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Factor Analysis of Persistent Post-Concussive Symptoms within a Military Sample with Blast Exposure

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Abstract

Objective—To determine the factor structure of persistent post-concussive syndrome (PPCS) symptoms in a blast-exposed military sample and validate factors against objective and symptom measures.

Setting—Veterans Affairs medical center and military bases.

Participants—One hundred eighty-one service members and veterans with at least one significant exposure to blast during deployment within the two years prior to study enrollment.

Design—Confirmatory and exploratory factor analysis of the Rivermead Post-concussion Questionnaire (RPQ).

Main Measures—RPQ, PTSD Symptom Checklist-Civilian, Center for Epidemiologic Studies Depression inventory, Sensory Organization Test, Paced Auditory Serial Addition Test, California Verbal Learning Test, Delis-Kaplan Executive Function System subtests.

Results—The three-factor structure of PPCS was not confirmed. A four-factor structure was extracted, and factors were interpreted as reflecting emotional, cognitive, visual, and vestibular functions. All factors were associated with scores on psychological symptom inventories; visual and vestibular factors were also associated with balance performance. There was no significant association between the cognitive factor and neuropsychological performance, nor between a history of mTBI and factor scores.

The authors report no conflicts of interest.

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Conclusion—Persistent post-concussive symptoms observed months after blast exposure seem to be related to four distinct forms of distress, but not to mTBI per se, with vestibular and visual factors possibly related to injury of sensory organs by blast.

Keywords

Factor Analysis; Rivermead Post-concussion Questionnaire; Blast; Post-Concussion Syndrome; Traumatic Brain Injury

INTRODUCTION

“Persistent Post-Concussion Syndrome” (PPCS) is a condition of non-resolving neurologic and behavioral symptoms following a concussion or mild traumatic brain injury (mTBI). PPCS is recognized in the current editions of both the Diagnostic and Statistical Manual (DSM-IV) and the International Classification of Diseases (ICD-10). At a minimum, diagnosis requires a prior traumatic brain injury (TBI) and persistence of at least three “post-concussive symptoms.” Symptoms differ somewhat across diagnostic manuals, but generally include headaches, dizziness, fatigue, irritability, sleep disturbance, depression/anxiety, sensory, and cognitive symptoms (ICD-10). While these symptoms are commonly reported after a concussion, it is their long-lasting nature that is considered the pathology of “PPCS.” Three months post-injury is the generally accepted outer time frame for recovery, beyond which chronic symptoms merit the term PPCS.¹ In the absence of objective markers of the condition, clinicians rely on patient report of their symptoms to detect PPCS, often using symptom inventories such as the Rivermead Post-concussion Questionnaire (RPQ),² a measure recommended by the National Institute of Neurological Disease and Stroke.

It is important to note that the origins of PPCS are unresolved.^{3,4} The symptoms may be directly related to the mTBI and/or may be consequences of maladjustment, depression, or unmet expectations; furthermore, many PPCS symptoms are common in the general population. In addition, it is very difficult to distinguish PPCS symptoms from some other possible sequelae of a head injury (such as depression). For example, five of the nine current criteria for major depressive disorder are present on the 16-item RPQ. PPCS symptoms also exhibit unclear diagnostic significance for the incident mTBI(s): the overall number of PPCS symptoms endorsed did not discriminate between mTBI groups at three months post injury.⁵ Therefore, it is difficult to interpret both overall scores on the inventory and individual questions taken alone.

Because of symptom overlap, it is useful to examine higher-order structure, that is, how symptoms group together. Factor analysis is well-suited to the question of interrelation among a diverse set of symptoms. Factors reflect distinct latent variables underlying the covariance among symptoms, and so redefine a collection of symptoms as a smaller group of clusters. Because factors are more reliable measures than individual symptoms, they may be useful in predicting recovery, measuring the effects of risk factors, and may better differentiate PPCS and mTBI late effects from other similar disorders. Previous studies have found that, in comparison with other injuries, a history of mTBI seems to differentially increase the somatosensory and cognitive types of symptoms. When comparing mTBI to

orthopedic controls, those with a history of mTBI endorse more somatic and cognitive symptom groups, with dizziness consistently endorsed at a higher rate in mTBI across studies.^{6,7} Dizziness, visual symptoms, and cognitive symptoms were higher in cases of mTBI as compared to persons with chronic pain.⁸ In contrast, distress most strongly affects the reporting of emotional and cognitive symptoms: patients with TBI and psychiatric comorbidities endorsed more symptoms overall than those with TBI alone, but specifically more cognitive and affective symptoms.⁹

The RPQ has been subjected to factor analyses in previous studies utilizing civilian samples. In a study of mild to moderate TBI, Potter and colleagues found that a confirmatory factor analysis (CFA) with a single factor did not fit the RPQ data well, but three- and two- factor models demonstrated better and equally good fit.¹⁰ For the two-factor model, the cognitive symptoms seemed to form a distinct factor while the remaining (emotional and somatic) loaded together. An exploratory factor analysis (EFA) in civilians¹¹ described two- and three- factor structures identical to those of Potter *et al.*, supporting the validity of these two models; the three-factor structure in particular being widely accepted. Collectively, these findings indicate that more than one process is implicated in the generation of PPCS symptoms (e.g. not just general distress), and that there may be important clusters of symptoms within the post-concussion syndrome.

