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Do Mild Traumatic Brain Injury Severity Sub-classification Systems Help to Identify People Who Go on to Experience Long-Term Symptoms?

Alice Theadom,[1] Suzanne Barker-Collo,[2] Andrea Greenwood,[2] Priya Parmar,[1] Kelly Jones,[1] Nicola Starkey,[3] Kathryn McPherson[4] and Valery L. Feigin[1], on behalf of the BIONIC Study Group

[1] *National Institute for Stroke and Applied Neurosciences, Faculty of Health and Environmental Studies, Auckland University of Technology, Auckland, New Zealand*
[2] *School of Psychology, University of Auckland, Auckland, New Zealand*
[3] *School of Psychology, University of Waikato, Hamilton, New Zealand*
[4] *Health Research Council of New Zealand, Auckland, New Zealand*

Objective: To identify the systems available to sub-classify mild traumatic brain injury (TBI) and to determine their utility in predicting 1-year outcome.
Methods: A systematic review to identify mild-TBI sub-classification systems was conducted until March 2016. The identified systems were applied to a cohort of $N = 290$ adults who had experienced a mild-TBI, and who had been assessed for post-concussion symptoms 1-year post injury. ANOVAs and regression models were used to determine whether each sub-classification system could distinguish between outcomes and to explore their contribution to explaining variance in post-concussion symptoms 1-year post injury.
Results: Nineteen sub-classification systems for mild-TBI met the inclusion criteria for this review. The Saal (1991) classification system significantly differentiated the experience of post-concussion symptoms in our cohort 1-year post injury ($F = 2.39$, $p = 0.05$). However, the findings did not remain significant following correction for multiple comparisons and inclusion of socio-demographic and contextual factors in the regression model.
Conclusions: Current sub-classification systems fail to explain much of the variance in post-concussion symptoms 1 year following mild-TBI. Further research is needed to identify the factors (including socio-demographic and contextual factors) to determine, who may be at risk of developing persistent post-concussion symptoms.

Keywords: mild traumatic brain injury, concussion, classification, post-concussion symptoms, adults

Introduction

Traumatic brain injury (TBI) is defined by the World Health Organization criteria as an acute brain injury resulting from mechanical energy to the head from external physical forces (Carroll, Cassidy, Holm, Kraus, & Coronado, 2004). There is wide variation in how people recover following mild-TBI (Culotta, Sementilli, Gerold, & Watts, 1996). Some people experience persistent cognitive, psychological and physical difficulties, whilst others appear to recover well, with few remaining

Address for correspondence: Alice Theadom, PhD, National Institute for Stroke and Applied Neurosciences, Faculty of Health and Environmental Studies, Auckland University of Technology, AUT North Shore Campus, AR417, 90 Akoranga Dr, Northcote 0627, Private Bag 92006, Auckland 1142, New Zealand. E-mail: alice.theadom@aut.ac.nz

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symptoms (Cassidy et al., 2004; Iverson, 2005; Lannsjo, Geijerstam, Johansson, Bring, & Borg, 2009; Theadom et al., 2016; Zumstein et al., 2011). Common symptoms, such as headache, fatigue, forgetfulness and poor concentration (Theadom et al., 2016) are referred to as post-concussion symptoms. It has been found that between 27.3% and 47.9% of people experience four or more symptoms 1 year after a mild-TBI (Røe, Sveen, Alvsåker, & Bautz-Holter, 2009; Scheenen et al., 2017; Theadom et al., 2016).

To reduce the on-going burden of persistent symptoms, guidelines for the acute treatment of mild-TBI (Marshall et al., 2015) highlight the importance of giving patients information on symptom management and gradual return to activity. Follow up and further treatment is advised for those experiencing persistent symptoms. Consequently, it is important to be able to distinguish between those individuals who are more likely to need clinical treatment to facilitate their recovery and those who can be discharged with advice following a mild-TBI (Andrade et al., 2011; Vos et al., 2002).

Current prognostic models used to predict outcome for moderate and severe TBI do not perform well for mild-TBI (Lingsma et al., 2015). Studies of people experiencing a mild-TBI, who sought medical treatment from hospital post injury, have highlighted that acute symptoms of headache, dizziness and nausea as well as age, pre-existing psychiatric conditions, alcohol intoxication at time of injury and extracranial injuries are the strongest predictors of global functioning after mild-TBI (Jacobs et al., 2010; Lingsma et al., 2015). Additionally, headache, dizziness and nausea on presentation to the emergency department have been associated with post-concussion symptoms (De Kruijk et al., 2002). However, many people experiencing a mild-TBI do not attend hospital (Feigin et al., 2013), and it is not clear if these findings are generalisable across the mild-TBI spectrum (Menon, Schwab, Wright, Maas, & Health, 2010). It is therefore important that the utility of mild-TBI classification systems is explored within a community-based sample.

An ideal severity classification system needs to be easy to implement within a busy clinical environment, capture the full breadth of possible presentations, have high intra- and inter-rater reliability and high predictive validity across outcomes of importance, such as post-concussion symptoms (Hawryluk & Manley, 2015). A number of sub-classification systems for mild-TBI (including sports concussion) have been proposed. However, there is a lack of consensus and evidence regarding, which system should be used and whether the systems have clinical utility within a general community setting (Anderson, Heitger, & MacLeod, 2006; Guskiewicz, 2001). With the move towards the use of precision medicine and an individualised treatment approach, the ability to distinguish between people who have experienced a mild-TBI, who go on to experience persistent symptoms and those who do not is urgently needed. Additionally, understanding likely prognosis and timeframes for recovery have been found to be important to help people understand their injury and facilitate recovery (Buck, Laster, Sagrati, & Kirzner, 2012).

Part 1 of this paper aims to identify the different mild sub-classification systems currently available, while Part 2 aims to apply these mild classification systems to a mild-TBI adult cohort to identify their ability to distinguish between the experiences of post-concussive symptoms 1-year post injury.

PART 1. Identification of sub-classification systems for mild-TBI

Methods

To identify available sub-classification systems for mild-TBI, a systematic review of the literature was conducted. Electronic searches of MEDLINE (1946-present), CINAHL (1937-present), Scopus (1970-present) and Psycinfo (1806-present) were conducted up to March 2016. Searches of reference lists were conducted and individual study data were extracted from a previous review (Anderson et al., 2006). Search terms included 'TBI' OR 'brain injury' OR 'head injury' OR 'concussion' AND 'grad$' OR 'severity system' OR 'severity classification', OR 'scale' AND 'mild'. A total of 4879 abstracts were identified, titles and abstracts were reviewed for relevance and 74 full papers were accessed. Systems were included in this review if they graded mild-TBI into two or more categories, were an independent system (if an updated version of a system was available only the revised system was included in the review) and did not require specialist physical assessment or MRI or CT scans (which would not be feasible to implement in a community setting) (Belanger, Vanderploeg, Curtiss, & Warden, 2007).

