American Psychological Association

Neuropsychology

ISSN: 0894-4105

2020, Vol. 34, No. 5, 560–568
http://dx.doi.org/10.1037/neu0000632

Change in Self-Reported Cognitive Symptoms After Mild Traumatic Brain Injury Is Associated With Changes in Emotional and Somatic Symptoms and Not Changes in Cognitive Performance

Jonas Stenberg
Norwegian University of Science and Technology (NTNU) and St Olavs Hospital, Trondheim University Hospital, Trondheim, Norway

Justin E. Karr and Douglas P. Terry
Harvard Medical School and Home Base, A Red Sox Foundation and Massachusetts General Hospital Program, Boston, Massachusetts

Asta K. Håberg, Anne Vik, and Toril Skandsen
Norwegian University of Science and Technology (NTNU) and St Olavs Hospital, Trondheim University Hospital, Trondheim, Norway

Grant L. Iverson
Harvard Medical School and Home Base, A Red Sox Foundation and Massachusetts General Hospital Program, Boston, Massachusetts

Objective: To investigate (a) whether self-reported cognitive symptoms after mild traumatic brain injury (MTBI) are associated with cognitive test performances, and (b) whether improvement in self-reported symptoms from 2 weeks to 3 months after MTBI is associated with improvement in cognitive test performances. ***Method:*** Patients with MTBI (n = 135), aged 16–59, who initially presented to the emergency department, completed the Rivermead Post Concussion Symptoms Questionnaire (RPQ), the Brief Symptom Inventory 18, and cognitive tests (i.e., Controlled Oral Word Association, Coding, Rey Auditory Verbal Learning, and Trail Making test) at 2 weeks and 3 months after MTBI. Using Spearman's rank correlations (ρ), associations were examined between self-report measures and cognitive test performances at each time point and between change scores (i.e., 3-month score minus 2-week score) on each outcome. ***Results:*** At 3 months, 27% reported cognitive symptoms to some extent. At both assessments, greater severity of RPQ cognitive symptoms was very weakly associated with worse cognitive test performances (2-week ρ range = −0.19 to −0.01; 3-month ρ range = −0.20 to −0.10). RPQ cognitive symptoms were, however, strongly related to greater somatic and emotional symptoms. Change in self-reported cognitive symptoms from 2 weeks to 3 months was not associated with change in cognitive test performance. In contrast, change in self-reported cognitive symptoms was strongly associated with change in emotional (ρ = 0.58) and somatic symptoms (ρ = 0.57). ***Conclusions:*** These

This article was published Online First April 9, 2020.

Jonas Stenberg, Department of Neuromedicine and Movement Science, Faculty of Medicine and Health Sciences, Norwegian University of Science and Technology (NTNU), and Department of Neurosurgery, St Olavs Hospital, Trondheim University Hospital, Trondheim, Norway. Justin E. Karr and Douglas P. Terry, Department of Physical Medicine and Rehabilitation and Department of Psychiatry, Harvard Medical School, and Home Base, A Red Sox Foundation and Massachusetts General Hospital Program, Boston, Massachusetts. Asta K. Håberg, Department of Neuromedicine and Movement Science, Norwegian University of Science and Technology (NTNU), and Department of Radiology and Nuclear Medicine, St Olavs Hospital, Trondheim University Hospital, Trondheim, Norway. Anne Vik, Department of Neuromedicine and Movement Science, Norwegian University of Science and Technology (NTNU), and Department of Neurosurgery, St Olavs Hospital, Trondheim University Hospital, Trondheim, Norway. Toril Skandsen, Department of Neuromedicine and Movement Science, Norwegian University of Science and Technology (NTNU), and Department of Physical Medicine and Rehabilitation, St Olavs Hospital, Trondheim University Hospital, Trondheim, Norway. Grant L. Iverson, Department of Physical Medicine and Rehabilitation, Harvard Medical School, and Home Base, A Red Sox Foundation and Massachusetts General Hospital Program.

The study was funded by the Liaison Committee between the Central Norway Regional Health Authority (RHA) and the Norwegian University of Science and Technology (NTNU). Unrestricted philanthropic support was provided by the Spaulding Research Institute. Grant L. Iverson serves as a scientific advisor for BioDirection, Inc., Sway Operations, LLC, and Highmark, Inc. He has a clinical and consulting practice in forensic neuropsychology, including expert testimony, involving individuals who have sustained mild traumatic brain injuries. He has received research funding from several test publishing companies, including ImPACT Applications, Inc., CNS Vital Signs, and Psychological Assessment Resources (PAR, Inc.). He receives royalties from one neuropsychological test (WCST-64; PAR, Inc.). He has received research funding as a principal investigator from the National Football League, and salary support as a collaborator from the Harvard Integrated Program to Protect and Improve the Health of National Football League Players Association Members. He acknowledges unrestricted philanthropic support from ImPACT Applications, Inc., the Heinz Family Foundation, and the Mooney-Reed Charitable Foundation.