Nevertheless, PPCS symptoms can be moderated by other comorbid conditions such that symptom structures may not generalize across mTBI groups. Herrmann *et al.*¹² performed an EFA on 96 individuals with mild to moderate TBI who exhibited symptoms of major depressive disorder on a structured interview. Again, the results supported that multiple latent variables underlie the RPQ score. Three factors were extracted, and were described as a combined emotional/cognitive factor, a somatic factor, and a visual factor. As these differed in structure compared to the factors derived from the unspecified samples of Potter *et al.*¹⁰ and Lannsjo *et al.*,¹¹ these data support the notion that major depression after TBI affects the experience of post-concussive symptoms.

PPCS symptoms in the military blast-exposed population

Many individuals deployed during recent U.S. military conflicts have experienced a blast, most often from improvised explosive devices. Blasts are reported to cause acute alterations in consciousness, whether by the primary blast wave or by striking or being struck by an object,^{13–15} and blasts are considered a risk factor for mTBI. Blast-exposed individuals are a sizeable population presenting for evaluation and treatment in military and Veterans Health Administration (VHA) medical facilities, and are also subject to mandatory TBI evaluations in the VHA system. PPCS symptoms after military-related blast generally seem similar in severity to those of other military groups,^{16–18} but certain individual symptoms (headaches, tinnitus, hearing loss) were shown to be more likely to occur in blast-injured compared to nonblast-injured populations.^{13,16,18} In addition, the circumstances under which military blast-exposed individuals experienced an mTBI are intensely stressful, as are the circumstances that may accompany their recovery (other injuries, sometimes severe; long separations from family; career changes if leaving the military, to name a few). Consequently, deployed service members and veterans with blast exposure and/or mTBI are

also at high risk for depression and PTSD.¹⁹ Thus, there are many reasons to expect that PPCS symptom patterns in this population may differ from those that comprise the standard model.

Although TBI is not a universal consequence of blast exposure, both blast-exposed individuals who did and did not sustain mTBI routinely present to VHA and other clinicians with PPCS-like symptoms. The RPQ is commonly employed within this population to track outcomes, to direct treatment for mTBI, to estimate symptom burdens for administrative purposes, and to test relations with risk factors and biomarkers in research. However, its factor structure in this population is not known, limiting the utility of the RPQ in all of these applications. The primary aim of the present study is to describe the symptom structure of the RPQ in a blast-exposed military sample at high risk for mTBI. Furthermore, we aim to validate the factors using objective measures of functioning and psychiatric symptom measures.

METHODS

This study received all appropriate institutional review board and governmental approvals, and all subjects provided informed consent before data collection.

Participants

A total of 181 participants were included in this analysis. This study sample was derived from the first 196 participants who completed baseline assessments in a larger epidemiological study examining the effects of blast exposure.²⁰ All participants were active-duty service members or veterans, had been deployed to Operation Enduring Freedom/Operation Iraqi Freedom (OEF/OIF), and had exposure to at least one blast event within the two years prior to enrollment. A blast event was defined as any of the following occurring during or shortly after the blast or explosion: feeling dazed, confused, saw stars, headache, dizziness, irritability, memory gap (not remembering injury or injury period), hearing loss, abdominal pain, shortness of breath, struck by debris, knocked over or down, knocked into or against something, helmet damaged, or evacuated. The lone exclusion criterion was failure on neuropsychological effort testing as determined by the Test of Memory Malingering (TOMM).²¹ Accordingly, 16 persons were excluded to yield the final sample size of 181. All participants were ambulatory and free of injury that would prevent them from engaging in regular physical activities.

The demographic and military characteristics of the sample are summarized in Table 1. The sample was primarily male (96%), with an average age of 27.6 (standard deviation [SD] = 7.9) years. The median number of months since most recent blast exposure was 9 (interquartile range [IQR] = 6 to 15). The majority reported multiple blast exposures, with 36% reporting more than five. Seventy-nine subjects also underwent a diagnostic interview for TBI developed by one of the study investigators. The interview was administered by a trained research assistant and consisted of both structured and unstructured components. The structured component focused on the acute effects of injury experienced by the patient (amnesia, loss or alteration of consciousness). Responses were independently reviewed by a group of five experienced TBI physicians who individually rated each participant's worst (or

only) blast exposure as Yes versus No in reference to the DoD/VA common definition for mTBI.²² A consensus diagnosis was obtained for each participant based on a simple majority. Of these 79, 66 (84%) received a diagnosis of mTBI and 13 (16%) did not (had no TBI).

Procedure

All measures were completed by each participant individually in a private testing space with a research coordinator or assistant available for questions.

Symptom measures

Post-concussive symptoms: The RPQ consists of 16 items: headaches, dizziness, nausea/vomiting, noise sensitivity, sleep disturbance, fatigue, irritability, feeling depressed/tearful, feeling frustrated/impatient, forgetfulness, poor concentration, taking longer to think, blurred vision, light sensitivity, double vision, and restlessness. The extent of each PPCS symptom is rated on a five point Likert scale, with 0 representing “not experienced at all” and 4 indicative of “a severe problem” as compared to before the blast experience. An individual was considered positive for PPCS if they rated 3 or more symptoms on the RPQ as 2 (greater than pre-injury) or higher, in accordance with symptom criteria for post-concussional disorder from the DSM-IV.

