vivo*. However, several potential pitfalls exist in the interpretation of neuroimaging results in people with persistent symptoms after mTBI. These include (i) the sensitivity of routine clinical and advanced imaging techniques for detecting injury after mTBI; (ii) the specificity of any abnormalities detected; (iii) their role in prognostication; and (iv) their relationship to persistent post-trauma symptoms. Over (or under) interpretation of imaging findings can lead to misdiagnosis in an individual and consequently inappropriate treatment and prognostication. At a research level, insufficiently powered studies or incorrect extrapolation of imaging findings to underlying pathophysiology can also lead to inappropriate conclusions being formed.

A variety of imaging methods are sensitive to changes in brain structure (e.g. volumetric and diffusion tensor imaging), functioning (e.g. functional MRI and magnetoencephalography) and alterations in cellular and biochemical milieu, including evidence of persistent inflammation (e.g. PET).[43–45] Using these methods, numerous studies have identified imaging changes at a group level in those with persistent symptoms after mTBI.[1] However, these changes are inconsistent and cannot easily be extrapolated to single cases of mTBI.[46–48]

It is also important to recognize that potential imaging changes may not necessarily be a direct consequence of the mTBI itself. Co-morbid conditions which might be relevant for causing persistent symptoms after mTBI, but not via structural damage, can also cause detectable changes using these neuroimaging techniques. For example, diffusion tensor imaging metrics have been shown to be altered in migraine,[49,50] depression[51] and post-traumatic stress disorder.[52] Equally, functional neuroimaging changes have been reported in the same conditions and in functional neurological disorder, irrespective of the presence of a TBI.[37–39] This complexity is not reliably accounted for in imaging studies of mTBI.

