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A novel approach to classifying postconcussion symptoms: The application of a new framework to the Post-Concussion Symptom Scale

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Introduction: Self-report measures such as the Post-Concussion Symptom Scale (PCSS) are frequently used during baseline and postconcussion testing to evaluate athletes' symptom profiles. However, the common approach of evaluating the total symptom score and/or symptom clusters may not allow for a complete understanding of the nature of athletes' symptom reporting patterns. The primary objective of this study was to apply three "global indices of distress" variables, derived from the Symptom Checklist-90-Revised (SCL-90-R) framework, to the PCSS at baseline and postconcussion. We aimed to evaluate the utility of these symptom indices in relation to four PCSS symptom clusters and the total PCSS symptom score. *Method*: Participants included college athletes evaluated at baseline ($N = 846$) and postconcussion ($N = 86$). Athletes underwent neuropsychological testing at both time points, including completion of the PCSS and a paper/pencil and computerized test battery. Eight symptom indices were derived from the PCSS, and a postconcussion neurocognitive composite score was calculated. *Results*: Results showed that there were significant mean increases from baseline to postconcussion on four of the eight symptom indices evaluated. Furthermore, a significant proportion of athletes showed *no change* from baseline to postconcussion when evaluating the total symptom score, but showed at least a one standard deviation *increase* in symptom reporting from baseline to postconcussion when evaluating at least one other symptom index (i.e., a global index of distress or symptom cluster). Finally, the three global indices of distress variables, two of the four symptom clusters, and the total symptom score significantly predicted a postconcussion neurocognitive composite score, such that greater postconcussion symptoms were associated with lower postconcussion neurocognitive performance. *Conclusions*: These findings suggest that, in addition to evaluating the postconcussion total symptom score, there may be value in examining more specific symptom indices such as the global indices of distress variables and symptom clusters.

Keywords: Sports-related concussion; Postconcussion symptoms; Collegiate athletes.

Understanding acute and long-term consequences of sports-related concussion has become a paramount concern within the scientific community. Important questions have been raised regarding when is it safe to clear a concussed athlete for return to play, and many research efforts have been devoted to better understanding what "safe" return to play means in the context of athletics (Cantu, 2001; Doolan, Day, Maerlender, Goforth, & Brolinson, 2012; Echemendia & Cantu, 2003; Lovell, Collins, & Bradley, 2004). Complicating matters further, though, is the

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awareness that outcome and recovery rates following sports-related concussion can differ greatly among athletes. Thus, another focus in recent literature has been to better understand why such disparate outcomes result following apparently similar injuries and to specifically determine whether there are reliable predictors of clinical outcome following concussion (Collins, Kontos, Reynolds, Murawski, & Fu, 2014; Dougan, Horswill, & Geffen, 2014; McCrea et al., 2013; Nelson, Janecek, & McCrea, 2013).

Given the widespread interest in the above topics, many sports concussion management programs have been established that focus on the assessment and treatment of athletes who have sustained concussions and their safe return to play. Currently, as a minimum threshold for returning to play, the standing recommendation is that athletes should return to sports participation only *after* postconcussion symptoms have resolved (Giza et al., 2013; McCrory et al., 2013). Thus, symptom monitoring and assessment are vital to concussion management.

In an effort to evaluate postconcussion symptoms and other sequelae of concussion, a variety of tools and techniques have been developed and implemented in sports concussion management programs, including sideline evaluations (McCrea, 2001; McCrea et al., 1998), neuropsychological testing (Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Maroon et al., 2000), balance/postural-stability testing (McCrea et al., 2003; Riemann & Guskiewicz, 2000), and symptom evaluation scales (Eyres, Carey, Gilworth, Neumann, & Tennant, 2005; Lovell et al., 2006; Piland, Motl, Guskiewicz, McCrea, & Ferrara, 2006; Randolph et al., 2009). Despite the potential limitations associated with the use of symptom evaluation scales—primarily, athletes' possible motivation to minimize existing symptoms—these subjective measures are readily used at all levels of sports participation to assess and monitor recovery following concussion.

One of the most widely used and well-validated symptom inventories is the Post-Concussion Symptom Scale (PCSS; Lovell et al., 2006). The PCSS consists of 22 symptoms that are evaluated on a 7-point scale ranging from 0 to 6 (with 0 indicating no symptoms and 6 indicating severe symptoms), and athletes are asked to rate the extent to which they are currently experiencing each symptom. Typically, the PCSS *total score* is the only index that is evaluated. For example, McClincy, Lovell, Pardini, Collins, and Spore (2006) investigated recovery rates following concussion in a group of high-school and college athletes. Participants underwent baseline testing, as well as postconcussion testing at 2, 7, and 14 days post injury. Athletes completed the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) neurocognitive battery and the PCSS at all testing time points, and postinjury scores were compared to baseline scores to determine when athletes were fully recovered. With respect to symptoms, athletes exhibited significantly higher PCSS total scores at Days 2 and 7 post injury, as compared to baseline, but by Day 14, the PCSS total score had decreased and no longer differed significantly from baseline. Though the findings of this study are certainly noteworthy, the results do not reveal information about the *severity* and *types* of symptoms that persist following concussion.

