*J Head Trauma Rehabil*
Vol. 00, No. 00, pp. 1–11


# Long-Term Correlates of Mild Traumatic Brain Injury on Postconcussion Symptoms After Deployment to Iraq and Afghanistan in the UK Military

*Roberto J. Rona, FFPH; Margaret Jones, BA; Norman Jones, PhD; Nicola T. Fear, DPhil (Oxon); Simon Wessely, FMedSci*

**Objectives:** We assessed whether mild traumatic brain injury (mTBI) reported by UK service personnel between 2007 and 2009 was associated with postconcussion symptoms (PCS) 7 to 8 years later**. Setting:** United Kingdom. **Participants:** A total of 4601 service personnel all of whom had deployed to Iraq and/or Afghanistan. **Design:** Longitudinal study. **Main Outcome Measures:** Nine PCS reported in a survey carried out between 2014 and 2016. The main independent variable was mTBI reported between 2007 and 2009. **Results:** A total of 2318 (50.4%) out of 4601 participants completed the follow-up questionnaire. Mild traumatic brain injury was associated with 2 of 9 PCS. Mild traumatic brain injury at baseline was associated with dizziness at follow-up in the fully adjusted model, in comparison with either "other injury" or "no injury" group. Mild traumatic brain injury was associated with loss of concentration in comparison with "no injury" but in comparison with the "other injury" group, it was not in the fully adjusted model. The prevalence of 7 of the 9 PCS increased over time regardless of mTBI status. **Conclusions:** Mild traumatic brain injury reported in 2007-2009 was associated with dizziness and possibly with loss of concentration 7 years later but not with most PCS. The prevalence of most PCS increased over time independently of mTBI. **Key words:** *concussion*, *deployment*, *military personnel*, *prospective studies*

MILD TRAUMATIC BRAIN INJURY (mTBI) is often characterized as the "signature injury" for those who deployed with the Coalition Forces in the recent wars in Iraq and Afghanistan. Prevalence rates vary from 12% to 23% in US personnel deployed to either conflict[1–5] and between 3% and 10% for the UK Armed Forces.[6,7] These prevalence rates are an understandable cause for concern because of the possible health impact of associated postconcussion symptoms (PCS).[8–10]

The PCS commonly associated with mTBI are headaches, difficulty in concentrating, irritability, dizziness, forgetfulness, fatigue, and sleep difficulties.[11] However, these symptoms are nonspecific and commonly reported in other conditions such as posttraumatic stress disorder (PTSD) and depression,[1,12] which may contribute to the uncertainty about the outcome of mTBI. Therefore, it is essential to design studies with an appropriate control group. Most studies of PCS have been cross-sectional with participants reporting mTBI and PCS in the same questionnaire. There are few military studies that use long-term follow-up assessments. Those that exist had a follow-up not longer than one year after reporting the mTBI event,[13] with just 1 study assessing longer-term neuropsychological performance not persistent PCS.[8]

We previously carried out a cross-sectional study of the prevalence of mTBI and its association with PCS in

***Author Affiliations:*** *King's Centre for Military Health Research (Messrs Rona and Wessely and Ms Jones) and Academic Department of Military Mental Health (Drs Fear and Norman Jones), King's College London, London, United Kingdom.*

*All authors are based on King's College London and the study receives funding from the Ministry of Defence (MOD). The salaries of Professors Rona and Fear and Ms Jones are paid totally or partially for this grant. Professor Rona is also partially paid by a grant of Forces in Mind Trust (FiMT). Dr Jones is a full-time member of the Armed Forces seconded to King's College London. Professor Fear reports grants from the US Department of Defense and the UK MOD, is a trustee (unpaid) of the Warrior Programme, and an independent advisor to the Independent Group Advising on the Release of Data (IGARD). Professor Wessely is a trustee (unpaid) of Combat Stress and Honorary Civilian Consultant Advisor in Psychiatry for the British Army (unpaid). He is affiliated to the National Institute for Health Research Protection Research Unit (NIHR HPRU) in Emergency Preparedness and Response at King's College London in Partnership with Public Health England in collaboration with the University of East Anglia and Newcastle University.*

*The authors declare no conflicts of interest.*

***Corresponding Author:*** *Roberto J. Rona, FFPH, King's Centre for Military Health Research, Weston Education Centre, King's College London, 10 Cutcombe Rd, London SE5 9RJ, England (Roberto.rona@kcl.ac.uk).*

*DOI: 10.1097/HTR.0000000000000497*

UK military personnel who had deployed to Iraq and Afghanistan.[12] In that study, we found that the prevalence of mTBI was 4.4%, which increased to 9.5% in those with a combat role. Eighty-three percent of those with mTBI had an altered mental state but not loss of consciousness. We also found that PTSD and to a lesser degree alcohol misuse and multiple physical symptoms were associated with mTBI. Mild traumatic brain injury was associated with headaches, double vision, and dizziness but none of the other 6 symptoms assessed. In the current study, we used follow-up data to assess whether PCS were explained by mTBI reported at baseline in the previous study (2007-2009) in comparison with those who suffered a non-mTBI injury and with those who reported no injury at all at baseline. A second aim was to identify remitted and new-onset PCS in each of the 3 groups over the same period.