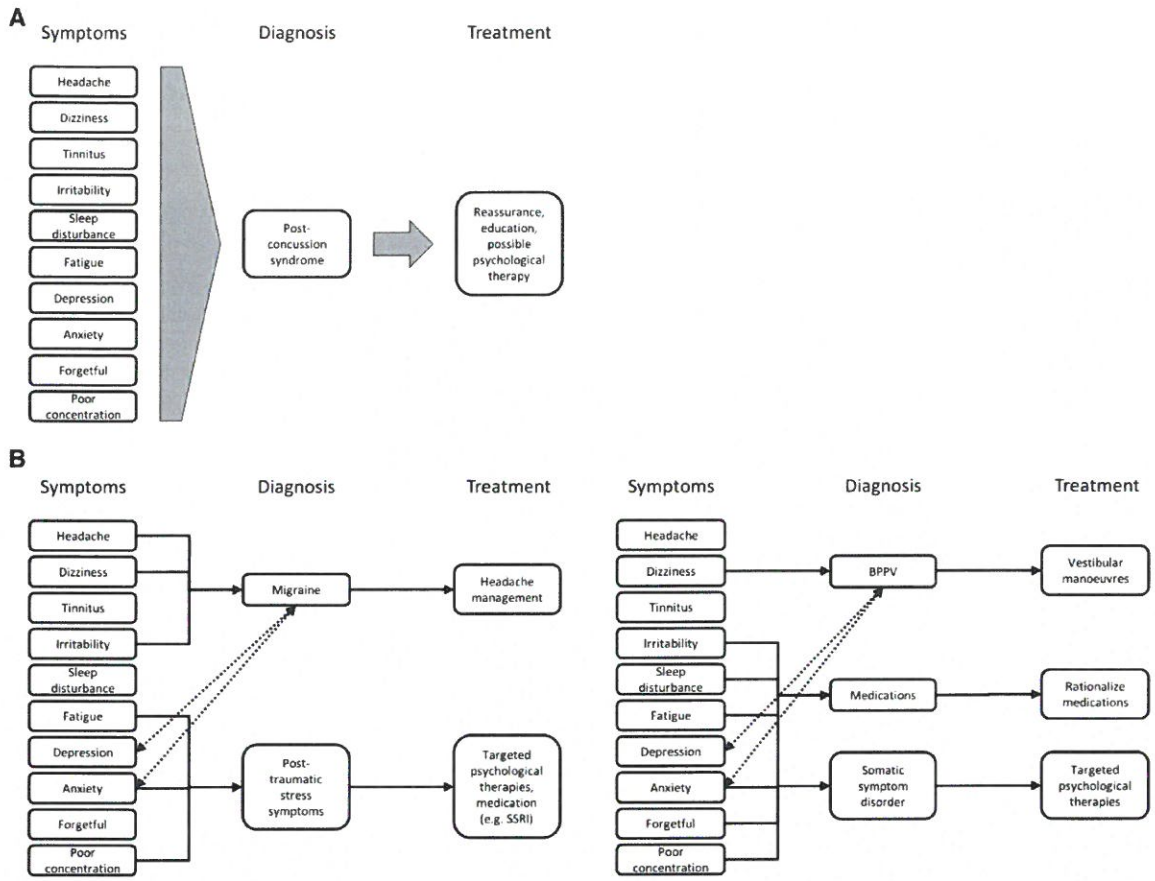


Figure 1 Two distinct approaches to the same symptom complex post mTBI. (**A**) Panel demonstrates the consequence of the PCS label being applied, resulting in a single non-specific treatment. (**B**) Adopting an individualized diagnostic formulation to consider and identify the multiple potential causative factors potentially underlying identical symptom complexes. The consequence is the instigation of targeted evidence-based individualized treatment plans. Dotted arrows represent contributory processes to symptom persistence/amplification.

Diagnoses that may underpin persistent symptoms after mild traumatic brain injury

The foundation of our approach to persistent symptoms after mTBI is the recognition that the symptoms are non-specific. This means that, in different people, there might be a range of possible diagnoses within which such symptoms could cluster. Alternatively, numerous different underlying diagnoses might be present in another individual with the same persistent symptoms and those symptoms may have a high degree of overlap between diagnoses. The assessment therefore needs to tease apart (or indeed cluster together) symptoms to establish a reasonable diagnostic formulation shared with the patient, with the express purpose of developing a rational bio-psycho-socio-ecological treatment plan informed by that formulation.[53] To illustrate this approach, we have used two of the most commonly described symptoms after mTBI; headache and dizziness (Fig. 1).[54]

When compared to primary headache disorders, post-traumatic headache most commonly represents a migraine-type headache with associated migraine symptoms, including nausea, light and noise sensitivity, irritability and cognitive symptoms—symptoms that are also listed as typical symptoms of PCS itself.[55] Furthermore, a pre-existing or family history of migraine are risk factors for prolonged post-traumatic headache.[56,57] However, although migraine and post-traumatic headache pathophysiology may overlap in some patients, there is likely to be a range of pathophysiological processes underpinning post-traumatic headache and treating all the same is unlikely to be successful.[58] For example, persistent psychological factors and medication overuse are recognized to prolong post-traumatic headache.[59] Therefore, treatment trials that fail to stratify patients and instead treat all post-traumatic headache as the same are at risk of failure. Despite these caveats, early treatment of post-traumatic headache, particularly in those at greatest risk, and a diagnostic explanation for the patient including the clustering of other 'postconcussional' symptoms are warranted.