In a more recent study, Covassin, Elbin, Harris, Parker, and Kontos (2012) examined how age and gender may affect outcomes following concussion. Athletes were administered the ImPACT and PCSS at baseline and 2, 7, and 14 days postconcussion, as well as a balance assessment at 1, 2, and 3 days postconcussion. Though no significant differences were found between high-school and college athletes with regard to total symptom reporting, differences were found between males and females. Specifically, the investigators reported that females endorsed a higher total symptom score than males at all time points that were examined (i.e., baseline and 2, 7, and 14 days postconcussion). Though this finding is important, and consistent with several previous studies (Broshek et al., 2005; Colvin et al., 2009; Preiss-Farzanegan, Chapman, Wong, Wu, & Bazarian, 2009), specificity is lacking regarding symptom types and severity responsible for the reported group differences.

Although there are some advantages to evaluating total symptom scores—namely, the PCSS total score is quick and easy to calculate and to compare to other variables of interest—the total score, as noted above, does not allow for a complete understanding of athletes' symptom-reporting patterns. For example, a PCSS total score of 22 could be obtained in a number of ways: One athlete could report severity ratings of "1" for *every* symptom listed on the PCSS, while another athlete could endorse *only four* of the 22 symptoms, rating two symptoms as "5s" and two symptoms as "6s." In this example, both athletes end up with the same PCSS total score, but the pattern of their reporting is clearly different, implying that they may have sustained very different injuries and may subsequently experience very different recovery trajectories.

One method that has been used to better understand the *type* of symptoms that athletes endorse is examining symptom clusters. Pardini et al. (2004) conducted an exploratory factor analysis of the PCSS using data from a group of 327 concussed athletes in order to determine whether symptom clusters would emerge. They reported that the PCSS could be divided into four distinct factors consisting of cognitive, sleep, emotional, and somatic symptoms. Building upon Pardini et al.'s (2004) work, Lau, Collins, and Lovell (2011) sought to determine the predictive value of neurocognitive variables and symptom reports on prolonged recovery (defined as taking longer than 14 days to recover) following concussion. Athletes who sustained concussions were administered the ImPACT and PCSS approximately two days post injury, on average, and were followed until they were deemed eligible to return to play. The investigators conducted discriminant function analyses using the ImPACT composite scores, the PCSS symptom clusters, and the PCSS total score. They concluded that the best predictors of prolonged recovery following concussion included the *combination* of both neurocognitive variables and symptom clusters. Interestingly, the authors also found that the PCSS symptom clusters, when taken together, showed greater sensitivity than the PCSS total score at predicting prolonged recovery following concussion.

More recently, Kontos et al. (2012) conducted separate exploratory factor analyses on the PCSS using baseline and postconcussion data from high-school and college athletes. The baseline sample consisted of 30,455 athletes, and the concussed sample consisted of 1,438 athletes. The authors found a four-factor solution at both time points. Specifically, at baseline, cognitive–sensory, sleep–arousal, vestibular–somatic, and affective symptom clusters emerged. Following concussion, the symptom clusters included cognitive–fatigue–migraine, affective, somatic, and sleep. In the same study, Kontos et al. (2012) found that when comparing males' and females' symptom cluster scores, females endorsed more symptoms than males at baseline on all four symptom clusters. Females also endorsed more symptoms than males at postconcussion on the affective-related symptom cluster (Kontos et al., 2012). These results provide additional support for the utility of examining symptom clusters.

Despite the added value of examining symptom clusters, questions remain regarding the specificity and severity of athletes' symptom reports. Largely, *is it meaningful when athletes have similar total symptom scores but very different symptom profiles?* In order to address this question, applying the symptom framework of the Symptom Checklist 90-Revised (SCL-90-R) to the PCSS could be informative. The SCL-90-R is a widely used self-report measure that was designed not only to assess symptoms of psychopathology, but also to provide a summary of patients' symptoms, in terms of both the number and intensity of endorsed symptoms (Derogatis, 1994). The measure is made up of nine primary symptom dimensions, as well as three "global indices of distress," including the global severity index (GSI), the positive symptom total (PST), and the positive symptom distress index (PSDI). The GSI takes into account the severity of endorsed symptoms, controlling for the total number of symptoms listed on the questionnaire; the PST is a count of the total number of symptoms endorsed, regardless of the severity level; and the PSDI is considered an intensity measure that is corrected for the number of symptoms endorsed. Applying the SCL-90-R symptom framework (e.g., the "global indices of distress") to the PCSS may allow for a better understanding of athletes' symptom profiles and ultimately may provide an opportunity to identify athletes showing significant changes in their symptom profile from baseline to postconcussion without changes in their total symptom score.

