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Psychometric Investigation of the Abbreviated Concussion Symptom Inventory in a Sample of U.S. Marines Returning from Combat

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This study describes the psychometric investigation of an 11-item symptom checklist, the Abbreviated Concussion Symptom Inventory (ACSI). The ACSI is a dichotomously scored list of postconcussive symptoms associated with mild traumatic brain injury. The ACSI was administered to Marines ($N = 1{,}435$) within the 1st month of their return from combat deployments to Afghanistan. Psychometric analyses based upon nonparametric item response theory supported scoring the ACSI via simple summation of symptom endorsements; doing so produced a total score with good reliability ($\alpha = .802$). Total scores were also found to significantly differentiate between different levels of head injury complexity during deployment, $F(3,\ 1{,}431) = 100.75$, $p < .001$. The findings support the use of the ASCI in research settings requiring a psychometrically reliable measure of postconcussion symptoms.

Key words: *Afghanistan, IRT, Marines, measurement, mild TBI, mild traumatic brain injury, Mokken nonparametric item response theory, postdeployment, psychometric, reliability, screening, symptoms, TBI, traumatic brain injury*

Since October 2001, more than 2 million U.S. military service members have deployed in support of Operation Enduring Freedom and Operation Iraqi Freedom (OEF and OIF, respectively; Bass & Golding, 2012).

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Traumatic brain injury (TBI) has become a "signature" injury of the OIF/OEF conflict (Hayward, 2008; Tanielian & Jaycox, 2008). Epidemiological studies have shown that 79% of combat injuries from Iraq and Afghanistan have involved head injuries resulting from blast trauma (Owens et al., 2008). Commonly reported sources for OIF/OEF head injuries include blasts from improvised explosive devices (IEDs), mortar shells, and rocket-propelled grenades (Elder & Cristian, 2009).

The U.S. Department of Defense (DoD, 2009) formally defined TBI as a "traumatically induced structural injury and/or physiologic disruption of brain function as a result of the external force"(p. 3). TBI is indicated by (a) new onset or worsening of decreased levels of consciousness, (b) memory loss immediately preinjury or postinjury, (c) alteration in mental state at time of injury, (d) focal neurological deficits (such as weakness, loss of balance, numbness), or (e) intracranial lesion (DoD, 2009). TBI severity is classified as mild, moderate, and severe, with mild TBI (mTBI) being the most prevalent form of TBI in combat-deployed service members (DoD, 2009). The DoD definition of mTBI requires that a service member sustain an alteration of consciousness lasting less than 24 hr, no loss of consciousness (LOC) or LOC less than 30 min, posttraumatic amnesia lasting less than 24 hr, and normal structural imaging (DoD, 2009).

Reported rates of TBI in recently returned combat-deployed service members range from 7.6% (Vasterling et al., 2006) to as high as 15% (Hoge et al., 2008) to 19% (Tanielian & Jaycox, 2008). Prior to the implementation of DoD directives mandating in-theater evaluation for mTBI, it was estimated that 60% of service members serving in OIF/OEF who were exposed to events that carry risk for mTBI were likely not evaluated by health care providers specifically for mTBI (Tanielian & Jaycox, 2008). One concern is that service members with mild, closed head injuries who experience no LOC or only very brief states of altered consciousness are at risk for being overlooked during battlefield medical evaluations (Schwab et al., 2007). Thus, postdeployment neurological assessment of OIF/OEF service members exposed to closed head trauma remains a compelling challenge for health care providers serving recently deployed service members.

One of the challenges facing postdeployment screening for mTBI is the paucity of studies investigating the psychometric properties of the many TBI screening instruments that were rapidly developed and applied to address the escalating frequency of TBIs stemming from OIF/OEF operations (U.S. Government Accountability Office, 2008). The current article strives to address the measurement properties of one such scale, the Abbreviated Concussive Symptom Inventory (ACSI).