Depressive symptoms: Participants completed the Center for Epidemiologic Studies Depression (CES-D) scale.²³ The CES-D consists of 20 items designed to measure current symptoms of clinical depression. Participants rate the degree to which they have experienced that symptom in the past week from one to three. Possible total scores range from 0 to 60, with higher scores indicative of greater levels of depression.

Post-traumatic stress symptoms: Participants completed the civilian version of the PTSD Checklist (PCL).²⁴ The PCL consists of 17 questions assessing the DSM-IV criteria symptoms of PTSD. The degree to which the participant has been bothered by each PTSD symptom over the last month is rated on a 5-point Likert scale with 1 representing “not at all” and 5 representing “Extremely.” The maximum total score is 80. The civilian version was used in lieu of the military version to avoid assuming the most stressful life event was related to military service; the two versions are otherwise identical.

Neuropsychological testing—One hundred and forty-one participants underwent neuropsychological testing across many domains as part of the larger study. Scores on tests of functions commonly affected by mTBI were selected *a priori* as outcome measures to be used in the present study. These tests included the Long Delay Free Recall score of the California Verbal Learning Test, second version (CVLT-II; assesses short and long term verbal memory²⁵), the 2.0-second pacing score of the Paced Auditory Serial Addition Test (PASAT; assesses selective attention and concentration²⁶) and the Delis-Kaplan Executive Function System (DKEFS) Category Fluency and Category Switching subtests (DKEFS; assesses several executive and strategic processes²⁷). Sixteen participants were missing PASAT scores due to a computer malfunction.

Balance testing—Data from computerized posturography testing (CPT) using the Sensory Organization Test (SOT; NeuroCom, Clackamas, OR) were available for 139 participants. This test measures the degree of body sway in response to a shifting plate on which the subject is standing. Sensory information is systematically adjusted to be either an effective or ineffective cue for balance. A composite measure capturing general balance performance is provided by the SOT, and was used as the outcome measure in the present study. More details on CPT have been described elsewhere.²⁸

Statistical Methods

The demographic, military, psychological (CES-D and PCL), and post-concussive (RPQ) characteristics of the study sample were described using frequency counts with percentages for categorical variables and means/medians with SDs/IQRs for continuous variables.

Confirmatory Factor Analysis—A confirmatory factor analysis (CFA) of the three-factor structure from a published study within a civilian population¹⁰ was conducted. The CFA was performed on the covariance matrix and was fit using the CALIS procedure in SAS v.9.3 (SAS Institute Inc., Cary, NC, USA). Global goodness of fit of the CFA model was evaluated using the standardized root mean square (SRMR), the root mean square error of approximation (RMSEA), the comparative fit index (CFI), and the non-normed fit index (NNFI). The model was considered to have an adequate fit if SRMR was less than 0.06,²⁹ RMSEA was less than 0.08,³⁰ and both CFI and NNFI exceeded 0.9.^{31,32}

Individual item reliabilities were examined, and the composite reliability index was calculated to assess the internal consistency of the indicators measuring a given factor. A value of 0.70 was considered the minimally acceptable level of reliability for each construct. In addition, variance-extracted estimates were calculated to describe the percentage of variance captured by each factor.

Exploratory Factor Analysis—An exploratory factor analysis (EFA) was planned in the event that the CFA was not successful. The number of factors explored was determined by a scree plot, principal components analysis, parallel analysis and *a priori* research using another PPCS inventory (the Neurobehavioral Symptom Inventory) in a similar population. The EFA was conducted on the correlation matrix using the FACTOR procedure in SAS v. 9.3. The factors were expected to be correlated and thus an oblique (promax) rotation was used. Squared multiple correlations (SMC) were used as prior communality estimates, and the maximum likelihood extraction method was employed. An item was assumed to load on a given factor if the factor loading was at least 0.40 for that factor and less than 0.40 for all other factors.

Additional Analyses—In order to characterize the sample with regards to the extracted factors, we calculated the factor scores for each participant using the regression method.³³ Bivariate correlations and analyses of variance were used to assess the relations among factor scores, symptom and performance measures, and TBI status. Analysis of variance was conducted on regression residuals where it was desired to control for the effects of a continuous variable on the dependent variable. It should be noted that the number of subjects

available for each analysis varied, and so the sample size varied for each of the estimated correlations.

RESULTS

Participants

Psychological characteristics—Mean CES-D score was 17 (SD = 2) which falls between “possible” and “probable” depressive disorder.³⁴ Mean PCL score was 47.1 (SD = 15), nearing the cut score of 50 for PTSD diagnosis,²⁴ a cut point accepted for use in military samples.³⁵ Thus, this sample is characterized by moderately elevated depressive symptoms and a very high degree of PTSD symptoms. Neither PCL nor CES-D scores were significantly different between TBI positive versus negative groups in the sub-sample for whom TBI status was determined.

RPQ Post-concussion Symptoms—RPQ scores were normally distributed with a mean total score of 28 (SD = 13). One hundred and sixty four participants (90.6%) met symptom criteria for PPCS. Compared to previously described mTBI samples, the mean score is consistent with a PPCS severity in the moderate range, higher than 90% of a nonclinical sample¹⁰ and thus the sample was highly symptomatic. TBI status (of those for whom it was determined) was not significantly related to RPQ score ($F_{(1,77)} = 0.139, p > 0.05$), nor was number of blast exposures ($F_{(6,174)} = 0.891, p > 0.05$). The correlation matrix for the 16 RPQ items is shown in Table 2. There was moderate correlation among most of the items (range $r = 0.11 - 0.75$), and thus the data were suited for data reduction.