With this in mind, the primary objective of this study was to evaluate the utility of the SCL-90-R global indices of distress variables, *as applied to the PCSS*, in relation to the more traditional symptom scores (i.e., the PCSS symptom clusters and total symptom score). In order to accomplish this overarching goal, several steps were taken. First, we applied the SCL-90-R global indices of distress framework to the PCSS at baseline and postconcussion and then calculated descriptive statistics for these symptom indices, as well as for the PCSS symptom clusters and PCSS total symptom score, at baseline and postconcussion. Next, we compared the baseline symptom indices with the postconcussion symptom indices and evaluated change from pre to post injury. Finally, we examined the predictive relationship between the postconcussion symptom indices and postconcussion cognitive outcome. Given that these aims were exploratory in nature, no specific a priori hypotheses were generated.

METHOD

Participants

Participants included male and female college athletes who were involved in a concussion management program at a Division I university. All athletes participating in the program were assessed via a neuropsychological test battery prior to their participation in collegiate athletics, and athletes who sustained concussions during their college athletic career were subsequently referred for postconcussion neuropsychological testing. Referrals for postconcussion testing were made by athletic trainers or team physicians, who defined concussion according to the following criteria: an injury to the head resulting from a trauma or biomechanical force wherein brain function is disrupted as evidenced by any alteration in mental status and/or postconcussion signs or symptoms at the time of injury, posttraumatic amnesia lasting less than 24 hours, and/or loss of consciousness lasting 30 minutes or less (Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group, 1993; Ruff, Iverson, Barth, Bush, & Broshek, 2009). Our concussion management program was modeled after the sports as a laboratory assessment model developed by Barth and colleagues (Barth et al., 1989) and serves to provide team physicians with objective return-to-play recommendations based on neuropsychological test data. The following varsity athletic teams participated in baseline and postconcussion testing: football, wrestling, men's and women's basketball, men's and women's lacrosse, men's and women's soccer, and men's ice hockey.

Two groups of participants—athletes tested at baseline and athletes tested postconcussion—were examined in this study. Baseline participants were selected from a larger sample comprised of 925 college athletes who had been enrolled in the concussion management program between 2002 and 2014. Participants were excluded from this larger sample if they did not complete the PCSS at baseline (n = 79). Thus, the final baseline sample included 846 college athletes (637 males, 209 females). Postconcussion participants were selected from a larger sample comprised of 98 athletes who had sustained concussions while participating in the concussion management program. Participants were excluded from the concussed athlete sample if postconcussion testing was completed more than two weeks post injury (n = 12). Thus, the final postconcussion sample included 86 college athletes (71 males, 15 females) tested, on average, about 3.5 days after their initial injury (M = 3.71, SD = 2.70). Baseline and postconcussion participant demographic characteristics are presented in Table 1.

TABLE 1
Baseline and postconcussion sample characteristics

	Baseline (N = 846)		*Postconcussion (N = 86)*	
Variable	*M*	*SD*	*M*	*SD*
Age (years)	18.53	1.06	19.98	1.44
Education (years)	12.18	0.80	13.44	1.34
	N	%	N	%
Sex				
Male	637	75.3	71	82.6
Female	209	24.7	15	17.4
Ethnicity				
Caucasian	626	74.0	54	62.8
African American	168	19.9	25	29.1
Other	52	6.1	7	8.1
Concussion history				
0	537	63.5	46	53.5
1	210	24.8	26	30.2
2 or more	99	11.7	14	16.3
History of ADHD or learning disorder				
Yes	47	5.6	6	7.0
No	799	94.4	80	93.0
Sport				
Football	256	30.3	37	43.0
Men's basketball	57	6.7	10	11.6
Men's ice hockey	83	9.8	5	5.8
Men's lacrosse	128	15.1	13	15.1
Men's soccer	95	11.2	4	4.7
Women's basketball	39	4.6	3	3.5
Women's lacrosse	70	8.3	6	7.0
Women's soccer	92	10.9	6	7.0
Wrestling	19	2.2	2	2.3
Other	7	0.9	0	0.0

Note. ADHD = attention-deficit/hyperactivity disorder.

Procedure

All athletes were administered a comprehensive neuropsychological test battery at baseline. The battery consisted of both neurocognitive and neurobehavioral measures, including a symptom evaluation scale. Athletes who subsequently sustained concussions were referred for postconcussion testing and were administered a similar test battery at their postinjury appointment. The neuropsychological test battery was individually administered by undergraduate research assistants or graduate students who were supervised by a PhD-level clinical neuropsychologist. Baseline and postconcussion testing appointments took approximately 2 hours to complete. The present study was approved by the university's Institutional Review Board, and we obtained informed consent for all participants.

Measures

Symptom variables

The Post-Concussion Symptom Scale (PCSS) is a self-report measure that was developed to assess not only the types of symptoms experienced following concussion, but also the severity of postconcussion symptoms (Lovell, Collins, Podell, Powell, & Maroon, 2000; Lovell et al., 2006). As indicated previously, the measure is comprised of 22 items (e.g., headache, dizziness, irritability, feeling mentally foggy, etc.), which are evaluated on a 7-point scale ranging from 0 to 6, with 0 indicating no symptoms and 6 indicating severe symptoms. Participants are administered the PCSS via the ImPACT computer program, and the measure has excellent internal consistency (.89–.94; Lovell et al., 2006).

