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Persistent impairment based symptoms post mild traumatic brain injury: Does a standard symptom scale detect them?

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ABSTRACT

Aim: To further explore symptoms in patients beyond the expected recovery period post mild Traumatic Brain Injury (mTBI) that are potentially indicative of impairment.
Methods: Ninety-four individuals (62 diagnosed with mTBI within the previous 4–24 weeks and 32 healthy controls) participated in the study. Participants in the mTBI group were further grouped as symptomatic (n = 33) or asymptomatic (n = 29) based on their spontaneous report of symptoms at the time of screening. Measures included a demographic questionnaire, 8 impairment specific self-report clinical tools, and a standard post-mTBI self-report symptom scale (Head Injury Scale (HIS)).
Results: Compared to the control group, scores for all instruments (including the HIS) were higher in the symptomatic mTBI group ($P < 0.05$), and higher for the neck disability and hyperarousal measures in the asymptomatic mTBI group ($p < 0.035$), but not the HIS ($p > 0.093$). Overall 94% of the symptomatic and 62% of the asymptomatic participants post-mTBI, recorded scores considered to be clinically relevant on at least one impairment screening tool. In contrast, only 28% of the asymptomatic mTBI group recorded a clinically relevant score for the HIS.
Conclusion: Symptoms indicative of persisting impairments beyond the expected recovery period were apparent in a substantial proportion of individuals post mTBI. Furthermore, a high percentage of individuals initially reporting as symptom free demonstrated clinically relevant scores on at least one impairment screening tool. Findings also suggest that a standard post-mTBI self-report symptom scale may often not detect the presence of persisting symptoms.

1. Introduction

Self-reported symptom resolution following a Mild Traumatic Brain Injury (mTBI) is thought to occur within the first 10–14 days post-injury in adults (Broglio et al., 2018; McCrory et al., 2017; Marshall et al., 2015; Giza et al., 2013; Harmon et al., 2013). As such self-reported symptom resolution is viewed as an initial indicator of recovery (Broglio et al., 2018; McCrory et al., 2017; Marshall et al., 2015; Giza et al., 2013; Harmon et al., 2013) and is often used as a guideline when returning individuals to pre-injury activity (including contact sports) (Broglio et al., 2018; McCrory et al., 2017; Giza et al., 2013; Harmon et al., 2013). Persistence of symptoms beyond 1–3 months is also a primary clinical indicator for diagnosis of post-concussion syndrome (McCrory et al., 2017; DSM-IV, 1994; World Health O, 1992). However, recent evidence suggests that the use of symptom behaviour post-mTBI to guide such decisions is not straightforward.

Studies have demonstrated persistent multi-system impairments, particularly sensorimotor and physiological disturbances, following mTBI, beyond expected recovery times (Abaji et al., 2016; Sung et al., 2016; Zhou et al., 2016; Baker and Cinelli, 2014; Catena et al., 2009; Parker et al., 2006; Johnson et al., 2015; McDevitt et al., 2016; Wright et al., 2017; Kamins et al., 2017) and following self-reported symptom abatement (Abaji et al., 2016; Baker and Cinelli, 2014; Parker et al., 2006; Johnson et al., 2015). One recent review (Galea et al., 2018) identified persistent impairments in 36 individual sensorimotor and/or physiological variables (postural control, oculomotor function, and sleep) in individuals subacutely post mTBI, with additional meta-analysis evidence of impaired heart-beat regulation. However only 9/13 studies in this review investigated concurrent symptoms, which were reported as absent in 5 studies, while the remaining 4 identified

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symptoms using impairment specific self-report clinical tools related to psychological distress and sleep quality, not standard post mTBI self-report symptom scales (Galea et al., 2018). Such findings suggest potentially greater diversity and persistence of impairments following mTBI than originally thought, which may not be detected with commonly used instruments.

Currently only a few validated self-reported symptom tools are used in practice post mTBI (Alla et al., 2009; Piland et al., 2003; Lovell et al., 2006). The Head Injury Scale (HIS) is one tool and contains 9 items measuring frequency and severity of symptoms relating to somatic, neurobehavioral and cognitive domains (Piland et al., 2003, 2010). Based on the recent studies indicating the diverse nature of impairments potentially presenting post-mTBI (Abaji et al., 2016; Sung et al., 2016; Zhou et al., 2016; Baker and Cinelli, 2014; Catena et al., 2009; Parker et al., 2006; Johnson et al., 2015; McDevitt et al., 2016; Wright et al., 2017; Galea et al., 2018; Kamins et al., 2017), it is unknown if the limited items contained within single instruments such as the HIS are sufficient to screen this patient population. Potentially a battery of validated impairment specific self-report clinical tools may be more appropriate. Evolving evidence suggests that clinical instruments relating to neck pain and disability (Vernon and Mior, 1991; Young et al., 2018), fatigue (Krupp et al., 1989), sleep quality (Buysse et al., 1989) and psychological distress (Lovibond and Lovibond, 1995) may also be relevant in patients post-mTBI (Fig. 1). Such instruments may give insight regarding persisting sensorimotor, musculoskeletal, endocrine, neurodegenerative, or affective deficits in these patients (McDevitt et al., 2016; Ponsford and Sinclair, 2014; Elliott et al., 2018; Dahm et al., 2013; Reneker et al., 2018).

The aim of this study was therefore to further investigate whether symptoms potentially indicative of impairment persist in patients beyond the expected recovery period post-mTBI, and whether a standard self-report symptom tool (ie. HIS) would also identify persistent symptoms. Specifically scores from several validated impairment specific self-report clinical tools (referred to as impairment specific tools) (Fig. 1) were compared in individuals post-mTBI and healthy controls. We hypothesised that scores from these impairment specific tools would be elevated (to a clinically relevant level) in a substantial proportion of individuals post-mTBI (Hypothesis 1) compared to healthy controls. We further hypothesised that these elevated scores would also be evident in some individuals who at the time of assessment spontaneously reported themselves to have complete symptom resolution (Hypothesis 2). Another aim of the study was to compare findings from the impairment specific tools to the HIS. It was hypothesised that the impairment specific tools would identify potentially relevant symptoms in a greater proportion of individuals post-mTBI than the HIS (Hypothesis 3).

2. Materials and methods

2.1. Participants

Participants included 62 individuals diagnosed with mTBI and 32 healthy controls aged between 18 and 60 years who had never sustained a mTBI. Participants were recruited via the institutions greater community, social media advertising, and the Emergency Department (ED) of a nearby teaching tertiary hospital. Data collection for this study took place between October 2016 and July 2018.