Precursors to the ACSI

One of the first efforts to improve screening and surveillance of TBI in large groups of service members returning from OIF/OEF deployments was the Brief Traumatic Brain Injury Screen (BTBIS; Schwab et al., 2007). Contained within the BTBIS were questions about the presence of deployment injuries due to experiences commonly associated with TBI (e.g., IEDs, bullets, falls, vehicles), questions pertaining to alteration of consciousness or LOC, and questions asking respondents about their current (during assessment) experience of seven specific postconcussive symptoms (PCS). Schwab and colleagues (2007) reported data from the BTBIS administered to a sample of soldiers ($N = 596$), predominately paratroopers, who served on the ground in OIF/OEF. The symptoms endorsed were: sleep problems (37.2%), ringing in the ears (37.2%), headache (36.2%), irritability (31.9%), memory problems (28.7%), dizziness (14.9%), and balance problems (7.4%). Evidence supporting the criterion validity of the BTBIS PCS inventory was that soldiers with self-reported TBI were significantly ($p < .001$) more likely to have three or more PCS (64%) compared with those who did not report TBI (41%). Evidence of convergent validity between the BTBIS PCS items and the Neurobehavioral Symptom Inventory (Cicerone & Kalmar, 1995) was also reported ($r = .477$, $p < .001$).

The Warrior-Administered Retrospective Casualty Assessment Tool (WARCAT) was adapted from the BTBIS and was designed to facilitate clinical interviews in large groups of returning service members at risk for mTBI (Terrio et al., 2009). The WARCAT PCS screen included five clinical symptoms. Terrio and colleagues (2009) reported WARCAT data provided by 907 soldiers with clinician-confirmed TBI returning from combat deployments in Iraq. Symptom endorsement was: irritability (21.3%), headache (20.2%), memory problems (16.3%), balance problems (6.4%), and dizziness (5.1%).

A third adaptation of the BTBIS was the Traumatic Brain Injury Screening Instrument (TBISI), which was implemented by the U.S. Department of Veterans Affairs (Van Dyke, Axelrod, & Schutte, 2010). The TBISI includes questions about the qualifying head injury event, questions regarding LOC and head injury, six PCS following head injury, and a final section pertaining to the absence or presence of the same six PCS currently being experienced at the time of assessment. The only known published account of TBISI psychometric properties (Van Dyke et al., 2010) is based on a small sample ($N = 44$) of OIF/OEF veterans undergoing neuropsychological evaluation for TBI. Symptom endorsement for current PCS included: headaches (79%), memory problems (74%), light sensitivity (69%), sleep problems (67%), irritability (62%), and balance problems (52%). Test–retest reliability was the only

ICD-10[2] PCS Criteria cited by Schwab et al. (2007)	BTBIS Item	WARCAT Item	ACSI Item
Dizziness	Dizziness	Dizziness	Balance problems, *dizziness*, sensation of spinning[1]
Headache	Headaches	Headache	Headaches
Difficulty concentrating and performing mental tasks			
Impairment of memory	Memory problems	Memory problems	Memory problems
Fatigue			
Insomnia	Sleep problems		Trouble sleeping
Irritability	Irritability	Irritability	Irritability (short temper)
Reduced tolerance to stress and emotional excitement			Feeling like you are "on alert" all the time
Reduced tolerance to alcohol			
	Balance problems	Balance problems	*Balance problems*, dizziness, sensation of spinning[1]
	Ringing in the ears		Ringing in the ears
			Sensitivity to bright light or noise
			Trouble seeing things
			Feeling distant or cut off from ones you love
			Emotionally numb

FIGURE 1 Item mapping of postdeployment postconcussive symptom (PCS) screenings across the Brief Traumatic Brain Injury Screen (BTBIS), Warrior-Administered Retrospective Casualty Assessment Tool (WARCAT), and the Abbreviated Concussion Symptom Inventory (ACSI). [1]One ACSI item (balance problems, dizziness, and sensation of spinning) appears twice due to content overlap with two of the WARCAT items. [2]International Statistical Classification of Diseases and Related Health Problems-10th Revision.

psychometric property reported in this study. Based on an average of 6 months between the first and second administrations, test–retest reliability coefficients ranged from $\kappa = .47$ (headaches) to $\kappa = .11$ (irritability). Given the considerable interval of time between the two survey administrations, these very modest test–retest reliability estimates might be expected.