For the present study, several symptom variables were derived from the PCSS at baseline and postconcussion. The PCSS total symptom score was calculated by summing the ratings for each individual PCSS item (possible range = 0–132), and the PCSS symptom clusters were calculated according to previous factor analytic work by our group (Merritt & Arnett, 2014). The symptom clusters included a cognitive factor (4 items; possible range = 0–24), a physical factor (7 items; possible range = 0–42), an affective factor (4 items; possible range = 0–24), and a sleep factor (4 items; possible range = 0–24). The list of symptoms that comprises each symptom cluster is listed in Table 2.

Additionally, individual responses to the PCSS were transformed into the following "global indices of distress" variables, adapted from the SCL-90-R symptom framework: global severity index (GSI), positive symptom total (PST), and positive symptom distress index (PSDI). The GSI was calculated by dividing the PCSS total symptom score by 22 (the total number of symptoms that could be endorsed); the PST was calculated by counting the total number of positively endorsed symptoms (possible range = 0–22); and the PSDI was calculated by dividing the PCSS total symptom score by the PST value (In the case of a zero value for the PST scale score, the PSDI scale score was set to zero). Thus, the GSI serves as an overall summary measure, providing an indication of the average level of symptomatology; the PST serves as a measure of symptom breadth; and the PSDI serves as a measure of symptom intensity (Derogatis, 1994).

In order to better understand the global indices of distress variables, we return to our example described previously. A total score of 22 could be obtained in a number of ways. For instance, Athlete X could report severity ratings of "1" for *every* symptom listed on the PCSS; in this case, global index scores would be as follows: GSI = 1, PST = 22, and PSDI = 1. Taking another example, Athlete Y could endorse *only four* of the 22 symptoms, rating two symptoms as "5s" and two symptoms as "6s." In this case, global index scores would be as follows: GSI = 1, PST = 4, and PSDI = 5.5.

Neurocognitive variables

The neurocognitive test battery administered at baseline and postconcussion was comprised of both computerized and paper and pencil measures. Our test battery included: the ImPACT (Lovell et al.,

TABLE 2
PCSS symptom clusters and their associated items

Cognitive	*Physical*	*Affective*	*Sleep*
Feeling slowed down	Nausea	Irritability	Fatigue
Feeling mentally "foggy"	Vomiting	Sadness	Trouble falling asleep
Difficulty concentrating	Balance problems	Nervousness	Sleeping less than usual
Difficulty remembering	Dizziness	Feeling more emotional	Drowsiness
	Sensitivity to light		
	Sensitivity to noise		
	Visual problems		

Note. PCSS = Post-Concussion Symptom Scale. Table adapted from Merritt, V. C., & Arnett, P. A. (2014). Premorbid predictors of postconcussion symptoms in collegiate athletes. *Journal of Clinical & Experimental Neuropsychology, 36(10)*, 1098–1111; Table 5, p. 1105.

2000), the Vigil/W Continuous Performance Test (Cegalis & Cegalis, 1994), the Brief Visuospatial Memory Test–Revised (BVMT–R; Benedict, 1997), the Comprehensive Trail-Making Test (CTMT; Reynolds, 2002), the Digit Span Test (Wechsler, 1997), the Hopkins Verbal Learning Test–Revised (HVLT–R; Brandt & Benedict, 2001), the Penn State University Cancellation Task (Echemendia & Julian, 2001), the Stroop Color–Word Test (SCWT; Trenerry, Crosson, DeBoe, & Leber, 1989), and the Symbol–Digit Modalities Test (SDMT; Smith, 1991).

RESULTS

The Statistical Package for the Social Sciences (SPSS), Version 22.0 (IBM Corp., 2010), was used for all data analyses, and significance levels were set at $p < .05$, unless otherwise indicated.

Step 1: Apply the SCL-90-R global indices of distress framework to the PCSS at baseline and postconcussion, and calculate descriptive statistics for the PCSS global indices of distress variables, symptom clusters, and total symptom score (at baseline and postconcussion) in order to better characterize athletes' symptom profiles.

Descriptive statistics were calculated on all symptom indices (i.e., 3 global indices of distress, 4 symptom clusters, and the total symptom score) for the baseline and postconcussion samples (see Table 3). With respect to both samples, the distribution of all eight symptom indices was not normal (W = .33–.94, all $p \leq .001$). As indicated in Table 2, all symptom variables showed positive skewness and kurtosis, with the exception of the PCSS–PSDI variable, which had negative kurtosis. However, the postconcussion symptom indices appeared to have slightly less skewness and kurtosis than the baseline symptom indices. Additionally, internal consistency for the PCSS symptom variables at baseline and postconcussion was evaluated using Cronbach's α. With respect to the baseline sample, Cronbach's α values were as follows: PCSS = .87; Cognitive = .78; Physical = .79; Affective = .79; and Sleep = .75. With respect to the postconcussion sample, Cronbach's α values were as follows: PCSS = .94; Cognitive = .94; Physical = .85; Affective = .76; and Sleep = .80. Reliability coefficients were not able to be generated for the global indices of distress variables because each variable represents a single item. However, given that the global index variables are derived from the PCSS, which has good–excellent internal consistency, it is presumed that the global index variables have equivalently strong reliabilities.