Participants in the mTBI group were included if they had received a diagnosis of mTBI or concussion from a medical specialist. Specifically, this had to be based on currently recommended diagnostic criteria for mTBI including: Glasgow Coma Scale score of 13–15, Post Traumatic Amnesia < 24 h, and loss of consciousness < 30 min following injury (McCrory et al., 2017; Ruff et al., 2009; Definition of mild trauma, 1993). In the absence of any of these specific criteria, persistent symptoms evident of head injury, such as confusion and disorientation, mental fog, headache, nausea or dizziness, for at least 30 min post-injury had to be present (Ruff et al., 2009) in addition to formal diagnosis of mTBI.

2.2. Exclusion criteria for both groups included

- intra-cranial bleed on computed tomography or magnetic resonance images
- past history of a diagnosed neurological condition (including but not limited to seizures, epilepsy, diagnosed brain tumours or behavioural conditions)
- autonomic nervous system disorders (including cardiac

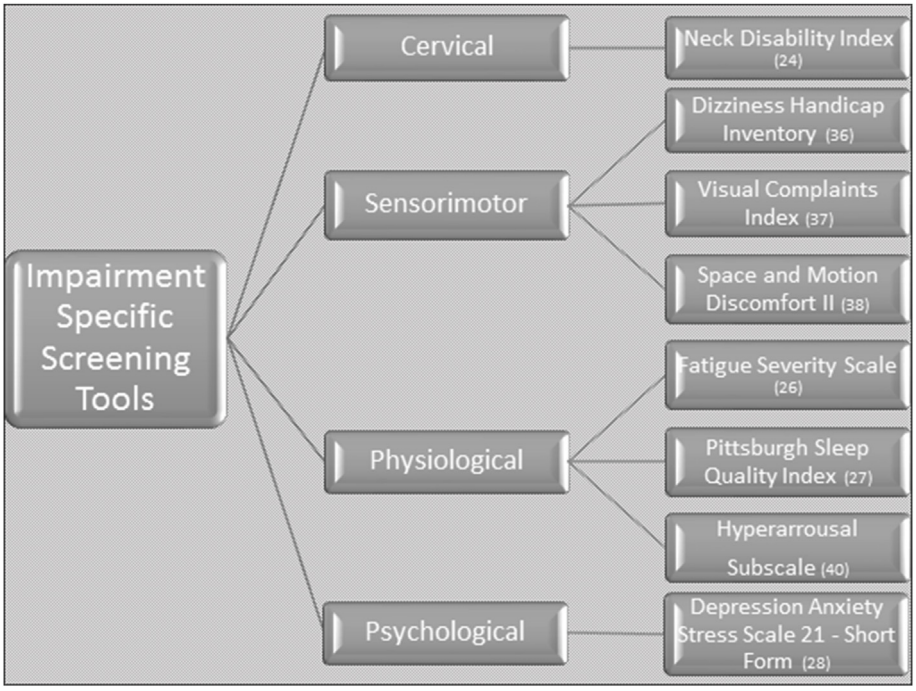

Fig. 1. Impairment specific self-reported clinical tools according to cervical, sensorimotor, physiological and psychological domains.

dysrhythmias and sleep disorders)
- persistent or prior idiopathic or trauma induced neck pain
- vestibular disorders
- concurrent acute orthopaedic conditions
- psychotropic medications use
- history of substance abuse

All participants provided written informed consent before participating. The study received ethical approval from the University of Queensland and Metro South Human Research Ethics Committees (Bellberry HREC 2016-04-311 and HREC/17/QPAH/30).

2.3. Measures

Measures including demographic information and three levels of self-report symptom measures were completed by all participants in the mTBI group 4 weeks to 6 months post-injury, and at a time of convenience for the healthy control group using an online tool (*Checkbox Survey Inc.*).

2.4. Demographic measures

Demographic measures were utilised for descriptive purposes and to pre-evaluate group comparability. All participants reported age, gender, and activity level (measured by the International Physical Activity Questionnaire short form (Craig et al., 2003)). Participants in the mTBI group also reported mechanism of their current mTBI, as well as total number of diagnosed mTBI's (including current).

2.5. Spontaneous self-reported symptoms measure

A spontaneous self-reported symptom measure was taken at the time of assessment for participants in the mTBI group prior to the other self-reported symptom measures for the purposes of subgrouping to either the symptomatic or asymptomatic mTBI groups. Grouping was based on individual responses (yes/no) to the question “Are you continuing to experience symptoms in relation to your most recent concussion?” The term concussion was used instead of “mild traumatic brain injury” since it is more widely utilised and understood with respect to the clinical manifestations of mTBI.

2.6. Standard self-reported symptoms measure

The *Head Impact Scale (9- items)* (Piland et al., 2003) was included as a standard post-concussion self-reported symptom measure. This tool lists commonly reported post-concussion symptoms and contains separate subscales for frequency (hours per day) and severity. Scores range from 0 to 6 with increasing frequency or severity indicated by higher scores then summed to provide a cumulative score for each scale. The HIS was selected based on its higher psychometric properties when compared to other available tools (Alla et al., 2009). In the absence of a published threshold, we used the averaged score of the frequency (3.87/54) and severity (4.96/54) subscales previously reported in healthy individuals (Piland et al., 2010) as a clinically relevant score (> 4) for the HIS.

2.7. Impairment specific self-report clinical tools

The following impairment specific tools were used to quantify impairments within specific system domains (Fig. 1) previously identified to potentially demonstrate impairment post mTBI (eg. sensorimotor, musculoskeletal, physiological, psychological) based on their established validity (Vernon and Mior, 1991; Krupp et al., 1989; Buysse et al., 1989; Lovibond and Lovibond, 1995; Tesio et al., 1999; Treleaven and Takasaki, 2014; Jacob et al., 1993; Ritchie et al., 2013; Foa et al., 1997; Antony et al., 1998).

The Neck Disability Index: comprised of 10 items examining neck pain related functional limitations (Vernon and Mior, 1991). Each item has 6 separate responses related to an activity. Scores are assigned between 0 and 5 and an overall possible score of 50, expressed as a percentage. A score of $> 10\%$ indicates significant impairment and was used as the clinically relevant threshold in this study (Vernon and Mior, 1991).