The Abbreviated Concussion Symptom Inventory

The ACSI (see Figure 1 for item description and content overlap with its precursors) was rationally derived by a team of military subject-matter experts with backgrounds in neurology and neuropsychology (see the Methods section for discussion of the development of the ACSI). The utility of this self-report symptom inventory is that it was relatively brief and could be conveniently and rapidly administered to large groups of redeploying service members to enable identification of service members who might need additional clinical evaluations. However, the ASCI had been limited by the absence of psychometric investigation to empirically justify scoring methods and estimate measurement error. The current study was therefore undertaken to address the limited psychometric foundation of the ASCI.

ACSI Measurement Model

A measurement model is essential to transform a set of responses on a questionnaire into a measure of a latent trait (Crocker & Algina, 1986). In the present situation, we wish to transfer ACSI responses into a measure of symptom severity. Although there are numerous measurement models, many are theoretically and practically limited in their application to data with certain sample characteristics. In the case of brief screening instruments such as the ACSI, the number of applicable measurement models is limited. Typically, instruments such as the ACSI have a very small number of items, a highly skewed distribution, and poor targeting items (the item difficulty is greater than the severity of the symptoms reported by most individuals). That is, brief screening instruments usually have asymmetric and long-tailed distributions stemming from a large proportion of healthy persons with low scores and fewer persons with higher scores reflecting the dysfunction being assessed. Distributions with such properties, coupled with a small number of items and poor targeting, present a major problem for measurement models that stem from parametric item response theory (DeMars, 2010). Consequently, our analysis will focus on the application of classical test theory and nonparametric item response theory Mokken analysis (Mokken, 1971; Sijtsma & Molenaar, 2002; van Schuur, 2011).

METHOD

Participants

The data analyzed for this study were provided by 1,435 active-duty U.S. Marines who were members of various units returning from OEF combat deployments in 2010 and 2011. Units were selected for additional TBI screening when they were suspected of being exposed to a heightened risk for TBI (e.g., elevated numbers of casualties, heightened combat experiences, and deployment to a region of Afghanistan known to be at elevated risk for blast exposure). The data indicate that 19% of the respondents had been exposed to a blast during their most recent deployment and that 23% had experienced a concussion. When asked about the prevalence of those same experiences pertaining to prior deployments, a far larger percentage reported blast exposures on previous deployments (68%). Reports of concussions on prior deployments were nearly the same (25%). Because the purpose of the additional TBI screening was to augment the standard postdeployment screening program (the U.S. DoD Postdeployment Health Assessment) conducted by the Marine's primary care provider (physician) or an independent duty corpsman, the only demographic data available for this study included age, which ranged from 19 years to 40 years ($M = 23.4$, $SD = 3.71$). Because the units that administered the augmented TBI screening were all combat arms units, all of the respondent Marines were male.

Procedure

Marines completed the ACSI in groups as part of their initial postdeployment TBI screening. Completion of the ACSI was within 2 to 8 weeks following return from deployment. Only deidentified ACSI data were made available to the first author for analysis following protocol approval by the Naval Air Warfare Center Aircraft Division Institutional Review Board of the DoD (Approval # NAWCAD.2011.0003-CR01-EMc).

Instrumentation

The ACSI is a low-cost, easy-to-administer, self-report method for evaluating the prevalence of symptoms thought to be associated with mTBI/concussion. The ACSI is scored as a dichotomous variable (1 = symptom present, 0 = symptom absent). Descriptive statistics for the 11 ACSI items are presented in Table 1. Item endorsement ranged from 36% (irritability) to 5% (trouble seeing) of the sample ($N = 1{,}435$).