Neuropsychological performance—Test scores were normally distributed with standardized means near the general population mean: DKEFS Category Fluency mean $z = -0.2$; Category Switching mean $z = 0.4$, and CVLT-II delayed free recall mean $z = -0.55$), with the exception of the PASAT with a mean score of $z = -1.02$. TOMM score distribution was heavily weighted to the ceiling, with 88% with the highest possible score and 1% just above the cut score for invalid effort.

Confirmatory Factor Analysis

The factor loadings from the CFA are shown in Table 3. The composite reliability indices were all over 0.7 (Table 3) indicating that each factor had good internal consistency. The variance-extracted estimates for the emotional and cognitive factors exceeded the minimally acceptable level of 0.50, indicating that these factors demonstrate good validity. However, the variance-extracted estimate for the somatic factor was less than 0.50, (i.e., the somatic factor explained only 34.4% of the variance) and thus the validity of this construct is questionable. Finally, the model fit statistics were all unsatisfactory (SRMR = 0.0798 > 0.06, RMSEA = 0.1034 > 0.08, CFI = 0.8660 < 0.9, and NNFI = 0.8408 < 0.9), suggesting that the proposed three-factor model did not adequately fit the data. In summary, the results of the confirmatory factor analysis indicated that the three-factor solution did not conform well in the present sample.

Exploratory Factor Analysis

Because the confirmatory analysis was unsuccessful, we next performed EFA. The scree plot indicated that four factors would likely improve on the three-factor model, but that five or more would not add substantial explanatory power. Principal components analysis showed that three factors had eigenvalues greater than 1, and parallel analysis indicated that two factors generated larger eigenvalues than a random dataset. The four-factor solution was preferred, because this solution showed the fewest items without strong loading and the fewest cross-loadings. This solution was also preferred from a theoretical standpoint because the two sensory systems, visual and vestibular-type, were clearly separated, which may prove useful in predicting specific clinical outcomes. The factor loadings for the four factor solution are shown in Table 4. The inter-factor correlations for the four-factor solution are shown in Table 5. A high degree of correlation among the four factors was observed. Factor 1 (noise sensitivity, sleep disturbance, fatigue, irritability, feeling depressed or tearful, feeling frustrated or impatient, and restlessness) can be described as an emotional factor, factor 2 (forgetfulness, poor concentration, and taking longer to think) can be considered a cognitive factor, factor 3 (blurred vision, light sensitivity, and double vision) can be described as a visual factor, and factor 4 (dizziness and nausea) appears to be a vestibular-type factor. Headaches did not load on any of the four factors. The final factor (vestibular) is identified by only two items and therefore may be empirically weak compared to the first two factors. Internal consistency measures (Cronbach's alpha) of factors were acceptable to very high: emotional factor (0.89), cognitive factor (0.90), visual factor (0.71), and vestibular factor (0.62). The lower alpha of the vestibular factor can be attributed in part to the small number of items comprising this subscale.

Factor scores and subscale validity

Factor scores, in general, were normally distributed, with some positive skewness in the visual Factor 3 (skewness = 1.0). Results of criterion validity analysis of factor scores are shown in Table 6. We adjusted for multiple comparisons by decreasing the overall criterion for significance to 0.01. All factor scores were significantly correlated with the PCL and CES-D symptom measures. For the PCL and the CES-D, the proportion of total variance explained by each factor progressively declined from emotional to cognitive, visual and vestibular factors. The CES-D showed weaker relations with all factors than did the PCL. The objective measure of balance performance (the Sensory Organization Test composite score) was significantly related to the vestibular and visual factor scores only. No neuropsychological test score was significantly related to any factor score, with the exception of the DKEFS Category Fluency score, which was significantly associated with the vestibular factor score. No factor scores were significantly related to TBI status, even after removing the effect of PCL score.

DISCUSSION

We found that the standard three-factor solution for PPCS measured by the RPQ was not optimal in the present blast-exposed military population. Instead, symptoms were better described by a four-factor solution with emotional, cognitive, visual and vestibular factors. All factors were related to measures of psychological status; sensory factors were related to

balance performance; lastly, no factors were related to TBI status. As with previous factor analytic studies of PPCS inventories, our findings do not support a unified construct of PPCS symptoms. Instead, there are multiple processes contributing to PPCS, producing coherent and distinct clusters of symptoms. This extractability of factors implies that individuals experiencing PPCS after blast exposure should not be presumed to lie on a unitary “PPCS” spectrum, but rather four spectra in more specific domains, and that differing pathoetiologies may exist. As with other complex, multi-dimensional constructs such as personality and pain, “PPCS” may be a general term that requires refinement to be fully and accurately described.

PPCS symptom structure in the military blast population

PPCS symptom structure in the present population differed from that previously described in two civilian samples recruited from emergency departments in Sweden and the U.K.^{10,11} This finding supports the notion that the perception or experience of post-concussive symptoms is different in the present population. Previous factor analytic studies of PPCS in the recently deployed blast-exposed population have also found more complex factor solutions than the standard three-factor model,^{36,37} while, in contrast, pre-OEF/OIF samples, neither combat- nor blast-exposed, have demonstrated good fit with the standard.³⁸ There are many distinguishing features of the present sample that may contribute to this difference, among which are psychiatric comorbidities, combat experience, multiple potential brain injuries (due to a high level of blast exposure), particular expectations or knowledge of their injuries, and/or the blast(s) itself.