Results

A total of 40 systems were identified, 19 met the inclusion criteria for analysis (see Table 1). Of the 22 excluded systems, three were duplicates, one system was a previous version of an included system, five did not sub-classify mild injuries, five required complex tests for classification (e.g., CT and MRI scans or neuropsychological/neurological exami-

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TABLE 1
Description of the Mild TBI Sub-Classification Systems

Classification system	Levels	Criteria
1. Servadei, Teasdale & Merry (2001)	Low	GCS of 15, absence of clinical and neurological findings, skull fracture and risk factors
	Medium	GCS: 15, presence of clinical findings, absence of neurological findings, skull fracture and risk factors
	High	GCS: 14–15, presence/absence of clinical findings, Presence of one of the following; neurological findings, skull fracture or risk factors
2. American Academy of Neurology ANN (1997)*	Grade 1	Transient confusion, no LOC, concussion symptoms or mental status abnormalities resolve in less than 15 minutes
	Grade 2	Transient confusion, no LOC. Concussion symptoms or mental status abnormalities >15 minutes
	Grade 3	Any LOC, either brief (seconds) or prolonged (minutes)
3. Cantu (2001)*	Grade 1	No LOC; PTA <30 minutes
	Grade 2	LOC <1 minute or PTA >30 minutes but <24 hours in duration
	Grade 3	LOC >1 minute or PTA > 24 hours
4. Ruff & Jurica (1999)	Type I	Altered mental state or transient LOC, 1–60 seconds of PTA, one or more neurological symptoms
	Type II	Definite LOC with time unknown or <5 minutes, 60 seconds to 12 hours of PTA, one or more neurological symptoms
	Type III	5-30 minutes of LOC, >12 hours of PTA, one or more neurological symptoms
5. Malec et al. (2007) (Mayo Head Injury Classification System)	Symptomatic (Possible)	No mild or moderate/severe criteria met and one or more of the following symptoms are present: blurred vision, confusion dazed, dizziness, focal neurological symptoms, headache, nausea
	Mild (Probable)	No moderate/severe criteria met and one or more of the following criteria apply: LOC <30 minutes, PTA <24 hours, and depressed, basilar or linear skull fracture (dura intact)
6. Kelly et al. (1991) Colorado Medical Society Grading System for Concussion)*	Grade 1	Confusion without amnesia; no LOC
	Grade 2	Confusion with amnesia; no LOC
	Grade 3	LOC
7. Roberts (1992)*	Bell Ringer	No LOC; no PTA; symptoms <10 minutes
	Grade 1	No LOC; PTA <30 minutes; symptoms >10 minutes
	Grade 2	LOC <5 minutes; PTA >30 minutes
	Grade 3	LOC >5 minutes; PTA >24 hours
8. Jordan & Tsairis (1989)	Grade 1	Confusion without amnesia; no LOC
	Grade 2	Confusion with amnesia <24 hours; no LOC
	Grade 3	LOC with an altered level of consciousness <2 minutes; PTA >24 hours
	Grade 4	LOC with an altered level of consciousness >2 minutes
9. Nelson, Jane, & Gieck (1984)	Grade 0	Head struck or moved rapidly; not stunned or dazed initially; subsequently complains of headache and difficulty concentrating
	Grade 1	Stunned or dazed initially; no LOC or amnesia; sensorium clears <1 minute
	Grade 2	Headache; cloudy sensorium >1 minute; no LOC; may have tinnitus or amnesia; may be irritable, hyperexcitable, confused, or dizzy

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TABLE 1
Continued

Classification system	Levels	Criteria
	Grade 3	LOC <1 minute in duration; no coma demonstrates grade 2 symptoms during recovery
	Grade 4	LOC >1 minute; no coma; demonstrates grade 2 symptoms during recovery
10. Torg (1991)	Grade 1	'Bell rung''; short-term confusion; unsteady gait; dazed appearance; no amnesia
	Grade 2	PTA only; vertigo; no LOC
	Grade 3	Posttraumatic retrograde amnesia; vertigo; no LOC
	Grade 4	Immediate transient LOC
11. Leclerc et al. (2001) (McGill Concussion Grading System)	Grade 1	No LOC, no PTA 1A: No PCS, only seconds of confusion 1B: PCS and/or confusion <15 minutes 1C: PCS and/or confusion >15 minutes
	Grade 2	PTA<30 min and/or LOC <5 minutes
	Grade 3	PTA>30 min and/or LOC >5 minutes
12. Vos et al. (2002) (European Federation of Neurological Societies Task Force Classification of TBI, EFNS)	Category 0	GCS = 15, no LOC, no PTA, no risk factors
	Category 1	GCS = 15, LOC <30 minutes, PTA <1 hour, no risk factors
	Category 2	GCS = 15 and risk factors present
	Category 3	GCS = 13–14, LOC <30 minutes, PTA <1 hour, with or without risk factors present
13. Stein & Spettell (1995) (Head Injury Severity Scale, HISS)	Minimal	GCS = 15, no LOC or amnesia
	Mild	GCS = 14 or 15, LOC <5 minutes or amnesia, impaired alertness or memory
	Moderate	GCS = 9 – 13, LOC ≥ 5 minutes, or focal neurologic deficit
	Severe	GCS = 3 – 8
14. Schneider & Kriss (1973) (Subcommittee on Classification of Sports Injury from the Congress of Neurological Surgeons)*	Grade 1	No LOC, slight confusion, none or very transient memory loss, very rapid recovery
	Grade 2	LOC <5 minutes, momentary confusion, mild retrograde amnesia, complete recovery within 5 minutes
	Grade 3	LOC >5 minutes, confusion >5 minutes, prolonged retrograde amnesia, slow recovery (>5 minutes)
15. Maroon, Steele, & Berlin (1980) (Committee on Head Injury Nomenclature of the congress of neurological surgeons)*	Grade 1:Mild	No LOC
	Grade 2: Moderate	LOC <5 minutes
	Grade 3: Severe	LOC > 5 minutes
16. Wilberger & Maroon (1989)*	Grade 1:Mild	Minimal or no LOC, PTA 15–20 minutes
	Grade 2: Moderate	LOC <5 min, PTA >20 minutes
	Grade 3: Severe	LOC >5 min, PTA >12 hours

