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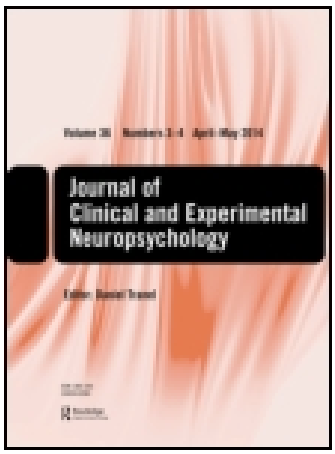

Journal of Clinical and Experimental Neuropsychology

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ncen20

Premorbid predictors of postconcussion symptoms in collegiate athletes

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Published online: 10 Dec 2014.

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To cite this article: Victoria C. Merritt & Peter A. Arnett (2014) Premorbid predictors of postconcussion symptoms in collegiate athletes, Journal of Clinical and Experimental Neuropsychology, 36:10, 1098-1111, DOI: 10.1080/13803395.2014.983463

To link to this article: http://dx.doi.org/10.1080/13803395.2014.983463

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Journal of Clinical and Experimental Neuropsychology, 2014
Vol. 36, No. 10, 1098–1111, http://dx.doi.org/10.1080/13803395.2014.983463

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Premorbid predictors of postconcussion symptoms in collegiate athletes

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(*Received 15 June 2014; accepted 29 October 2014*)

Introduction: In recent years, the sports community has been faced with the challenge of determining when it is safe to return concussed athletes to play. Given that return-to-play decisions are partially dependent upon athletes' endorsement of symptoms, better understanding what factors contribute to the presence of symptoms following concussion is crucial. The purpose of the present study was to better characterize the symptoms that athletes endorse at baseline and to determine what impact various premorbid (or preinjury) characteristics have on the presence and severity of postconcussion symptoms in the acute injury period following concussion. *Method:* Two groups of participants with similar ages and levels of education were examined: athletes at baseline (N = 702) and postconcussion (N = 55). Athletes were administered a comprehensive battery of neuropsychological tests, consisting of neurocognitive and neurobehavioral measures, at both time periods. The main outcome measure was the Post-Concussion Symptoms Scale (PCSS). A factor analysis was conducted on the participants' baseline PCSS data to determine the factor structure of the PCSS, and separate logistic regression analyses were conducted that examined the baseline PCSS symptom clusters (derived from the factor analysis), demographic variables, and baseline neurocognitive variables as predictors of dichotomized postconcussion PCSS total scores (i.e., low versus high symptom reporting following concussion). *Results:* Four distinct clusters emerged from the factor analysis measuring cognitive, physical, affective, and sleep symptoms. Logistic regression results indicated that the physical and affective symptom clusters at baseline reliably predicted athletes' postconcussion symptom group, as did sex and the neurocognitive composite score. *Conclusions:* These findings show that certain baseline characteristics of athletes confer risk for greater symptomatology postconcussion. Knowledge of these risk factors can assist the management and treatment of sports-related concussion.

Keywords: Closed head injury; Concussion; Postconcussion symptoms; Sports injuries; Collegiate athletes.

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Interest in sports-related concussion has intensified in recent years as a result of the increased awareness of the effects of such injuries. While the majority of sports-related concussions are considered "mild" brain injuries, physical, cognitive, and affective sequelae frequently develop after a concussion (McCrory et al., 2013; Moser et al., 2007). Some of the more common symptoms that concussed athletes report include headache, dizziness, difficulty concentrating, drowsiness, fatigue, feeling slowed down, and feeling mentally foggy (Lovell et al., 2006).

It is difficult to estimate the prevalence of sports-related concussion, as many go undetected or are not reported, but the Centers for Disease Control and Prevention suggests that 1.6 to 3.8 million sports-related concussions occur annually in the United States (Langlois, Rutland-Brown, &

The authors would like to thank Gray Vargas, Amanda Rabinowitz, Fiona Barwick, Aaron Rosenbaum, and Chris Bailey for their help as project coordinators of the program over the years, as well as the following individuals for their help with running participants and data entry for this project: Karissa Arthur, Dan Brynien, Saima Farooq, Caitlin Gaffney, Alex Garrison, Briana Hauser, Mark Petusky, Matt Phillips, Jordyn Sessel, Julie Turco, and Steven Yacovelli.

The authors report no conflicts of interest, and no formal grant funding was obtained for this project. However, they would like to thank Wayne Sebastianelli and Penn State Sports Medicine for their generous support of this research.