Correspondence concerning this article should be addressed to Jonas Stenberg, Department of Neuromedicine and Movement Science, Faculty of Medicine and Health Sciences, Norwegian University of Science and Technology (NTNU), N-7491 Trondheim, Norway. E-mail: jonas.stenberg@ntnu.no

findings indicate that improvements in subjective cognitive symptoms after MTBI co-occur with improvements on other subjective metrics, but are not related to improvements in objectively measured cognitive functioning.

Key Points

Question: After a mild traumatic brain injury (MTBI), many individuals have subjective cognitive concerns, and this study examined how changes in these concerns related to changes in cognitive test performances and emotional and physical symptoms from 2 weeks to 3 months after MTBI. ***Findings:*** A reduction in cognitive concerns was unrelated to improvements in cognitive test performances but was related to reductions in emotional and physical symptoms. ***Importance:*** These findings can be informative for clinical practice, where treatment of emotional or physical symptoms may result in perceived improvement in cognitive functioning. ***Next Steps:*** Future researchers should continue to examine the relationships between *changes* in different outcomes typically evaluated after MTBI (e.g., cognitive concerns, cognitive test performances, and emotional and physical symptoms) rather than continuing to explore these associations at a single point in time.

Keywords: neuropsychology, brain concussion, cognition

Cognitive test performances and self-reported cognitive, emotional, and somatic symptoms are routinely evaluated after traumatic brain injury (TBI). In mild TBI (MTBI), which is the most common severity of brain injury (Nguyen et al., 2016), the majority of evidence suggests that reduced cognitive test performances are common within the first few days and weeks of injury; while after 3 months, there are often no group differences between patients with and without MTBI (Carroll et al., 2014; Karr, Areshenkoff, & Garcia-Barrera, 2014). Postconcussion symptoms, commonly assessed via clinical interview or self-report questionnaires, follow a similar trajectory as cognitive test performance, in that symptoms often arise and subside within the first months after injury. However, a subgroup of patients with MTBI continue to report persistent cognitive, emotional, and/or somatic symptoms more than 3 months after MTBI (Cassidy et al., 2014; Polinder et al., 2018; Williams, Potter, & Ryland, 2010). The relationship between overall postconcussion symptom burden and cognitive test performance is poorly understood, and findings are mixed regarding whether patients who report more symptoms also have lower cognitive test performances (Lange et al., 2015; Losoi et al., 2016; Oldenburg, Lundin, Edman, Nygren-de Boussard, & Bartfai, 2016; Stenberg et al., 2020; Sterr, Herron, Hayward, & Montaldi, 2006).

Postconcussion symptoms are notably heterogeneous, which could possibly explain the mixed findings on their association with cognitive performances. It seems intuitive that self-reported *cognitive* symptoms would show stronger associations with *cognitive* performance than other domains of postconcussion symptoms. However, although some previous research has found statistically significant associations between cognitive test performances and self-reported cognitive symptoms (French, Lange, & Brickell, 2014; Jamora, Young, & Ruff, 2012; Ngwenya et al., 2018; Stillman, Madigan, Torres, Swan, & Alexander, 2019), these associations are often weak or negligible in terms of effect sizes (French et al., 2014; Karr et al., 2019; Spencer, Drag, Walker, & Bieliauskas, 2010; Stillman et al., 2019; Stulemeijer, Vos, Bleijenberg, & van der Werf, 2007). The relationship between self-reported cognitive symptoms and cognitive test performance may be further complicated by premorbid characteristics that differ between patients who report and who do not report cognitive symptoms, such as level of education and psychiatric history (Ngwenya et al., 2018; Stillman et al., 2019; Stulemeijer et al., 2007). In addition, prior studies use multiple different definitions for MTBI (Kristman et al., 2014), possibly contributing to mixed findings in the field.