The Dizziness Handicap Inventory short form (DHI-13): a shortened version (Tesio et al., 1999) of the original 25 item checklist (42), explores the effects of eye and head, or full body motion as well as mood on dizziness related impairment. Recommended conversion of the final score (out of 13) to a value out of 100 is performed (Tesio et al., 1999), so that higher values represent increasing handicap and the threshold of 16/100 for mild impairment can be applied as clinically relevant (Jacobson and Newman, 1990).

Visual Complaint Index: consists of 16 visual symptoms with options to rate frequency and severity on 3 and 4 point rating scales respectively (Treleaven and Takasaki, 2014). Scores for each item are then multiplied and added overall to achieve a score out of 164. A mean score of 27.4 previously identified in individuals with neck pain (Treleaven and Takasaki, 2014) was used to identify clinically relevant vision related complaints.

Space and Motion Discomfort II (SMD II): a 9-item index of space and motion discomfort (Jacob et al., 1993) aids in identify individuals with situational vertigo due to vestibular impairment. Scores for each item (0–3 rating scale) are multiplied by a factor of 10 and summed for cumulative score. A mean total score of 82.4/270 previously recorded in a vestibular population (Jacob et al., 1993) was the nominated clinically relevant threshold.

The Hyperarousal Subscale: a measure of arousal, forms one of three subscales in the symptom component of the Posttraumatic Diagnostic Scale (Foa et al., 1997). Each of the five subscale items are scored with respect to frequency using a 4-point scale (McCarthy, 2008) and summed. A value of 6/15, predictive of poor long-term outcome following whiplash (Ritchie et al., 2013) was selected as the clinically relevant threshold. While this is traditionally used as a psychological measure of stress related to injury, it could potentially be indicative of ANS dysfunction post mTBI (Cohen et al., 2000).

Fatigue Severity Scale (FSS): a 9-item questionnaire for measurement of disabling fatigue over the previous week requires responders to rate agreement with various statements on a 7-point Likert scale. Item scores are summed, then divided by nine for a final score out of 7. Scores of > 4.7 was selected as the clinically relevant threshold since this has previously been reported in patient groups with known susceptibility to fatigue (Krupp et al., 1989).

Pittsburgh Sleep Quality Index (PSQI): a measure of sleep quality over the previous month (Buysse et al., 1989), consists of 19 items scored individually and further grouped into 7 equally weighted component scores. The global score/21 is the summed result of all component scores. A score of > 5 has been found to exhibit 84.4% specificity when used to identify clinically relevant poor sleep (Buysse et al., 1989).

Depression, Anxiety and Stress Scale short form (DASS-21): a 21 item abbreviated form of the 45 item DASS (Lovibond and Lovibond, 1995) consists of three individual subscales scored independently to measure dimensions of depression and anxiety as well as physical arousal (Antony et al., 1998). Each item is scored on a 4-point scale and symptom cluster scores for depression, anxiety or stress are summed to give an overall value for each disorder. Minimal clinically relevant scores are 9, 7 and 14 for depression, anxiety and stress respectively (Lovibond et al., 1995; Henry and Crawford, 2005).

2.8. Statistics

All data were analysed using the statistic software SPSS (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.). Data were grouped via the spontaneous self-reported

symptom measure response into symptomatic mTBI, asymptomatic mTBI, and healthy control (HC) groups.

Group Comparisons (Hypotheses 1 and 2) - Group data were analysed for descriptive and comparative purposes. Group comparisons were undertaken by exploring central tendency of the recorded scores as well as dichotomising individual scores based on clinically relevant thresholds.

A Shapiro-Wilk test investigated distribution of data overall and by group. One-way between-groups ANOVA identified demographic differences between groups where data was normally distributed. Non-normally distributed data was analysed using the Kruskal-Wallis test with Bonferroni correction for type-1 error (*a priori* sig. value $p < 0.05$). Post-hoc analysis using Spearman's Rho Correlation identified any relationships between; 1/IPAQ scores and self-reported symptoms, and 2/total number of concussions and attainment of one or more impairment specific tools reaching clinically relevant thresholds.

Individual scores for both the HIS and the 8 individual impairment specific tools were dichotomised as either clinically relevant (=1) or not clinically relevant (=0). For each participant, overall evidence of clinical impairment (i.e. at least one score was clinically relevant) was also rated as present (=1) or absent (=0). Fishers Exact Test was used to identify significant proportional differences between groups of individuals scoring clinically relevant thresholds on one or more impairment specific tool, or the HIS.

Comparison of Standard and Impairment Specific Tools (Hypothesis 3) – Individual cases where scores were clinically relevant for one or more of the impairment specific tools but not for the HIS (and vice versa) were identified. The PSQI measure was not included in this analysis as the proportion of individuals exceeding clinically relevant scores was high in all groups with no proportional difference between healthy controls and asymptomatic mTBI participants ($p = 0.437$).

3. Results

Overall 94 (32 Healthy controls, 29 asymptomatic and 33 symptomatic) participants were included in the current study. Mechanisms of injury for individuals post mTBI included falls (n = 17), motor vehicle accidents (n = 8), sport-related mTBI (n = 28) and being struck in the head by an object (n = 9).

Group Comparisons - There were no age or gender group differences. Despite the symptomatic mTBI group recording significantly less activity levels (IPAQ) than healthy controls ($p = 0.03$) (Table 1), IPAQ scores were not significant correlated with any of the screening tool scores (including the HIS subscales) (Spearman's Rho $\rho < \pm 0.16$, $p > 0.12$). Furthermore the number of prior concussions was not associated with at least one impairment specific tool reaching the clinical threshold ($p = 0.07$).

The symptomatic mTBI group demonstrated significantly elevated scores for all impairment specific tools and HIS subscales compared to healthy controls ($p \leq 0.01$, Table 2) and the asymptomatic mTBI group ($p < 0.05$, with the exception of the DASS-A measure). The asymptomatic mTBI group also reported significantly higher levels of neck pain and disability ($p = 0.03$) and hyperarousal when compared to healthy controls ($p = 0.00$) (Table 2).

Thirty one (94%), 18 (62%), and 4 (13%) individuals in the symptomatic mTBI, asymptomatic mTBI, and healthy control groups respectively, returned scores above the clinically relevant thresholds for one or more of the impairment specific tools. Thirty-two (97%), 10 (34%) and 4 (13%) individuals in the symptomatic mTBI, asymptomatic mTBI, and healthy control groups, respectively, displayed clinically relevant scores for the HIS (Table 3).