## METHODS

### Sample

This study used data collected as part of a longitudinal cohort study of UK Armed Forces personnel initiated in 2004 to monitor the health of individuals who took part in the initial phase of the war in Iraq in 2003. Data collection was carried out between 2004 and 2006 (phase 1) and again between 2007 and 2009 (phase 2) and between 2014 and 2016 (phase 3). Phase 1 included a random sample of personnel deployed to Iraq in 2003 and another randomly selected sample of serving personnel who had not deployed at that time.[14] Another 2 samples were added at phase 2 to reflect changes in the pattern of deployment and to preserve the representative nature of the sample: a random sample of those deployed to Afghanistan between April 2006 and April 2007 and a random sample of personnel who joined the military between April 2003 and April 2007, termed the replenishment sample.[15]

Between November 2007 and September 2009 (phase 2), 4620 participants had deployed to Iraq and/or Afghanistan and provided information about mTBI (details in the Measures section); they provide the baseline data for the current analyses. A total of 2333 were members of the cohort originally sampled in 2004, 847 were members of the group of personnel deployed to Afghanistan between April 2006 and April 2007, and finally 1440 were service personnel recruited into the UK Armed Forces after the start of the war in Iraq in 2003. Participants included regulars and reserves and those who had subsequently left the Armed Forces.[12] Those who gave consent to be contacted again were followed up between October 2014 and December 2016 as part of the third phase of the cohort study. We approached 4601 baseline participants, as 19 individuals were lost to follow-up. Individuals were sent an invitation to complete the online survey along with an information leaflet. Nonresponders to the initial invitation were sent a repeat invitation by e-mail. Subsequently, all nonresponders were sent a paper version of the questionnaire, login details for the online version, and a reply-paid envelope. An intensive period of follow-up and tracing continued for those who did not reply to our invitation.[16]

### Measures

The main outcomes of this follow-up study were the PCS comprising headache, dizziness, irritability or outburst of anger, double vision, loss of concentration, forgetfulness, ringing in the ears, fatigue, and sleeping difficulties that were also included in our previous report. These were chosen to include the 7 symptoms shown to differentiate between individuals with mTBI and a control group 1 month after head injury[11] and another 2 symptoms included in our previous study of PCS.[17] Postconcussion symptoms at baseline were included in a list of 53 symptoms based on the Hopkins Symptom Checklist.[18] Participants were asked whether each symptom had been experienced in the past month (yes/no). In phase 3 of the cohort study, we used the PHQ-15,[19] but we added to it 5 symptoms from the cohort baseline measure that were not included in the PHQ-15. The PHQ-15 uses 3 response categories to indicate concern related to symptoms; "not bothered at all," "bothered a little," and "bothered a lot." In the analysis, we assessed symptoms as binary variables by combining "bothered a little" and "bothered a lot" to produce a symptoms present or absent response scale.

We assessed mTBI in 2007-2009 (phase 2) and new-onset mTBI occurring within the 3 years prior to the 2014-2016 (phase 3) of the cohort study using a modified version of the Brief Traumatic Brain Injury Screen.[20] In phase 3, we asked for events occurring both in-service and after leaving service, unlike our previous survey (phase 2) that asked only about events experienced during deployment. The mTBI assessment was similar in both phases of the study. The first question asked about falls, vehicle accident, blast or explosion, fragment or bullet, or other event that caused injury. The second question asked whether any of the events described resulted in being dazed or confused, not remembering the injury, losing consciousness, concussion, head injury, other physical injury, or none of these. Being dazed or confused, not remembering the injury, losing consciousness, or concussion was categorized as "mTBI," head injury or other physical injury was categorized as "other injury," and none of these was categorized as "no injury." An additional question asked, "If you were knocked out, for how long?" Seven individuals who reported loss of consciousness for 30 minutes or more in the follow-up study were excluded from the analysis.

The PCS were in a different section of the questionnaire to the Brief Traumatic Injury Screen in both the 2007-2009 survey and the latest survey.

We asked the following information in both surveys: age, gender, education, marital status, service, rank, and engagement type (regular/reserve). We assessed symptoms of common mental disorder using the 12-item General Health Questionnaire (GHQ-12)[21]; probable PTSD using the 17-item National Centre for PTSD Checklist Civilian (PCL-C)[22]; and alcohol use, using the 10-item World Health Organization Alcohol Use Disorders Identification Test (AUDIT).[23] Binary outcome variables were defined using the following cutoff scores: 4 or more for the GHQ-12 (scores range from 0 to 12),[21] scores of 50 or more for the PCL-C (scores range from 17 to 85), and 16 or more for the AUDIT (scores range from 0 to 40).[24]

### Analysis

The main analyses were the comparison of each of the PCS at follow-up in those who were classified as having experienced an mTBI in the 2007-2009 (baseline) study with those who suffered an "other injury" but not mTBI and, separately, with those who reported "no injury." We carried out multivariable Poisson regression analysis and standard sociodemographic (sex, age, education, and marital status) and military demographic (service branch, rank, and enlistment type [regular or reserve]) factors were included in the models.

The rationale for our analytical approach was that sociodemographic and military demographic factors would influence the likelihood of endorsing PCS, that is, they could be potential confounders. It was also appropriate to adjust for PTSD because of the known overlap with the nonspecific symptoms of PCS.[1,2,17] We adjusted for alcohol misuse and symptoms of common mental disorder because they share some of the PCS.[12] Finally, we adjusted for a new mTBI event as this might be associated with the current pattern of PCS, and those who already suffered mTBI in the past might be likely to report a new mTBI event.[10]

We also assessed changes for each PCS between 2007 and 2009 and 2014 and 2016 to identify remitted and new-onset symptoms. We used the McNemar test to assess the significance of remission and new-onset changes for each PCS.

Response weights were calculated as the inverse probability of responding once sampled and driven by factors shown empirically to predict response (sex, rank, engagement type, age, sample, and the interaction between sample and engagement type). The weighted analyses provide valid results under the assumption that the data are missing at random and that the observed variables modeled to drive nonresponse were correctly identified. Response weights are used to compensate for the fact that baseline participants with certain characteristics are not as likely to respond to the survey at follow-up.