Blast injury has been a common historical characteristic across the samples where complex PPCS factor structures have been found, but these studies suffer from the same potential confounding variables that usually accompany military blast injury. In particular, combat exposure and its psychological consequences are likely to have a strong influence on processes underlying symptom reporting. PTSD symptoms were very high in this sample, and depressive symptoms were moderately elevated on average. Depression has been shown to be a strong factor in PPCS symptom reporting after mTBI in this same population³⁹ as have post-traumatic stress symptoms,^{16,40} with the conclusion being that it is hazardous to attribute PPCS symptoms to mTBI in the presence of these comorbidities. Taken together, though, this and other factor analysis studies confirm that contributing processes to PPCS symptoms in this population are likely more complex than the standard model, with the same symptoms possibly having different origin, meaning, or recovery course than in non-blast-exposed and/or non-military groups.

Interpretation of the factors

The first factor, the emotional factor, was characterized by more items than the similar factor in civilian samples, suggesting greater complexity in the present population. The emotional factor in particular overlapped considerably with post-traumatic symptoms, suggesting that the emotional factor structure may be attributable in part to PTSD. This interpretation is supported by (1) the high degree of PTSD symptoms in the current sample, (2) the finding that the relation between PTSD symptoms and this factor was the strongest observed in the study, and (3) the fact that the items which switched loading relative to the

comparison sample are all related to symptoms of PTSD: noise sensitivity (vigilance), sleep disturbance (nightmares), and fatigue (secondary to sleep disturbance and vigilance). Depressive symptoms were also strongly related to emotional factor scores, supporting that this factor originates partly in perceived mood disturbance as well.

A second, cognitive, factor was observed that was correlated with - but independent of - the emotional factor. The cognitive factor was not related to objective cognitive performance as reflected by the tests in the present analysis. Thus, symptoms of cognitive dysfunction in this population may not be accompanied by actual impairment (and vice-versa). In general, research has shown that individuals are often inaccurate in assessing their own cognitive abilities; instead, the strongest influence on self-assessment is self-esteem, not actual performance.⁴¹ Therefore, a belief that one is impaired will have greater influence on cognitive symptom reporting than the actual presence of impairment. The lack of a relation with TBI further supports the conclusion that high cognitive factor scores to some degree reflect a distressed self-perception with regard to cognition. This cognitive-focused distress may be generated in a number of ways: Some individuals may respond to cognitive problems as a more “valid” expression of distress than emotional symptoms, or they may have expectations of poor cognition due to knowledge of mTBI. Symptoms may reflect their sense of increased mental effort required to maintain normal performance, which could stem from decreased cognitive reserves and/or accompanying PTSD or depression (symptoms of which were correlated with the cognitive factor). It is possible that the measures chosen for the present study were not sensitive enough to capture participants’ cognitive deficits, but since many studies using a variety of measures have shown that neuropsychological impairment resolves by 3 months after injury,⁴² it is more likely that these participants are not cognitively impaired. It is also worth noting that many of the relations between the memory tests and the cognitive factor were marginally significant, showing the need for further study of this issue. However, as the present correlations were very small as well as non-significant, these results are not consistent with a strong relation between cognitive complaints and neuropsychological impairment.

Both somatic factors were significantly related to PCL and CES-D scores, suggesting that emotional distress was also implicated in these symptoms. At the same time, however, posttraumatic stress symptoms and depression explained less variance in the sensory factors than in the emotional and cognitive ones, suggesting that vestibular and visual symptoms were less a product of depression and anxiety than the other two types. Further, the somatic factors were both significantly related to balance behavior, and the strongest relation with balance behavior was with the vestibular-type factor. This suggests a dysfunction of the balance network behind these symptoms. However, given that the balance dysfunction was presumed to result at least in part from TBI, it was unexpected that TBI status was not related to either the visual or vestibular factors. It is possible that one or multiple blasts could have caused a non-TBI injury (i.e., no alteration of consciousness), such as inner ear, cervical, or eye damage, which would affect balance and elicit sensory symptoms. One executive function test was associated with the vestibular factor, suggesting that such injuries could affect this cognitive domain. More work is needed to understand this relation and to investigate the potential dysfunctions of the visual, vestibular, and auditory systems that may contribute to the sensory symptoms measured by the RPQ.

While “somatic” symptoms are usually considered together when PPCS symptom structure is discussed (e.g. Williams *et al.*⁴³; King *et al.*⁴⁴), there is support from the factor structure for separable sensory system dysfunction in the present population. If the result of blast injury, the possibility is raised that damage to the two systems (visual and vestibular) is not always symmetrical, and thus the concept of “somatic” symptoms in this population may be misleading. It is possible that blast, cognitive dysfunction, distress symptoms or responsiveness to interventions may relate differently to sensory deficits in different domains; these relations would not be detectable without considering the visual and vestibular symptoms separately. Further, general “somatic” PPCS symptoms might be conceptually conflated with “somatization,” a psychiatric process resulting in medically unexplained physical complaints.⁴⁵ In the present sample, some conventionally “somatic” complaints were better characterized as emotional (fatigue, noise sensitivity, and sleep disturbance), resulting perhaps in a less “somatized” character for the visual and vestibular factors. However, at present these factors are unsatisfactorily defined, due to small numbers of associated items and somewhat imprecise (dizziness) and selective (double vision but not reduced acuity or reading difficulty) symptoms. More questions might be added to the RPQ to adequately capture vestibular-type, visual, and auditory symptoms in order to increase the reliability and utility of these factors and enhance the instrument’s sensitivity to distinct sensory system dysfunction, especially when used in a blast-exposed population.