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Wald, 2006). Proper management of concussions has therefore become an issue of importance in the sports community in general, and among neuropsychologists in particular, with a key challenge being the development of appropriate guidelines for return to play. The current policy, developed by a consensus panel during the 4th International Conference on Concussion in Sport, requires athletes to refrain from physical and cognitive exertion while they are experiencing postconcussion symptoms and to return to play only after they are asymptomatic (McCrory et al., 2013). As such, being able to better understand what factors contribute to athletes' symptom reporting in the acute injury period following concussion may facilitate return to play decisions.

Examining premorbid or preinjury characteristics (i.e., "risk factors") that influence athletes' report of symptoms following concussion can provide a context for interpreting post injury symptom elevations. Very limited research in the sports-concussion literature, however, has examined the impact of premorbid characteristics on postconcussion symptom reporting. Identifying risk factors would, however, be extremely valuable, as the presence of postconcussion symptoms typically precludes return to play and may be indicative of ongoing brain dysfunction. Furthermore, this knowledge would allow team physicians and athletic trainers to provide more realistic expectations to athletes regarding their return-to-play status and may have implications for the management and treatment of concussions.

While there appears to be limited research on premorbid predictors of postconcussion symptoms in the acute injury period following sports-related concussion, one's sex may be important. Broshek et al. (2005) reported that females experienced greater neurocognitive declines and reported a greater number of symptoms than males in the acute injury period following sports-related concussions. While other studies have drawn similar conclusions with respect to postconcussion symptom reporting (Colvin et al., 2009; Covassin, Elbin, Harris, Parker, & Kontos, 2012), the finding that females endorse more symptoms than males is not consistent across all studies. An earlier study by Covassin, Schatz, and Swanik (2007) found that, overall, there were no differences in total symptom reporting between males and females. However, when examining individual symptoms, males were more likely than females to endorse specific symptoms such as "sadness" and "vomiting" (Covassin et al., 2007). Similarly, Frommer et al. (2011) found no differences in total symptom score between males and females, but males were more likely to endorse "amnesia" and "confusion/disorientation," whereas females were more likely to endorse "drowsiness" and "sensitivity to noise."

In addition to sex differences, there is some evidence to support the notion that a history of concussion will result in increased symptom reporting or prolonged recovery following a subsequent concussion (Collins et al., 2002; Guskiewicz et al., 2003), while other studies have shown no effects associated with concussion history (Colvin et al., 2009; Covassin, Stearne, & Elbin, 2008; Iverson, Brooks, Lovell, & Collins, 2006). When evaluating the results of these studies, interpretation of the findings becomes difficult because (a) it is unclear how concussion history was defined and/or measured in the various studies, and (b) the cited studies have examined concussion history in a number of ways. Specifically, among the mentioned studies, history of concussion has been defined in a bivariate fashion (i.e., yes versus no, 0 versus 2 or more previous concussions, and 0 versus 3 or more previous concussions; Collins et al., 2002; Colvin et al., 2009; Covassin et al., 2008; Guskiewicz et al., 2003), as well as in a continuous fashion (0, 1, or 2 or more previous concussions; Iverson et al., 2006). Given these methodological concerns, as well as the mixed findings, further investigation into the effects of previous concussions seems warranted.

Next, although few sports-concussion studies have examined premorbid affective and/or psychiatric symptoms as risk factors for increased symptom reporting following concussion, a number of nonsports-concussion studies have examined premorbid affective/psychiatric symptoms in adults and children. Cicerone and Kalmar (1997) explored whether premorbid depression influenced postconcussion symptom reporting in adults and found no differences in symptom reporting between those with and those without premorbid depression. However, since then, several other studies have reported that premorbid psychiatric difficulties such as depression and anxiety are associated with increased symptom reporting following mild traumatic brain injury (mTBI) in adult samples (Kashluba, Paniak, & Casey, 2008; Luis, Vanderploeg, & Curtiss, 2003; Ponsford et al., 2000; Ponsford et al., 2012). Similarly, Ponsford et al. (1999) reported that among children who sustained a mTBI, premorbid emotional/psychiatric distress was associated with persisting postconcussion symptoms. More recently, Yeates et al. (2012) examined the relationship between premorbid, retrospectively rated, symptoms and postconcussion symptoms following mTBI in a sample of children (8–15 years of age) and reported that

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higher ratings of premorbid symptoms (based on parent and child ratings) were associated with higher postconcussion symptoms following mTBI. However, it is important to note that Yeates's findings were based on general (i.e., not sports-related) mTBI so the confound of greater trauma associated with the injuries in this study may have elevated symptom reporting. Other studies examining mTBI in children have reported similar findings (McNally et al., 2013; Taylor et al., 2010). Still, many of these studies have focused on longer term outcomes (and/or persisting postconcussion symptoms) following mTBI, and thus, there remains a need, especially within the sports-concussion literature, to better understand the influence of premorbid symptoms on postconcussion symptom reporting within the acute injury period following concussion. Furthermore, to our knowledge, no studies have specifically examined the influence of prospectively obtained baseline symptom reporting patterns on postconcussion symptom reports.