Analyses were undertaken using the statistical software package, STATA (version 10.0; StataCorp LP, College Station, Texas). All analyses take account of the weighting by using the survey (svy) commands in STATA. Weighted percentages and prevalence ratios are presented in the tables related to the main analysis, together with unweighted cell counts.

## RESULTS

A total of 2318 (50.4%) out of 4601 eligible participants from the baseline survey responded to the follow-up survey carried out 7 years later. As in all our studies, those who were female, older, with a higher level of education, higher rank, in the reserve, and in the Royal Air Force were more likely to complete the follow-up questionnaire (see Table 1). It is important to note that the response rate was unrelated to both PTSD and GHQ-12 status at baseline. However, those fulfilling the criteria for mTBI and those with an alcohol misuse problem at baseline were less likely to complete the questionnaire, while those with PCS at baseline were slightly more likely to complete the questionnaire. After adjustment for baseline social and military demographic characteristics (sex, age, education, marital status, service, rank, and regular/reserve status), completing at follow-up was no longer associated with baseline alcohol misuse, with reporting 1 or 2 PCS, or mTBI.

The association of mTBI at baseline with each PCS at follow-up was assessed in relation to "other injury" (see Table 2) and "no injury" (see Table 3). Mild traumatic brain injury at baseline was associated with dizziness and loss of concentration at follow-up in comparison with both "other injury" and "no injury" regardless of the adjustments made: social and military demographic characteristics, PTSD or new-onset mTBI, PTSD, new-onset mTBI, symptoms of common mental disorder based on the GHQ-12 and alcohol misuse at follow up, except that loss of concentration was borderline nonsignificant (prevalence ratio = 1.29; 95% confidence interval, 0.98-1.71) after adjustment for demographic and military factors, and new mTBI when compared with the "other injury" control group. Mild traumatic brain injury was associated with most PCS in the comparison with the "no-injury" group when adjusted for social and military demographic variables (see Table 3) but became nonsignificant in models that included new-onset mTBI, PTSD, symptoms of common mental disorder, and alcohol misuse at follow-up (see Table 3). Of those who reported an mTBI at baseline, 25% reported another mTBI at follow-up (new-onset mTBI), and in the "other injury" and "no injury" at

**TABLE 1** *Comparison of follow-up responders and nonresponders (N = 4601)*

| | Nonresponders at follow-up, *N* = 2283 | Responders at follow-up, *N* = 2318 | OR (95% CI) |
|---|---|---|---|
| Sex | | | |
| Male | 2117 (92.7%) | 2081 (89.8%) | 1.00 |
| Female | 166 (7.3%) | 237 (10.2%) | 1.45 (1.18-1.79) |
| Age, y | | | |
| <29 | 1252 (54.8%) | 800 (34.5%) | 1.00 |
| ≥29 | 1031 (45.2%) | 1518 (65.5%) | 2.30 (2.05-2.60) |
| Education | | | |
| No qualifications or O level | 1202 (54.5%) | 841 (37.4%) | 1.00 |
| A level or degree | 1003 (45.5%) | 1409 (62.6%) | 2.01 (1.78-2.26) |
| Marital status | | | |
| In a relationship | 1647 (72.8%) | 1759 (76.1%) | 1.00 |
| Single or ex-relationship | 616 (27.28%) | 553 (23.9%) | 0.84 (0.74-0.96) |
| Service | | | |
| Naval services | 237 (10.4%) | 211 (9.1%) | 0.95 (0.78-1.16) |
| Army | 1686 (73.9%) | 1573 (67.9%) | 1.00 |
| RAF | 360 (15.8%) | 534 (23.0%) | 1.59 (1.37-1.85) |
| Rank | | | |
| Officer | 290 (12.7%) | 681 (29.4%) | 1.00 |
| NCO | 1276 (55.9%) | 1318 (56.9%) | 0.44 (0.38-0.52) |
| Other rank | 717 (31.4%) | 319 (13.8%) | 0.19 (0.16-0.23) |
| Engagement type | | | |
| Regular | 2117 (92.7%) | 2034 (87.8%) | 1.00 |
| Reserve | 166 (7.3%) | 284 (12.3%) | 1.78 (1.46-2.18) |
| PCL case (49/50) | | | |
| No | 2158 (96.0%) | 2231 (96.8%) | 1.00 |
| Yes | 93 (4.1%) | 74 (3.2%) | 0.77 (0.56-1.05) |
| GHQ-12 case (3/4) | | | |
| No | 1823 (81.6%) | 1869 (81.2%) | 1.00 |
| Yes | 412 (18.4%) | 432 (18.8%) | 1.02 (0.88-1.19) |
| Alcohol misuse (15/16) | | | |
| No | 1791 (80.5%) | 1991 (86.6%) | 1.00 |
| Yes | 434 (19.5%) | 308 (13.4%) | 0.64 (0.54-0.75) |
| Postconcussion symptoms | | | |
| No symptoms | 601 (27.1%) | 509 (22.4%) | 1.00 |
| 1 or 2 symptoms | 760 (34.2%) | 784 (34.4%) | 1.22 (1.04-1.42) |
| ≥3 symptoms | 859 (38.7%) | 984 (43.2%) | 1.35 (1.17-1.57) |
| mTBI status at baseline | | | |
| Other injury | 225 (9.9%) | 261 (11.3%) | 1.00 |
| mTBI | 112 (4.9%) | 90 (3.9%) | 0.69 (0.50-0.96) |
| No injury | 1946 (85.2%) | 1967 (84.9%) | 0.87 (0.72-1.05) |

Abbreviations: CI, confidence interval; GHQ-12, General Health Questionnaire-12; mTBI, mild traumatic brain injury; NCO, noncommissioned officer; OR, odds ratios; PCL, Posttraumatic Stress Disorder Checklist; RAF, Royal Air Force.

baseline groups, 17% and 10% reported a new-onset mTBI, respectively.

