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Neuropsychiatric Outcomes in UK Military Veterans with Mild Traumatic Brain Injury and Vestibular Dysfunction

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Abstract

Objective: To estimate the frequency of vestibular dysfunction following blunt, blast, and blunt & blast mild traumatic brain injury (mTBI) and thereon assess the long-term impact of vestibular dysfunction on neurobehavioral function and disability independently of co-morbid psychiatric symptoms. **Setting:** Combat Stress residential and Veterans' Outreach drop-in centres for psychological support. **Participants:** 162 help-seeking UK military veterans. **Main measures**: Self-reported frequency and severity of mTBI (using the Ohio State Identification Method), Vertigo Symptom Scale, PTSD checklist for DSM5, Kessler Psychological Distress Scale, Neurobehavioral Symptom Inventory, HIT6, Memory Complaints Inventory, WHO Disability Assessment Scale 2.0. **Results:** 72% of the sample reported one or more mTBI over their lifetime. Chi-square analyses indicated that vestibular disturbance, which affected 69% of participants, was equally prevalent following blunt (59%) or blast (47%) injury and most prevalent following blunt and blast combined (83%). Mediation analysis indicated that when PTSD, depression and anxiety were taken into account, vestibular dysfunction in participants with mTBI was directly and independently associated with increased postconcussive symptoms and functional disability. **Conclusion**: Vestibular dysfunction is common after combined blunt and blast mTBI and singularly predictive of poor long-term mental health. From a treatment perspective, vestibular rehabilitation may provide relief from postconcussive symptoms other than dizziness and imbalance.

Keywords: *Balance, mTBI, blast, blunt, veterans.*

Introduction

Between the periods of 2003 to 2011 there were 2440 UK casualties in Operations Herrick (Afghanistan) and TELIC (Iraq).[1] Approximately 19% of casualties sustained a traumatic brain injury and although 87% were graded as moderate-to-severe, estimates derived from US personnel give reason to believe that the incidence of mild TBI (mTBI) was likely under-reported.[2] mTBI acquired during combat is significantly associated with long-term neuro-behavioural and psychiatric (most notably PTSD) disturbance, and is a risk factor for alcohol abuse and general disability. Elevated exposure to munitions explosions leave military personnel uniquely susceptible to blast-induced mTBI which, perhaps unsurprisingly, is associated with damage to the vestibular organs of the inner ear. Vestibular injury can also be sustained through blunt injury to the back of the head via projectile or fall. Of particular interest here, studies in civilians show overlap in the neurobehavioural and psychiatric symptoms that accompany vestibular dysfunction and mTBI. Coupled with the fact that vestibular assessment is not routinely performed on military personnel, this raises the possibility that some symptoms which are vestibular in origin have been misattributed to mTBI. In the present study, we compared the relative prevalence of vestibular symptoms in blast and blunt mTBI in help-seeking UK veterans to determine the group most at risk of vestibular-related impairment. We then determined the contribution of vestibular dysfunction to neuropsychiatric function and more general disability.

The estimated incidence of mTBI ranges between 15%[3] and 23%[4] in US personnel to 3.2%[5] and 13.5% in UK personnel.[1,6] Several factors may help explain this discrepancy including the greater reliance on self-report rather than medical records in the US, and the shorter deployment periods of UK soldiers (6 months compared to 12-18 months for US personnel). There is however an emerging consensus that the effects of mTBI sustained during deployment are best understood within the context of lifetime TBI exposure.[7]

mTBI is associated with a broad range of psychiatric and neurological symptoms, the most common of which are headache, fatigue, sleep disorder, dizziness, amnesia, information processing slowing, executive dysfunction, depression and anxiety.[8] mTBI sustained in combat is often accompanied by PTSD and bodily trauma which can make it difficult to determine the relative contribution of each of these factors. Studies indicate that mTBI is not by itself a strong determinant of well-being and general functional outcome in veterans.[9] Rather, it becomes so when accompanied by co-morbid neurological and psychiatric complications. For example, Lippa et al,[9] found that while combat veterans with a history of mTBI reported more psychiatric and behavioural conditions, their disability (as measured by the World Health Organisation Disability Assesment Schedule II) was not significantly affected. By contrast, Lippa et al.,[9] found that the concurrence of mTBI with PTSD and depression afforded a unique vulnerability to poor general outcome, causing a substantial worsening of independent function, self-care and social reintegration.