Effect of mTBI on factor scores

We expected that the factor scores would differentiate between mTBI groups, particularly the cognitive and sensory factors, as these symptoms have shown some discriminative power in previous studies. However, in the present study, TBI status was not related to the factor scores or the overall score on the RPQ, even after controlling for the effects of PTSD symptom severity. A reduction in power due to unequal group variances is not a likely explanation, because the differences in means in all cases were very small in relation to standard deviation, and some means were actually higher for the non-TBI groups. This residual unexplained variance that was unrelated to mTBI suggests that non-specific effects beyond PTSD (e.g., of combat and deployment experience) strongly influence PPCS symptom reporting. Participants in the present study were under a great deal of stress unrelated to trauma caused by pain, sleep deprivation, long periods of deployment, and separation from their families, among other factors. Both TBI+ and TBI- groups had high levels of stress, PTSD symptoms, and depression symptoms. In this situation, post-concussive symptom scores on the RPQ as written, even by factor, cannot discriminate the effects of the mTBI alone. Overall the findings support that PPCS symptom reporting, even when considering factors independently, is strongly influenced by stressful injury circumstances, with mTBI having a negligible effect in this context.

Clinical significance

PPCS symptoms are often the basis for treatment and healthcare policy decisions, as well as conclusions regarding mTBI outcomes. Thus, it is essential to clarify as much as possible what PPCS symptoms reflect in the patient population being treated. Results of the present study of a blast-injured military sample support previous findings that caution against considering PPCS symptoms as a unitary phenomenon or syndrome with a single cause and

recovery course or as a collection of disparate symptoms. The 1995 statement of Cicerone and Kalmar is still relevant: “We suggest that the depiction of patients as having a uniform postconcussive syndrome has frequently resulted in vague clinical characterizations, often with negative connotations. It may be more meaningful to think in terms of a number of possible postconcussive syndromes that have different symptom profiles and courses, despite some degree of overlap.”⁴⁶ As research progresses, consideration should be given to the four separable domains with distinguishable contributing factors as described above.

Results do not support the use of the current RPQ factors as a stand-alone mTBI outcome measure in this post-deployment blast- and combat-exposed population. However, the factors presently described do appear to reflect meaningful and distinct features of subjective outcome from blast injury in a military setting. For instance, distinct cognitive and emotional types of distress were observed, which suggests that the nature of the post-blast distress is neither general nor derived solely from emotional disturbance; thus, treatment solely for emotional disturbance may not be enough. Also, treatment and assessment for cognitive symptoms in this population should take into account the tenuous relation between complaints and neuropsychological dysfunction, as well as the distinct psychological issues that may generate cognitive symptoms (as opposed to emotional symptoms). Results support the current approach of VA Polytrauma Centers of treatment for “somatic” symptoms addressing specific sensory domains.⁴⁷ Clinicians examining interventions for PPCS may question whether a treatment is appropriate for PPCS in general or whether it may differentially affect symptom domains. Further, the description of factors makes feasible the description of clinical subtypes of PPCS; such descriptions can generate new hypotheses about etiology and shape treatment approaches. Distinct treatment pathways may be needed for PPCS subtypes analogous to headache management where treatments differ for migraine versus tension type headache.

Results also support that injury circumstances are relevant to the nature of PPCS, not only increasing or decreasing severity, but also changing the interrelations of symptoms in complex ways. Biopsychosocial and individualized approaches that take this context into account, such as that advocated by Howe,⁴⁸ are in line with this finding. Future research will be needed to specify the role of blast injury and combat circumstances in generating symptoms and clarify how recovery from mTBI and the resolution of PPCS may differ for this population. At this time, caution is indicated in comparing either overall severity or individual symptoms between blast-exposed military samples and others with mTBI, as the same symptom may have different causes in groups with different injury circumstances.

Limitations

Some limitations are noted to the present study. One, no RPQ data from a non-blast-injured military group were available to compare with the present sample. Therefore, we are unable to draw conclusions regarding the specific effects of blast on PPCS symptom reporting. Two, the inclusion criteria for this study did not include a definitive diagnosis of mTBI, so the sample includes some participants with blast exposure who did not sustain an accompanying mTBI. However, the sample is representative of that encountered in military and veterans medical facilities, where many individuals are evaluated for PPCS symptoms

when the history of mTBI is not definitive. As the sample was predominantly Caucasian, non-Hispanic, and male, the patterns of symptom complaint and their external validity may not generalize to females or other racial or ethnic groups. Symptom patterns may not generalize to other recovery periods, whether earlier or later. Lastly, potential participants who failed effort measures were removed from the present sample, a procedure not commonly performed in factor analyses of PPCS symptoms. This may be considered a limitation when comparing the present results to other similar studies. However, additional analyses indicated that this action did not affect overall factor structure or significance, only loading and criterion validity correlation values.