In comparison with "other injury" and "no injury," several PCS were significantly associated in the model adjusted for social and military demographic variables and for "other injury" in addition for adjustment for PTSD (see Tables 2 and 3). However, we found no evidence that there was a long-term association with an mTBI event 7 years ago for 7 of the 9 PCS at follow-up when adjusted for new mTBI and mental disorders as a group.

We assessed the stability of each PCS between baseline and follow-up in the total sample (see Table 4). The largest groups usually, but not always, consisted of those who did not experience symptoms at either time point (fatigue, 27%, to double or blurred vision, 87%). Of the discordant responses (yes to no or no to yes), for most PCS more participants reported new onset (no to yes) than reported remitted symptoms (yes to no), except for headache that was more frequently reported at baseline than at follow-up and irritability that was similar at both time points. The relative frequency of those with a persistent PCS was variable, being high for sleeping difficulties (34%), fatigue (30%), and headaches (23%), and infrequent for dizziness (3%) and double or blurred vision (1.4%). The percentages of concordance (yes-yes)

**TABLE 2** *Prevalence and adjusted association in terms of prevalence ratios of each postconcussion symptom at follow-up with mTBI at baseline: mTBI versus "other injury," N = 351*[a,b]

| PCS at follow-up | mTBI, *N* (%) | Other injury, *N* (%) | Adjusted for demographic variables[c] APR (95% CI) | Adjusted for demographic variables[c] and PTSD at follow-up APR (95% CI) | Adjusted for demographic variables[c] and mTBI at follow-up APR (95% CI) | Adjusted for demographic variables[c], mTBI, PTSD, GHQ-12, alcohol misuse at follow-up APR (95% CI) |
|---|---|---|---|---|---|---|
| Headache | 45 (49.5) | 104 (39.7) | 1.28 (0.93-1.76) | 1.13 (0.80-1.59) | 1.19 (0.79-1.78) | 1.20 (0.82-1.77) |
| Dizziness | 27 (38.7) | 37 (17.2) | 2.26 (1.39-3.68) | 1.64 (1.03-2.60) | 1.89 (1.08-3.32) | 2.51 (1.45-4.34) |
| Fatigue | 72 (78.0) | 184 (70.9) | 1.15 (0.97-1.36) | 1.09 (0.91-1.30) | 1.06 (0.80-1.41) | 1.07 (0.80-1.42) |
| Sleeping difficulties | 61 (72.3) | 167 (62.9) | 1.12 (0.91-1.38) | 1.02 (0.83-1.26) | 1.08 (0.84-1.40) | 1.08 (0.84-1.38) |
| Irritability | 50 (55.7) | 121 (52.6) | 1.11 (0.87-1.42) | 1.00 (0.78-1.28) | 1.18 (0.88-1.58) | 1.21 (0.90-1.62) |
| Double or blurred vision | 22 (26.8) | 37 (15.2) | 1.82 (1.00-3.34) | 1.34 (0.71-2.52) | 1.65 (0.82-3.78) | 1.71 (0.63-4.68) |
| Forgetfulness | 50 (59.4) | 127 (45.5) | 1.31 (1.02-1.68) | 1.19 (0.93-1.52) | 1.07 (0.78-1.48) | 1.10 (0.79-1.54) |
| Ringing in ears | 46 (56.4) | 93 (38.7) | 1.48 (1.10-1.99) | 1.33 (0.98-1.81) | 1.16 (0.80-1.71) | 1.16 (0.80-1.70) |
| Loss of concentration | 57 (67.3) | 118 (46.9) | 1.48 (1.19-1.84) | 1.37 (1.00-1.70) | 1.29 (0.98-1.71) | 1.35 (1.02-1.80) |

Abbreviations: APR, adjusted prevalence ratio; CI, confidence interval; GHQ-12, General Health Questionnaire-12; mTBI, mild traumatic brain injury; PCS, postconcussion symptoms; PTSD, posttraumatic stress disorder.

[a]The unweighted unadjusted prevalence ratio can be calculated dividing the percentage in the mTBI group by the percentage in the "other injury" group, for example, for headache 49.5%/39.7% = prevalence ratio: 1.25.

[b]Percentages and prevalence ratios are weighted to take account of nonresponse.

[c]Sex, age, education, marital status, service, rank, and enlistment type (regular or reserve).

**TABLE 3** *Prevalence and adjusted association in terms of prevalence ratios of each postconcussion symptom at follow-up with mTBI at baseline: mTBI versus "no injury," N = 2057*[a,b]