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TABLE 1
Continued

Classification system	Levels	Criteria
17. Hugenholtz & Richard (1982)*	Mild	No LOC, PTA ≤1 hour
	Moderate	LOC ≤5minutes, PTA 1–24 hours
	Severe	LOC ≤5 minutes, PTA ≥24 hours
18. Saal (1991)*	Type 1	No LOC, no neurological signs, no amnesia
		Headache, dizziness, balance difficulties (clear quickly), no change in orientation/neurological signs
	Type 2	LOC momentary/seconds, no neurological signs
		No amnesia, headache, balance difficulties
	Type 3A	No or momentary LOC, no neurological signs, amnesia, headache, dizziness, balance difficulties
	Type 3B	LOC minutes, no neurological signs, amnesia resolves quickly, headache, dizziness, nausea no vomiting, balance difficulties resolve <15-30 minutes
	Type 4	LOC 5–10 mins, neurological signs: sluggish pupillary reflexes and vestibular signs, presence of amnesia, headache, vertigo, disorientation, nausea with vomiting, lethargy, balance difficulties
19. Ommaya (1985)	Grade 1	Confusion, no amnesia
	Grade 2	Confusion with amnesia

*Denotes the system was originally developed for use within the sports context.

nations), five provided insufficient details of the system to enable classification of participants, and two were dependent on the exact timing of amnesia (currently only the presence of amnesia is recorded due to many people not seeking treatment for some time after injury). Descriptions of the 19 included systems and their classification criteria are outlined in Table 1. Any criteria referring to moderate or severe injuries (e.g., coma >6 hours) have been omitted here due to the focus on mild-TBI.

On review of the systems outlined in Table 1, it was evident that the systems used different wording for their sub-classification criteria (minimal/mild/moderate or low/medium/high risks or different numerical grade/types). For the purposes of comparison in the analysis, the names were removed and the systems were graded ranging from 1 to 5 from least severe to more severe.

PART 2. Application of mild sub-classification systems to an adult mild-TBI cohort

Methods

Mild-TBI Cohort

A cohort of N=869 adult participants (aged ≥16 years at the time of injury) who had experienced a mild-TBI was extracted from a population-based epidemiological study of incidence of outcomes of TBI (Feigin et al., 2013; Theadom et al., 2012). Within this study, people who had experienced a TBI (both hospitalised and non-hospitalised) across the severity spectrum were identified in the Hamilton (129,249 residents) and Waikato Districts (43,956 residents) in the central North Island of New Zealand over a 12-month period (1st March 2010 to 28th February 2011). All cases were reviewed by neurologists and neuropsychologists to determine eligibility based on the World Health Organization criteria. TBI severity was broadly defined using the Glasgow Coma Scale (GCS, Teasdale & Jennett, 1974) 13–15 and/or Post-Traumatic Amnesia (PTA, Marosszeky, Ryan, Shores, Batchelor, & Marosszeky, 1997) <24 hours; moderate TBI – as GCS 9–12 and/or PTA 1–6 days; and severe TBI – as GCS 8 or less and/or PTA 7 or more days (Carroll et al., 2004). If GCS and PTA severities differed, the more severe category was assigned. If no information on PTA was available, severity was based on the GCS score only. All adult TBI participants classified as mild (including concussion) were extracted for this analysis.

A participant flow diagram outlining the reasons for non-inclusion in this analysis is presented in Figure 1. There were no differences between those who were included in the analysis and those who were not, based on age t=0.06, p=0.95, gender X^2 = 1.85, p=0.17, urban/rural living status

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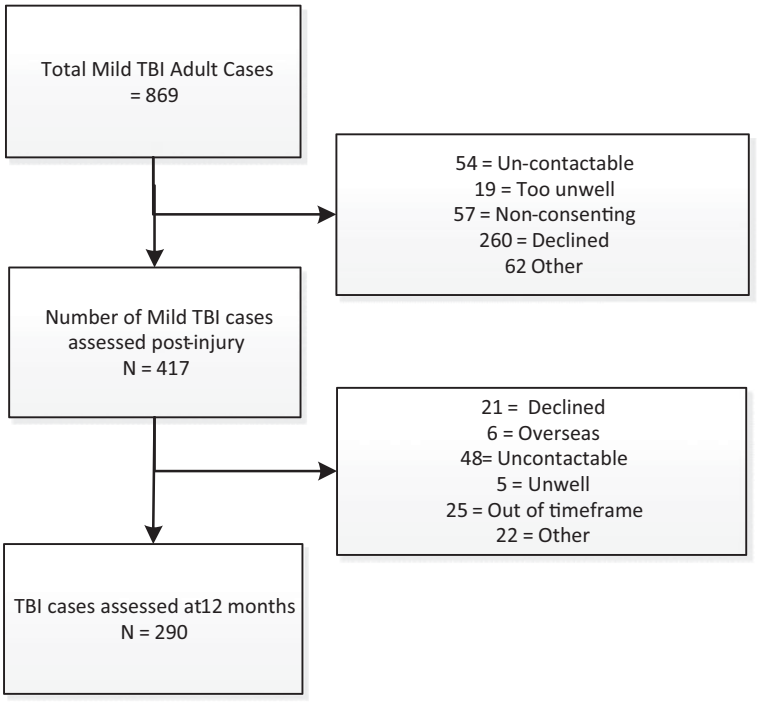


FIGURE 1

Participant flow diagram.

X^2 =1.65, p=0.71 and mechanism of injury X^2 = 1.65, p=0.80. Of the sample, 33% of participants were identified from community-based services or self-referrals and did not attend hospital post injury. Ethical approval was obtained from the Northern Y Health and Disability Ethics Committee of New Zealand (NTY/09/09/095) and the Auckland University of Technology Ethics Committee (09/265). All participants taking part in the study provided written informed consent.

Assessment Procedure

On identification of each participant, details of their injury were obtained from hospital/GP or other clinical records (e.g., physiotherapy). Alternatively, if the participant did not seek medical treatment, information about the injury and acute symptoms experienced was collected from self-report. Each eligible participant was invited to complete follow-up assessments over the year following their injury.