Another common co-morbidity in military mTBI is vestibular impairment although its effect on mental health is less clear. The vestibular system comprises peripheral organs located within the labyrinth of the inner ear which detect angular and linear acceleration of the head. These organs convey information via the brainstem vestibular nuclei to cortical and sub-cortical regions involved in sensori-motor control, interoception and spatial cognition. Although not as well characterised as audiological impairment, vestibular impairment can be induced by the blast wave from a nearby munitions explosion which induces an over-pressurisation followed by an under-pressurisation in the air and fluid filled chambers of the inner ear.[10] The mechanical damage caused by such a blast wave can be compounded by noise-induced damage (typically >140dB), toxin exposure, and, if the individual falls over and bangs the back of the head or is hit by a projectile, blunt injury.[11] Aside from causing middle and inner ear damage, white matter abnormalities and diffuse axonal injury have been observed in cerebellum, thalamus and ventral posterior cerebral cortex in mTBI patients presenting with vestibulopathy.[12] The presence of these abnormalities has been shown to correlate with time to recovery and neurocognitive test performance. Unfortunately, vestibular symptoms are among the most common after mTBI. In the large-scale study (n=907) conducted by Terrio et al,[4] dizziness and balance problems were the second most commonly reported symptom reported by individuals immediately after sustaining mTBI, with 11.5% reporting persistent problems post-deployment. In a case series, Hoffer et al.[13] reported that 84% of mTBI veterans who had sustained a blast-related mTBI had acute dizziness symptoms more than 30days after injury.[13] A follow-up study in a smaller cohort indicated persistent postural instability up to 7 years later,[14] a concerning finding given that dizziness at just 6 months post-onset is closely linked to psychological distress and failure to return to work.[15]

A growing number of studies indicate that damage to the vestibular system affects neuropsychiatric function in a manner quite similar to that found in postconcussive syndrome. In a seminal paper, Grimm et al. reported cognitive disturbances in patients diagnosed with perilymph fistula syndrome including general forgetfulness, a specific deficit in auditory short-term memory, apraxia, and a general slowing of information processing.[16] Fatigue, anxiety, depression and unexplainable dread were also commonly observed, and contributed to a clinical picture that the authors described as functionally devastating. More recent study has shown similar symptoms in patients diagnosed with vestibular migraine and other non-traumatic pathologies,[17] while a large-scale survey of 20,950 adults in the US revealed that the 8% who self-reported vestibular vertigo were eight times more likely to have serious difficulty concentrating or remembering, four times more likely to have limitations on daily living, and three times more likely to suffer from depression, anxiety or panic disorder.[18]

Veterans who show balance impairment, either via questionnaire[19] or vestibulography[20] are also much more likely to report PTSD symptoms, a finding that may derive from the shared neurochemical features of the ascending vestibular afference and limbic and arousal systems.[21] This same network has also been implicated in the strong association between balance impairment and migraine headache.[21] More recently, Haber et al,[20] reported high correlations in 30 veterans between balance/postural impairment and self-reports of fatigue, depression and PTSD. Together these indicate that the disturbances in gravitational and head-centred frames of reference induced by vestibular disorder compromise brain processes not only involved in balance and autonomic motor control but intellectual, emotional, interoceptive and arousal regulation too. Such indications raise the possibility that vestibular impairment makes an independent contribution to the neuro-behavioural and functional capacity of military veterans, regardless of whether mTBI has been sustained.

The aims of the present study were two-fold. First, we sought to establish, for the first time, the relative prevalence of chronic vestibular injury in veterans with either blunt, blast or blunt+blast lifetime mTBI. Although each of these mechanisms of injury can damage the vestibular system, there is uncertainty over which, if any, show the strongest association and thereby constitute the greatest risk for vestibular-related impairment. By means of comparison, studies of auditory dysfunction in military traumatic brain injury show a stronger association with blast injury; 62% and 38% of combat veterans who had sustained blast TBI reported hearing loss and reported tinnitus respectively, while only 44% and 18% of veterans in the non-blast group reported hearing loss and tinnitus respectively.[22] The second, and most important, study aim was to conduct an exploratory investigation of the direct and indirect associations between vestibular symptoms and both postconcussive symptoms and more general disability. Statistical mediation analysis was applied to determine whether postconcussive symptoms and more general disability are linked with vestibular symptoms independently of depression, anxiety and PTSD which have also been shown to exert influence. Mediation analysis also made it possible to examine the interplay between vestibular and psychiatric factors which in studies of UK veterans has been hampered by the absence of standardised vestibular and neuro-behavioural measures.