The vast majority of studies on the association between self-reported symptoms and test performances compare individuals by examining correlations between self-reported symptoms and performances at a single time point rather than change in both outcomes within individuals over time (French et al., 2014; Jamora et al., 2012; Ngwenya et al., 2018; Spencer et al., 2010; Stillman et al., 2019; Stulemeijer et al., 2007). Longitudinal data, where both self-reported symptoms and test performances are repeatedly assessed, enables within-person analyses. Such analyses could investigate whether *change* in self-reported symptoms is accompanied by *change* in test performances, with the advantage that participants serve as their own controls, thereby reducing the potential effect of confounding variables (Curran & Bauer, 2011; van de Pol & Wright, 2009). This study design aligns with neuropsychological practice. Patients are assessed to investigate whether a condition, such as MTBI, has induced a change in test performance, or to assess the rate of cognitive recovery in an individual. Studying both differences between persons, and changes within persons, in the context of self-reported symptoms and cognitive test performances, could contribute to the understanding of these commonly reported outcomes in TBI research. In this study, participants with MTBI completed self-report symptom scales and cognitive tests at 2 weeks and 3 months after MTBI, with the aims of (a) examining the relationship between self-reported symptoms (e.g., cognitive, emotional, and somatic) and cognitive test performances at both measurement occasions, and (b) investigating whether changes in self-reported cognitive symptoms from 2 weeks to 3 months after MTBI were associated with changes in cognitive test performances or changes in other symptom domains.

Method

Participants

Patients between the ages of 16 and 59 were recruited from April 2014 to December 2015 as part of the Trondheim MTBI follow-up study (N = 378; Skandsen et al., 2018). They had experienced a physical trauma toward the head or high energy trauma followed by either (a) witnessed loss of consciousness (LOC) or confusion, (b) self-reported amnesia for the event or the time period after the event (PTA), and/or (c) traumatic brain lesions on computed tomography (CT). The TBI was further defined as mild per the criteria recommended by the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury: Glasgow Coma Scale (GCS) score of 13–15 at presentation to the emergency department, LOC <30 min, and PTA <24 hr (Carroll, Cassidy, Holm, Kraus, & Coronado, 2004). Exclusion criteria were nonfluency in the Norwegian language; pre-existing severe neurological (e.g., stroke, multiple sclerosis), psychiatric, somatic, or substance use disorders, determined to be severe enough to likely interfere with follow-up; a prior history of a complicated mild, moderate, or severe TBI; or other concurrent major trauma. The research collaborators (a medical doctor or a medical student under supervision) conducted a structured interview to identify pre-existing conditions.

Recruitment took place at two emergency departments: a Level 1 trauma center in Trondheim, Norway, and the Trondheim Municipal Emergency clinic, an outpatient clinic run by general practitioners. Of the enrolled patients, 199 participated in an extended follow-up study including neuropsychological assessment and magnetic resonance imaging (MRI). Intracranial traumatic findings were obtained from acute head CT and MRI, performed within 72 hr (Einarsen et al., 2019). The study was approved by the regional committee for research ethics (REK 2013/754) and was conducted in accordance with the Helsinki declaration. All participants, and caregivers of participants younger than 18 years old, gave informed consent.

Neuropsychological Testing

Participants with MTBI underwent neuropsychological testing approximately 2 weeks (M = 16.5 days, SD = 3.0 days) and 3 months (M = 95.0 days, SD = 6.3 days) after injury. A licensed psychologist or student in psychology or neuroscience with at least a bachelor's degree (supervised by a licensed psychologist) performed the testing. The testing involved a larger battery, with only a selection of tests corresponding to specific cognitive domains analyzed in the current study: the Rey Auditory Verbal Learning Test (RAVLT, verbal learning and memory), the Trail Making Test Part B (TMT-B, executive functioning), the Controlled Oral Word Association Test (COWAT, verbal fluency), and the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV) Coding subtest (processing speed). These tests have all been recommended as common data elements outcome measures after MTBI (Hicks et al., 2013). The same tests were administered at both time points.

The RAVLT is a widely used test of verbal learning and memory (Strauss, Sherman, & Spreen, 2006). The examiner reads a list of 15 words aloud, and the participant is asked to orally recall as many words as possible. The test includes five trials during which the full word list is read. Then, a distractor list is read and participants are asked to recall the words from the distractor list. Thereafter, they are asked to recall the words from the original list immediately after the distractor list and again after 20 min. The total number of words remembered across the five trials and the delayed recall score were used as outcome measures. A higher number of words recalled are indicative of a better performance. Different word lists were administered for the 2-week and the 3-month assessments. The TMT-B measures cognitive set shifting (i.e., an executive function), visual attention, and processing speed (Strauss et al., 2006). The participant is asked to draw a line alternating between numbers and letters (e.g., 1 – A – 2 – B – 3 – C). The outcome measure used was time-to-completion, with a faster time indicative of a better performance. The COWAT is a measure of verbal fluency, which is a construct related to language and executive function (Strauss et al., 2006; Tombaugh, Kozak, & Rees, 1999). The task is to generate as many words as possible beginning with a specific letter (i.e., F, A, and S) in 1 min. The total number of words produced across all three trials was used as the outcome measure, with a greater number of words indicative of a better performance. In the WAIS-IV Coding subtest (Wechsler, 2008, 2011), the participant is presented with a series of numbers and a coding key, which provides an abstract symbol that corresponds to each number. The participant must match as many symbols as possible to their corresponding number within 2 min. The total correct items completed within the time limit were used as the outcome measure, with a higher score indicative of better performance. For all tests, published norms (Mitrushina, Boone, Razani, & D'Elia, 2005; Schmidt, 1996; Tombaugh et al., 1999; Wechsler, 2011) were used to calculate age-adjusted T scores (M = 50, SD = 10, higher scores equal better performances on all tests), which were used in the analyses.