The Rivermead Post Concussion Symptoms Questionnaire (RPQ, King, Crawford, Wenden, Moss, & Wade, 1995) was used to assess the severity and frequency of symptoms commonly experienced after a brain injury. Participants were asked to rate the severity with which they have experienced each symptom over the past 24 hours compared with how severe it was before the injury on a scale of 0 = 'not experienced', 1 = 'no more of a problem', 2 = 'mild problem', 3 = 'moderate problem', 4 = 'severe problem'. A total score was calculated by a sum of all symptom scores. Scores can range from 0 (no change in symptoms since TBI) to 64 (severe post-concussion symptoms). The RPQ has demonstrated good concurrent and predictive validity in people with TBI and sound test–retest reliability (King, Crawford, Wenden, Caldwell, & Wade, 1999; King et al., 1995). Data on the RPQ collected 1-year post injury was extracted for this analysis.

Sub-classification of Mild-TBI Participants

Eligible participants were sub-classified based on the criteria outlined by each of the identified TBI classification systems using data extracted from the medical record or self-reported by the participant. If there was no mention of a particular criterion

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in the data, the sign or symptom was deemed not to have been present and the lowest category was assigned. If a specific criterion was not able to be applied, categorisation was based on all other available information.

Statistical Analysis

A series of univariate ANOVAs were run (one for each classification system) to determine if the different grades of injury led to variation in post-concussive symptoms at 1-year post injury. Each sub-classification system's grades were used as the grouping variable, and the RPQ total score as the dependent variable. Bonferroni correction was applied to account for multiple comparisons. The Bonferroni-corrected p value was 0.05/19 tests = 0.0026. Adjusted R-Squared values are reported to show how much variation in the RPQ outcome measure was accounted for by each sub-classification system.

Following the identification of the most predictive sub-classification system (as determined by the adjusted R-squared value and p value resulting from the univariate ANOVA), a multivariate hierarchical regression model was employed to determine the contribution of the system to post-concussion symptoms at 1 year. The classification system was entered into the first step of a hierarchical regression analysis to explore the amount of variance explained by the system. In the second step, known prognostic factors of mild-TBI, including age, sex, ethnicity, substance use, extracranial injury, living situation, comorbidities, previous psychiatric disorder and prior TBI, were entered into the model to explore the relative contribution of the model to socio-demographic and contextual factors to outcome.

Results

First, the proportions of mild-TBI participants classified into the different sub-classification system grades are outlined, the results of a series of ANOVAs are then presented to determine whether there were any differences in post-concussion mean scores between the different system grades at 1-year post injury. The results of correlation analysis and multivariate hierarchical regression model are then presented.

Classification of Mild-TBI Participants into System Grades

The proportions of mild-TBI participants classified into the different sub-classification grades are shown in Table 2. Classification varied considerably between different systems. Some sub-classification systems judged the majority of participants' injury severity to fall more in the lower/less severe grade (e.g., Ommaya, Maroon, Wilberger, Hugenholtz and Ruff systems), while others tended to classify our sample in the higher/more severe grades (e.g., Servadei system). Classification using the Maroon, Wilberger and Hugenholtz systems yielded the same results, as they were based only on loss of consciousness and/or PTA and were therefore combined. The system by Scheider yielded similar results, but as the system included other criterion such as confusion and memory loss, this system was retained separately in the analysis. Seventeen (5.9%) participants did not experience any symptoms following their injury (as identified by self-report or medical records) and were therefore unable to be classified by the Malec system. Consequently, an additional category of 'unsymptomatic' was added to capture these participants for this system. The data for post-concussion symptoms were skewed towards the lower end of the scale. Whilst ANOVA results have not been found to be sensitive to moderate deviations from normality, in order to check for the influence of the non-normal distribution of the data, Kruskal–Willis tests were conducted. These analyses revealed comparable findings, with no systems able to significantly distinguish between groups, with the exception of the Saal (1991) system, $\chi^2 = 9.47, p = 0.05$.

Identifying Differences in Post-Concussion Symptoms by System Grade

As outlined in Table 3, only the Saal (1991) system was able to statistically determine a difference in group means for post-concussion symptoms at 1-year post injury. On exploration for points of difference between the Saal (1991) system and the other systems, it was evident that there was a greater focus on the symptoms experienced after the injury and this system included more sub-classification levels. Systems relying on GCS and PTA for the mild-TBI sample revealed low clinical utility in differentiating outcome at 1 year. Following adjustment for multiple comparisons, no system was able to retain the ability to significantly distinguish between post-concussion symptoms at 1 year.

Determining the Individual Contribution of System Variables on Post-Concussion Symptoms

On examining correlations between the criterion highlighted by the Saal (1991) system and post-concussion symptoms (Table 4), it was evident

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TABLE 2
Classification of Sample based on Mild-TBI Sub-classification Systems ($N = 290$)

First Author	Grade 1 *N* (%)	Grade 2 *N* (%)	Grade 3 *N* (%)	Grade 4 *N* (%)	Grade 5 *N* (%)
Servadei	14 (4.8)	29 (10.0)	247 (85.2)		
AAN	33 (11.4)	148 (51.0)	109 (37.6)		
Cantu	171 (59.0)	72 (24.8)	47 (16.2)		
Ruff	180 (62.1)	91 (31.4)	19 (6.6)		
Malec (Mayo)	17 (5.9) (Unsymptomatic, participants not classified by system)	109 (37.6)	164 (56.5)		
Kelly (Colorado)	124 (42.8)	56 (19.3)	110 (37.9)		
Roberts	123 (42.4)	57 (19.7)	90 (31.0)	20 (6.9)	
Jordan	124 (42.8)	56 (19.3)	83 (28.6)	27 (9.3)	
Nelson	42 (14.5)	21 (7.2)	122 (42.1)	1 (0.3)	104 (0.3)
Torg	124 (42.8)	56 (19.3)	110 (37.9)		
Leclerc (McGill)	26 (9.0)	98 (33.8)	147 (50.7)	19 (6.6)	
Vos (EFNS)	13 (4.5)	6 (2.1)	236 (81.4)	35 (12.1)	
Stein (HISS)	164 (56.6)	110 (37.9)	16 (5.5)		
Schenider	163 (56.2)	106 (36.6)	21 (7.2)		
Maroon	180 (62.1)	90 (31.0)	20 (6.9)		
Wilberger	180 (62.1)	90 (31.0)	20 (6.9)		
Hugenholtz	180 (62.1)	90 (31.0)	20 (6.9)		
Saal	70 (24.1)	48 (16.6)	62 (21.4)	90 (31.0)	20 (6.9)
Ommaya	190 (65.5)	100 (34.5)			

that acute symptoms of headaches, dizziness, balance difficulties and nausea/vomiting and impaired hearing were significantly associated with outcomes at 1 year.