Post-traumatic dizziness is another good example of symptom clustering. The commonest causes following mTBI are benign paroxysmal positional vertigo (40%) and vestibular migraine (34%).[60] Vestibular migraine is associated with other migrainous symptoms as discussed above but, perhaps surprisingly, benign paroxysmal positional vertigo is also associated with cognitive impairments and heightened anxiety, especially if left untreated.[61]

Relationship to psychiatric disorders

Mild TBI increases the risk of developing a subsequent psychiatric condition nearly threefold.[62] However, trying to distinguish

psychiatric conditions such as anxiety, depression or post-traumatic stress disorder from the effects of a mTBI can be challenging due to symptom overlap, yet has important implications for symptom persistence (Table 3).[54,63,64] It is important to remember that symptom overlap can obscure diagnostic clarity, 50% of people with depression who have not had a TBI meet the criteria for moderate to severe PCS.[65] Alongside the psychosocial impact of head injury, it is of course also possible for depression and anxiety to be related to structural brain injury, either as a result of macroscopic damage or triggering of a secondary inflammatory process.[66–68]

There also remains stigma surrounding mental health diagnoses, which results in a higher likelihood of misattributing the cognitive changes to the injury, rather than potentially reversible psychological or psychiatric causes. The unfortunate consequence of this is that appropriate, evidence-based treatment may not be accessed in a timely way, subsequently worsening the treatment responsiveness and prognosis of the psychiatric condition.

Functional neurological disorder and somatic symptom disorder

Functional neurological disorder is characterized by internal inconsistency, typically demonstrated by the complaint of abnormal function in a system that can be demonstrated (usually clinically, but sometimes by investigation) to be capable of normal function.[69] Over 80% of people with functional neurological disorder report a health event near to the onset of functional symptoms.[70] These events, which include accidental injuries, are typically minor and would be expected to improve and not produce lasting symptoms in their own right.

This preceding discussion clearly has relevance for the development of persistent symptoms after mTBI. The immediate and lasting physical and psychological consequences of accidents and injuries causing TBI could undoubtedly act as triggers to the onset of functional neurological disorder and/or somatic symptom disorder in some people, also interacting with pre-morbid risk factors and subsequent behaviours such as fear avoidance.[71] Positive diagnosis of such symptoms is possible within normal clinical practice, and diagnostic explanation according to best practice is typically a positive and empowering experience for patients.

Medicolegal impact

Medicolegal processes appear to be correlated with persistence of symptoms in some people, a finding that is often interpreted as evidence that mTBI is psychological in nature.[72] The fact that there is often someone at fault or to blame, resulting in adversarial circumstances between involved parties, means that primary psychological reactions are naturally triggered by the litigation process, such as loss aversion, anger or revenge. The financial implications in this context are not necessarily the motivator for the feigning behaviour.[73,74] It is notable that often from the outset of the medicolegal process, the injury might not be acknowledged by the other party. This can result in anger from the injured individual, particularly if they are subject to independent assessments where the assumption is that they are not injured at all, or perhaps not as severely as thought, or even that they are malingering.[73] These effects translate into an increased likelihood of feigning behaviour as a behavioural expression of the emotional sequelae of the mTBI or the need for revenge if trust is violated.[75]

Miscellaneous factors

In addition to the above causes, it is important to consider the potential effect of non-brain injury factors. For example, extracranial injuries influence symptom persistence.[76] This may be related to effects on sleep, pain and psychological impact. Finally, medications commonly prescribed after traumatic injuries, particularly opiate based analgesics, can impair cognitive functions, disrupt sleep and cause dizziness and nausea.

Recommendations on how to implement assessment and treatment

The use of PCS as a diagnosis remains pervasive despite its removal from the latest iterations of the DSM-5 and ICD-11.[77,78] As discussed above, this syndromic diagnosis belies the complexity of the underlying condition and its use acts to close off diagnostic and treatment pathways. In addition, misinformation or lack of understanding about the nature of the condition can lead to unrealistic expectations, frustration with the medical process and symptom amplification.[79] Therefore, a conceptual change, brought about by the abandonment of these syndromic terms, is important to improve understanding and to facilitate the additional assessments and treatments needed.