Study recruitment was restricted to veterans actively seeking psychological support given their poor life outcomes and the higher likelihood of vestibular impairment in individuals reporting psychiatric disturbance.

Methods

Participants

162 participants (158 White British, 4 Black British) were recruited for study - see Table I for their demography and military background. 137 were recruited from a 6week programme of in-patient psychiatric treatment at one of three *Combat Stress* treatment centres in the UK, and 25 participants were recruited from drop-in counselling sessions at the *Portsmouth Veterans Outreach* Centre. Individuals were eligible if over 18 years old, retired from the UK armed forces, and willing to consent to study participation. Potentially eligible participants were approached shortly after their treatment/counselling session and asked if they would be willing to conduct a survey aimed at assessing military veterans' experience of head injury. Favourable ethical opinions were given prior to study commencement from the University of Kent School of Psychology and Combat Stress research ethics review panels.

Procedure

Following written informed consent, participants completed the survey in a quiet corner room accompanied by the experimenter. The survey comprised a number of validated, standardised self-report assessments presented serially using the on-line survey software *Qualtrics* on an iPad. These assessments were administered in the order in which they appear below and were preceded by questions about demographic background and military service. Participants were told that they could take breaks throughout the survey as needed.

Self-Report Measures

Participants' lifetime history of TBI was measured using The Ohio State TBI Identification Method (OSTIM).[23] Additional questions were added from the Boston Assessment of TBI-lifetime (BAT-L) to determine blast proximity.[24] Responses to the OSTIM determined the presence/absence and severity of TBI using the US Department of Defense and Department of Veterans Affairs screening definitions.[25] mTBI classification involved an alteration of consciousness or mental state for a moment up-to 24hours post injury, and/or a loss of consciousness (LOC) of 0 to 30minutes and/or a presence of post-traumatic amnesia lasting less than one day. Moderate TBI was defined by a LOC for more than 30minutes and less than 24hours. Severe TBI was categorized as a LOC lasting more than 24hours. Vestibular symptoms were assessed using the Vertigo Symptom Scale Long form (VSSL) which comprises 22 items that quantify the duration and severity of vertigo and other dizziness symptoms.[26] Current postconcussive symptoms were mainly assessed using the Neurobehavioral Symptom Inventory (NSI),[27] although the Headache Impact Test (HIT6)[28] and Epworth Sleepiness Scale (ESS)[29] were also administered to more comprehensively probe the predicted association between vestibular symptoms and headache and daytime sleepiness. PTSD symptoms were assessed via the PTSD Checklist for DSM-5 (PCL-5),[30] and depression and anxiety were assessed using the Kessler Psychological Distress Scale (K10).[31] Functional Disability was assessed using the World Health Organisation Disability Assesment Schedule II short version (WHODAS 2.0).[32] Symptom exaggeration was assessed using the Memory Complaints Inventory (MCI) which has been validated in military personnel with a history of concussion and in civilian populations presenting with anxiety and depression. [34,33]

Results

Statistical Analyses

Summary statistics were calculated for the demographic, TBI and co-morbid characteristics of the sample. Chi-square analyses were then applied to compare the relative frequency of vestibular impairment in participants with self-endorsed blunt, blast, or blunt+blast (i.e. both blunt and blast) mTBI. For the purpose of the chi-square analysis, participants who reported dizziness symptoms more than 3 times per year were classified as suffering from vestibular disturbance while those who reported symptoms either never or only 1-3 times per year were classified as not suffering from vestibular disturbance. Mediation analyses[35] were conducted on scores provided by those who self-endorsed mTBI to determine if the severity of their vestibular symptoms (as measured by the VSSL total score) independently contributed to the broad profile of postconcussive symptoms (as measured by the NSI and HIT6) and disability (WHO-DAS 2.0) when depression, anxiety and PTSD were taken into account as mediators. The mediation analysis was also used to interrogate the relationship between vestibular symptoms and each of these mediators, and between these mediators and each of the outcome variables (NSI, HIT6 and WHO-DAS 2.0). Finally, the analysis allowed us to assess the combined association (i.e. total effect) of the predictor and mediator variables with the outcome measures.