Hierarchical regression analyses showed that the Saal (1991) sub-classification system alone predicted 1% of the variance in post-concussion symptoms at 1 year. As can be seen in Table 5, adjusting for all known covariates or predictors that could confound the results the model explained 26% of the variance in post-concussion symptoms at 1-year post injury. The factors contributing most to explaining the variance in post-concussion symptoms were gender, ethnicity, living alone at time of the injury and a prior TBI.

Discussion

This study aimed to identify whether an existing sub-classification system could help to predict outcome following a mild-TBI. There were 19 mild sub-classification systems identified in the search of the literature. Only one system (Saal, 1991) that incorporated loss of consciousness and presence of symptoms, including nausea/vomiting, headache, dizziness and balance difficulties, was able to significantly differentiate post-concussion symptoms 1-year post injury. However, after adjusting for multiple comparisons and following the addition of socio-demographic variables into the regression model, the system no longer remained a significant predictor of outcome. Existing sub-classification systems for mild-TBI revealed poor utility in differentiating outcome 1-year post injury.

The links between acute symptoms of headache, dizziness and nausea on presentation and poorer outcomes identified in this study supports previous findings from hospital-based studies of mild-TBI (De Kruijk et al., 2002). The significant association between balance difficulties and post-concussion symptoms found in this study extends that of previous research and suggests that balance difficulties should also be screened for on medical presentation to assist in outcome prediction. As these symptoms are also included in the RPQ outcome measure, it was expected that significant correlations would be observed. However, it was interesting that the Saal (1991) system's prognostic value, when including these symptoms alongside loss of consciousness as part of its criteria, was low. This suggests that other factors may

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TABLE 3

Sub-classification According to the Different Systems and Utility in Differentiating Experience of Post-concussion Symptoms at 12 Months

	Post-Concussion Symptoms Mean (SD)					ANOVA	
System	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	*F*	*p*
Servadei	13.93 (13.37)	14.76 (13.05)	16.69 (14.36)			0.46	0.64
AAN	16.63 (16.06)	15.72 (145.72)	17.16 (13.98)			0.33	0.72
Cantu	16.09 (14.39)	17.94 (14.15)	14.89 (13.36)			0.73	0.48
Ruff	15.86 (14.33)	16.87 (13.93)	18.63 (14.12)			0.42	0.66
Malec (Mayo)	14.58 (15.09)	16.63 (13.99)	16.40 (14.29			0.15	0.93
Kelly (Colorado)	16.20 (13.79)	15.09 (15.57)	17.17 (13.92)			0.41	0.67
Roberts	16.19 (13.85)	15.66 (15.40)	16.73 (13.95)	17.7 (14.36)		0.13	0.94
Jordan	16.20 (13.79)	15.09 (15.57)	17.17 (14.07)	17.19 (13.71)		0.27	0.85
Nelson	15.74 (14.51)	11.95 (11.16)	16.37 (14.54)	19.00 (0.00)	17.46 (14.18)	0.69	0.60
Torg	16.56 (14.11)	14.75 (14.96)	16.94 (13.88)			0.46	0.63
Leclerc (McGill)	12.77 (12.93)	17.11 (13.93)	16.55 (14.57)	15.89 (14.11)		0.66	0.58
Vos (EFNS)	13.54 (13.83)	16.50 (13.69)	16.81 (14.45)	14.32 (12.55)		0.48	0.70
Stein (HISS)	15.96 (14.59)	16.67 (13.43)	18.40 (15.36)			0.25	0.78
Schenider	15.90 (14.11)	16.90 (14.35)	17.30 (14.19)			0.21	0.81
Maroon/Wilberger/Hugenholtz	15.86 (14.33)	17.06 (13.89)	17.70 (14.36)			0.31	0.74
Saal	12.48 (12.36)	15.63 (13.71)	19.81 (15.97)	17.06 (13.89)	17.07 (14.36)	2.39	0.05
Ommaya	16.76 (14.01)	15.60 (14.51)				0.44	0.51

TABLE 4
Correlations Between Factors Highlighted by the Saal (1991) Classification System and Post-concussion Symptoms at 1 Year

	Symptoms
Loss of consciousness	0.032
Post-traumatic amnesia	0.042
Nausea/vomiting	0.141*
Headache	0.131*
Balance difficulties	0.148*
Dizziness	0.239**
Neurological signs	
Impaired vision	0.124
Impaired speech	0.059
Impaired hearing	0.13*
Weakness	0.068

*$p < 0.05$, **$p < 0.01$

be more important in explaining variance in longer term outcomes.

It was often difficult to apply some sub-classification symptoms to our data, as it was not clear how some criteria were defined. For example, it was not clear exactly what was meant by the terms 'mental status abnormalities', 'focal neurological symptoms' and 'sensorium'. Some criteria, such as hyperexcitability, vacant stare, inability to focus attention, emotionality out of proportion and lack of awareness of surroundings, were also unable to be utilised as they were not routinely collected within the medical record or reported by participants. Additionally, routinely collected data rarely distinguished the presence and duration of retrograde and anterograde amnesia as outlined by several of the included systems making application of the systems challenging. There were also instances, where it was unclear as to whether participants needed to experience all symptoms outlined to be graded at that level, (e.g., within the Saal, 1991 system, dizziness is specified in Type 1 and Type 3, but not Type 2). This may have influenced the lack of statistical significance of the findings. Definitions of the terms used (and examples of what each term does or does not include) within the sub-classification systems would assist in their application.

When considering classification of injuries, there may have been an impact on time of health care seeking and reporting of symptoms (Rapp & Curley, 2012). In some participants, people may have been seen quickly post injury by ambulance personnel, in other cases, people may have seen their GP the following day or several days later, if at all. Consequently, the timing of symptom reporting may need to be taken into account when exploring the utility of sub-classification systems. The RPQ asks people to rate the frequency and severity of symptoms, comparing themselves now with before the accident. This helps in trying to distinguish between symptoms related more directly