Step 2: Compare baseline symptom indices with postconcussion symptom indices and evaluate change from baseline to postconcussion.

TABLE 3

Descriptive statistics for baseline and postconcussion PCSS symptom indices

PCSS symptom indices	*Mean*	*SD*	*Median*	*Min*	*Max*	*Skewness*	*Kurtosis*	*W-stat*[a]	*p*[b]
Baseline PCSS symptom indices									
Global severity index	0.25	0.40	0.09	0.00	3.27	2.86	10.78	.66	.000
Positive symptom total	2.74	4.02	1.00	0.00	22.00	2.58	8.05	.69	.000
Positive symptom distress index	1.22	1.19	1.00	0.00	5.00	0.65	–0.39	.88	.000
Cognitive symptom cluster	1.03	2.38	0.00	0.00	17.00	3.34	13.48	.50	.000
Physical symptom cluster	0.52	1.77	0.00	0.00	19.00	5.45	39.31	.33	.000
Affective symptom cluster	1.22	2.72	0.00	0.00	21.00	3.27	12.92	.52	.000
Sleep symptom cluster	2.04	3.29	0.00	0.00	20.00	2.28	6.05	.68	.000
Total symptom score	5.48	8.73	2.00	0.00	72.00	2.86	10.78	.658	.000
Postconcussion PCSS symptom indices									
Global severity index	0.52	0.67	0.32	0.00	2.95	2.01	3.83	.74	.000
Positive symptom total	5.81	6.26	3.50	0.00	22.00	1.36	1.15	.82	.000
Positive symptom distress index	1.47	0.99	1.41	0.00	3.78	0.17	–0.47	.94	.001
Cognitive symptom cluster	2.60	4.44	1.00	0.00	20.00	2.31	5.03	.64	.000
Physical symptom cluster	2.36	4.21	0.00	0.00	18.00	2.19	4.19	.63	.000
Affective symptom cluster	1.51	2.70	0.00	0.00	11.00	2.06	3.75	.63	.000
Sleep symptom cluster	2.97	3.88	1.00	0.00	17.00	1.68	2.57	.77	.000
Total symptom score	11.40	14.72	7.00	0.00	65.00	2.01	3.83	.74	.000

Note. PCSS = Post-Concussion Symptom Scale. Baseline sample: N = 846 (637 males, 209 females); postconcussion sample: N = 86 (71 males, 15 females).

[a] The W-stat refers to the Shapiro–Wilk statistic, a measure of normality. [b] The p value refers to the significance of the Shapiro–Wilk test. A significant p value indicates that the data are not normally distributed.

Given that the symptom indices were not normally distributed, Wilcoxon signed-rank tests were used to compare baseline symptom reports to postconcussion symptom reports to determine whether there were any significant changes in symptom reporting following concussion. Due to the number of symptom variables evaluated, it is recognized that applying a correction for multiple comparisons would be appropriate. However, given that the symptom variables are not independent from one another, procedures such as the Benjamini–Hochberg approach or a Bonferroni correction were not suitable; thus, we applied a more conservative p value ($p < .01$).

Results showed that there were significant *increases* from baseline to postconcussion on the following symptom indices: the GSI, the PST, the physical symptom cluster, and the total symptom score. There was a similar trend found for the cognitive symptom cluster (see Table 4). Additionally, the proportion of participants who showed at least a one-standard-deviation *increase* from baseline to postconcussion on each symptom index was calculated, and the results are provided in Table 5. Given that we did not have test–retest values for the symptom indices, we were unable to calculate reliable change; thus, a common clinical metric for change (i.e., one standard deviation) was used (Lezak, Howieson, & Loring, 2004). Finally, the proportion of athletes who *did not* show a significant increase on the total symptom score (as defined by one standard deviation or more) but *did* show a significant increase on at least one other symptom index was calculated (Table 6).