TABLE 1
Item Descriptive Statistics and Loadings of Exploratory Factor Analysis of Tetrachoric Item Correlations

ACSI Item Abbreviated Name in Parentheses	*% Endorsing Item (N = 1,435)*	*M*	*SD*	*Factor Loading*
Irritability, short temper (Irritability)	35.7%	0.08	0.272	.78
Memory Problems	23.3%	0.23	0.423	.78
Trouble Sleeping	34.1%	0.34	0.474	.74
Feeling distant or cut off from the ones you love (Feeling Distant)	11.3%	0.11	0.317	.72
Balance Problems/Dizziness/Sensation of Spinning (Balance Problems)	8.0%	0.08	0.272	.72
Sensitivity to Bright Light or Noise (Sensitive to Light)	12.1%	0.12	0.327	.70
Emotionally Numb	12.3%	0.12	0.328	.69
Headaches	26.6%	0.27	0.442	.68
Trouble seeing things (Trouble Seeing)	5.4%	0.05	0.227	.68
Feeling like you are "on alert" all the time (Feeling on Alert)	19.7%	0.20	0.398	.64
Ringing in Ears	33.3%	0.33	0.471	.51

Note. Respondents are asked, "At the moment, do you have any of the following?" and are scored "1" if they endorse an Abbreviated Concussion Symptom Inventory (ACSI) item and "0" if the symptom is not endorsed. The mode for all items is 0.

Analysis Strategy

Psychometric analysis proceeded in four stages. First, the dimensionality of the ACSI was investigated. Dimensionality is a central assumption of both classical test theory and Mokken models. At present, the dimensionality of the ACSI is unknown. Although there are several multicategorical taxonomies of TBI symptoms (Centers for Disease Control and Prevention, 2012; DoD, 2009), it is not clear that they exist as separate entities in the patients as they report their symptoms. The DoD (2009) organizes TBI symptoms into three domains (somatic, cognitive, and psychological/behavioral), and the U.S. Centers for Disease Control and Prevention (2012) cites four symptom categories for TBI (physical, cognitive, emotional, and sleep-related). Yet, if each category of symptoms increases with the severity of TBI, then the likelihood of any patient reporting these symptoms may result in a high degree of item covariance that is manifest psychometrically as a single dimension. Therefore, the question of dimensionality is an empirical question that we will examine as the first step of this study.

Second, analyses were undertaken to investigate appropriateness of three measurement models from classical test theory (parallel, tau-equivalent, and congeneric) and two measurement models from the nonparametric item response theory framework (monotonic and double monotonic). These measurement models are not incompatible, but instead are potentially complementary as both assume a single underlying latent trait but provide different approaches to scoring and interpretation. Classical test theory assumptions are familiar and scoring is straightforward; however, item response theory analysis provides a nuanced understanding of individual item characteristics and the scale's ability to identify a person's place along the latent trait dimension. Thus, evaluating the ACSI with both classical and item response models yields a comprehensive evaluation of scaling assumptions. Third, the reliability of the ACSI was investigated. Lastly, a preliminary exploration of ACSI validity was undertaken to investigate the ability of the ACSI to differentiate between varying levels of head injury complexity.

RESULTS

Dimensionality

A preliminary check on unidimensionality was conducted via exploratory factor analysis. The program FACTOR 8.1 (Lorenzo-Seva & Ferrano, 2006) was employed using unweighted least squares applied to tetrachoric correlations that accommodated the dichotomous scoring of the ACSI. The number of factors was determined by parallel analysis (PA) and the Minimum Average Partial (MAP) Correlation Test (Velicer, 1976). The PA was based upon randomly generated correlation matrices using marginally bootstrapped samples (Lattin, Carroll, & Green, 2003, pp. 114–116). The results from the exploratory factor analysis are reported in Table 1. Neither PA nor MAP analyses produced evidence of a second factor version of the ACSI. The percent variance accounted for by the first two factors of the ACSI data was 59% and 11%, while the variance accounted for by the randomly generated data was 29% and 18%. MAP values increased in both ACSI and random data after the first factor—a situation consistent with a single dimensional factor structure. Similar results were found when Pearson correlations were used in place of tetrachoric correlations.