Post hoc exploratory analysis interrogated the statistical outcomes of the NSI mediation analysis. A sensitivity analysis was conducted in which the mediation analysis was re-run on the adjusted NSI total score scores after the 3 items (items 1-3) on the NSI that relate to imbalance/unsteadiness were removed. This was carried out to determine if the observed association partly reflects the fact that both questionnaires probe several common symptoms. To estimate the extent to which the observed relationship between VSSL and NSI scores reflect vertigo and balance factors as opposed to autonomic and anxiety-related factors, two other modified versions of the original NSI mediation analysis were run; the first replaced the VSSL total score with the VSSL vertigo-balance subdomain score while the second replaced the VSSL total score with the autonomic-anxiety subdomain score.

Participants with missing data were excluded from analysis. All inferential analyses were computed using SPSS 24.

Overview of Sample Characteristics

Please see Table 1 for the sample demographic, Table 2 for participants' lifetime history and prevalence of mTBI, and Table 3 for their co-morbid neuropsychiatric symptoms. The mean age of the group, which was mostly male, was 46.6 years (standard deviation = 9.3) and had been deployed to a war zone an average of 4 times. Seventy two percent of the sample reported a lifetime history of one or more mTBIs (M age = 24.4, SD = 10.52), 74% of which resulted in a visit to an A&E department or acute military medical facility. 49% reported that they had periods in their lives where they had sustained repeated mTBIs. As shown in Table 3, the majority reported neuro-behavioural and neuro-psychiatric symptoms including imbalance, headache, daytime sleepiness, PTSD, and depression/anxiety. The average WHODAS score was 20.49 (*SD* = 10.70), which is worse than approximately 90% of the general international population.[36] Seventy-three participants (50%) indicated that they drank alcohol regularly, consuming a weekly average of 20.9 units (alcohol units defined by the UK Department of Health)[37]. Most of the sample (*n* = 118) had never used recreational drugs. 56 of the 110 participants with one or more mTBI who completed the MCI fell below the cut-off score (<40%) for symptom exaggeration. The mean MCI score was 39.59 (*SD* = 19.8).

Tables 1 and 2 here

Blast & Blunt mTBI

Sports related mTBI (62%) was the most common method of blunt injury although injuries sustained via road traffic accidents (49%) were also prevalent. The majority of the mTBI sample (81%) indicated that they had been exposed to blast during their military career. 50% sustained one or more blast mTBIs, and 53% of this sub-group reported 3 or more blast mTBIs. Of these blast mTBIs, 38 were sustained within a proximity of 0-10meters, 15 within 11-25 meters and 5 within 26-100 meters.

47% (n=8) of participants in the blast only category reported vestibular disturbance, 59% (n=35) reported vestibular disturbance in the blunt only category, and 83% (n=34) reported vestibular disturbance in the blunt and blast category. Chi-square analysis indicated a significant association between mechanism of injury and the presence of vestibular disturbance $\chi^2(2) = 9.70$, $p = .008$. Interpretation of the 2x2 contingency tables (using a bonferonni corrected alpha of 0.017) indicated no significant difference between the observed frequencies of vestibular disturbance following blunt or blast ($\chi^2(1) = 1.46$, $p = .223$). However, the frequency of vestibular disturbance was significantly greater for blunt+blast compared to blast ($\chi^2(1) = 9.19$, p =.006) and marginally greater for blunt+blast compared to blunt ($\chi^2(1) = 5.61$, p =.018).