Self-Reported Symptom Assessment

The Rivermead Post Concussion Symptoms Questionnaire (RPQ) is recommended for the assessment of postconcussion symptoms after MTBI (Hicks et al., 2013) and was administered at the same time points as the cognitive tests. The RPQ includes 16 symptoms, on which the participant is asked to rate the severity of each symptom during the last 24 hr compared with before the injury (0 = *not experienced at all*, 1 = *no more of a problem*, 2 = *a mild problem*, 3 = *a moderate problem*, 4 = *a severe problem*). Consistent with previous studies on the RPQ (Eyres, Carey, Gilworth, Neumann, & Tennant, 2005; King, Crawford, Wenden, Moss, & Wade, 1995), all ratings of 1 (i.e., no more of a problem) were converted to zeros before the scores were combined. Three symptom subscales were calculated for the RPQ, with the items included summed for each subscale listed in parentheses: cognitive (i.e., forgetfulness, poor memory; poor concentration; and taking longer to think), emotional (i.e., being irritable, easily angered; feeling depressed or tearful; feeling frustrated or impatient; and restlessness), and somatic symptoms (i.e., headaches; feelings of dizziness; nausea and/or vomiting; noise sensitivity, easily upset by loud noise; sleep disturbance; fatigue, tiring more easily; blurred vision; light sensitivity, easily upset by bright light; and double vision; Potter, Leigh, Wade, & Fleminger, 2006; Smith-Seemiller, Fow, Kant, & Franzen, 2003). Participants also com-

pleted the Brief Symptom Inventory-18 (BSI-18), which consists of 18 items, with six items belonging to each subscale: depression, anxiety, and somatization (Derogatis, 2000). On a 5-point Likert-type scale, participants reported how much a given problem bothered them during the past week. The items for each subscale are summed to calculate a score (range = 0–24), where higher scores correspond to more psychological symptoms.

Statistical Analyses

Spearman's rank correlations (ρ) were used to investigate the associations between self-report measures and cognitive test performances. Participants who had one missing item on the RPQ ($n = 1$) or BSI-18 ($n = 2$) had the missing value replaced with the mean of their answers to the completed items on that subscale. Differences in self-reported symptom severity and cognitive test performances between the 2-week and 3-month assessments were analyzed with Wilcoxon signed-ranks test and r is reported as the effect size (the z-statistic associated with the Wilcoxon signed-ranks test divided by the squared root of the sample size; Fritz, Morris, & Richler, 2012; Pallant, 2007), interpreted as: 0.1 = a small effect, 0.3 = a medium effect, 0.5 = a large effect (Cohen, 1988). To investigate whether change in self-reported symptoms from 2 weeks to 3 months was associated with change in cognitive test performances, change scores were calculated. For each participant, self-reported symptom scores at 2 weeks were subtracted from scores at 3 months (i.e., a negative score means reduced symptom severity at the 3-month assessment). Similarly, cognitive test scores at 2 weeks were subtracted from scores at 3 months (i.e., a positive score means better performance at 3 months). The associations between these change scores were then investigated with Spearman's rank correlations. Because change scores are correlated with the scores at the first assessment, a phenomenon known as regression to the mean (Barnett, van der Pols, & Dobson, 2005; Clifton & Clifton, 2019), we also present analyses accounting for this potential effect. The residuals were saved from a regression model where the change score was the dependent variable and the 2-week score was the independent variable. These residuals were analyzed in place of the raw change scores for this analysis. Spearman's rank correlations and Mann–Whitney U tests, with r reported as effect sizes (the z-statistic associated with the Mann–Whitney U tests divided by the squared root of the sample size), were used to investigate the association between demographic and injury-related variables and change in self-reported cognitive symptoms. All analyses were conducted in Stata v. 15.1 (StataCorp, 2017).