In addition to exploring risk factors that influence postconcussion symptom reporting, there is a need to better characterize the symptoms that athletes endorse at baseline and postconcussion. The Post-Concussion Symptoms Scale (PCSS) is often used to assess symptom severity, but the PCSS total score is typically the only dependent variable that is evaluated. Unfortunately, this approach provides an incomplete understanding of athletes' symptom reporting patterns. In an attempt to better understand the types of symptoms that are endorsed following concussion, previous studies have implemented factor analytic strategies on various symptom questionnaires, including the PCSS. Pardini et al. (2004) conducted an exploratory factor analysis of the PCSS using data from a group of 327 concussed athletes and reported that the PCSS could be divided into four distinct factors consisting of cognitive, sleep, emotional, and somatic symptoms. Lau, Collins, and Lovell (2011) later utilized the symptom clusters generated from the Pardini et al. (2004) study and concluded that there was value in examining symptom clusters, especially when predicting protracted recovery following concussion.

A more recent study by Kontos, Elbin, et al. (2012) examined the factor structure of the PCSS at baseline and postconcussion. At both time points, the PCSS was composed of four factors, but the composition of the factors differed at baseline (cognitive–sensory, sleep–arousal, vestibular–somatic, and affective; n = 30,455) and postconcussion (cognitive–fatigue–migraine, affective, somatic, and sleep; n = 1,438). Given these findings, Kontos, Elbin, et al. (2012) concluded that the postconcussion symptom profiles of athletes are likely to vary significantly from their baseline symptom reports, lending support to the notion that evaluating symptoms at both time points (e.g., baseline and postconcussion) is merited. Interestingly, though, when comparing the results of the Pardini et al. (2004) and Kontos, Elbin, et al. (2012) studies, the factor analyses for the concussed athlete samples are remarkably similar. Nevertheless, the Kontos, Elbin, et al. (2012) study appears to be the only study that has examined the factor structure of the PCSS at baseline; thus, there remains a need to better understand the nature of baseline symptom reporting patterns.

With the above considerations in mind, the purpose of the present study was twofold: Aim 1 was to better characterize the symptoms that athletes endorse at baseline by determining the factor structure of the PCSS at baseline in our collegiate athlete sample, and Aim 2 was to identify premorbid/preinjury characteristics that are predictive of postconcussion symptom reporting. Regarding Aim 2, we hypothesized that sex and concussion history would be significant predictors of higher symptoms postconcussion, such that females would be more likely than males to endorse higher symptoms and that athletes with a greater number of previous concussions would be more likely than athletes with a history of fewer concussions to endorse higher symptoms postconcussion. Additionally, other premorbid/preinjury variables were explored as predictor variables, including the PCSS symptom clusters derived from Aim 1, additional demographic variables, and baseline neurocognitive variables. We expected that symptom clusters at baseline would predict postconcussion symptom group, in part because the symptom clusters were derived from the same measure. Otherwise, due to limited research examining the other variables, no additional hypotheses were generated.

METHOD

Participants

Participants included male and female college athletes who were enrolled in an ongoing concussion management program at a large university between 2004 and 2013; thus, the study was based on clinical research data and was a sample of convenience. All athletes participating in the program were administered baseline neuropsychological tests prior to their participation in varsity athletics, and athletes were referred for postconcussion

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testing if they sustained a mTBI/concussion, defined by experiencing posttraumatic amnesia (lasting less than 24 hours), loss of consciousness (lasting 30 min or less), or any alteration in mental status and/or postconcussion signs or symptoms at the time of injury (Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group, 1993). Athletes were referred to our clinically-based concussion management program by an athletic trainer or team physician who determined when the athlete was ready for postconcussion testing. Typically testing is conducted as soon as possible following the injury and referral, but referrals can sometimes be delayed because of other clinical concerns.