| PCS at follow-up | mTBI, *N* (%) | No injury, *N* (%) | Adjusted for demographic variables[c] APR (95% CI) | Adjusted for demographic variables[c] and PTSD at follow-up APR (95% CI) | Adjusted for demographic variables[c] and mTBI at follow-up APR (95% CI) | Adjusted for demographic variables,[c] mTBI, PTSD, GHQ-12, alcohol misuse at follow up APR (95% CI) |
|---|---|---|---|---|---|---|
| Headache | 45 (49.5) | 700 (37.9) | 1.36 (1.02-1.80) | 1.18 (0.88-1.58) | 1.09 (0.75-1.58) | 1.06 (0.75-1.50) |
| Dizziness | 27 (38.7) | 289 (14.8) | 2.60 (1.79-3.77) | 2.02 (1.40-2.90) | 1.80 (1.16-2.80) | 1.82 (1.19-2.79) |
| Fatigue | 72 (78.0) | 1245 (63.9) | 1.26 (1.08-1.46) | 1.16 (1.00-1.35) | 0.99 (0.77-1.26) | 0.94 (0.74-1.20) |
| Sleeping difficulties | 61 (72.3) | 1078 (55.8) | 1.28 (1.08-1.50) | 1.15 (0.97-1.35) | 1.15 (0.95-1.38) | 1.09 (0.90-1.32) |
| Irritability | 50 (55.7) | 676 (36.7) | 1.50 (1.17-1.92) | 1.29 (1.03-1.61) | 1.33 (0.99-1.79) | 1.26 (0.94-1.70) |
| Double or blurred vision | 22 (26.8) | 216 (10.9) | 2.58 (1.58-4.20) | 1.68 (1.01-2.77) | 1.47 (0.79-2.73) | 1.42 (0.68-2.99) |
| Forgetfulness | 50 (59.4) | 796 (40.6) | 1.43 (1.11-1.84) | 1.32 (1.05-1.65) | 1.16 (0.87-1.54) | 1.11 (0.83-1.48) |
| Ringing in ears | 46 (56.4) | 551 (30.4) | 1.71 (1.35-2.17) | 1.45 (1.13-1.86) | 1.32 (0.96-1.83) | 1.22 (0.86-1.74) |
| Loss of concentration | 57 (67.3) | 756 (39.2) | 1.66 (1.35-2.05) | 1.49 (1.23-1.81) | 1.39 (1.10-1.76) | 1.31 (1.01-1.70) |

Abbreviations: APR, adjusted prevalence ratio; CI, confidence interval; GHQ-12, General Health Questionnaire-12; mTBI, mild traumatic brain injury; PCS, postconcussion symptoms; PTSD, posttraumatic stress disorder.

[a]The unweighted unadjusted prevalence ratio can be calculated by dividing the percentage in the mTBI group divided by the percentage in the "no injury" group, for example, for headache 49.5%/37.9% = prevalence ratio: 1.31.

[b]Percentages and prevalence ratios are weighted to take account of nonresponse.

[c]Sex, age, education, marital status, service, rank, and enlistment type (regular or reserve).

**TABLE 4** *Stability of PCS in terms of change of status endorsement over time in the total sample*[a]

| PCS | Persistent (yes-yes), *N* (%) | Remitted (yes-no), *N* (%) | New onset (no-yes), *N* (%) | No endorsement of symptom (no-no), *N* (%) | Total |
|---|---|---|---|---|---|
| Headache | 528 (23.4) | 457 (20.2) | 318 (14.1) | 958 (42.4) | 2261 |
| Dizziness | 74 (3.3) | 116 (5.1) | 278 (12.3) | 1791 (79.3) | 2259 |
| Fatigue | 686 (30.3) | 153 (6.8) | 808 (35.7) | 619 (27.3) | 2266 |
| Sleeping difficulties | 771 (34.0) | 284 (12.5) | 531 (23.4) | 682 (30.1) | 2268 |
| Irritability | 498 (22.0) | 359 (15.8) | 346 (15.3) | 1063 (46.9) | 2266 |
| Double or blurred vision | 32 (1.4) | 27 (1.2) | 241 (10.7) | 1962 (86.7) | 2262 |
| Forgetfulness | 438 (19.4) | 200 (8.9) | 527 (23.3) | 1096 (48.5) | 2261 |
| Ringing in ears | 259 (11.5) | 91 (4.0) | 425 (18.8) | 1487 (65.7) | 2262 |
| Loss of concentration | 376 (16.7) | 187 (8.3) | 547 (24.3) | 1146 (50.8) | 2256 |

Abbreviation: PCS, postconcussion symptoms.
[a] $N = 2318$ (completed baseline and follow-up assessments) unweighted.

were similar in the 3 groups, mTBI, other injury, and no injury for most PCS. The changes to remitted or new onset were broadly similar regardless of group (mTBI, "other injury," and "no injury") (see Table 5).

The McNemar tests demonstrated a highly significant tendency for sleeping difficulties, fatigue, double vision/blurred vision, dizziness, loss of concentration, and ringing in the ears to be higher for the sequence no-yes (new onset) than the sequence yes-no (remitted). However, the McNemar test was not significant for the mTBI group for sleeping difficulties, dizziness, and loss of concentration, probably because of lack of statistical power. There were 2 exceptions to the general trend: for irritability the McNemar test was not significant in any of the 3 groups, while for headache remission was more common. Overall, this analysis demonstrates that changes in PCS between baseline and follow-up were consistent between groups and independent of experiencing an mTBI event at baseline.

## DISCUSSION

The main findings of this study were that retrospective accounts of mTBI experienced during deployment were not associated with 7 of 9 PCS reported after 7 years of follow-up in the fully adjusted models. However, mTBI was associated with 2: dizziness and in most analyses, loss of concentration. These associations persisted after adjusting for social and military demographic confounders and in the case of dizziness, the association persisted after further adjustment for a subsequent mTBI event occurring in the 3 years before completing the follow-up questionnaire and that could have influenced the current PCS. Adjustment for current PTSD, symptoms of common mental disorder, recent mTBI, and alcohol misuse, which were considered possible confounders did not account for the association. The effect sizes were intermediate with prevalence ratios greater than 2 and lower than 4.[25] We also found that the prevalence of PCS increased over time, the only exceptions were irritability that remained stable and headache that tended to decrease over time. The increases in prevalence rates of most PCS at follow-up were independent of mTBI at baseline.

### Long-term correlates of mTBI

Our study showed some support for both dizziness and loss of concentration being long-term correlates of an earlier mTBI. That this is a specific link is supported by the results from the 2 control samples, although the results for loss of concentration were less compelling. We used 2 types of controls in the current study, whereas in our previous cross-sectional study, we followed the Hoge and colleagues'[1] approach of comparing an mTBI group with a group that experienced an injury during deployment but no mTBI symptoms. These 2 groups were similar in that they both experienced an adverse event with physical consequences during deployment.[1,12] Seven years after reporting the initial event, many other events may have occurred and injury during deployment may have become less salient. Following the example of numerous authors who compared the mTBI group with the rest of their sample,[2,26,27] we also used a second comparison group that reported having "no injury" during deployment. Our results were remarkably consistent regardless of the comparison group used, except that the statistical power was lower when making comparisons between the mTBI and the "other injury" groups.