Results

Participant Characteristics

Among the 199 participants with MTBI taking part in the extended follow-up, 178 completed the 2-week cognitive assessment, of which 135 (76%) completed the 3-month cognitive assessment and the two RPQ assessments. Demographic and clinical information is presented in Table 1. The mean age of the participants was 33.7 years and 34.8% were women ($n = 47$). The most common cause of injury was a fall. LOC was witnessed in 47.4% of participants, 25.2% had PTA exceeding 1 hr, and intracranial findings on CT or MRI were found in 11.1% of participants. Participants in the extended follow-up who did not complete one or both of the assessments ($n = 64$) were younger ($M = 29.2$ years old, $p = .015$) and had a higher frequency of PTA exceeding 1 hr (43.8%, $p = .008$), but the frequency of women ($p = .427$), LOC ($p = .986$), and intracranial findings ($p = .370$) did not differ.

Table 1
Characteristics of Participants With Mild Traumatic Brain Injury

Variable	Value
Age, years	
Median (IQR)	30.2 (22.2–46.6)
Mean (*SD*)	33.7 (13.2)
Sex, women, *n* (%)	47 (34.8)
Education, years	
Median (IQR)	13.0 (12–16)
Mean (*SD*)	14.2 (2.7)
Cause of injury (%)	
Fall	39.3
Bicycle	21.5
Sports accidents	14.8
Violence	9.6
Motor vehicle accidents	7.4
Hit by object	6.7
Unknown	0.7
Loss of consciousness	
(% witnessed/no/unknown-not witnessed)	47.4/17.0/35.6
Glasgow Coma Scale score	
(% 13/14/15/unknown)	2.2/12.6/77.8/7.4
Posttraumatic amnesia (%)	
(% 1–24 hr/<1 hr)	25.2/74.8
Intracranial findings (on CT or MRI)	
(% yes/no)	11.1/88.9
Level of care (%)	
Not admitted	71.9
Observed <24 hr	15.6
Admitted to neurosurgery department	8.9
Admitted to other department	3.7

Note. CT = computed tomography; IQR = interquartile range; MRI = magnetic resonance imaging.

Associations Between Self-Reported Symptoms and Cognitive Test Performances

Descriptive statistics for self-reported symptoms and cognitive test performances are presented in Table 2. On the cognitive tests, the mean group level performances were within the normal range at both the 2-week and the 3-month assessment (i.e., all mean scores were within ±5 T scores of the norm group mean of T score 50; Table 2). At the 2-week and the 3-month assessments, a greater severity of RPQ cognitive symptoms was significantly associated with worse performance on the delayed trial of the RAVLT (ρ = −0.19 and −0.20, respectively), but not with the other cognitive tests, and the effect sizes were uniformly small and similar across assessments (2-week ρ range = −0.19 to −0.01, 3-month ρ range = −0.20 to −0.10; Table 3). The RPQ emotional symptoms were significantly associated with the delayed trial of the RAVLT at the 2-week assessment (ρ = −0.18), but not with the other cognitive tests. The RPQ somatic symptoms were not significantly associated with any of the cognitive tests. For BSI-18,

Table 2
Self-Reported Symptoms and Cognitive Test Performances at 2 Weeks and 3 Months

Variable	2-Week assessment				3-Month assessment					
	Mean	*SD*	Median	IQR	Mean	*SD*	Median	IQR	*p*-value[a]	*r*
RAVLT-1 to 5	46.6	11.3	47.7	40.8–54.5	48.4	11.7	49.0	39.7–56.1	0.104	0.10
RAVLT-Delayed	49.3	10.6	50.3	42.5–56.8	48.9	10.9	49.6	40.8–56.8	0.189	0.08
TMT Part B	48.9	12.5	52.2	43.6–56.7	51.5	12.7	54.6	46.8–57.9	<.001	0.27
COWAT	47.3	12.5	47.3	38.9–55.2	50.8	14.3	49.9	40.3–60.2	<.001	0.31
Coding	50.9	8.9	50.0	43.4–56.7	54.9	10.2	53.3	46.7–60.0	<.001	0.45
RPQ-Cognitive	2.4	3.1	0	0–5	1.4	2.7	0	0–2	0.002	0.19
RPQ-Emotional	1.6	2.8	0	0–2	1.1	2.5	0	0–2	0.271	0.07
RPQ-Somatic	6.0	6.6	4	0–10	3.3	5.2	0	0–5	<.001	0.30
RPQ-Total Score	10.0	10.9	6	0–16	5.9	9.1	2	0–9	<.001	0.26
BSI-18-Depression	2.1	3.2	1	0–3	1.9	3.3	0	0–2	0.238	0.07
BSI-18-Anxiety	2.0	3.1	1	0–3	1.6	3.0	0	0–2	0.010	0.16
BSI-18-Somatic	3.4	3.3	2	1–5	2.0	2.8	1	0–3	<.001	0.32