Measurement Models

The three most common measurement models in classical test theory are: (a) the parallel model, (b) the tau-equivalent model, and (c) the congeneric model

TABLE 2
Fit Statistics for the Confirmatory Factor Analysis

Model	*CFI*	*TLI*	*RMSEA*	*Dχ^2*	*Ddf*	*p*
Parallel	.98	.98	.064			
Tau-Equivalent	.98	.98	.066	58.89	10	.001
Congeneric	.99	.98	.065	77.38	10	.001

Note. Dχ^2 and Ddf are scaled according to Satorra & Bentler (1988). CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; RMSEA = root mean square error of approximation.

(Nunnally & Bernstein, 1994). The fit of the three measurement models to the data was evaluated from the most to least restrictive forms using confirmatory factor analysis (Graham, 2006). ACSI model parameters were estimated by robust maximum likelihood with covariance. Standard errors were calculated from the asymptotic covariance matrix. Model fit was determined by the root mean square error of approximation (RMSEA), which examines residual error, and the Comparative Fit Index (CFI) and the Tucker-Lewis Index (TLI), which indicate the percent improvement in fit over the null model (Kline, 2011). Acceptable fit is suggested if the CFI is greater than .95, TLI is greater than .96, and RMSEA is less than .08 (Schreiber, Stage, King, Nora, & Barlow, 2006; Yu, 2002). A scaled chi-square statistic was used to assess the fit, standard errors, and chi-squares (Satorra & Bentler, 1988). The results from the confirmatory factor analysis of the ACSI are reported in Table 2. Although most of the fit indexes for the ACSI were satisfactory for all three models (see Table 2), the chi-square change comparisons suggested the tau-equivalent model was a better fit to ACSI data than the parallel model, and further, that the congeneric model was a better fit than the tau-equivalent model. Accordingly, classical test theory may be appropriate for evaluating the psychometric properties of ACSI data. Thus, additional psychometric analyses proceeded utilizing all 11 items with a total score scale ranging from 0 (*no symptom endorsement*) to 11 (*all symptoms endorsed*).

Reliability

Table 3 presents Cronbach's alpha and three estimates more appropriate for a congeneric model (Revelle & Zinbarg, 2009). Those estimates of reliability and their magnitude in the current sample based on the 11 ACSI items were: Greatest Lower Bound (GLB; .85), McDonald's omega (.85), Guttman's lambda-2 (.81), and Cronbach's alpha (.80). The magnitudes of the reliability estimates are all greater than .80, thereby indicating that the ACSI has adequate reliability to serve as a screening instrument.

Scalability

The variation in the endorsement rate of ACSI items suggests a hierarchy of symptoms associated with more or less severe postconcussive syndrome. A true hierarchy implies an invariant item ordering (double monotonicity)—that is, a consistent ordering of symptom endorsement at all levels of the latent trait. The scalability of the ACSI was examined with a nonparametric item response theory Mokken analysis (Mokken, 1971; Stochl, Jones, & Croudace, 2012). Two models

TABLE 3
Percent Endorsing ACSI Item and Total ACSI Score Descriptive Statistics by Brain Injury Complexity Groups