It is notable that mTBI was associated with dizziness in both this longitudinal analysis and our previous

**TABLE 5** *Change of postconcussion symptoms from phase 2 to phase 3*[a]

| | Phase 2 mTBI status | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | mTBI (LOC + AMS), *N* = 90 | | | Other injury, *N* = 261 | | | No injury, *N* = 1967 | | |
| **Symptom at p2 and p3** | **Remitted[b], *N* (%)** | **New onset[c], *N* (%)** | ***P* (exact McNemar)** | **Remitted[b], *N* (%)** | **New onset[c], *N* (%)** | ***P* (exact McNemar)** | **Remitted[b], *N* (%)** | **New onset[c], *N* (%)** | ***P* (exact McNemar)** |
| Headache | 23 (25.8) | 12 (13.5) | .09 | 59 (23.4) | 39 (15.5) | .05 | 375 (19.5) | 267 (13.9) | <.0001 |
| Dizziness | 10 (11.5) | 18 (20.7) | .13 | 10 (4.0) | 27 (10.7) | .008 | 96 (5.0) | 233 (12.1) | <.0001 |
| Fatigue | 7 (7.8) | 34 (37.8) | <.0001 | 18 (7.1) | 79 (31.1) | <.0001 | 128 (6.7) | 695 (36.2) | <.0001 |
| Sleeping difficulties | 15 (17.1) | 15 (17.1) | 1.00 | 34 (13.4) | 51 (20.1) | .08 | 235 (12.2) | 465 (24.1) | <.0001 |
| Irritability | 15 (16.9) | 12 (13.5) | .70 | 48 (19.0) | 44 (17.4) | .75 | 296 (15.4) | 290 (15.1) | .84 |
| Double or blurred vision | 4 (4.4) | 18 (20.0) | .004 | 3 (1.2) | 34 (13.6) | <.0001 | 20 (1.0) | 189 (9.8) | <.0001 |
| Forgetfulness | 7 (7.8) | 23 (25.6) | .005 | 21 (8.3) | 62 (24.6) | <.0001 | 172 (9.0) | 442 (23.0) | <.0001 |
| Loss of concentration | 12 (13.5) | 21 (23.6) | .16 | 24 (9.7) | 63 (25.4) | <.0001 | 151 (7.9) | 463 (24.1) | <.0001 |
| Ringing in ears | 7 (8.0) | 18 (20.5) | .04 | 15 (5.9) | 49 (19.4) | <.0001 | 69 (3.6) | 358 (18.6) | <.0001 |

Abbreviations: AMS, altered mental status; LOC, loss of consciousness; mTBI, mild traumatic brain injury.

[a] *N* = 2318 (completed baseline and follow up assessments) unweighted.

[b] Symptom at baseline, no symptom at follow-up.

[c] No symptom at baseline, symptom at follow-up.

cross-sectional analysis,[12] which would be consistent with Hoge and colleagues'[1] findings if their 2 groups of mTBI (those with loss of consciousness and those with altered mental status) had been merged, as they were in this study. However, this association was not reported in a longitudinal study carried out a year after baseline data were collected.[28] It is worth noting that the consistency in the association between mTBI and dizziness was maintained over time, despite the increased prevalence of these symptoms in the total sample.

On the contrary, there was no association between mTBI and headache in the fully adjusted model in this study in contrast to previous cross-sectional studies,[1,12] nor was there an association with double or blurred vision in the fully adjusted model in contrast to our previous study.[12]

Our finding that mTBI is related to loss of concentration is consistent with a meta-analysis by Karr and colleagues[9] assessing the cognitive sequelae of mTBI and a meta-analysis assessing blast-related mTBI.[29] These meta-analyses showed compromise of executive function associated with mTBI, albeit mainly in relation to those reporting multiple mTBI events in the analysis including all studies[9] and specifically affecting set-shifting, an element of the executive function, in the study including only military personnel.[29] These symptoms may be related to the finding of loss of concentration associated with mTBI in our study. Most of the studies included in Karr and colleagues' meta-analyses were cross-sectional, which limits causal inferences derived from their studies and their conclusion that the executive function fully recovered 90 days post-mTBI is at variance with our finding that loss of concentration is related to mTBI long after deployment. Our study extends this finding by showing that it is possible that loss of concentration may be a persistent symptom associated with mTBI, a finding not possible to assess in the study by Karr and colleagues.

As far as we know, there has been only 1 previous long-term study exploring the outcomes of mTBI in the military.[8] Vasterling and colleagues[8] did not find a single association between mTBI and neuropsychological performance. They reported some association between PTSD and neuropsychological performance, but we adjusted for PTSD, so our findings cannot be explained by underadjustment. In a previous study with a shorter follow-up, the same authors found that mTBI was associated with only 1 of 13 neuropsychological outcomes (visual reproductions).[30] A prospective longitudinal study of US army personnel concluded that mTBI during deployment increased the risk for persistent PCS, but the authors did not compare PCS with a group that did not report mTBI.[13] A longitudinal study of National Guard Soldiers did not find an association with PCS[28] but on the contrary, a Canadian study reported that mTBI was highly associated with continued lack of fitness for duty, but this association was mainly explained by mental disorders and musculoskeletal problems.[31] Finally, another study reported that a substantial proportion of those who reported mTBI during deployment reported PCS 3 months after the end of deployment.[32] Our study seems to be alone among those that show a long-term effect of mTBI in terms of loss of concentration.