Given the incidence of mTBI, it is not feasible for all patients to be seen by specialist interdisciplinary teams. We argue that by abandoning syndromic diagnostic labels and reframing the conceptualization of persistent symptoms as described above, primary care and non-specialist professionals would be more alert to potential diagnoses for symptoms, be able to counsel patients more effectively and instigate relevant treatments. Furthermore, it would allow the selection of those patients who would benefit most from referral to a specialist service. For example, rather than attributing dizziness following a head injury to 'PCS', without this diagnostic label further assessment for the cause of the dizziness would be required. This would allow, for example, the identification of potentially treatable causes such as benign paroxysmal positional vertigo. It would also improve the initial education process for patients, with early education recognized to reduce persistent symptoms following mTBI.[80]

For those patients referred for a specialist opinion, given the potential of this disorder to span neurology, psychiatry and psychology, the clinician must be trained to assess the biological and psychological elements within a patient, in addition to considering ecological factors such as social and economic circumstances.[53] This interface across disciplines is not unique to mTBI, with increasing recognition that the assessment and management of many 'neurological' and 'psychiatric' disorders would benefit from expertise across these specialties.[81,82]

The aim of this assessment would be to map the cause for an individual's symptoms to a pathophysiological or psychopathological process, or both (Fig. 1). This should allow:

(i) An individualized treatment plan which could be based within primary care with appropriate support and training (e.g. migraine treatment, psychological treatment and medication for neuropsychiatric disorders, management of sleep disturbance or vestibular manoeuvres for benign paroxysmal positional vertigo).
(ii) Appropriate explanation and psychoeducation for the patient to understand the cause of their symptoms, including an understanding of the key role that somatic hypervigilance and emotional conditioning play in the chronicity of symptoms.[83]
(iii) A specialist multidisciplinary service which can provide specialist assessment and treatment for a subset of patients with high symptom complexity/severity, treatment resistance or diagnostic uncertainty.
(iv) Development of clinical trials and experimental research studies within a properly stratified group of patients.

Table 3 Diagnoses and important differentials for persistent symptoms post head injury from DSM-5

	Timing	Trigger	General	Physical	Emotional	Cognition
PTSD[a]	>1 month of persistent symptoms With delayed expression: Full symptom expression >6 months after event.	Actual/threatened harm including head injury.	Impaired social, occupational and other aspects of functioning.	*Disturbed sleep* (e.g. **recurrent distressing dreams related to trauma**), change in arousal, hypervigilance for potential threats, episodic physical symptoms can act as trigger for PTSD symptoms.[b]	*Irritability, outbursts*, recklessness, **flashbacks**, intense/prolonged distress **related to cues** with/without *avoidance, persistent negative emotional state.*	*Difficulty concentrating*, inability to remember important aspects of event (not due to head injury), recurrent distressing memories (consider obsessive compulsive disorder criteria for obsession if unrelated to trauma).
Generalized anxiety disorder	Persistent symptoms for more than 50% of the time for >6 months.		Impaired social, occupational and other aspects of functioning.	*Disturbed sleep*, fatigue, exaggerated startle, muscle tension or soreness, *change in arousal including panic attacks*, somatic symptoms e.g. sweating, diarrhoea.	*Irritability, anxiety/fear* **not related to traumatic event or specific triggers**, overestimate dangers/future threat with *avoidance*, **worry about multiple events, situations or activities**.	*Difficulty concentrating* **owing to worrisome thoughts**, mind going blank.
Major depressive disorder	>2 weeks duration of new or clearly worsened symptoms, can be discrete episodes.	Can be traumatic/stressful event, often on a background of adverse childhood experiences.	Impaired social, occupational and other aspects of functioning.	*Sleep disturbance, fatigue*, weight change, loss of libido, *general heaviness of* limbs,[c] somatic symptoms especially pain,[d] *psychomotor agitation or retardation.*	*Irritation,*[e] *outbursts*, ***excessive guilt/worthlessness***, *low/dysphoric mood* or ***anhedonia***, diminished interest, suicidal thoughts, *anxiety, phobias, excessive worry.*	*Difficulty concentrating*, thinking, distractibility, indecisiveness, **obsessive rumination** (compare PTSD where related to a specific event).
Functional neurological disorder	Acute: <6 months duration (may have similar previous episodes). Persistent: >6 months.	Onset may be preceded by injury (physical/psychological).	Impaired social, occupational and other aspects of functioning.	Disturbance of any neurological system, internal inconsistency on examination.	Can be associated with dissociative symptoms at onset or during attacks, **distress associated with loss of function**.	Absent from definition.
Somatic symptom disorder	Any one symptom may not be persistent but state of being symptomatic >6 months.	Can be precipitated by stressful life events	Symptoms are distressing or result in significant disruption of daily life.	May represent normal bodily sensations/discomfort, may be specific (e.g. localized *pain*) or generalized (e.g. *fatigue*).	*Persistently high levels of anxiety* **related to symptom and/or family history of disease, appraise bodily symptoms as threatening**.[f]	Excessive thoughts **related to somatic symptom** (thoughts are less intrusive than obsessive compulsive disorder).