		Brain Injury Complexity Groups			
Item	*Total*	*A*	*B*	*C*	*D*
Irritability	.36	.29	.44	.48	.70
Trouble Sleeping	.34	.26	.40	.53	.70
Ringing in Ears	.33	.27	.33	.51	.58
Headaches	.27	.16	.34	.51	.76
Memory Problems	.23	.14	.28	.45	.64
Feeling on Alert	.20	.15	.25	.29	.50
Emotionally Numb	.12	.09	.18	.19	.28
Sensitive to Light	.12	.07	.15	.26	.32
Feeling Distant	.11	.08	.15	.18	.30
Balance Problems	.08	.04	.09	.20	.26
Trouble Seeing	.05	.03	.04	.11	.18
N	1,435	976	123	286	50
Total Score Mean	2.21	1.57	2.66	3.71	5.22
Total Score *SD*	2.47	2.00	2.60	2.77	2.48
95% CI by Group		(A) 1.45, 1.70	(B) 2.19, 3.12;	(C) 3.39, 4.04	(D) 4.51, 5.93

A = no injury; B = non-blast-related traumatic brain injury (TBI); C = blast-related TBI; D = both blast-related and non-blast-related TBI.

were examined: (a) a monotone homogeneity model, which assumes that as a person's severity of PCS increases, so too does the probability of that person endorsing a symptom; and (b) a double monotonicity model, which assumes that in addition to the monotone model, the order of symptom endorsement remains the same for all levels of the latent trait—that is, item response functions do not cross (Stochl et al., 2012). Fit of the observed ACSI data to the two item response theory models was evaluated with the R program MOKKEN (Van der Ark, 2007). The data fit the monotone homogeneity model very well, as all items demonstrated simple monotonicity with no violations. Loevinger's H was .42 (minimum acceptable H is .30), and monotonicity analysis did not indicate deviation from monotonicity. All individual to total H values were greater than .30. The "CRIT" value, which is an index of violations of monotone homogeneity, for all items was equal to 0, indicating no items deviated from monotonicity (van Schuur, 2011). The reliability of the scale was acceptable: MS Rho = .82 (Sijtsma & Molenaar, 2002).

In contrast, the fit of ACSI data to the double monotonicity model was poor. The overall fit of the double monotonicity model may be examined with the Ht coefficient, which should ideally exceed .30. In the current ACSI data, the Ht was only .27. The CRIT value from the RESTSCORE check on double monotonicity specified two items that were unacceptable: "ringing in ears" and "emotionally numb."

The failure of the double monotonicity model to fit the data can also be observed in Table 3 by reviewing the percentages of the sample that endorsed an item at various levels of brain injury complexity. Four brain injury complexity groups were observed in the current sample. In order of increasing complexity those groups were: (a) non-head-injured ($n = 976$); (b) non-blast-related head-injured (had injury but no blast exposure; $n = 123$); (c) blast-related head injury ($n = 286$); or (d) both blast-related and non-blast-related head injury ($n = 50$). For the two most complex groups (blast-related only and blast-related plus non-blast-related injury), the frequency of item endorsement dropped for two items: "ringing in ears" and "emotionally numb." Removing those two items results in Ht = .33, individual negative Ht less than 10%, and none of the critical scores greater than .20. Furthermore, symptom endorsement percentages remain constant across the four TBI complexity groups (table not reported), and the reliability of the ACSI is not affected if those two items are omitted (i.e., omega and GLB = .83; lambda-2 and rho = .80). Despite the psychometric plausibility of excluding these items, the items retain substantive value; namely, those items may prove to be more sensitive to mTBI as opposed to more severe and complex TBI injuries.

Scoring the ACSI

The use of item response theory-based item weights was considered. However, based on the finding of single-factor structure and applicability of the classical test theory measurement model, as well as consideration of practical field applications requiring simple scoring and interpretation of results, we recommend that the ACSI be scored using a simple summation of symptom endorsement, regardless of whether one chooses to retain all items or drop the two items that violate double monotonicity. It should be noted that in the context of classical test theory, weighted sums tend to be highly correlated with the unweighted sum; thus, differential weighting of items would only increase the complexity of scoring the ACSI while netting little of practical significance (de Gruijter & van der Kamp, 2007). Accordingly, for the sake of convenience for a screening tool and because both classical test theory and the Mokken model support the use of a simple sum score, we recommend a simple unit summation be applied to obtain the ACSI total score.