### Trends over time of PCS

Seven of the 9 PCS in our study showed an increase in prevalence over a 7-year period. The exceptions were headaches and irritability. We have shown that increases in prevalence rates are not restricted to mTBI. Despite the general increasing trend of nonspecific PCS, dizziness and loss of concentration were still associated with mTBI in our study.

### Strengths and limitations

This is the only military study that has evaluated the long-term correlates of mTBI in relation to PCS based on a longitudinal design though another study looked at long-term correlates in terms of neurocognitive functioning.[8] The response rate in our study was satisfactory (50%) considering that the follow-up study took place after 7 years. Many members of the cohort left service and it is difficult to keep up-to-date contact information for this highly mobile, young, male population. We performed a weighted analysis to account for varying response rates in relation to social and military demographic factors. As for most, if not all population studies in the military, the information collected was subject to some degree of reporting bias in relation to mTBI experienced during deployment. We were able to account for the lack of specificity of PCS by adjusting for new possible episodes of mTBI and current mental disorders. In the interpretation of our results, it is worth noting that recall of mTBI is indeed inconsistent over time, in particular, there is a tendency to inflate the recall of an mTBI event over time,[28,33] which may have been the reason why a study we conducted during deployment had lower prevalence than another carried out postdeployment, albeit in different samples.[7,34] Another report found that inconsistent reporting might have been partly due to current PTSD symptoms.[35] The validity of the instrument has also been queried. The sensitivity and specificity of self-report mTBI using the same questions we used compared with a brief structural clinical interview were 80% and 93%, respectively,[36] but lower in another study where sensitivity was 61% and specificity was 88%.[37] Although we adjusted for many potential confounders, we cannot be sure that some residual effects of unknown confounders have not been accounted for in the analysis. It is worth

noting that the PCS were embedded within a different set of questions in phase 2 and phase 3. This should not affect the main analysis related to associations over time as the structure was the same for the mTBI group and the 2 control groups. However, we cannot discard the possibility that this may partly explain the increase of PCS over time.

## CONCLUSIONS

We found that mTBI is still associated with dizziness and loss of concentration 7 years after the index event. On the contrary, most of the nonspecific PCS increased over time among both mTBI and 2 control groups and so were not specific to mTBI. Only headache decreased in prevalence, but mTBI was not associated with headaches in this longitudinal study, although previous cross-sectional studies showed an association.[1,12] Of clinical relevance, dizziness or loss of concentration in a patient who experienced mTBI may be a complaint long after the event, but for the great majority of those who experienced mTBI during deployment, PCS would have remitted.