PTSD = post-traumatic stress disorder.

Within symptom columns: bold denotes useful differentiating features; italics denotes shared symptoms across more than one category.

[a]More than 80% likely to have symptoms that meet diagnostic criteria for another mental disorder eg depression, bipolar disorder, anxiety, substance use compared to those without PTSD.

[b]New onset of somatic symptoms within the context of posttraumatic distress may indicate PTSD rather than a functional neurological disorder.

[c]Versus focal and more prominent in functional neurological disorder.

[d]Depression single diagnosis if somatic symptoms and related thoughts, feelings or behaviours occur only during major depressive episodes.

[e]If mood disturbance characterized by irritability alone in the absence of sadness/anhedonia consider alternative diagnoses, e.g. attention deficit hyperactivity disorder.

[f]Anxiety is focused on symptoms and distress caused by the symptoms (*cf.* generalized anxiety disorder). Absence of repetitive behaviours aimed to reduce anxiety that occur in obsessive compulsive disorder.

Finally, there must be capacity for patients to be reviewed if required beyond their initial appointment to allow modification of interventions by monitoring the symptom trajectory and response.

Conclusions

Persistent symptoms after mTBI represent a common and disabling problem resulting in major personal and societal impact. The use of broad syndromic labels for these symptoms, such as PCS and neurocognitive disorder, which build upon the very broad categorization of head injury severity encompassed by the term mTBI are directly unhelpful in advancing treatment, outcomes and scientific understanding. We conceptualize mTBI instead as an 'interface disorder'. This means that clinicians and researchers need to appreciate the complexity of the biological, psychological and ecological interfaces that are often present in people with mTBI. This does not equate to a simple, binary biological and psychological split. Recognizing this complexity and abandoning the current syndromic terms is an important first step in preventing the premature closure of the diagnostic and treatment pathways. Given the prevalence of the condition, not all patients can be, or indeed need to be, referred to specialist interdisciplinary teams. By supporting accurate diagnosis, patient education and early instigation of evidence-based treatment within primary and non-specialist services, the specialist multidisciplinary team is likely to be more effective in providing diagnostic and treatment input for those patients with higher levels of complexity and need.

This approach places the person with mTBI at the center of a diagnostic formulation, which can be used collaboratively to develop a rational and personalized therapeutic prescription. Such work, coupled with research developments in biomarkers and clinical trials, should result in better outcomes for the many people who experience persistent symptoms after mTBI.

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Competing interests

M.D.D. provides expert evidence and clinical treatment in medicolegal settings. M.J.E. provides expert evidence and clinical treatment in medicolegal settings. He receives royalties from the Oxford University Press for *The Oxford Specialist Handbook of Parkinson's Disease and Other Movement Disorders*. In the past year he has received honoraria for education work for Merz Pharma. P.O.J. provides expert evidence in medicolegal settings.

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