Table 3 about here

Mediation analyses

Multiple linear regression was first conducted to identify which test variables listed in Table 3 were statistically associated with vestibular impairment and could therefore be included in the mediation analysis. This showed significant associations (p<0.01) between the severity of vestibular symptoms and all variables (coefficient scores ranged from 0.5 to 0.8) except sleepiness (see supplemental Tables 5, 6 and 7 for correlation matrices). Age was also added to this regression but did not show a statistically significant association so was not carried forward. Mediation analysis were then conducted using Hayes PROCESS macro for SPSS[38], which bias-corrected the sample by bootstrapping a sample of 10,000 using 95% confidence intervals. Coefficients were considered statistically significant at p <.05. Three mediation analysis were applied to determine if the severity of vestibular disturbance, as defined by VSSL total score, imposed a direct effect on postconcussive symptoms (NSI), headache (HIT6) and disability (WHODAS) independent of mediators PTSD (PCL-5), depression and anxiety (K10).

As can be seen in Figure 1, the VSSL scores exerted a direct effect on the NSI (Figure 1.1), HIT6 (Figure 1.2) and WHO-DAS 2.0 (Figure 1.3) scores independently of the psychiatric mediators in all three mediation models. There was also a significant association between VSSL score and the psychiatric mediators of depression, anxiety (K10) and PTSD (PCL-5) (see a_1 and a_2 pathways in figures). As expected, depression and anxiety were strongly associated with outcome in all three mediation models (see b_2 in figures), although PTSD symptoms showed no significant influence (see b_1 in figures).

While VSSL scores directly affected NSI scores, they showed no effect when combined with PTSD scores within the indirect pathway a_1*b_1. By contrast, when combined with the depression and anxiety scores within the indirect a_2*b_2 pathway, VSSL scores were significantly associated with NSI scores. Finally, there were a significant total effect across all three mediation analyses, indicating that vestibular symptoms were significantly associated with outcome both independently and in conjunction with the psychiatric mediators.

Figure 1 about here

Exploratory Analysis

Sensitivity analysis indicated that both the direct and indirect effects of VSSL scores on the NSI remained significant after the 3 dizziness-related items on the NSI were removed (see Table 4a.) Likewise, the pattern of statistical significance remained unchanged when the mediation analysis was re-run after replacing the VSSL total scores with first the VSSL vertigo subdomain scores and then the VSSL anxiety-related scores (see Table 4b).

Table 4 about here

Discussion

This is the first study to systematically assess if vestibular impairment, both directly and in conjunction with psychiatric co-morbidities, is associated with long-term postconcussive symptoms and general disability in military veterans reporting a lifetime history of mTBI. Seventy two percent reported one or more mTBI in their lifetime, a prevalence that is almost identical to the 71% lifetime estimate for US veterans[7] but higher than other UK estimates which have focused on mTBI acquired during service or utilised less detailed lifetime assessments. Approximately one half of those with mTBI reported periods in their life when they sustained repeated injury. The most frequent mechanism of injury was blunt mTBI, mainly acquired during sports activity and road traffic accident. 81% of the mTBI sample indicated they had been exposed to blast, with 50% reporting mTBI as a consequence. 53% of this subgroup reported blast mTBI on three or more occasions with approximately two-thirds occurring within 10 meters of the explosion which is notable given that such close exposure has been associated with decreased parietal-frontal connectivity.[39] Three quarters of those who sustained an mTBI visited either an A&E department or acute military medical facility. Over the longer-term, more than one half of those who sustained mTBI reported persistent postconcussive neurobehavioural symptoms including dizziness, headache and daytime sleepiness, as well as depression, anxiety, and PTSD. Alcohol consumption exceeded current UK government guidelines of 14 units per week,[37] and general disability fell within the bottom 10% of the general international population.[36] Together these data highlight significant, long-term care needs in help-seeking UK military veterans with a self-reported history of mTBI.

Consistent with the high prevalence reported in other military samples, 69% reported symptoms consistent with a chronic vestibular disturbance. To our knowledge, this is the first study to determine whether the likelihood of vestibular disturbance is influenced by the manner in which mTBI is acquired. Chi-square analysis indicated that vestibular disturbance was most commonly experienced following blunt and blast injury combined rather than by only blunt or blast; 83% of blunt+blast mTBI reported vestibular disturbance compared to 47% and 59% for blast and blunt respectively. This finding contrasts with the predominance of blast injury in soldiers with auditory impairment and may partly reflect the insulation afforded by the deep-lying, bony labyrinth to external pressure waves. Although it is unclear how much the vestibular impairment sustained by blunt and blast injury reflects peripheral as opposed to central nervous damage, its high prevalence suggests that this blunt and blast group should be considered most at risk for vestibular-related complaints for many years post-injury.