## REFERENCES


1. Hoge CW, McGurk D, Thomas JL, Cox AL, Engel CC, Castro CA. Mild traumatic brain injury in US soldiers returning from Iraq. *N Engl J Med*. 2008;358:453–463.
2. Pietrzak RH, Johnson DC, Goldstein MB, Malley JC, Southwick SM. Posttraumatic stress disorder mediates the relationship between mild traumatic brain injury and health and psychosocial functioning in veterans of Operations Enduring Freedom and Iraqi Freedom. *J Nerv Ment Dis*. 2009;197:748–753.
3. Schneiderman AI, Braver ER, Kang HK. Understanding sequelae of injury mechanisms and mild traumatic brain injury incurred during the conflicts in Iraq and Afghanistan: persistent postconcussive symptoms and posttraumatic stress disorder. *Am J Epidemiol*. 2008;167:1446–1452.
4. Tanielian T, Jaycox LH, Schell TL, Marshall GN, Vaiana ME. Treating the invisible wounds of war: conclusions and recommendations. In: Tanielian T, Jaycox LH, eds. *Invisible Wounds of War: Psychological and Cognitive Injuries, Their Consequences, and Services to Assist Recovery*. Santa Monica, CA: RAND; 2008.
5. Terrio H, Brenner LA, Ivins BJ, et al. Traumatic brain injury screening: preliminary findings in a US Army Brigade Combat Team. *J Head Trauma Rehabil*. 2009;24:14–23.
6. Rona RJ, Jones M, Fear NT, Sundin J, Hull L, Wessely S. Frequency of mild traumatic brain injury in Iraq and Afghanistan: are we measuring incidence or prevalence? *J Head Trauma Rehabil*. 2012;27:75–82.
7. Jones N, Fear NT, Rona R, et al. Mild traumatic brain injury (mTBI) among UK military personnel whilst deployed in Afghanistan in 2011. *Brain Inj*. 2014;28:896–899.
8. Vasterling JJ, Aslan M, Lee LO, et al. Longitudinal associations among posttraumatic stress disorder symptoms, traumatic brain injury, and neurocognitive functioning in army soldiers deployed to the Iraq War. *J Int Neuropsychol Soc*. 2018;24:311–323.
9. Karr JE, Areshenkoff CN, Garcia-Barrera MA. The neuropsychological outcomes of concussion: a systematic review of meta-analyses on the cognitive sequelae of mild traumatic brain injury. *Neuropsychology*. 2014;28:321–336.
10. Dretsch MN, Silverberg ND, Iverson GL. Multiple past concussions are associated with ongoing postconcussive symptoms but not cognitive impairment in active-duty army soldiers. *J Neurotrauma*. 2015;32:1301–1306.
11. Kashluba S, Casey JE, Paniak C. Evaluating the utility of ICD-10 diagnostic criteria for postconcussion syndrome following mild traumatic brain injury. *J Int Neuropsychol Soc*. 2006;12:111–118.
12. Rona RJ, Jones M, Fear NT, et al. Mild traumatic brain injury in UK military personnel returning from Afghanistan and Iraq: cohort and cross-sectional analyses. *J Head Trauma Rehabil*. 2012;27:33–44.
13. Stein MB, Ursano RJ, Campbell-Sills L, et al. Prognostic indicators of persistent postconcussive symptoms after deployment-related mild traumatic brain injury: a prospective longitudinal study in U.S. army soldiers. *J Neurotrauma*. 2016;33:2125–2132.
14. Hotopf M, Hull L, Fear NT, et al. The health of UK military personnel who deployed to the 2003 Iraq war: a cohort study. *Lancet*. 2006;367:1731–1741.
15. Fear NT, Jones M, Murphy D, et al. What are the consequences of deployment to Iraq and Afghanistan on the mental health of the UK armed forces? A cohort study. *Lancet*. 2010;375:1783–1797.
16. Stevelink SAM, Jones M, Hull L, et al. Mental health outcomes at the end of the British involvement in the Iraq and Afghanistan conflicts: a cohort study. *Br J Psychiatry*. 2018;213(6):690–697.
17. Fear NT, Jones E, Groom M, et al. Symptoms of post-concussional syndrome are non-specifically related to mild traumatic brain injury in UK Armed Forces personnel on return from deployment in Iraq: an analysis of self-reported data. *Psychol Med*. 2009;39:1379–1387.
18. Derogatis LR, Lipman RS, Rickels K, Uhlenhuth EH, Covi L. The Hopkins Symptom Checklist (HSCL): a self-report symptom inventory. *Behav Sci*. 1974;19:1–15.
19. Kroenke K, Spitzer RL, Williams JB. The PHQ-15: validity of a new measure for evaluating the severity of somatic symptoms. *Psychosom Med*. 2002;64:258–266.
20. Iverson GL, Langlois JA, McCrea MA, Kelly JP. Challenges associated with postdeployment screening for mild traumatic brain injury in military personnel. *Clin Neuropsychol*. 2009;23:1299–1314.
21. Goldberg DP, Gater R, Sartorius N, et al. The validity of two versions of the GHQ in the WHO study of mental illness in general health care. *Psychol Med*. 1997;27:191–197.
22. Blanchard EB, Jones-Alexander J, Buckley TC, Forneris CA. Psychometric properties of the PTSD Checklist (PCL). *Behav Res Ther*. 1996;34:669–673.
23. Babor TF, Higgins-Biddle JC, Saunders JB, Monteiro MG. *Audit. The Alcohol Use Disorders Identification Test. Guidelines for Use in Primary Care*. 2nd ed. Geneva, Switzerland: Department of Mental Health and Substance Dependence, World Health Organization; 2001.
24. Fear NT, Iversen A, Meltzer H, et al. Patterns of drinking in the UK Armed Forces. *Addiction*. 2007;102:1749–1759.
25. Sullivan GM, Feinn R. Using effect size-or why the P value is not enough. *J Graduate Med Educ*. 2012;4:279–282.
26. Meares S, Shores EA, Taylor AJ, et al. Mild traumatic brain injury does not predict acute postconcussion syndrome. *J Neurol Neurosurg Psychiatry*. 2008;79:300–306.
27. Vanderploeg RD, Belanger HG, Curtiss G. Mild traumatic brain injury and posttraumatic stress disorder and their associations with health symptoms. *Arch Phys Med Rehabil*. 2009;90:1084–1093.

28. Polusny MA, Kehle SM, Nelson NW, Erbes CR, Arbisi PA, Thuras P. Longitudinal effects of mild traumatic brain injury and posttraumatic stress disorder comorbidity on postdeployment outcomes in national guard soldiers deployed to Iraq. *Arch Gen Psychiatry*. 2011;68:79–89.
29. Karr JE, Areshenkoff CN, Duggan EC, Garcia-Barrera MA. Blast-related mild traumatic brain injury: a Bayesian random-effects meta-analysis on the cognitive outcomes of concussion among military personnel. *Neuropsychol Rev*. 2014;24:428–444.
30. Vasterling JJ, Brailey K, Proctor SP, Kane R, Heeren T, Franz M. Neuropsychological outcomes of mild traumatic brain injury, posttraumatic stress disorder and depression in Iraq-deployed US Army soldiers. *Br J Psychiatry*. 2012;201:186–192.
31. Garber BG, Rusu C, Zamorski MA, Boulos D. Occupational outcomes following mild traumatic brain injury in Canadian military personnel deployed in support of the mission in Afghanistan: a retrospective cohort study. *BMJ Open*. 2016;6: e010780.
32. Schwab K, Terrio HP, Brenner LA, et al. Epidemiology and prognosis of mild traumatic brain injury in returning soldiers: a cohort study. *Neurology*. 2017;88:1571–1579.
33. Alosco ML, Aslan M, Du M, et al. Consistency of recall for deployment-related traumatic brain injury. *J Head Trauma Rehabil*. 2016;31:360–368.
34. Rona RJ, Jones M, Sundin J, et al. Predicting persistent posttraumatic stress disorder (PTSD) in UK military personnel who served in Iraq: a longitudinal study. *J Psychiatr Res*. 2012;46(9):1191–1198.
35. Nelson NW, Anderson CR, Thuras P, et al. Factors associated with inconsistency in self-reported mild traumatic brain injury over time among military personnel in Iraq. *Br J Psychiatry*. 2015; 206:237–244.
36. Terrio HP, Nelson LA, Betthauser LM, Harwood JE, Brenner LA. Postdeployment traumatic brain injury screening questions: Sensitivity, specificity, and predictive values in returning soldiers. *Rehabil Psychol*. 2011;56:26–31.
37. Vanderploeg RD, Belanger HG. Stability and validity of the Veterans Health Administration's traumatic brain injury clinical reminder screen. *J Head Trauma Rehabil*. 2015;30:E29–E39.