Note. RAVLT = Rey Auditory Verbal Learning Test; TMT = Trail Making Test; COWAT = Controlled Oral Word Association Test; RPQ = Rivermead Post Concussion Symptoms Questionnaire; BSI-18 = Brief Symptom Inventory-18. Neuropsychological test scores are presented as *T*-scores ($M = 50$, $SD = 10$). One participant had six missing items on BSI-18 at the 3-month assessment and was excluded from these analyses. r = The effect size (0.1 = small, 0.3 = medium, 0.5 = large). A positive effect size indicates improvement.
[a] Wilcoxon signed-rank tests.

the depression and anxiety subscales were not significantly associated with any of the cognitive tests. The BSI-18 somatization scale showed significant associations with 2-week performance on the COWAT ($\rho = -0.17$) and 3-month performance on the WAIS-IV Coding subtest ($\rho = -0.19$), but not with the other cognitive tests. Associations between different types of self-reported symptoms (i.e., the cognitive, emotional, and somatic symptoms on the RPQ, and the depression, anxiety, and somatization scales on BSI-18) were considerably stronger (ρ range = 0.23–0.67; Table 3).

Table 3
Spearman Correlations Between Self-Report Measures and Cognitive Test Scores at 2 Weeks and 3 Months After Injury

Variable	1	2	3	4	5	6	7	8	9	10	11
2 Weeks											
1. RAVLT-Trials 1 to 5	1										
2. RAVLT-Delayed	.712**	1									
3. TMT Part B	.299**	.310**	1								
4. COWAT	.327**	.266**	.308**	1							
5. Coding	.383**	.445**	.515**	.346**	1						
6. RPQ-Cognitive	−.129	−.185*	−.005	−.117	−.033	1					
7. RPQ-Emotional	−.121	−.176*	−.053	−.134	−.089	.610**	1				
8. RPQ-Somatic	−.009	−.072	.132	−.067	−.022	.602**	.501**	1			
9. RPQ-Total Score	−.057	−.134	.069	−.116	−.050	.803**	.695**	.928**	1		
10. BSI-18-Depression	−.058	−.072	−.061	−.111	−.018	.413**	.487**	.335**	.434**	1	
11. BSI-18-Anxiety	.002	−.044	−.123	−.064	.036	.396**	.471**	.282**	.382**	.547**	1
12. BSI-18-Somatization	.099	.006	.005	−.172*	.012	.499**	.458**	.599**	.630**	.460**	.448**
3 Months											
1. RAVLT-Trials 1 to 5	1										
2. RAVLT-Delayed	.776**	1									
3. TMT Part B	.275**	.237**	1								
4. COWAT	.459**	.324**	.389**	1							
5. Coding	.456**	.398**	.452**	.271**	1						
6. RPQ-Cognitive	−.129	−.195*	−.125	−.144	−.096	1					
7. RPQ-Emotional	−.111	−.076	−.003	.000	−.011	.625**	1				
8. RPQ-Somatic	−.116	−.078	−.055	−.053	.027	.668**	.571**	1			
9. RPQ-Total Score	−.157	−.115	−.083	−.066	−.037	.777**	.735**	.924**	1		
10. BSI-18-Depression	−.001	.068	−.013	.080	−.028	.308**	.422**	.226**	.312**	1	
11. BSI-18-Anxiety	.004	−.038	−.040	.136	.031	.339**	.406**	.252**	.299**	.577**	1
12. BSI-18-Somatization	−.152	−.149	−.122	−.116	−.188*	.411**	.447**	.379**	.437**	.498**	.504**

Note. RAVLT = Rey Auditory Verbal Learning Test; TMT = Trail Making Test; COWAT = Controlled Oral Word Association Test; RPQ = Rivermead Post Concussion Symptoms Questionnaire; BSI-18 = Brief Symptom Inventory-18.
* $p < .05$. ** $p < .01$.