The Fishers Exact Test showed that both symptomatic and asymptomatic mTBI groups recorded clinically relevant scores on at least one of the impairment specific tools more frequently than controls, regardless of PSQI results ($P < 0.01$). Additionally the symptomatic group recorded clinically relevant scores more frequently than the asymptomatic group ($p < 0.05$) (Table 4).

Comparison of Standard and Impairment Specific Tools – The 31 individuals in the symptomatic mTBI group who recorded clinically relevant scores for at least one impairment specific tool also scored above clinical threshold for the HIS. Of the 18 individuals in the asymptomatic group scoring above threshold on at least one impairment specific tool, only 8 scored above threshold on the HIS. One individual in the symptomatic group, two in the asymptomatic group and two in the healthy control group recorded clinically relevant scores for the HIS but not for any impairment specific tool.

4. Discussion

Findings support our first study hypothesis of significantly elevated impairment specific symptom scores in those in the subacute phase (both symptomatic and asymptomatic) post-mTBI compared to healthy controls. In particular a substantial proportion of individuals (79% overall) in the mTBI group reported clinically relevant scores on one or more of the impairment specific tools compared to healthy controls (12.5% overall). This large proportion of mTBI cases recording clinically relevant symptom scores attests to the potentially diverse range of persisting impairments in this patient population.

Elevated symptom levels for all sensorimotor and physiological impairment specific tools (as well as the HIS subscales) were identified in the symptomatic mTBI group compared to the asymptomatic mTBI and healthy control groups ($p < 0.00$). Ninety-four percent (31/33) of symptomatic individuals recorded clinically relevant scores on the impairment specific tools indicative of potential underlying impairments. In support of our second hypothesis, 18 (62%) asymptomatic mTBI participants also recorded clinically relevant scores on at least one impairment specific tool. Overall higher levels of neck disability and hyperarousal were observed in the asymptomatic mTBI group compared to the healthy control group ($p < 0.05$). These results indicate that individuals may not recognise the persistence of symptoms post-mTBI. Collectively the findings from the symptomatic and asymptomatic mTBI groups align with previous research reporting persistent physiological and sensorimotor impairment following mTBI (Abaji et al., 2016; Baker and Cinelli, 2014; Parker et al., 2006; Johnson et al.,

Table 1
Characteristics of the Healthy Control (HC), Asymptomatic (Asymp) and Symptomatic (Symp) mild Traumatic Brain Injury (mTBI) groups.

	Group			ANOVA		
	HC (N = 32)	Asymp mTBI (N = 29)	Symp mTBI (N = 33)	p-value (HC*Asymp)	p-value (HC*Symp)	p-value (Asymp*Symp)
Gender (% F)	59%	45%	51%	0.50	0.81	0.86
Age (years)	29.8 (8.9)	30.03 (11.7)	33.70 (14.3)	0.99	0.38	0.45
IPAQ (METs)	3177.4 (1827.8)	5193.2 (4335.8)	5862.8 (936.6)	0.14	**0.03***	0.80
Days Since Injury	NA	80.74 (31.7)	75.67 (41.1)	NA	NA	0.79
No. mTBI	0	1.57 (1.2)	1.45 (0.8)	NA	NA	0.84

Values presented as mean (± SD). Abbreviations: N= Number, F = females, IPAQ= International Physical Activity Questionnaire, METs = Metabolic Equivalent of Task, No. mTBI = Number of diagnosed (including current) mTBI, NA = Not applicable *Sig $p < 0.05$.

Table 2
Comparative data for all of the impairment specific tools and Head Injury Scale (both subscales) for the Healthy Control (HC), Asymptomatic (Asymp) and Symptomatic (Symp) mild Traumatic Brain Injury (mTBI) groups.

Questionnaire	Group			Kruskal-Wallis (adjusted for multiple tests)		
	HC (N = 32)	Asymp mTBI (N = 29)	Symp mTBI N = 33)	p-value (HC*AS)	p-value (HC*SY)	p-value (AS*SY)
Head Injury Scale- F (/54)	0 (0–2.25)	3 (0–6)	14 (9–24)	0.09	**0.00***	**0.00***
Head Injury Scale- S (/54)	0 (0–2.25)	3 (0–6)	12 (8–22)	0.10	**0.00***	**0.00***
Neck Disability Index (%)	0 (0–2)	4 (0–6)	16 (10–24)	**0.03***	**0.00***	**0.00***
Dizziness handicap inventory † (/100)	100 (100-100)	100 (89–100)	62 (51–89)	0.68	**0.00***	**0.00***
SMDII (/27)	0 (0–0)	0 (0–1.11)	5.56 (3.33–10)	0.27	**0.00***	**0.00***
Fatigue Severity Scale (/7)	1.61 (0.97–2.69)	3.11 (1.67–3.89)	4.44 (3.67–5.33)	0.06	**0.00***	**0.00***
Hyper arousal Subscale PDS (/15)	0 (0–0)	2 (1–4)	6 (4–9)	**0.00***	**0.00***	**0.00***
Visual complaints index (/164)	0 (0–2.25)	4 (0–7)	20 (5–34)	0.14	**0.00***	**0.00***
Pittsburgh Sleep Quality Index (/21)	4 (3–6)	5 (3–8)	7 (5–9)	0.69	**0.00***	**0.04***
DASS21_Depression (/42)	0 (0–2)	2 (0–8)	8 (2–16)	0.40	**0.00***	**0.02***
DASS21_Anxiety (/42)	1 (0–4)	4 (0–4)	4 (2–10)	0.41	**0.00***	0.29
DASS21_Stress (/42)	2 (0–6.5)	4 (2–8)	12 (8–18)	0.67	**0.00***	**0.00***

Values presented as median (Q1-Q3). Abbreviations: HC = Healthy Control AS = asymptomatic group, S = symptomatic group, N = number, F = frequency, S = severity, SMD II = Space and Motion Discomfort II, PDS = Posttraumatic Diagnostic Scale, DASS21 = Depression Anxiety and Stress Subscale short form (21 questions) and the respective subscale of this scale, *Sig $p < 0.05$.

Table 3
Number of cases recording clinically relevant scores for the Head Injury Scale (HIS) and the Impairment Specific Tools for each group.