In order to assess the validity of the symptom reports, we used objective effort testing that was included in the neuropsychological assessment battery as a proxy for valid symptom reporting. The ImPACT Impulse Control Composite (ICC) was evaluated in the sample at baseline and postconcussion, using the previously established cutoff of 30 as a reference point for sufficient effort/motivation (ImPACT Applications, Inc., 2012). Thus, athletes with ICCs below the cutoff were presumed to be putting forth sufficient effort, thereby suggesting valid symptom reporting. Alternatively, athletes with ICCs above the cutoff were presumed to be putting forth questionable effort, thereby suggesting the possibility of inaccurate symptom reporting. When evaluating the ImPACT ICC in our sample, all but four athletes (4.7%) scored below the designated cutoff of 30, suggesting that the majority of the sample demonstrated valid symptom reporting. When the analyses were

TABLE 4
Wilcoxon signed-rank test results comparing change from baseline to postconcussion on the PCSS symptom indices

PCSS symptom indices	*Z*	*p*
Global severity index	–2.67	.008*
Positive symptom total	–3.24	.001*
Positive symptom distress index	–1.23	.221
Physical symptom cluster	–2.80	.005*
Cognitive symptom cluster	–2.13	.033
Affective symptom cluster	–0.75	.456
Sleep symptom cluster	–0.98	.329
Total symptom score	–2.67	.008*

Note. PCSS = Post-Concussion Symptom Scale. $N = 86$ (71 males, 15 females).

*To adjust for multiple comparisons, a value of $p < .01$ was considered significant.

TABLE 5
Proportion of participants who showed an increase of 1 standard deviation or more from baseline to postconcussion on each of the PCSS symptom indices

Symptom indices	*N*	*%*
1. Global severity index	23	26.7
2. Positive symptom total	30	34.9
3. Positive symptom distress index	27	31.4
4. Physical symptom cluster	29	33.7
5. Cognitive symptom cluster	24	27.9
6. Affective symptom cluster	17	19.8
7. Sleep symptom cluster	19	22.1
8. Total symptom score	22	25.6

Note. PCSS = Post-Concussion Symptom Scale.

TABLE 6
Proportion of participants who showed an increase of 1 standard deviation or more from baseline to postconcussion on each of the PCSS symptom indices without showing an increase on the PCSS total symptom score

Symptom indices	*N*	*%*
1. Global severity index	1	1.2
2. Positive symptom total	9	10.5
3. Positive symptom distress index	12	14.0
4. Physical symptom cluster	10	11.6
5. Cognitive symptom cluster	6	7.0
6. Affective symptom cluster	4	4.7
7. Sleep symptom cluster	2	2.3
8. Symptom Indices 1–7 combined	26	30.2

Note. PCSS = Post-Concussion Symptom Scale. Symptom indices 1–7 are not mutually exclusive; thus, the same athlete could appear in more than one symptom index for Items 1–7. For Item 8, "Symptom Indices 1–7 Combined," the "*N*" value represents the number of participants who showed an increase of 1 standard deviation or more *on at least one* of the symptom indices 1–7, but did not show an increase on the PCSS total symptom score. For example, a participant could show an increase of 1 standard deviation on 3 of the 7 symptom indices 1–7, but would only be counted once under the "*N*" for Item 8.

redone without the four subjects who demonstrated questionable effort, the findings did not change in any meaningful way; thus, these participants were retained.

Step 3: Examine the relationship between the postconcussion symptom indices and postconcussion cognitive outcome.

In order to address this aim, we first derived a postconcussion neurocognitive composite index according to methods described previously (Merritt & Arnett, 2014). Briefly, the neurocognitive composite score was comprised of the following *postconcussion* test indices: ImPACT Verbal Memory, ImPACT Visual Memory, ImPACT Visual Motor Speed, ImPACT Reaction Time, BVMT–R Total Immediate Recall, BVMT–R Total Delayed Recall, HVLT–R Total Immediate Recall, HVLT–R Total Delayed Recall, SDMT Total Correct, SDMT Incidental Memory, Stroop 1 Time, Stroop 2 Time, CTMT Trial 1 Time, and CTMT Trial 2 Time. For the above variables, all raw scores were converted to standard scores (M = 100, SD = 15) using the means and standard deviations from our baseline sample as our normative data, and all standard scores were calculated so that higher scores would indicate *better* performance. The neurocognitive composite variable was found to have acceptable internal consistency (α = .79) in our postconcussion sample.

After calculating the postconcussion neurocognitive composite score, Spearman correlations were used to determine the relationship between the various postconcussion symptom indices and the postconcussion neurocognitive composite score. Significant inverse relationships were found between the neurocognitive composite score and the following symptom variables: the GSI (r_s = –.39, p < .001), the PST (r_s = –.38, p < .001), the PSDI (r_s = –.30, p = .005), the physical symptom cluster (r_s = –.37, p < .001), the cognitive symptom cluster (r_s = –.38, p < .001), the sleep symptom cluster (r_s = –.33, p = .002), and the total symptom score (r_s = –.39, p < .001). The nature of the relationships was such that higher symptom scores were associated with lower neurocognitive composite performance.

Due to the significant multicollinearity among the predictor variables, separate linear regression analyses were conducted to assess the degree to which the postconcussion PCSS symptom-related indices predict cognitive performance postconcussion. For each regression model, the baseline symptom index was entered in Step 1, followed by its respective postconcussion symptom index in Step 2, in order to control for baseline symptom reporting. Table 7 displays the results of each linear regression analysis. As displayed in the table, all of the symptom variables, with the exception of the affective and sleep symptom clusters, independently predicted the postconcussion neurocognitive composite score. Additionally, all significant symptom variables represented medium–large effects. Thus, increased symptom reporting from baseline to postconcussion across most indices predicted worse neurocognitive performance postconcussion.