It has been known for some time that co-morbid psychiatric symptoms of depression and anxiety exacerbate postconcussive symptoms.[9,40] The current data are the first to endorse these deleterious effects in a UK military mTBI sample, and likely only fail to do so for PTSD because most participants reported significant PTSD symptoms so together produced too little variability for the correlation to reach statistical significance. But while all previous studies have identified dizziness/imbalance as a common postconcussive symptom, they have overlooked the fact that the vestibular impairment may explain other aspects of post-concussion syndrome. Here we confirm that when these co-morbidities are controlled, vestibular impairment is separately associated with a range of mental competencies. A strong association was found between the severity of self-reported vestibular impairment and neuro-behavioural symptoms, as measured by the NSI which contains items that probe sensory perception, motor co-ordination, sleep/fatigue, mood and executive function. Additional analyses showed that when psychiatric co-morbidity was taken into account, this strong association also held for both headache, an especially common symptom of mTBI, and general disability as measured by the WHO-DAS 2.0 which encompasses activities of daily living and social interaction. Interestingly, these direct effects of vestibular impairment on postconcussive symptoms and general disability held when scores from only the vertigo subdomain of the VSSL were entered into the mediation analysis. This result gives support to the idea that the primary vestibular deficit (as opposed to vestibular-induced psychiatric deficits which can be difficult to disentangle from psychiatric deficits of alternative origin) contributed to the direct effects.

In addition to uncovering a direct link between vestibular and postconcussive symptoms, the mediation analysis also uncovered an indirect link which incorporated co-morbid psychiatric disturbance. Previous study tells us that vestibular disorder can promote psychiatric disturbance so it is perhaps unsurprising that this pathway was also linked to outcome. However, the relationship between psychiatric and vestibular function is partly reciprocal which makes it difficult to reach strong inferences about causality, a problem deepened by the fact that many military veterans with mTBI present with psychiatric complaints that are partly non-vestibular in origin. Some insight can be gleaned from the significant direct effects of the VSSL autonomic-anxiety subdomain on outcome which suggest that, at the very least, the vestibular disturbance was exacerbating symptoms of a psycho-somatic and somato-psychic nature.

Reflecting more broadly on the clinical presentation of the present study sample, the constellation of vestibular, cognitive and affective symptoms mirrors the general neuropsychiatric profile of civilians with diagnosed vestibular impairment but without a history of mTBI.[16,17] It further demonstrates the pervasive influence of the vestibular system on human cognition,[17] affecting higher-level processes rather than only the low-level autonomic motor control processes with which it has traditionally been associated. From a therapeutic perspective, the implication is that veterans with mTBI might broadly benefit from a programme of vestibular rehabilitation. In preliminary support of this idea, Kleffelgaard et al.[41] showed in a case series of 3 civilians with mTBI and dizziness/imbalance that a programme of vestibular rehabilitation was associated with reduced psychological distress and improved health-related quality of life. In veterans, Carric et al.[42] showed a reduction in PTSD, as measured by the CAPS, after 2 weeks of vestibular-ocular co-ordination involving gaze stabilisation, visual pursuit and saccadic eye movement. Carric et al.[42] also noted that treating PTSD as a physical injury rather than as a psychiatric disorder helped lessen the stigma that veterans often feel towards help-seeking which in turn could encourage treatment uptake.

Several methodological aspects limit the conclusions that can be drawn from the current study. First and foremost, the absence of routine prospective screening for mTBI and vestibular disorder meant that our investigations were founded on self-report data rather than clinical examination which may have led to an over-estimation of effect. This over-estimation may have been exacerbated by the relative ease with which vestibular and other postconcussive symptoms can be conflated by clinically-naïve participants. Also, the study was cross-sectional rather than longitudinal, and all participants were help-seeking and receiving psychiatric support so although high in clinical need were not representative of the broader veteran population. To this end, it would be informative to address the current study questions in a participant sample with more varied mental health needs. On a related note, the high prevalence of depression in the sample may help explain the relatively high number of MCI failures which is of potential concern here because symptom exaggeration in one neurological modality predicts exaggeration in other modalities.[43,44,45,46] Given that this study is the first to assess symptom exaggeration in UK veterans, this result should perhaps be treated cautiously, not least because the study design does not allow the underlying drivers of malingering and psychological dissociation to be separated. But for the present purpose it is important to point out that the statistical outcomes from the mediation analyses are the same if only those participants who passed the memory complaints inventory are included.