Associations Between Change in Cognitive Symptoms and Test Performances

The RPQ cognitive symptom severity was significantly higher at the 2-week assessment compared with the 3-month assessment (see Table 2). At 2 weeks after MTBI, 55% ($n = 74$) of the participants had a score of 0 on the RPQ cognitive items (i.e., endorsed no cognitive symptoms as worse compared with before their injury), 10% ($n = 14$) had a score of 2 on the cognitive items (i.e., reported a minor problem on one of the items), and 35% ($n = 47$) had a score between 3 and 12. At 3 months after MTBI, 73% ($n = 99$) had a score of 0 on the RPQ cognitive symptoms, 5% ($n = 7$) had a score of 2, and 22% ($n = 29$) had a score between 3 and 12. Significantly more RPQ somatic symptoms and BSI-18 anxiety and somatization symptoms were also reported on the 2-week compared with the 3-month assessment. Participants performed better on all cognitive tests at 3 months after injury compared with 2 weeks, except on the RAVLT, on which the scores did not differ statistically at the two time points (see Table 2). Change in self-reported cognitive symptoms from 2 weeks to 3 months was not significantly associated with change in cognitive test performances (ρ range = −0.11 to 0.05). Thus, improvement in self-reported cognitive symptoms was not related to improvement in test performance. In contrast, improvement in RPQ cognitive symptoms was strongly associated with improvement in RPQ emotional symptoms and RPQ somatic symptoms; and also, but to a lesser extent, with improvement in depression, anxiety, and somatization symptoms as measured with the BSI-18 (see Table 4). Reanalysis of these data controlling for the potential regression to the mean effect produced the same results (see Table 4).

Variables Associated With Change in Self-Reported Cognitive Symptoms

Age (ρ = 0.01, $p = .924$) and years of education (ρ = −0.07, $p = .431$) were not associated with improvement (i.e., change) in self-reported cognitive symptoms from 2 weeks to 3 months. There was a nonsignificant trend that women had a greater improvement in self-reported cognitive symptoms than men ($U = 1703.5$, $p = 0.070$, $r = .16$). Among the injury-related variables, there were no differences in the improvement of self-reported cognitive symptoms between patients with and without LOC ($U = 659$, $p = .416$, $r = .09$), between patients with GCS 15 versus GCS 13–14 ($U = 1037.5$, $p = .928$, $r = .01$), between patients with long versus short PTA ($U = 1422$, $p = .108$, $r = .14$), or between patients with and without traumatic intracranial findings ($U = 792.5$, $p = .418$, $r = .07$).

Table 4
Correlations Between Change in RPQ Cognitive Symptoms and Change in Other Self-Report Measures and Cognitive Tests

Variable	RPQ-cognitive change scores (raw)		RPQ-cognitive change scores (residual)[a]	
	Spearman's ρ	*p*-value	Spearman's ρ	*p*-value
RAVLT-Trials 1 to 5	−0.029	0.738	−0.032	0.710
RAVLT-Delayed	−0.114	0.189	−0.141	0.103
TMT Part B	0.043	0.618	−0.029	0.738
COWAT	0.051	0.558	0.080	0.356
Coding	−0.055	0.523	−0.089	0.306
RPQ-Emotional	0.576	<.001	0.611	<.001
RPQ-Somatic	0.568	<.001	0.616	<.001
BSI-18-Depression	0.251	0.003	0.256	0.003
BSI-18-Anxiety	0.228	0.008	0.287	<.001
BSI-18-Somatization	0.268	0.002	0.301	<.001

Note. RAVLT = Rey Auditory Verbal Learning Test; TMT = Trail Making Test; COWAT = Controlled Oral Word Association Test; RPQ = Rivermead Post Concussion Symptoms Questionnaire; BSI-18 = Brief Symptom Inventory-18.
[a] The residuals from a regression model where the change score is the dependent variable, and the 2-week score is the independent variable, were analyzed instead of the raw change scores.

Discussion

This study focused on the association between subjectively experienced and objectively measured cognitive functioning at 2 weeks and 3 months after MTBI. Consistent with previous research, weak and mostly nonsignificant associations were observed between self-reported cognitive symptoms and cognitive test performances at both time points, whereas the associations between self-reported cognitive, somatic, depressive, and anxiety-related symptoms were considerably stronger (French et al., 2014; Karr et al., 2019; Spencer et al., 2010; Stillman et al., 2019; Stulemeijer et al., 2007). Similarly, *change* in cognitive symptom severity from 2 weeks to 3 months was unrelated to change in cognitive test performance, whereas *change* in cognitive symptoms was strongly associated with change in depression, anxiety, and somatic symptoms over this same time period.