TABLE 7
Linear regression analyses using symptom variables to predict the postconcussion neurocognitive composite score

Variable	R	R^2	ΔR^2	F	p
Step 1: BL GSI	.00	.00	.00	0.00	.980
Step 2: PC GSI	.32	.10	.10	4.56	.013
Step 1: BL PST	.05	.00	.00	0.21	.652
Step 2: PC PST	.34	.12	.12	5.39	.006
Step 1: BL PSDI	.16	.02	.02	2.06	.155
Step 2: PC PSDI	.33	.11	.09	4.95	.009
Step 1: BL physical	.03	.00	.00	0.07	.797
Step 2: PC physical	.30	.09	.09	4.16	.019
Step 1: BL cognitive	.02	.00	.00	0.04	.851
Step 2: PC cognitive	.34	.11	.11	5.31	.007
Step 1: BL affective	.03	.00	.00	0.08	.784
Step 2: PC affective	.08	.01	.01	0.25	.782
Step 1: BL sleep	.02	.00	.00	0.04	.835
Step 2: PC sleep	.25	.06	.06	2.78	.068
Step 1: BL TSS	.00	.00	.00	0.00	.980
Step 2: PC TSS	.32	.10	.10	4.56	.013

*Note.*Regression analyses were run independently for each symptom variable. In order to control for baseline symptom reports, the baseline symptom variable was entered into the regression first, followed by its respective postconcussion symptom variable. Thus, for each analysis listed in the table, “Step 1” represents the model fit for the baseline symptom variable only, and “Step 2” represents the model fit for both the baseline and postconcussion symptom variables. BL = baseline; PC = postconcussion; GSI = global severity index; PST = positive symptom total; PSDI = positive symptom distress index; TSS = total symptom score.

DISCUSSION

The total symptom score is often the only symptom variable evaluated in concussion outcome studies. Although investigators have started to report on the *types* of symptoms that are experienced by concussed athletes (i.e., by examining symptom cluster scores such as physical, cognitive, affective, and sleep-related symptoms), questions still remain regarding the specificity and severity of athletes' symptom reporting patterns. In particular, an important phenomenon that deserves further consideration is when concussed athletes have similar *total symptom scores* but very different symptom profiles. As a way to begin addressing this matter, the present study applied the framework of the SCL-90-R global indices of distress variables to the PCSS at baseline and postconcussion, and in doing so, sought to determine whether there was value in examining these variables with respect to the more commonly used symptom cluster variables and total symptom score.

In order to address the main study objective, we first calculated the global indices of distress scores (three variables), followed by the symptom clusters (four variables) and total symptom score (one variable), for our baseline and postconcussion samples, and then computed descriptive statistics for all eight symptom indices. Next, we compared the baseline symptom indices to the postconcussion symptom indices and evaluated the degree of change in symptom reporting from baseline to postconcussion. Finally, we used correlational analyses, followed by a series of independent linear regression analyses, to determine the extent of the relationship between the symptom indices and cognitive outcome following concussion.

Results showed that four of the eight symptom indices showed a significant increase from baseline to postconcussion; these included two of the global indices of distress variables (the GSI and PST), one symptom cluster (physical), and the total symptom score. Although a number of prior studies (Covassin, Moran, & Wilhelm, 2013; Covassin, Schatz, & Swanik, 2007; Makdissi et al., 2010; McClincy et al., 2006; McCrea et al., 2003) have compared the baseline PCSS total symptom score to the postconcussion PCSS total symptom score and have found similar findings (i.e., significant increases from baseline to postconcussion), to our knowledge, this is the first study to have compared baseline and postconcussion symptom cluster scores and global indices of distress variables. Given that two of the global indices of distress variables, as well as the physical symptom cluster, showed significant increases from baseline to postconcussion, there appears to be added value to assessing both the global indices of distress variables and symptom cluster scores.

Upon evaluating the proportion of athletes who showed at least a one-standard-deviation increase in symptom reporting from baseline to postconcussion (see Table 5), the greatest increase (~35%) was found with the PST index. The PST, again, is a measure of the number of symptoms that the athlete endorses, regardless of severity; thus, it appears as though this particular symptom index may be sensitive to concussion and worthwhile to examine in future studies. Other notable variables were the physical symptom cluster, where ~34% of the athletes showed at least a one-standard-deviation increase from baseline to postconcussion, as well as the PSDI score, where ~31% of the athletes showed at least a one-standard-deviation increase. While many of these indices showed a comparable number of athletes demonstrating a significant increase in symptoms, it is important to highlight that these were not always the same athletes showing an increase across indices (see Table 6). In fact, nearly one third (30.2%) of athletes in this study showed an increase on *at least one of the symptom indices* without showing an increase on the total symptom score. Thus, these results suggest that a significant number of athletes showing postconcussion changes in symptoms may be missed by only looking for changes in the total symptom score rather than examining the more complete symptom profile. As symptom reporting often serves as the foundation for return-to-play procedures, these undetected changes in symptoms could have serious implications for athletes' safety and recovery.