Participants were composed of two groups—baseline and postconcussion. Baseline participants were selected from a sample consisting of 799 athletes and were excluded from the study if (a) they did not complete the PCSS (n = 94), and (b) the PCSS total score was greater than five standard deviations above the mean (n = 3). (Given the variability in baseline PCSS total scores, a wider cutoff score was utilized to classify outliers.) The final baseline sample thus consisted of 702 college athletes (74.5% male; age at baseline: M = 18.44 years, SD = 0.93), with the mean years of education equal to 12.14. Additional sample characteristics for baseline participants are presented in Table 1. From this sample, 80 participants went on to sustain a concussion/mTBI. Ten participants were excluded from the study because the mechanism of injury was not a sports-related event, and another 15 athletes were excluded because they were tested more than one week post injury. Although research shows that some athletes are symptom free by this time postconcussion, this one-week window was desirable for our study because we wanted to be able to predict which athletes would be symptomatic and those who would be relatively asymptomatic postconcussion. The final postconcussion sample consisted of 55 male and female athletes (85.5% male; age at concussion: M = 19.91 years, SD = 1.40), with the mean years of education equal to 13.40. The average time tested post injury was 61 hours (SD = 33.59). Additional sample characteristics for postconcussion participants are also presented in Table 1.

TABLE 1
Baseline and postconcussion sample characteristics

	Baseline (N = 702)		*Postconcussion (N = 55)*	
Variable	*N*	*%*	*N*	*%*
Sex				
Male	523	74.5	47	85.5
Female	179	25.5	8	14.5
Ethnicity				
Caucasian	523	74.5	31	56.4
African American	137	19.5	18	32.7
Other	42	6.0	6	10.9
Concussion history				
0	453	64.5	28	50.9
1	172	24.5	17	30.9
2 or more	77	11.0	10	18.2
Diagnosis of developmental disorder[a]				
Yes	138	19.7	11	20.0
No	564	80.3	44	80.0
Sport				
Football	229	32.6	28	50.9
Men's basketball	46	6.6	5	9.1
Men's ice hockey	53	7.6	2	3.6
Men's lacrosse	102	14.5	10	18.2
Men's soccer	80	11.4	2	3.6
Women's basketball	31	4.4	1	1.8
Women's ice hockey	1	0.1	0	0
Women's lacrosse	67	9.5	3	5.5
Women's soccer	76	10.8	4	7.3
Wrestling	12	1.7	0	0
Other	5	0.7	0	0

Note. [a]This included attention-deficit/hyperactivity disorder (ADHD) and learning disorders.

Measures

Participants were administered a comprehensive battery of neuropsychological tests, consisting of both neurocognitive and neurobehavioral measures.

Neurocognitive measures

The neurocognitive test battery included measures designed to assess a variety of cognitive domains such as memory, attention, and executive functioning, and consisted of the Brief Visuospatial Memory Test–Revised (BVMT–R; Benedict, 1997), the Hopkins Verbal Learning Test–Revised (HVLT–R; Brandt & Benedict, 2001), the Digit Span Test (Wechsler, 1997), the Symbol Digit Modalities Test (SDMT; Smith, 1991), the Comprehensive Trail-Making Test (CTMT; Reynolds, 2002), the PSU Cancellation Task (Echemendia & Julian, 2001), the Vigil/W Continuous Performance Test (Cegalis & Cegalis, 1994), and the Stroop Color–Word Test (SCWT; Trenerry, Crosson, DeBoe, & Leber, 1989). Additionally, the ImPACT (Immediate Post-concussion Assessment and Cognitive Testing; Lovell, Collins, Podell, Powell, & Maroon, 2000) and the Wechsler Test of Adult Reading (WTAR; Psychological Corporation, 2001) were administered. The ImPACT is a computerized test that was designed specifically for use in the assessment and

management of sports-related concussions (Lovell et al., 2000). The test contains six modules that assess the following cognitive domains: attention, memory, visual scanning, reaction time, and processing speed. Five composite scores can be derived from the modules: verbal memory, visual memory, reaction time, processing speed, and impulse control. In addition to the six modules, the ImPACT also collects information pertaining to demographics, medical history, and current symptoms. Finally, the WTAR estimates premorbid intellectual function (Psychological Corporation, 2001) and has previously been used in collegiate athletes (Rabinowitz & Arnett, 2013).

Neurobehavioral measures

The Post-Concussion Symptoms Scale (PCSS) is a 22-item self-report measure that was designed to assess the severity of concussion-related symptoms. Using a 7-point scale ranging from 0 to 6, with 0 indicating no symptoms and 6 indicating severe symptoms, athletes are asked to rate the extent to which they are currently experiencing each symptom. The PCSS is administered via computer through the ImPACT program (Lovell et al., 2006).