With respect to practical application of the ACSI, the standard deviation of the total score observed in the present sample ($N = 1{,}435$; $SD = 2.47$) and the most conservative reliability estimate (.80) yield a standard error of measurement of 1.10. Hence, one can be 95% confident that a score is within ± 2.2 of the observed total score. Total symptom scores pertaining to the 50th, 75th, 90th, and 95th percentiles for the observed sample were, respectively, 1, 4, 6, and 7.

Validity

Some validity for the ACSI might be substantiated if higher ACSI scores corresponded to increasing complexity of brain injury sustained on deployment, with more complex brain injuries producing higher symptom endorsement. To test this hypothesis, the mean total ACSI scores of the four injury complexity groups were compared. Descriptive statistics for the four brain injury complexity groups are presented at the bottom of Table 3; note that the 95% confidence intervals for the groups do not overlap. The one-way analysis of variance, $F(3, 1431) = 100.75$, $p < .001$, indicated very significant differences in ACSI means across the four levels of blast injury complexity. Post-hoc comparisons with Tukey's honest significant difference (HSD) indicated all groups were significantly different from each other beyond the .001 probability level. Identical results were found when using an ACSI total score based only on those nine items that did not violate double monotoncity (i.e., removing "ringing in ears" and "emotionally numb"). At the item level, symptom endorsement increases across the groups when they are ordered as (a) no head injury,

(b) non-blast-related head injury, (c) blast-related head injury, and (d) both blast-related and non-blast-related head injury. The ordinal correlation (Goodman's gamma) between each item and group was highly significant ($p < .001$) and ranged from .38 to .65.

DISCUSSION

Interpretation of the Single-Factor Structure

The endorsement of 11 symptoms thought to represent postconcussive syndrome in U.S. Marines returning from combat deployment to Afghanistan was subjected to psychometric evaluation. The factor analysis of tetrachoric correlations indicated a single-factor model provided the best fit with the data. In contrast, some prior studies of the factor structure of PCS inventories have reported that the best fitting models contain oblique but distinct factors for cognitive, somatic, and emotional symptoms in samples of emergency room patients (Herrmann et al., 2009; Potter, Leigh, Wade, & Fleminger, 2006) and concussed high school football players (Piland, Motl, Guskiewicz, McCrea, & Ferrara, 2006). Could it be that the type (combat-induced) and frequency (multiple head injury exposures from multiple deployments) of head injuries unique to this sample accounted for the better fit of a single factor? Obviously, replication is needed in this case; but it should be noted that others (Hoge et al., 2008; Polusny et al., 2011) have argued that psychological factors (e.g., posttraumatic stress disorder, depression, anxiety) may form the underlying basis of some self-reported PCS in combat-exposed populations, especially when those symptoms occur in the absence of a self-reported LOC. Arguing from the perspective posited by Hoge and colleagues (2008), one might contend that psychological factors best account for the presence of a single PCS factor in the combat-deployed population evaluated in the current study. Revisiting the data, just 12% ($n = 167$) of the sample reported an LOC during their most recent deployment; thus, Hoge and colleagues' proposition seems plausible. Not to be overlooked, though, is the more parsimonious psychometric explanation that the ACSI single-factor structure is a consequence of reliance upon a single method of data collection (self-report).