TABLE 5
Hierarchical Regression Analyses for Post-concussion Symptoms at 1 Year

				95.0% Confidence Intervals	
Model	Beta	t	Sig.	Lower Bound	Upper Bound
1 (Constant)		5.22	0.00	29.06	64.30
Saal classification system	0.13	2.21	0.03	0.16	2.77
				Adjusted R^2	0.01
2 (Constant)					
Saal classification system	0.13	2.46	0.14	0.28	2.55
Age at time of injury	0.01	0.09	0.93	−0.10	0.11
Sex	0.22	3.85	0.000*	3.04	9.40
Ethnicity	0.17	3.17	0.002*	1.91	8.18
Substance use	0.07	1.27.56	0.21	−1.26	5.82
Extracranial injury	0.04	0.72	0.47	−2.08	4.46
Living status	−0.23	−4.03	0.000*	−5.56	−1.91
Comorbidity	0.13	2.12	0.04	0.28	7.95
Prior psychiatric disorder	0.13	1.52	0.04	0.28	7.95
Prior TBI	0.23	4.26	0.000*	1.42	3.86
				Adjusted R^2	0.26

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to the TBI than those commonly experienced in everyday life. However, there is evidence suggesting that patients report that their pre-injury functioning is better than the average person, suggesting a potential recall bias (Iverson, 2010). With many symptoms being subjective in their nature, there is a need to explore the predictors of increased self-reported symptoms noting the limitations of this approach. What this study has also highlighted is that future research also needs to take into account the timing of symptom reporting to explore if this affects utility of mild sub-classification systems.

As the aim of the study was to predict how well the systems were able to predict the overall symptom experience, and to identify whether some symptoms were more indicative of outcome than others, all RPQ items were analysed as one scale or as individual items. Whilst in line with the original scale proposed by King et al. (1995), it is acknowledged that subsequent research has found little evidence to support a unidimensional structure. Due to inconsistent findings regarding the underlying factor structure of the RPQ measure, there was no clear evidence to support the use of an alternative scoring method for this analysis. Further research across difference TBI severities to confirm the underlying factor structure of the RPQ is needed to inform how the measure should be applied most accurately.

Our results challenge previous findings regarding the utility of the GCS and PTA systems for mild-TBI populations. GCS and PTA were not found to differentiate or correlate with post-concussion symptoms in this sample. Additionally, as many participants sought medical attention in the community in this mild-TBI sample, 42.4% did not have a GCS or PTA recorded. Inclusion of participants who did not seek medical attention and therefore did not have a GCS or PTA recorded was strength of our sample, as sub-classification systems need to be able to be applied to these people who are also at risk of poor outcomes. There can be challenges in determining GCS/LOC and PTA in retrospect, as they can be highly variable over time and the patient needs to be examined by a health care professional to apply them accurately. As GCS and PTA were not routinely collected in the community and were not linked to longer term symptoms in participants where this information was available, whilst they may be useful indicators of outcome from moderate to severe TBI, GCS and PTA may not be useful factors in predicting outcome for mild-TBI.

It was interesting that as the severity grading for each system increased, this did not necessarily equate to increased severity and frequency of post-concussion symptoms experienced at 1 year. For example, in the Saal (1991) classification system the first three grades showed a gradual increase in mean scores as would be expected, but grades 4 and 5 had lower mean symptom scores than grade 3. This may reflect the reliance on accuracy of the timing of loss of consciousness in order to be assigned the higher severity grades (as those without experiencing LOC but where this was not accurately recorded were assigned a lower severity grade). Consequently, the first three grades of the Saal (1991) classification system performed as would be expected from an ordinal scale, but there may be a need to refine grades 4 and 5 specifically, to enhance the performance of this system in predicting outcome.

Whilst many mild sub-classification systems emerged from the need to screen for concussion in sport, it is of note that many sports clinicians have moved away from using brief classification systems in favour of more complex assessments, such as Sports Concussion Assessment Tool or King-Devick tests (Galetta et al., 2011). Both tools include a cognitive assessment, and the SCAT also incorporates an assessment of symptoms, loss of consciousness, GCS and a balance, neck and coordination examination. Whilst such tools are important for assisting health professionals in assessing concussion sustained during a supervised sports activity, such a comprehensive assessment would be difficult to administer within a busy Accident and Emergency clinic and are not designed for use by members of the general public (or require access to the Internet). The Sports Concussion Recognition Tool (McCrory et al., 2013) is useful to assist in identification of concussion in the general population, however, the tool does not provide any mechanism of identifying those who may be more at risk of persistent symptoms in primary or acute care. With the emergence of new technologies, diagnostic approaches, such as diffusion tensor imaging and functional magnetic resonance imaging hold promise for the prediction of post-concussion symptom, following mild-TBI (Studerus-Germann, Thiran, Daducci, & Gautschi, 2016). However, these technologies remain unavailable to many, and therefore it is important to identify factors that can be easily assessed and recorded in both primary (general practice) and secondary (hospital) care as well as by sports coaches and other personnel to help identify those at increased risk of long-term problems, where medical supervision is not available.

Further, the need for mild sub-classification systems is important both for health care planning and for providing information on prognosis to patients. One the most common challenges those affected as well as families and friends experience

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following mild-TBI is understanding, recognising and acknowledging the persistence of their often 'invisible' symptoms (Morris et al., 2005; Saban, Hogan, Hogan, & Pape, 2015). Given the extensive heterogeneity in mild-TBI, it has been highlighted that the term mild-TBI may actually be unhelpful (McMahon et al., 2014; Tellier et al., 1991). A mild-TBI sub-classification system that can accurately predict outcome may assist in providing clarity and enable practitioners to tailor their information to each person to prevent causing unnecessary concern in those at low risk of persistent symptoms, whilst informing those of the possibilities to those at higher risk. A tool that clearly identifies sub-categories may also assist in generating and defining a new term(s) for referring to mild-TBI.

Symptoms of dizziness, nausea/vomiting, headaches and balance difficulties (factors included in the Saal classification system) only explained 1% of the variance of post-concussion symptoms 1-year post injury. Consequently, the findings of this study highlight that these factors need to be considered alongside sociodemographic and injury characteristics to most effectively predict outcome following mild-TBI. A modified sub-classification/prognostic system encompassing both acute symptoms and contextual factors is needed to better predict outcomes following mild-TBI.

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Conflict of Interest

Kathryn McPherson was appointed as the Chief Executive of the Health Research Council in 2015, but was neither in post nor involved in the funding decisions for this study. The authors declare no conflicts of interest.

Ethical Standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

Bionic Study Group Members

Valery Feigin, Alice Theadom, Suzanne Barker-Collo, Kathryn McPherson, Robert Kydd, P. Alan Barber, Varsha Parag, Paul Brown, Nicola Starkey, Anthony Dowell, Michael Kahan, Shanthi Ameratunga, Grant Christey, Kelly Jones, Amy Jones, Natalie Hardaker and Braden Te Ao.

References

American Academy of Neurology (1997). Practice parameter: the management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee. *Neurology, 48*(3), 581–585.