The longitudinal design of the present study allowed us to evaluate how change in one variable is related to changes in other variables. Our results extend previous findings from cross-sectional studies (French et al., 2014; Jamora et al., 2012; Ngwenya et al., 2018; Spencer et al., 2010; Stillman et al., 2019; Stulemeijer et al., 2007) by showing that that the association between change in self-reported cognitive symptoms and change cognitive test performance was as weak, or even weaker, than the association between self-reported cognitive symptoms and test performance at a single time point. As a group, the patients with MTBI improved significantly in self-reported cognitive symptom severity from 2 weeks to 3 months. These same patients showed, on average, improvement on most objective cognitive outcomes from 2 weeks to 3 months as well. However, the negligible associations between change in self-reported cognitive symptoms and change in test performances suggest a discrepancy in recovery trajectories between these two outcomes. This finding adds to previous research suggesting different recovery pace for different outcome domains (Losoi et al., 2016), in that cognitive performances and symptoms will not necessarily improve in tandem. The limited relationship between objective and subjective cognition and the prominent relationship between different symptom domains can be informative for clinical practice. For instance, a patient who reports cognitive symptoms will not necessarily show reduced cognitive performances; and improvement in these cognitive symptoms could occur with reductions in emotional and somatic symptoms, but may not correspond with any change in objectively measured cognitive functioning.

Demographic characteristics suggested to be associated with outcome after MTBI, such as age (van der Naalt et al., 2017), gender (Merritt, Padgett, & Jak, 2019), and education (van der

Naalt et al., 2017), could possibly affect the association between self-reported and performance-based cognition; but, the nonparametric methods used in the present study did not allow us to control for these variables. However, for the within-person analyses, in which the association between change in self-reported cognitive symptoms and performance-based cognition was examined, by design, participants served as their own controls, and the possible effects of confounding variables were minimized. We did, however, examine whether improvement in self-reported cognitive symptoms was related to demographic and injury-related factors and found only a weak and nonsignificant tendency of greater improvement in women.

We did not find any significant associations between depressive and anxiety symptoms reported on the BSI-18 and cognitive test performance. These correlations were in fact weaker than the correlations between self-reported cognitive symptoms and cognitive test performance. These findings are in contrast to some previous studies linking depression to poorer cognitive test performance after MTBI (Barker-Collo et al., 2015; Levin et al., 2001; Rapoport, McCullagh, Shammi, & Feinstein, 2005; Terry, Brassil, Iverson, Panenka, & Silverberg, 2019). However, unlike many previous studies, the present study did not include patients who sought health care because of persistent symptoms, but rather recruited patients from the emergency department and followed them prospectively. Although this approach yields a representative sample of patients with MTBI, the symptom severity is likely less pronounced than in many other studies. Further, we did not examine if patients' symptoms met a threshold typical of a depression diagnosis or whether these symptoms caused sufficient impairment to rationalize a diagnosis. Our findings may have differed if we focused solely on patients meeting criteria for Major Depressive Disorder after MTBI, and these differences in study design could contribute to the differences in results between the present study and some previous findings.

The present study had several limitations that are important to consider when interpreting the findings. The RPQ is worded so that individuals rate their symptoms in relation to their perceived preinjury baseline. The reliance on a perceived baseline has inherent issues, in that patients may underestimate their preinjury symptoms (Lange, Iverson, & Rose, 2010) and their perception of their preinjury symptoms may change over time (Yang et al., 2014). Further, a substantial proportion of the sample may have recovered at the time of the first assessment at 2 weeks (Carroll et al., 2014; Cassidy et al., 2014; Karr et al., 2014). This is exemplified by the majority of participants reporting no cognitive symptoms, and the mean *T* scores for every cognitive test falling broadly within the average range at both assessments. Stronger associations between change in self-reported symptoms and change in test performances may have been observed if the first assessment was conducted more proximal to injury. A final limitation was that improvement in cognitive test performances from 2 weeks to 3 months is partly because of practice effects rather than recovery (Stenberg et al., 2020). Of note, the only test on which participants did not improve at retest was the RAVLT, for which an alternative form was used to reduce the impact of practice. However, it is unlikely that this practice effect confounded the main analyses of our study (i.e., the associations between self-reported cognitive symptoms and test performances), which examined *variability* in improvement between patients rather than group mean improvement.

Self-reported cognitive symptoms and cognitive test performances appear to be unique outcomes after MTBI, with cognitive symptom severity being more closely related to emotional and somatic symptom severity than objective cognitive functioning. Being commonly used outcomes in MTBI research, neuropsychological test performance and self-reported cognitive symptoms are not redundant, and both have a role in a comprehensive assessment of outcome after MTBI. The present findings may be useful for guiding interventions among patients who experience persistent cognitive complaints after MTBI. The correspondence between change in mental health symptoms and cognitive symptoms over the course of recovery suggests that patients with persistent subjective cognitive symptoms may benefit from an evidence-based mental health intervention.

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Received November 4, 2019
Revision received January 3, 2020
Accepted February 16, 2020 ■