Removal of those who failed effort measures may actually be viewed as a strength of the present study as confounding issues of symptom complaint and performance validity were minimized, particularly important for tests of associations between cognitive performance and PPCS symptoms. Furthermore, objective performance measures were utilized to examine the subscale factors for criterion validity. TBI status was determined by diagnostic interview with each participant and so many problems associated with self-report of TBI have been avoided.

Future directions

This study builds on previous reports of PPCS symptoms in blast-exposed military populations, supporting a four factor structure in this group with distinct sensory domains of visual and vestibular symptoms. Future directions include better defining PPCS after blast and the potential clinical subtypes of the disorder, based on the present factors. Important questions remain concerning the role of multiple sub-concussive blast injuries and brain function, blast-impaired sensory function, and comorbid mood and anxiety disorders in the development of symptoms in each domain. Future studies should examine the relations of each domain to other measures of cognition not presently tested, such as basic choice reaction time, and more in-depth evaluation of sensory function such as static and dynamic visual acuity. Conversely, more data is needed concerning the relations between true sensory and cognitive impairment and symptom report. These questions of symptom predictive value, sensitivity, and comprehensiveness are critical to ensure that the most relevant PPCS outcomes are measured. External validation of PPCS symptoms - the sensory symptoms in particular - is an under-developed area of research. It is hoped that the field will continue to move toward better validated, sensitive, specific, and empirically defined PPCS symptoms for both blast-injured and non blast-injured individuals.

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Table 1

Sample Characteristics

Characteristic	Count	Percent
Sex		
Female	7	3.9
Male	174	96.1
Marital Status		
Married	85	47.0
Divorced	15	8.3
Single	81	44.8
Race		
Caucasian	143	79.0
African American	27	14.9
Other	11	6.1
Ethnicity		
Hispanic	15	8.3
Non-Hispanic	166	91.7
Level of Education		
Less than High School	2	1.1
High School Graduate	94	51.9
Some College	62	34.3
College Graduate	20	11.0
Post-Graduate Degree	3	1.7
Number of Blasts		
1	36	20.0
2	36	20.0
3	25	13.9
4	14	7.8
5	5	2.8
More than 5	64	35.6
Branch of Service		
Air Force	2	1.1
Army	78	43.1
Navy	4	2.2
Marine Corps	97	53.6
Army and Marine Corps	2	1.1
PTSD (PCL Total Score $\geq$ 50)		
No	105	58.3
Yes	75	41.7
Severe or Probable Major Depression (Total CES-D Score $\geq$ 27)		
No	143	81.7
Yes	32	18.3

Table 2

Correlation Matrix for the 16 Symptoms Measured by the RPQ

	Headaches	Dizziness	Nausea/vomiting	Noise Sensitivity	Sleep Disturbance	Fatigue	Irritability	Depressed	Frustrated	Forgetfulness	Poor Concentration	Longer to Think	Blurred Vision	Light Sensitivity	Double Vision	Restlessness
Headaches	1.00	0.46	0.28	0.36	0.44	0.38	0.38	0.31	0.39	0.47	0.34	0.43	0.40	0.44	0.26	0.36
Dizziness		1.00	0.45	0.28	0.30	0.43	0.26	0.32	0.30	0.42	0.32	0.34	0.41	0.32	0.33	0.37
Nausea/Vomiting			1.00	0.31	0.26	0.36	0.19	0.33	0.24	0.15	0.11	0.09	0.35	0.35	0.29	0.32
Noise Sensitivity				1.00	0.52	0.41	0.50	0.37	0.53	0.45	0.45	0.49	0.31	0.34	0.23	0.45
Sleep Disturbance					1.00	0.52	0.57	0.45	0.61	0.43	0.46	0.44	0.28	0.33	0.26	0.64
Fatigue						1.00	0.52	0.51	0.62	0.50	0.47	0.51	0.28	0.25	0.13	0.51
Irritability							1.00	0.50	0.75	0.44	0.45	0.52	0.22	0.20	0.23	0.53
Depressed								1.00	0.62	0.39	0.45	0.45	0.36	0.27	0.23	0.54
Frustrated									1.00	0.58	0.58	0.62	0.31	0.30	0.20	0.59
Forgetfulness										1.00	0.75	0.75	0.29	0.33	0.16	0.47
Poor Concentration											1.00	0.73	0.25	0.26	0.17	0.41
Longer to Think												1.00	0.32	0.31	0.24	0.49
Blurred Vision													1.00	0.55	0.56	0.39
Light Sensitivity														1.00	0.35	0.34
Double Vision															1.00	0.29
Restlessness																1.00

Table 3

Properties of the Measurement Model (Confirmatory Factor Analysis)