Anderson, T., Heitger, M., & MacLeod, A. D. (2006). Concussion and mild head injury. *Practical Neurology, 6*(6), 342–357.

Andrade, A. F., Paiva, W. S., Soares, M. S., De Amorim, R. L., Tavares, W. M., & Teixeira, M. J. (2011). Classification and management of mild head trauma. *International Journal of General Medicine, 27*(4), 175–179.

Belanger, H. G., Vanderploeg, R. D., Curtiss, G., & Warden, D. L. (2007). Recent neuroimaging techniques in mild traumatic brain injury. *The Journal of Neuropsychiatry and Clinical Neurosciences, 19*(1), 5–20.

Buck, P. W., Laster, R. G., Sagrati, J. S., & Kirzner, R. S. (2012). Working with mild traumatic brain injury: voices from the field. *Rehabilitation Research and Practice*, *Feb 7*, 1–6.

Cantu, R. C. (2001). Posttraumatic retrograde and anterograde amnesia: pathophysiology and implications in grading and safe return to play. *Journal of Athletic Training, 36*(3), 244–248.

Carroll, L. J., Cassidy, J. D., Holm, L., Kraus, J., & Coronado, V. G. (2004). Methodological issues and research recommendations for mild traumatic brain injury: the WHO collaborating centre task force on mild traumatic brain injury. *Journal of Rehabilitation Medicine*, *Feb* (Suppl. 43), 113–125.

Cassidy, J. D., Carroll, L. J., Peloso, P. M., Borg, J., von Holst, H., Holm, L.,... Coronado, V. G. (2004). Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO collaborating centre task force on mild traumatic brain injury. *Journal of Rehabilitation Medicine*, *Feb* (Suppl. 43), 28–60.

https://doi.org/10.1017/BrImp.2017.11 Published online by Cambridge University Press

Culotta, V., Sementilli, M. E., Gerold, K., & Watts, C. C. (1996). Clinicopathological heterogeneity in the classification of mild head injury. *Neurosurgery, 38*(2), 245–250.

De Kruijk, J. R., Leffers, P., Menheere, P. P., Meerhoff, S., Rutten, J., & Twijnstra, A. (2002). Prediction of post-traumatic complaints after mild traumatic brain injury: early symptoms and biochemical markers. *Journal of Neurology, Neurosurgery and Psychiatry, 73*(6), 727–732.

Feigin, V. F., Theadom, A., Barker-Collo, S. L., Starkey, N., McPherson, K., Kahan, M., ... on behalf of the BIONIC Research Group, . (2013). Incidence of traumatic brain injury in New Zealand: a population-based study. *The Lancet Neurology, 12*(1), 53–64.

Galetta, K. M., Barrett, J., Allen, M., Madda, F., Delicata, D., Tennant, A. T., ... Balcer, L. J. (2011). The King-Devick test as a determinant of head trauma and concussion in boxers and MMA fighters. *Neurology, 76*(17), 1456–1462.

Guskiewicz, K. M. (2001). Concussion in sport: the grading-system dilemma. *Athletic Therapy Today, 6*(1), 18–27.

Hawryluk, G. W. J., & Manley, G. T. (2015). *Part 1. Classification of traumatic brain injury: past, present and future*. *Handbook of Clinical Neurology*, In Grafman, J. & Salazar, A.M. Elsevier (Eds.), Vol. 127, pp. 15–21.

Hugenholtz, H., & Richard, M. T. (1982). Return to athletic competition following concussion. *Canadian Medical Association Journal, 127*(9), 827–829.

Iverson, G. L. (2005). Outcome from mild traumatic brain injury. *Current opinion in psychiatry, 18*(3), 301–317.

Iverson, G. L. (2010). Mild traumatic brain injury meta-analyses can obscure individual differences. *Brain Injury, 24*(10), 1246–1255.

Jacobs, B., Beems, T., Stulemeijer, M., van Vugt, A. B., van der Vliet, T. M., Borm, G. F., & Vos, P. E. (2010). Outcome prediction in mild traumatic brain injury: age and clinical variables are stronger predictors than CT abnormalities. *Journal of Neurotrauma, 27*(4), 655–668.

Jordan, B. J., & Tsairis, P. T. (1989). *Sports neurology* (Vol. 227). Gaithersburg, MD: Aspen Publishers.

Kelly, J. P., Nichols, J. S., Filley, C. M., Lillehei, K. O., Rubinstein, D., & Kleinschmidt-DeMasters, B. K. (1991). Concussion in sports: guidelines for the prevention of catastrphic outcome. *Journal of the American Medical Association, 266*(20), 2867–2869.

King, N. S., Crawford, S., Wenden, F. J., Caldwell, F. E., & Wade, D. T. (1999). Early prediction of persisting post-concussion symptoms following mild and moderate head injuries. *British Journal of Clinical Psychology, 38*(1), 15–25.

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. *Journal of Neurology, 242*(9), 587–592.

Lannsjo, M., Geijerstam, J. L., Johansson, U., Bring, J., & Borg, J. (2009). Prevalence and structure of symptoms at 3 months after mild traumatic brain injury in a national cohort. *Brain Injury, 23*(3), 213–219.

Leclerc, S., Lassonde, M., Delaney, S., Lacroix, V. J., & Johnston, K. M. (2001). Recommendations for the grading of concussion in athletes. *Sports Medicine, 31*(8), 629–636.

Lingsma, H., Yue, J. K., Maas, A., Steyerberg, E. W., Manley, G. T. M. D. P. D., Cooper, S. R., ... Yuh, E. L. (2015). Outcome prediction after mild and complicated mild traumatic brain injury: external validation of existing models and identification of new predictors using the TRACK-TBI pilot study. *Journal of Neurotrauma*, *32*(2), 83–94.

Malec, J. F., Brown, A. W., Leibson, C. L., Flaada, J. T., Mandrekar, J. N., Diehl, N. N., & Perkins, P. K. (2007). The mayo classification system for traumatic brain injury severity. *Journal of Neurotrauma, 24*(9), 1417–1424.

Maroon, J. C., Steele, P. B., & Berlin, R. (1980). Football head and neck injuries – an update. *Clinical Neurosurgery, 27*, 414–429.

Marosszeky, N. E. V., Ryan, L., Shores, E. A., Batchelor, J., & Marosszeky, J. E. (1997). *The PTA Protocol: Guidelines for using the Westmead Post-Traumatic Amnesia (PTA) Scale*. Sydney: Wild & Wooley.