In conclusion, we report preliminary evidence that the long-term mental health of help-seeking military veterans with mTBI is directly associated with the presence of vestibular dysfunction. This finding is important because although anecdotal reports of dizziness are common, vestibular function is not routinely assessed and, as a consequence, neuro-otological referrals are not often made. Yet the current data raise the possibility that by treating the vestibular disorder it may also be possible to treat a range of neurobehavioral symptoms that accompany mTBI and which have so far proven difficult to manage.

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Table 1. Sample Demographic (*n* = 162). Parenthesised values show standard deviation. *M* = mean.

	n		*n* or *M (SD)*
Males	151	Part-time student	2
Females	11	Unemployed	53
Relationship Status		Retired	32
Married	92	**Military Service Branch**	
Divorced	39	Royal Navy	23
Single	29	Army	123
Widowed	2	Royal Airforce	11
Vocational Status		Royal Marines	6
Full-time employment	55	**Armed Service History**	
Part-time employment	19	Mean length of Service (years)	12.8 (7.2)
Full-time student	1	Mean deployments to a war zone	3.7 (1.8)

Table 2. Lifetime History and Prevalence of mTBI (n=117)

	n		*n*
Lifetime history ≥1mTBI	117	Blunt & Blast	41
		Blast only	17
Hospitalised due to mTBI	82	Blunt only	59
mTBI with LOC	69	**Blast Proximity**	
		0-10 meters	38
Sustained >1 TBI	112	11-25 meters	15
Periods of repeated mTBI	57	26-100 meters	5
		Method of blunt injury	
History of moderate TBI	23	Road traffic	57
History of severe TBI	12	Sports-related	73
No TBI	10	Assault	54

Table 3. Frequency of comorbid symptoms in mTBI sample

Comorbid Symptoms	*n*	%	missing cases
PCS (NSI)	89	77.4	2
Vestibular (VSSL)	78	69.0	4
PTSD (PCL-5)	100	88.5	4
Depression/anxiety (K10)	104	92.9	5
Daytime sleepiness (ESS)	59	52.7	5
Headaches (HIT-6)	79	70.5	5

Table 4. Correlation matrices underpinning the exploratory NSI mediation analysis in which (a) responses to the 3 dizziness questions were omitted and (b) responses to only the vertigo-balance or autonomic-anxiety subdomains were included

(a)

	Total Effects	Direct Effects	Mediator	Indirect Effects	LCI	UCI
VSSL total score	*B* = .50	*B* = .311	PCL-5	*B* = .055	-.016	.130
	p = < .001	*p* = < .001	Kessler	*B* = .134	.055	.245

(b)

	Total Effects	Direct Effects	Mediator	Indirect Effects	LCI	UCI
VSSL vertigo-balance	*B* = .773	*B* = .540	PCL-5	*B* = .092	.017	.222
	p = < .001	*p* = < .001	Kessler	*B* = .139	.015	.343
VSSL autonomic-anxiety	*B* = 1.129	*B* = .767	PCL-5	*B* = .100	-.109	.287
	p = < .001	*p* = < .001	Kessler	*B* = .268	.038	.496

Table 5 (supplemental). Correlation matrix for the multiple linear regression analysis in which the NSI was the outcome variable (*N*=113)

	NSI		VSSL		PCL-5		K10	
NSI			*r* = .69	*p* = <.001	*r* = .65	*p* = <.001	*r* = .66	*p* = <.001
VSSL	*r* = .69	*p* = <.001			*r* = .54	*p* = <.001	*r* = .44	*p* = <.001
PCL-5	*r* = .65	*p* = <.001	*r* = .54	*p* = <.001			*r* = .79	*p* = <.001
K10	*r* = .66	*p* = <.001	*r* = .44	*p* = <.001	*r* = .79	*p* = <.001		