Implications of the Findings for Future Applications of the ACSI

The results from the present study also carry more applied implications. First, ACSI responses conform to classical test theory measurement models, and all associated forms of reliability estimates are greater than .80, the threshold considered sufficient in most research contexts (Nunnally & Bernstein, 1994). Second, item response theory analyses supported monotonicity, but only double monotonicity when two poorly fitting items were dropped from the ACSI. One reason for this finding is that the sample is skewed toward a minimal number of symptoms—that is to say, the majority of the sample did not report many symptoms (37% of the sample did not endorse a single ACSI item). Consequently, item endorsement at the extreme ends of the latent trait that underlies postconcussion symptoms often does not represent the overall data set, thus resulting in poor model fit when attempting to constrain item response theory parameter estimates across various levels of the latent ACSI trait. Specifically, the two symptoms in question ("ringing in ears" and "emotionally numb") are less likely to be endorsed with greater levels of blast exposure and head injury. Although double monotonicity is typically a desirable measurement characteristic, in the present study, the lack of this psychometric property in the ACSI may point toward the need to investigate whether these two symptoms are more sensitive to less severe blast injury exposures, or in the vein of Hoge and colleagues (2008), whether those two items are more affected by psychological factors. More research is needed to replicate this finding and justify such interpretations. Third, the results reported in this study, combined with the practical need to minimize the complexity of ACSI scoring and interpretation, lead us to recommend that (a) the two items in question be retained, and (b) that the ACSI be scored using a simple symptom summation scoring method for all 11 items. However, for those who do wish to drop the two items, the unweighted summation method is also compatible. Lastly, both the 11- and 9-symptom versions of the ACSI appeared to differentiate between more and less complex exposures to head injury (i.e., ACSI scores increase with brain injury exposure complexity), thereby lending some preliminary credence to the criterion validity of the ACSI.

This study also confirmed that a greater total ACSI score was seen in blast-related plus non-blast-related mTBI compared with blast-related mTBI alone, and that both groups had higher scores than the group with non-blast-related causes of mTBI. Even in the non-TBI group (control), the symptoms of irritability, trouble sleeping, and tinnitus were seen in more than a quarter of the group, while memory problems, headaches, and a heightened state of arousal were also commonly reported.

Limitations of the Present Study

Despite the promise of the ACSI, some limitations to this study and the instrument should be noted, starting with the utilization of cross-sectional, self-report data. Clearly, validation of the ACSI as well as true evaluation of ACSI scoring methodology will require concurrent application of the ACSI with other distinct methods of evaluating TBI exposure, postconcussion symptom severity, and ideally, some form of functional evaluation and structural neurological imaging. Further, it will be important to determine if the single-factor structure observed in the current sample can be replicated in samples that are either predominantly or exclusively composed of participants who concurrently report LOC associated with their brain injuries, thereby permitting a more empirical investigation of Hoge and colleagues' (2008) assertion that the presence of PCS in the absence of LOC might be primarily attributable to psychosomatic complaints. If Hoge and colleagues are correct, then one might expect single-factor models to provide a better fit to data in samples that report no LOC, while multiple-factor models (e.g., somatic, cognitive, psychological) might provide a better fit to data in samples that do report LOC.

Conclusions and Future Prospects

The current study establishes the psychometric properties of the ACSI, an instrument developed by the U.S. Navy Bureau of Medicine in response to the need for enhanced screening for TBI and PCS in large units returning from combat deployments in Iraq and Afghanistan. Along those lines, this study is the first investigation of a postdeployment, TBI-specific survey instrument employing both factor analysis (with tetrachoric correlations) and item response theory (either parametric or nonparametric) to examine the psychometric properties of a PCS scale. Additional strengths of the study are the large sample size ($N = 1{,}435$) and the unique background of the sample (i.e., Marines returning from arduous combat deployment with single or multiple blast exposures).

In sum, those who wish to employ the ACSI in future studies can now estimate measurement error utilizing the upper- and lower-bound reliability estimates reported in this study. Additionally, the findings indicate the use of a single total score is justifiable. This last finding, that the ACSI is underpinned by a single factor, is consistent with the notion advocated by Hoge and colleagues (2008) and others (Polusny et al., 2011) that psychological symptoms are deeply interwoven into the fabric of PCS experienced by those who have suffered TBI in combat, thereby accounting for the presence of a single factor despite somewhat heterogeneous symptom content. However, given the present data, such an interpretation remains speculative. In summary, we conclude that the ACSI total score is psychometrically reliable, with evidence of a valid factor structure and limited criterion validity for differentiating between more and less complicated brain injury exposures.

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