Impairment Specific Tool	Individuals exceeding cut off scores		
	HC (N = 32)	Asymp mTBI (N = 29)	Symp mTBI (N = 33)
Neck Disability Index (> 10/100)	0	6	25
Dizziness Handicap Inventory (> 16/100)	1	5	23
Space and Motion Discomfort II (> 8.2/27)	0	0	14
Visual Complaints Index (> 28/168)	0	0	13
Hyperarrousal subscale PDS (> 6/15)	0	1	19
Fatigue Severity Scale (> 4.7/7)	1	4	14
Pittsburgh Sleep Quality Index (> 5/21)	10	12	23
DASS_Depression Subscale (> 9/54)	3	7	15
DASS_Anxiety Subscale (> 7/54)	0	4	14
DASS_Stress Subscale (> 14/54)	1	4	13
Head Injury Scale > 4	4	10	32
At least 1 Impairment Specific Tool exceeded clinically relevant scores (not incl. PSQI)	4	18	31

Abbreviations: HC = Healthy control group; Asymp mTBI = asymptomatic mTBI group; Symp mTBI = symptomatic mTBI group; PDS= Posttraumatic Diagnostic Scale, DASS = Depression, Anxiety, Stress Scale; No. = number of individual participants; HIS = Head Impact Scale scores above average of 4/54.

2015).

The most frequent findings related to elevated levels of neck pain and disability, dizziness and hyperarousal (Table 2). Fifty percent of individuals post mTBI (76% symptomatic and 21% asymptomatic) reported clinically relevant levels of neck pain and disability, and 45% (70% symptomatic and 17% asymptomatic) reported clinically relevant levels of dizziness associated handicap. These findings are consistent with that of Reneker et al. (2018) (Reneker et al., 2018) who observed evidence of cervical musculoskeletal impairment in 81.6% of mTBI cases, as well as studies associating neck pain and dysfunction with initial injury or long term outcome (Collins et al., 2014; van Der Naalt et al., 2017). Findings also align with previous studies which identify dizziness as a common symptom post mTBI (King et al., 1995; Reneker et al., 2015). These findings now warrant further mechanistic research to identify the impairments associated with these symptoms that may include factors such as vestibular (peripheral or central) (Brandt and Dieterich, 2017; Strupp and Brandt, 2013), and or cervical musculoskeletal or sensorimotor impairments (Treleaven, 2017; Kristjansson and Treleaven, 2009).

Clinically meaningful levels of hyperarrousal were also identified in 58% (19/33 individuals) of the symptomatic mTBI group. Hyperarrousal symptoms were also elevated among asymptomatic individuals ($p < 0.00$), albeit clinically relevant in only one asymptomatic mTBI participant (Table 3). Elevated levels of hyperarousal symptoms may be relevant with regard to observed evidence of altered heart rate variability (HRV) and persistent ANS dysregulation post mTBI (Abaji et al., 2016; Sung et al., 2016; Cohen et al., 2000; Ulmer et al., 2018). Reduced beat-to-beat variability thought to represent altered sympathovagal autonomic balance (Heart rate variability. S, 1996) has been identified in early and late stages (> 4 weeks) post-mTBI (Abaji et al., 2016). While HRV changes have been observed in both symptomatic (Sung et al., 2016; Liao et al., 2016) and asymptomatic individuals (Abaji et al., 2016), no study has investigated the utility of symptom presentation in predicting ANS dysregulation post-mTBI.

Poorer reported sleep quality was also noted for all groups using the PSQI. Notably poorer sleep quality was observed in approximately twice the number of symptomatic (70%) compared to healthy control (32%) or asymptomatic (41%) participants. Multiple previous sleep studies (Zhou et al., 2016; Mollayeva et al., 2017) including those using the PSQI (Zhou et al., 2016; Huang et al., 2015) have identified disturbed sleep patterns post mTBI. However, similar to findings in this current study, a high proportion of reported poor sleep quality has also been found among healthy individuals (Huang et al., 2015) indicating that impaired sleep quality may or may not be a useful indicator of recovery post-mTBI. Nevertheless, further investigation of the

Table 4
Proportional group differences of clinically relevant scores for one or more impairment specific tools or for the HIS.

	Group			Exact Sig. (2-Sided)		
	HC (N = 32)	Asymp mTBI (N = 29)	Symp mTBI (N = 33)	p-value (HC*AS)	p-value (HC*SY)	p-value (AS*SY)
> 1 Impairment specific tool exceeded clinical thresholds (PSQI excluded)	4	18	31	0.00*	0.00*	0.00*
> 1 Impairment specific tool exceeded clinical thresholds (PSQI included)	11	22	31	0.01*	0.00*	0.03*
HIS > 4	4	10	32	0.07	0.00	0.00

Abbreviations: Sig. = Significance, HC = Healthy Control group, Asymp mTBI/AS = asymptomatic mTBI group, Symp mTBI/SY = symptomatic mTBI group, N = number, PSQI = Pittsburgh Sleep Quality Index, *Sig $p < 0.05$.

relationship between sleep and specific impairments post-mTBI is warranted given the impact of sleep quality on health and recovery following TBI (Duclos et al., 2017).

The findings suggest that for some individuals, standard self-report symptom scales such as the HIS may be inadequate to detect potentially relevant symptoms post-mTBI. In the 18 asymptomatic participants in this study recording clinically relevant scores on impairment specific tools (NDI, hyperarousal, DHI, FSS, and DASS-21 depression), only 8 of these individuals attained clinically relevant scores using the HIS. Similar findings were also reported by Leddy et al. (2015) whose retrospective analysis demonstrated that no individual self-report symptom, or symptom cluster from a standard self-report symptom scale, could accurately subgroup individuals according to their physiologic, vestibular or cervical impairments. Hence, items in standard self-reported symptom scales (such as the HIS) may be too limited to identify those with potentially ongoing impairments. Given the elevated risk of injury recurrence (Zemper, 2003; Guskiewicz et al., 2003) and serious ramifications of repeated injury (Moser and Schatz, 2002; Stein et al., 2015), further prospective investigation as to appropriateness of these commonly used standard self-reported symptom scales to infer recovery post mTBI is warranted. This is particularly relevant given the absence of questions related to factors such as neck pain and disability in any of the widely used self-reported symptoms scales (Lovell et al., 2006; King et al., 1995; Randolph et al., 2009; Lovell and Collins, 1998) with the exception of the sport concussion assessment tools used for acute concussion assessment (Echemendia et al., 2017; Davis et al., 2017).