When considering these findings within the context of clinical applicability, our preliminary data suggest that paying attention to the additional symptom variables may be just as important, if not more important, than simply evaluating the total symptom score. By using the symptom clusters we derived, in addition to the PCSS global indices of distress variables, our data show that it is possible to provide a more nuanced picture of symptom recovery postconcussion. Such an approach can potentially provide much greater information to treatment care providers in monitoring symptom recovery. For example, it would be useful to know if an athlete was back to baseline on physical symptoms, but not affective symptoms. Such knowledge would inform treatment by suggesting that brief psychotherapy or counseling could be initiated to address such persisting symptoms in a timely fashion to prevent the development of a postconcussion syndrome. Additionally, the SCL-90-R analogue scales provide more nuanced symptom summary measures, providing a better sense of the average level of symptomatology, symptom breadth, and symptom intensity. For example, it would be important for treatment purposes to know whether someone was endorsing a few symptoms at high severity levels versus many symptoms at lower severity levels. Even though these two individuals may end up with similar total symptom scores, their symptom profiles greatly differ, and they may ultimately benefit from different forms of treatment. Although examining specific treatment options is beyond the scope of this paper, our results indicate that diverse symptom profiles are present in our sample, suggesting that future research examining targeted treatments is warranted.

This is the first study, to our knowledge, that has applied the SCL-90-R global indices of distress framework to the PCSS; thus, while our findings are notable, replication is necessary before these results may be used clinically. Nevertheless, these findings do clearly indicate that examination of more than just the total symptom score is worthwhile. Related, it would be valuable for future research to further evaluate the global indices of distress within the context of concussion outcome, as well as to determine how symptom profiles relate to various aspects of the recovery process.

Finally, with respect to determining the relationship between the various postconcussion symptom indices and the postconcussion neurocognitive composite score, we found a significant *negative* relationship between seven of the eight symptom indices (the only nonsignificant finding was for the affective symptom cluster) and the postconcussion neurocognitive index, such that as the postconcussion symptom variables increased, the neurocognitive composite score decreased. As for the linear regression results, when controlling for baseline symptom reports, six postconcussion symptom indices significantly predicted the postconcussion neurocognitive composite score. Results revealed medium to large effect sizes, with the PST score accounting for the greatest variance (12%) in neurocognitive performance following concussion. Thus, consistent with previous work (Erlanger et al., 2003; Fazio, Lovell, Pardini, & Collins, 2007; Peterson, Ferrara, Mrazik, Piland, & Elliott, 2003), our study further established that increases in symptoms from baseline to postconcussion are associated with neurocognitive deficits post concussion. Additionally, the linear regression results add further support for the potential value in examining not only traditional markers of symptom reporting, but also global indices of distress, and may offer some additional support for the reliability and convergent validity of the global indices of distress variables as applied to the PCSS.

Limitations to the study largely relate to the generalizability of our findings. Given that our sample was comprised of collegiate athletes, our findings may not be as applicable to older and younger groups. Furthermore, our postconcussion sample included athletes who had sustained concussions, or mild traumatic brain injuries; thus, it is not known whether the same conclusions can be drawn for those who have sustained more severe brain injuries. Finally, our postconcussion sample was predominately male (82.6%). Consequently, our findings may be more representative for males than for females. Future studies should address these limitations.

Another limitation of the present study concerns the use and evaluation of symptom measures that are based on athletes' self-report. It is recognized that the possibility exists for athletes to misrepresent their symptoms at baseline (in order to provide a cushion for postconcussion testing) or following concussion (in order to minimize their chances of being withheld from play). However, given that the concussed athletes in this study performed adequately on effort testing, it is presumed that their responses on the PCSS reflect their true symptomatology. Related to this, athletes' symptom reports were inversely related to their overall performance on an objective measure of cognitive functioning, suggesting that there is convergence between objective and subjective experiences post concussion. Nevertheless, there is no way to definitively determine the accuracy of self-reported symptoms, but given that symptom reporting remains a critical feature of the return to play process (Giza et al., 2013; McCrory et al., 2013), it seems fruitful to continue evaluating symptom profiles beyond just the total symptom score. A final limitation that is worth noting is that there is no test–retest reliability data on the PCSS indices in healthy control participants. However, a study is underway in order to address this limitation.

CONCLUSIONS

Consideration of athletes' self-reported symptoms has been at the hallmark of concussion management for years, and it remains an essential characteristic of current return to play decision-making processes. Most prior research has focused on evaluating the total symptom score, and although evaluating this variable is essential, the present study sought to determine whether there may be some benefit to examining athletes' symptom reporting patterns and symptom profiles. In order to reliably measure and capture meaningful differences between individual athletes, it may be necessary to examine more than just the total symptom score; this paper evaluated exactly that and showed that there is added value to examining symptom variables beyond just the total symptom score.

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