Marshall, S., Bayley, M., McCullagh, S., Velikonja, D., Berrigan, L., Ouchterlony, D., ... on behalf of the mTBI Expert Consensus Group, . (2015). Updated clinical practice guidelines for concussion/mild traumatic brain injury and persistent symptoms. *Brain Injury, 29*(6), 688–700.

McCrory, P., Meeuwisse, W. H., Aubry, M., Cantu, B., Dvorak, J., Echemendia, R. J., ... Turner, M. (2013). Consensus statement on concussion in sport: the 4th international conference on concussion in sport held in Zurich, November 2012. *British Journal of Sports Medicine, 47*(5), 259–262.

McMahon, P., Hricik, A., Yue, J. K., Puccio, A. M., Inoue, T., Lingsma, H. F., ... Vassar, M. J. (2014). Symptomatology and functional outcome in mild traumatic brain injury: results from the prospective track-TBI study. *Journal of Neurotrauma*, *31*(1), 26–33.

Menon, D. K., Schwab, K., Wright, D. W., Maas, A. I., & The Demographics and Clinical Assessment Working Group of the International and Interagency Initiative toward Common Data Elements for Research on Traumatic Brain Injury and Psychological Health. (2010). Position statement: definition of traumatic brain injury. *Archives of Physical Medicine & Rehabilitation, 91*(11), 1637–1640.

Morris, P. G., Prior, L., Shoumitro, D., Lewis, G., Mayle, W., Burrow, C. E., & Bryant, E. (2005). Patients' views on outcome following head injury: a qualitative study. *BMC Family Practice, 6*(30).

https://doi.org/10.1017/BrImp.2017.11 Published online by Cambridge University Press

Nelson, W. E., Jane, J. A., & Gieck, J. H. (1984). Minor head injury in sports: a new system of classification and management. *Physician Sports Medicine, 12*(3), 103–107.

Ommaya, A. K. (1985). Biomechanis of head injury: experimental aspects. In A.M. Nahum & J. Melvin (Eds.), *The biomechanics of trauma* (pp. 245–269). Norwalk, Conneticut: Appleton-Century-Crofts.

Rapp, P. E., & Curley, K. C. (2012). Is a diagnosis of "mild traumatic brain injury" a category mistake?. *Journal of Trauma and Acute Care Surgery, 73*(2 Suppl. 1), S13–23. doi:10.1097/TA.0b013e318260604b

Roberts, W. (1992). Who plays? Who sits? Managing concussions in sport. *Physician Sports Medicine, 20*(6), 66–72.

Røe, C., Sveen, U., Alvsåker, K., & Bautz-Holter, E. (2009). Post-concussion symptoms after mild traumatic brain injury: influence of demographic factors and injury severity in a 1-year cohort study. *Disability and Rehabilitation, 31*(15), 1235–1243.

Ruff, R. M., & Jurica, P. (1999). In search of a unified definition for mild traumatic brain injury. *Brain Injury, 13*(12), 943–952.

Saal, J. A. (1991). Common American football injuries. *Sports Medicine, 12*(2), 132–147.

Saban, K. L., Hogan, N. S., Hogan, T. P., & Pape, T. L. (2015). He looks normal but . . . challenges of family caregivers of veterans diagnosed with a traumatic brain injury. *Rehabilitation Nursing, 40*(5), 277–285.

Scheenen, M. E. Spikman, J. M., de Koning, M. E., van der Horn, J. J., Roks, G., Hageman, G., & van der Naalt, J. (2017). Patients "At Risk" of suffering from persistent complaints after mild traumatic brain injury: the role of coping, mood disorders, and post-traumatic stress. *Neurotrauma*, *34*(1), 31–37.

Schneider, R. C., & Kriss, F. C. (1973). First aid and diganosis – the treatment of head injuries. In R.C. Schneider (Ed.), *Head and neck injuries in football: mechanisms, treatment and prevention* (pp. 163–187). Baltimore, MA: Williams and Wilkins Co.

Servadei, F., Teasdale, G., & Merry, G. (2001). Defining acute mild head injury in adults: a proposal based on prognostic factors, diagnosis and management. *Journal of Neurotrauma, 18*(7), 657–664.

Stein, S. C., & Spettell, C. (1995). The Head Injury Severity Scale (HISS): a practical classification of closed-head injury. *Brain Injury, 9*(5), 437–444.

Studerus-Germann, A. M., Thiran, J. P., Daducci, A., & Gautschi, O. P. (2016). Diagnostic approaches to predict persistent post-traumatic symptoms after mild traumatic brain injury – a literature review. *International Journal of Neuroscience, 126*(4), 289–298.

Teasdale, G., & Jennett, B. (1974). Assessment of coma and impaired consciousness. A practical scale. *Lancet, 2*(7872), 81–84.

Tellier, A., Della Malva, L. C., Cwinn, A., Grahovac, S., Morrish, W., & Brennan-Barnes, M. (1991). Mild head injury: a misnomer. *Brain Injury, 13*(7), 463–475.

Theadom, A., Barker-Collo, S., Feigin, V., Starkey, N., Jones, K., Jones, A., ... on behalf of the BIONIC Research Group, . (2012). The spectrum captured: a methodological approach to studying incidence and outcomes of traumatic brain injury on a population level. *Neuroepidemiology, 38*(1), 18–29.

Theadom, A., Parag, V., Dowell, T., McPherson, K., Starkey, N., Barker-Collo, S., ... Group, B. R. (2016). Persistent problems 1 year after mild traumatic brain injury: a longitudinal population study in New Zealand. *British Journal of General Practice, 66*(642), e16–23.

Torg, J. S. (1991). *Athletic injuries to the head, neck and face*. St Louis, MO: Mosby Year Book: 226.

Vos, P. E., Battistin, L., Birbamer, G., Gerstenbrand, F., Potapov, A., Prevec, T., ... von Wild, K. (2002). EFNS guideline on mild traumatic brain injury: report of an EFNS task force. *European Journal of Neurology, 9*(3), 207–219.

Wilberger, J. E., & Maroon, J. C. (1989). Head injuries in athletes. *Clinics in Sports Medicine, 8*(1), 1–9.

Zumstein, M. A., Moser, M., Mottini, M., Ott, S. R., Sadowski-Cron, C., Radanov, B. P., ... Exadaktylos, A. (2011). Long-term outcome in patients with mild traumatic brain injury: a prospective observational study. *Journal of Trauma, 7*(1), 120–127.

https://doi.org/10.1017/BrImp.2017.11 Published online by Cambridge University Press