From a clinical perspective the diverse nature of symptoms identified in this study demonstrates the need for differential examination and diagnosis post-mTBI (Barlow, 2016). Results suggest multiple impairments may manifest post-mTBI. It is plausible that cervical spine or vestibular impairments, even in those reportedly symptom-free, may be present and should be routinely investigated post-injury with a view to secondary prevention (Collins et al., 2014). Additionally hyperarousal following mTBI can be a factor to consider given the well-documented relationship between these symptoms and HRV changes (Dennis et al., 2017; Green et al., 2016).

4.1. Limitations

Scores derived from the impairment specific tools used in this study can only infer potential of underlying physical impairment; they are not diagnostic of impairment. Therefore, findings need to be taken in light of the need for further research to explore relationships between persisting symptoms and physical impairments. Additionally, since study inception a tool specifically for brain injury related vision symptoms has been developed (Laukkanen et al., 2017). Thus, use of this tool may have identified differing results respecting presence of vision related symptoms, particularly among asymptomatic individuals. Furthermore, only the HIS was used in this study and therefore the utility of other self-reported symptoms scales remains unknown. Potentially other self-reported symptom scales may demonstrate better capacity to stratify individuals into asymptomatic or symptomatic subgroups. Nevertheless, given the high prevalence of neck pain and disability in the current study and the absence of questions specifically related to the neck in standard self-reported symptom scales commonly used, it is not unreasonable to conclude that results may have been similar had a different scale been used.

5. Conclusion

A diverse range of symptoms potentially indicative of persisting impairments (eg. cervical, vestibular, physiological) may be present in individuals following mTBI beyond expected recovery time. Symptoms may also be present in individuals who overall consider themselves symptom-free. Potentially generic self-reported symptom scales may

not detect symptoms in these apparently asymptomatic individuals, questioning their appropriateness in determining recovery and ability to return to activity post-mTBI. Studies exploring the relationships between symptoms and system impairments in this patient group is urgently needed. Findings suggest that decisions regarding recovery and return to activity following mTBI require differential examination that considers several factors including potential impairment of the cervical spine.

Conflicts of interest

None declared.

Ethical approval

University of Queensland and Metro South Health Human Research Ethics Committees (Bellberry HREC 2016-04-311 and HREC/17/QPAH/30).

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Appendix A. Supplementary data