	Standardized Loading	t-Value	Indicator Reliability	Error Variance	Variance Extracted
Somatic			0.822		0.344
Q1 Headaches	0.62	8.78	0.388	0.612	
Q2 Dizziness	0.57	7.82	0.321	0.679	
Q3 Nausea	0.47	6.21	0.216	0.784	
Q4 Noise Sensitivity	0.65	9.27	0.423	0.577	
Q5 Sleep disturbance	0.71	10.49	0.510	0.490	
Q6 Fatigue	0.69	10.07	0.480	0.520	
Q13 Blurred Vision	0.55	7.55	0.303	0.697	
Q14 Light Sensitivity	0.54	7.29	0.286	0.714	
Q15 Double Vision	0.42	5.48	0.173	0.827	
Emotional			0.857		0.602
Q7 Irritability	0.79	12.29	0.624	0.376	
Q8 Depressed	0.69	10.23	0.480	0.520	
Q9 Frustrated	0.90	14.88	0.802	0.198	
Q16 Restless	0.71	10.54	0.502	0.498	
Cognitive			0.896		0.741
Q10 Forgetfulness	0.87	14.25	0.758	0.242	
Q11 Poor Concentration	0.85	13.68	0.718	0.282	
Q12 Taking Longer to Think	0.87	14.10	0.747	0.253	

Table 4

Standardized Factor Loadings for 4-Factor Solution Structure

Item	Emotional	Cognitive	Visual	Vestibular
Noise sensitivity	0.43[†]	0.17	0.10	0.05
Sleep disturbance	0.64[†]	0.03	0.03	0.10
Fatigue	0.48[†]	0.17	−0.17	0.35
Irritability	0.89 [†]	−0.01	−0.03	−0.11
Depressed	0.58 [†]	0.02	0.09	0.10
Frustrated	0.85 [†]	0.13	−0.02	−0.08
Restlessness	0.55[†]	0.05	0.13	0.14
Forgetfulness	−0.01	0.90[†]	−0.06	0.09
Poor concentration	0.14	0.78[†]	−0.02	−0.07
Taking longer to think	0.20	0.73[†]	0.10	−0.14
Blurred vision	−0.01	0.01	0.83[†]	0.03
Light sensitivity	−0.01	0.11	0.51[†]	0.14
Double vision	0.06	−0.08	0.67[†]	−0.03
Dizziness	−0.09	0.23	0.10	0.59[†]
Nausea	0.14	−0.23	0.08	0.66[†]
Headaches	0.10	0.26	0.19	0.26

[†] Indicates significant factor loading

Table 5

Inter-Factor Correlations (4-Factor Solution Structure)

	Emotional	Cognitive	Visual	Vestibular
Emotional	1.00	0.62	0.41	0.46
Cognitive		1.00	0.37	0.38
Visual			1.00	0.55

Table 6

Criterion Validity of RPQ Factors

	<i>N</i>	Factor	Slope	<i>R</i> ²	<i>t</i> -Value	<i>p</i>
PCL Total	180	Emotional	8.99	0.52	13.88	<0.001 [†]
		Cognitive	6.68	0.31	8.91	<0.001 [†]
		Visual	6.34	0.19	6.54	<0.001 [†]
		Vestibular	6.46	0.19	6.39	<0.001 [†]
CESD Total	175	Emotional	5.02	0.35	9.63	<0.001 [†]
		Cognitive	3.82	0.22	7.02	<0.001 [†]
		Visual	2.80	0.08	3.93	<0.001 [†]
		Vestibular	4.28	0.18	6.17	<0.001 [†]
SOT Composite	139	Emotional	-1.60	0.04	-2.40	0.018
		Cognitive	-1.30	0.03	-2.10	0.037
		Visual	-2.39	0.08	-3.35	0.001 [†]
		Vestibular	-3.23	0.14	-4.67	<0.001 [†]
DKEFS Category Fluency	142	Emotional	-0.69	0.01	-1.15	0.253
		Cognitive	-0.10	0.00	-0.18	0.860
		Visual	-0.82	0.01	-1.19	0.237
		Vestibular	-1.76	0.05	-2.61	0.010 [†]
DKEFS Category Switching	142	Emotional	0.07	0.00	0.33	0.745
		Cognitive	-0.02	0.00	-0.10	0.920
		Visual	0.03	0.00	-0.11	0.913
		Vestibular	0.01	0.00	0.05	0.961
PASAT 2.0 s Pacing	126	Emotional	0.41	0.00	0.41	0.685
		Cognitive	-0.35	0.00	-0.39	0.698
		Visual	-0.45	0.00	-0.39	0.701
		Vestibular	-0.52	0.00	-0.45	0.656

	<i>N</i>	Factor	Slope	<i>R</i> ²	<i>t</i> -Value	<i>p</i>
CVLTIII Long Delay Cued Recall	142	Emotional	-0.12	0.00	-0.48	0.629
		Cognitive	-0.40	0.02	0.02	0.081
		Visual	-0.36	0.01	-1.28	0.204
		Vestibular	-0.43	0.02	-1.53	0.128
CVLTIII Long Delay Free Recall	142	Emotional	-0.33	0.01	-1.22	0.223
		Cognitive	-0.47	0.03	0.03	0.058
		Visual	-0.55	0.02	-1.82	0.070
		Vestibular	-0.73	0.04	-2.44	0.016
BVM-T-R Delayed Recall	142	Emotional	-0.10	0.00	-0.53	0.599
		Cognitive	-0.28	0.02	-1.68	0.096
		Visual	-0.28	0.01	-1.37	0.173
		Vestibular	-0.29	0.01	-1.40	0.164
BVM-T-R Recognition Hits	142	Emotional	-0.07	0.02	-1.52	0.132
		Cognitive	-0.10	0.04	-2.30	0.023
		Visual	-0.05	0.01	-0.88	0.383
		Vestibular	-0.08	0.02	-1.50	0.136

[†] correlation significant at $p < 0.01$.