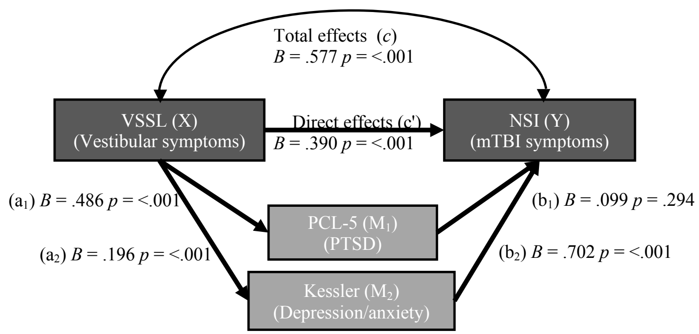
Table 6 (supplemental). Correlation matrix for the multiple linear regression analysis in which the HIT6 was the outcome variable (N=112)

	HIT6		VSSL		PCL-5		K10	
HIT6			r = .51	p = <.001	r = .49	p = <.001	r = .54	p = <.001
VSSL	r = .51	p = <.001			r = .55	p = <.001	r = .45	p = <.001
PCL-5	r = .49	p = <.001	r = .55	p = <.001			r = .78	p = <.001
K10	r = .54	p = <.001	r = .45	p = <.001	r = .78	p = <.001		

Table 7 (supplemental). Correlation matrix for the multiple linear regression analysis in which the WHODAS 2.0 was the outcome variable (*N*=111)

	WHODAS		VSSL		PCL-5		K10	
WHODAS			*r* = .60	*p* = <.001	*r* = .63	*p* = <.001	*r* = .68	*p* = <.001
VSSL	*r* = .60	*p* = <.001			*r* = .55	*p* = <.001	*r* = .45	*p* = <.001
PCL-5	*r* = .63	*p* = <.001	*r* = .55	*p* = <.001			*r* = .78	*p* = <.001
K10	*r* = .68	*p* = <.001	*r* = .45	*p* = <.001	*r* = .78	*p* = <.001		

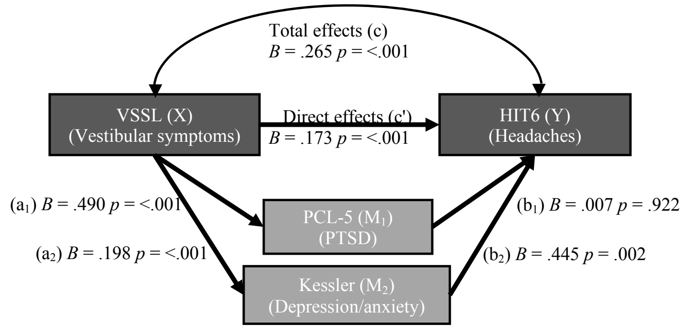
Figure 1A Mediation analysis NSI (*N* =113)



Indirect effects a_1*b_1 *B* = .048 BootULLCI = -.0369 BootULCI = .1335

Indirect effects a_2*b_2 *B* = .138 BootULLCI = .0549 BootULCI = .2569

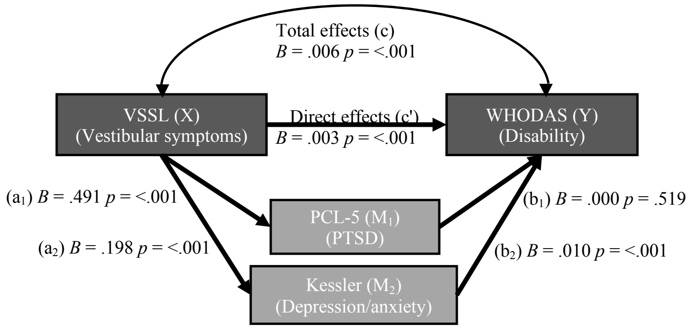
Figure 1B Mediation analysis HIT6 (N = 112)



Indirect effects a_1*b_1 B = .003 BootULLCI = -.0657 BootULCI = .0899

Indirect effects a_2*b_2 B = .088 BootULLCI = .0287 BootULCI = .1738

Figure 1C Mediation analysis WHODAS ($N = 111$)



Indirect effects $a_1 * b_1$ B = .000 BootULLCI = -.0007 BootULCI = .0017

Indirect effects $a_2 * b_2$ B = .002 BootULLCI = .0009 BootULCI = .0039