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References

Abaji, J.P., Curnier, D., Moore, R.D., Ellemberg, D., 2016. Persisting effects of concussion on heart rate variability during physical exertion. J. Neurotrauma 33 (9), 811–817.
Alla, S., Sullivan, S.J., Hale, L., McCrory, P., 2009. Self-report scales/checklists for the measurement of concussion symptoms: a systematic review. Br. J. Sports Med. 43 (Suppl. 1), i3–i12.
Antony, M.M., Bieling, P.J., Cox, B.J., Enns, M.W., Swinson, R.P., 1998. Psychometric properties of the 42-item and 21-item versions of the depression anxiety stress scales in clinical groups and a community sample. Psychol. Assess. 10 (2), 176–181.
Baker, C.S., Cinelli, M.E., 2014. Visuomotor deficits during locomotion in previously concussed athletes 30 or more days following return to play. Physiol. Rep. 2 (12).
Barlow, K.M., 2016. Postconcussion syndrome: a review. J. Child Neurol. 31 (1), 57–67.
Brandt, T., Dieterich, M., 2017. The dizzy patient: don't forget disorders of the central vestibular system. Nat. Rev. Neurol. 13 (6), 352–362.
Broglio, S.P., Kontos, A.P., Levin, H., Schneider, K., Wilde, E.A., Cantu, R.C., et al., 2018. The national institute of neurological disorders and stroke and department of defense sport-related concussion common data elements version 1.0 recommendations. J. Neurotrauma 35 (23), 2776–2783.
Buysse, D.J., Reynolds 3rd, C.F., Monk, T.H., Berman, S.R., Kupfer, D.J., 1989. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatr. Res. 28 (2), 193–213.
Catena, R.D., van Donkelaar, P., Chou, L.S., 2009. Different gait tasks distinguish immediate vs. long-term effects of concussion on balance control. J. NeuroEng. Rehabil. 6, 25.
Cohen, H., Benjamin, J., Geva, A.B., Matar, M.A., Kaplan, Z., Kotler, M., 2000. Autonomic dysregulation in panic disorder and in post-traumatic stress disorder: application of power spectrum analysis of heart rate variability at rest and in response to recollection of trauma or panic attacks. Psychiatr. Res. 96 (1), 1–13.
Collins, C.L., Fletcher, E.N., Fields, S.K., Kluchurosky, L., Rohrkemper, M.K., Comstock, R.D., et al., 2014. Neck strength: a protective factor reducing risk for concussion in high school sports. J. Prim. Prev. 35 (5), 309–319.
Craig, C.L., Marshall, A.L., Sjostrom, M., Bauman, A.E., Booth, M.L., Ainsworth, B.E., et al., 2003. International physical activity questionnaire: 12-country reliability and validity. Med. Sci. Sports Exerc. 35 (8), 1381–1395.
Dahm, J., Wong, D., Ponsford, J., 2013. Validity of the Depression Anxiety Stress Scales in assessing depression and anxiety following traumatic brain injury. J. Affect. Disord. 151 (1), 392–396.
Davis, G.A., Purcell, L., Schneider, K.J., Yeates, K.O., Gioia, G.A., Anderson, V., et al., 2017. The child sport concussion assessment tool 5th edition (child SCAT5): background and rationale. Br. J. Sports Med. 51 (11), 859–861.
Definition of mild traumatic brain injury. J. Head Trauma Rehabil. 8 (3), 86.
Dennis, P.A., Kimbrel, N.A., Sherwood, A., Calhoun, P.S., Watkins, L.L., Dennis, M.F., et al., 2017. Trauma and autonomic dysregulation: episodic-versus systemic-negative affect underlying cardiovascular risk in posttraumatic stress disorder. Psychosom. Med. 79 (5), 496–505.
DSM-IV, 1994. Proposed Criteria for Postconcussive Disorder.
Duclos, C., Dumont, M., Arbour, C., Paquet, J., Blais, H., Menon, D.K., et al., 2017. Parallel recovery of consciousness and sleep in acute traumatic brain injury. Neurology 88 (3), 268–275.
Echemendia, R.J., Meeuwisse, W., McCrory, P., Davis, G.A., Putukian, M., Leddy, J., et al., 2017. The sport concussion assessment tool 5th edition (SCAT5): background and rationale. Br. J. Sports Med. 51 (11), 848–850.
Elliott, J.E., Opel, R.A., Weymann, K.B., Chau, A.Q., Papesh, M.A., Callahan, M.L., et al., 2018. Sleep disturbances in traumatic brain injury: associations with sensory sensitivity. J. Clin. Sleep Med. JCSM Offic. Publ. Am. Acad. Sleep Med. 14 (7), 1177–1186.
Foa, E.B., Cashman, L., Jaycox, L., Perry, K., 1997. The validation of a self-report measure of posttraumatic stress disorder: the Posttraumatic Diagnostic Scale. Psychol. Assess. 9 (4), 445–451.
Galea, O.A., Cottrell, M.A., Treleaven, J.M., O'Leary, S.P., 2018. Sensorimotor and physiological indicators of impairment in mild traumatic brain injury: a meta-analysis. Neurorehabilitation Neural Repair 32 (2), 115–128.
Giza, C.C., Kutcher, J.S., Ashwal, S., Barth, J., Getchius, T.S., Gioia, G.A., et al., 2013. Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the Guideline Development Subcommittee of the American Academy of Neurology. Neurology 80 (24), 2250–2257.
Green, K.T., Dennis, P.A., Neal, L.C., Hobkirk, A.L., Hicks, T.A., Watkins, L.L., et al., 2016. Exploring the relationship between posttraumatic stress disorder symptoms and momentary heart rate variability. J. Psychosom. Res. 82, 31–34.
Guskiewicz, K.M., McCrea, M., Marshall, S.W., Cantu, R.C., Randolph, C., Barr, W., et al., 2003. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA concussion study. J. Am. Med. Assoc. 290 (19), 2549–2555.
Harmon, K.G., Drezner, J.A., Gammons, M., Guskiewicz, K.M., Halstead, M., Herring, S.A., et al., 2013. American Medical Society for Sports Medicine position statement: concussion in sport. Br. J. Sports Med. 47 (1), 15–26.
Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task force of the European Society of Cardiology and the North American society of pacing and electrophysiology. Eur. Heart J. 17 (3), 354–381.
Henry, J.D., Crawford, J.R., 2005. The short-form version of the Depression Anxiety Stress Scales (DASS-21): construct validity and normative data in a large non-clinical sample. Br. J. Clin. Psychol. 44 (Pt 2), 227–239.
Huang, T.Y., Ma, H.P., Tsai, S.H., Chiang, Y.H., Hu, C.J., Ou, J., 2015. Sleep duration and sleep quality following acute mild traumatic brain injury: a propensity score analysis. Behav. Neurol. 2015.
Jacob, R.G., Woody, S.R., Clark, D.B., Lilienfeld, S.O., Hirsch, B.E., Kucera, G.D., et al., 1993. Discomfort with space and motion: a possible marker of vestibular dysfunction assessed by the situational characteristics questionnaire. J. Psychopathol. Behav. Assess. 15 (4), 299–324.
Jacobson, G.P., Newman, C.W., 1990. The development of the dizziness handicap inventory. Arch. Otolaryngol. Head Neck Surg. 116 (4), 424–427.
Johnson, B., Hallett, M., Slobounov, S., 2015. Follow-up evaluation of oculomotor performance with fMRI in the subacute phase of concussion. Neurology 85 (13), 1163–1166.
Kamins, J., Bigler, E., Covassin, T., Henry, L., Kemp, S., Leddy, J.J., et al., 2017. What is the physiological time to recovery after concussion? A systematic review. Br. J. Sports Med. 51 (12), 935–940.
King, N.S., Crawford, S., Wenden, F.J., Moss, N.E., Wade, D.T., 1995. The Rivermead Post Concussion Symptoms Questionnaire: a measure of symptoms commonly experienced after head injury and its reliability. J. Neurol. 242 (9), 587–592.
Kristjansson, E., Treleaven, J., 2009. Sensorimotor function and dizziness in neck pain: implications for assessment and management. J. Orthop. Sports Phys. Ther. 39 (5), 364–377.
Krupp, L.B., LaRocca, N.G., Muir-Nash, J., Steinberg, A.D., 1989. The fatigue severity scale. Application to patients with multiple sclerosis and systemic lupus erythematosus. Arch. Neurol. 46 (10), 1121–1123.
Laukkanen, H., Scheiman, M., Hayes, J.R., 2017. Brain injury vision symptom Survey (BIVSS) questionnaire. Optom. Vis. Sci. Offic. Publ. Am. Acad. Optom. 94 (1), 43–50.
Leddy, J.J., Baker, J.G., Merchant, A., Picano, J., Gaile, D., Matuszak, J., et al., 2015. Brain or strain? Symptoms alone do not distinguish physiologic concussion from cervical/vestibular injury. Clin. J. Sport Med. Offic. J. Can. Acad. Sport Med. 25 (3), 237–242.
Liao, K.H., Sung, C.W., Chu, S.F., Chiu, W.T., Chiang, Y.H., Hoffer, B., et al., 2016. Reduced power spectra of heart rate variability are correlated with anxiety in patients with mild traumatic brain injury. Psychiatr. Res. 243, 349–356.
Lovell, M.R., Collins, M.W., 1998. Neuropsychological assessment of the college football player. J. Head Trauma Rehabil. 13 (2), 9–26.
Lovell, M.R., Iverson, G.L., Collins, M.W., Podell, K., Johnston, K.M., Pardini, D., et al., 2006. Measurement of symptoms following sports-related concussion: reliability and normative data for the post-concussion scale. Appl. Neuropsychol. 13 (3), 166–174.
Lovibond, P.F., Lovibond, S.H., 1995. The structure of negative emotional states: comparison of the depression anxiety stress scales (DASS) with the beck depression and anxiety inventories. Behav. Res. Ther. 33 (3), 335–343.
Lovibond, S.H., Lovibond, P.F., Psychology Foundation of, A., 1995. Manual for the Depression Anxiety Stress Scales. Psychology Foundation of Australia, Sydney,

N.S.W.
Marshall, S., Bayley, M., McCullagh, S., Velikonja, D., Berrigan, L., Ouchterlony, D., et al., 2015. Updated clinical practice guidelines for concussion/mild traumatic brain injury and persistent symptoms. Brain Inj. 29 (6), 688–700.
McCarthy, S., 2008. Post-traumatic stress diagnostic scale (PDS). Occup. Med. 58 (5), 379.
McCrory, P., Meeuwisse, W., Dvorak, J., Aubry, M., Bailes, J., Broglio, S., et al., 2017. Consensus statement on concussion in sport-the 5th international conference on concussion in sport held in Berlin, October 2016. Br. J. Sports Med. 51 (11), 838–847.
McDevitt, J., Appiah-Kubi, K.O., Tierney, R., Wright, W.G., 2016. Vestibular and oculomotor assessments may increase accuracy of subacute concussion assessment. Int. J. Sports Med. 37 (9), 738–747.
Mollayeva, T., Colantonio, A., Cassidy, J.D., Vernich, L., Moineddin, R., Shapiro, C.M., 2017. Sleep stage distribution in persons with mild traumatic brain injury: a polysomnographic study according to American Academy of Sleep Medicine standards. Sleep Med. 34, 179–192.
Moser, R.S., Schatz, P., 2002. Enduring effects of concussion in youth athletes. Arch. Clin. Neuropsychol. 17 (1), 91–100.
Parker, T.M., Osternig, L.R., VAND, P., Chou, L.S., 2006. Gait stability following concussion. Med. Sci. Sports Exerc. 38 (6), 1032–1040.
Piland, S.G., Motl, R.W., Ferrara, M.S., Peterson, C.L., 2003. Evidence for the factorial and construct validity of a self-report concussion symptoms scale. J. Athl. Train. 38 (2), 104–112.
Piland, S.G., Ferrara, M.S., Macciocchi, S.N., Broglio, S.P., Gould, T.E., 2010. Investigation of baseline self-report concussion symptom scores. J. Athl. Train. 45 (3), 273–278.
Ponsford, J.L., Sinclair, K.L., 2014. Sleep and fatigue following traumatic brain injury. Psychiatr. Clin. N. Am. 37 (1), 77–89.
Randolph, C., Millis, S., Barr, W.B., McCrea, M., Guskiewicz, K.M., Hammeke, T.A., et al., 2009. Concussion symptom inventory: an empirically derived scale for monitoring resolution of symptoms following sport-related concussion. Arch. Clin. Neuropsychol. 24 (3), 219–229.
Reneker, J.C., Cheruvu, V., Yang, J., Cook, C.E., James, M.A., Moughiman, M.C., et al., 2015. Differential diagnosis of dizziness after a sports-related concussion based on descriptors and triggers: an observational study. Injury Epidemiol. 2 (1), 22.
Reneker, J.C., Cheruvu, V.K., Yang, J., James, M.A., Cook, C.E., 2018. Physical examination of dizziness in athletes after a concussion: a descriptive study. Musculoskel. Sci. Pract. 34, 8–13.
Ritchie, C., Hendrikz, J., Kenardy, J., Sterling, M., 2013. Derivation of a clinical prediction rule to identify both chronic moderate/severe disability and full recovery following whiplash injury. Pain 154 (10), 2198–2206.
Ruff, R.M., Iverson, G.L., Barth, J.T., Bush, S.S., Broshek, D.K., 2009. Recommendations for diagnosing a mild traumatic brain injury: a National Academy of Neuropsychology education paper. Arch. Clin. Neuropsychol. 24 (1), 3–10.
Stein, T.D., Alvarez, V.E., McKee, A.C., 2015. Concussion in chronic traumatic encephalopathy. Curr. Pain Headache Rep. 19 (10), 47.
Strupp, M., Brandt, T., 2013. Peripheral vestibular disorders. Curr. Opin. Neurol. 26 (1), 81–89.
Sung, C.-W., Chen, K.-Y., Chiang, Y.-H., Chiu, W.-T., Ou, J.-C., Lee, H.-C., et al., 2016. Heart rate variability and serum level of insulin-like growth factor-1 are correlated with symptoms of emotional disorders in patients suffering a mild traumatic brain injury. Clin. Neurophysiol. 127 (2), 1629–1638.
Tesio, L., Alpini, D., Cesarani, A., Perucca, L., 1999. Short form of the dizziness handicap inventory: construction and validation through rasch analysis. Am. J. Phys. Med. Rehabil. Assoc. Acad. Physiatr. 78 (3), 233–241.
Treleaven, J., 2017. Dizziness, unsteadiness, visual disturbances, and sensorimotor control in traumatic neck pain. J. Orthop. Sports Phys. Ther. 47 (7), 492–502.
Treleaven, J., Takasaki, H., 2014. Characteristics of visual disturbances reported by subjects with neck pain. Man. Ther. 19 (3), 203–207.
Ulmer, C.S., Hall, M.H., Dennis, P.A., Beckham, J.C., Germain, A., 2018. Posttraumatic stress disorder diagnosis is associated with reduced parasympathetic activity during sleep in US veterans and military service members of the Iraq and Afghanistan wars. Sleep 41 (12).
van Der Naalt, J., Timmerman, M.E., de Koning, M.E., van Der Horn, H.J., Scheenen, M.E., Jacobs, B., et al., 2017. Early predictors of outcome after mild traumatic brain injury (UPFRONT): an observational cohort study. Lancet Neurol. 16 (7), 532–540.
Vernon, H., Mior, S., 1991. The Neck Disability Index: a study of reliability and validity. J. Manipulative Physiol. Therapeut. 14 (7), 409–415.
World Health O, 1992. The ICD-10 Classification of Mental and Behavioural Disorders: Clinical Descriptions and Diagnostic Guidelines. World Health Organization, Geneva.
Wright, W.G., Tierney, R.T., McDevitt, J., 2017. Visual-vestibular processing deficits in mild traumatic brain injury. J. Vestib. Res. Equilib. Orientat. 27 (1), 27–37.
Young, Ia Pt D., Dunning, J.Pt DPT., Butts, R.Pt P., Mourad, F.Pt DPT., Cleland, Ja Pt P., 2018. Reliability, construct validity, and responsiveness of the neck disability index and numeric pain rating scale in patients with mechanical neck pain without upper extremity symptoms. Physiother. Theory Pract. 1–8.
Zemper, E.D., 2003. Two-year prospective study of relative risk of a second cerebral concussion. Am. J. Phys. Med. Rehab. 82 (9), 653–659.
Zhou, D., Zhao, Y., Wan, Y., Wang, Y., Xie, D., Lu, Q., et al., 2016. Neuroendocrine dysfunction and insomniain mild traumatic brain injury patients. Neurosci. Lett. 610, 154–159.