Additionally, athletes were asked to complete the "Previous Head Injury Questionnaire" (PHIQ), a self-report measure generated by our research group to assess the number of concussions that the athlete has sustained. The PHIQ includes a definition of concussion that is based on common, generally accepted definitions of concussion, including the Mild Traumatic Brain Injury Committee definition (Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group, 1993) and the American Academy of Neurology definition (American Academy of Neurology, 1997; Kelly & Rosenberg, 1997). The PHIQ then asks the athletes to indicate, based on the provided definition, how many concussions they have sustained in their lifetime. Following this initial inquiry, athletes are asked several questions about each concussion they have sustained, such as when they were injured, how they were injured, what treatment was provided after the injury, what symptoms they experienced after the injury, and how long before they returned to play.

Procedure

All participants were individually administered a neuropsychological test battery at baseline. Athletes who subsequently sustained a concussion were referred for testing by one of the team physicians and were administered a similar battery of tests postconcussion, using alternate forms as available. Our sports-concussion program models the "sports as a laboratory assessment model" discussed by Bailey, Barth, and Bender (2009). The neuropsychological measures were administered by doctoral students and undergraduate research assistants who were extensively trained and subsequently supervised by a PhD-level clinical neuropsychologist. Baseline and postconcussion testing sessions took approximately two hours to complete. The university's Institutional Review Board approved the study, and informed consent was obtained for all participants.

Approach to data analysis

All analyses were conducted with the Statistical Package for the Social Sciences (SPSS), Version 19.0 (IBM Corp., 2010), and significance levels were set at .05.

Aim 1: Conduct a factor analysis to determine the factor structure of the PCSS at baseline. An exploratory factor analysis (EFA) was performed on the 22 items that comprise the PCSS. Factors were extracted using principal components analysis, and varimax (orthogonal) rotation with Kaiser normalization was utilized. It was determined *a priori* that, given the sample size, individual symptoms with rotated component loadings greater than 0.4 would be retained in the final factor solution (Floyd & Widaman, 1995). If an item cross-loaded (>0.4) on two or more factors, the item was assigned to the factor with the highest loading.

Aim 2: Identify premorbid/preinjury characteristics that are predictive of postconcussion symptom reporting in the acute injury period. Separate binary logistic regression analyses were conducted to assess the extent to which the following *a priori* selected premorbid/preinjury characteristics contributed to the postconcussion PCSS total score (referred to as "postconcussion total symptom score" below), the main outcome variable:

- Analysis 1: PCSS-related variables. Predictor variables included the factors (i.e., symptom clusters) that emerged from the factor analysis of the PCSS at baseline (Aim 1). All variables were entered into the logistic regression analysis as continuous variables.
- Analysis 2: Demographic variables. Predictor variables included sex, concussion history, height, and weight. Sex was entered into the logistic regression analysis as a categorical variable, and concussion history, height, and

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weight were treated as continuous variables. Regarding concussion history, as a result of outliers in the data, we classified the variable as 0, 1, and 2 or more previous concussions.

- Analysis 3: Neurocognitive variables. Predictor variables included the baseline neurocognitive composite score (see below) and the WTAR standard score. Both variables were entered into the logistic regression analysis as continuous variables.

For all regression analyses, the dependent variable (the postconcussion total symptom score) was dichotomized into a "low symptoms" and a "high symptoms" group, based on gender-specific median values of the baseline PCSS total score. (Given the positive skewness of the PCSS baseline data, the baseline median, instead of the mean, was thought to provide a more accurate representation of low versus high postconcussion symptom reporting.) The baseline median for males was 2, and the baseline median for females was 4; therefore, males having postconcussion total symptom scores falling at or below 2 were included in the "low symptoms" group, and males with postconcussion total symptom scores falling above 2 were included in the "high symptoms" group. With respect to females, those having postconcussion total symptom scores falling at or below 4 were included in the "low symptoms" group, and females with postconcussion total symptom scores falling above 4 were included in the "high symptoms" group. Descriptive statistics for the baseline and postconcussion PCSS total symptom scores are provided in Table 2 for the entire sample, as well as by gender. Descriptive statistics pertaining to the low and high symptom groups are provided in Table 3. There were no significant differences

TABLE 2
Sample descriptive statistics for baseline and postconcussion PCSS total score for entire sample and by gender

Variable	*Mean*	*SD*	*Median*	*Min*	*Max*	*Range*	*Skewness*	*Kurtosis*
Baseline PCSS total symptom score								
Entire sample	5.49	8.26	2.00	0.00	47.00	47.00	2.35	6.09
Males only	5.10	7.98	2.00	0.00	47.00	47.00	2.48	6.90
Females only	6.63	8.94	4.00	0.00	44.00	44.00	2.06	4.53
Postconcussion PCSS total symptom score								
Entire sample	11.38	15.05	7.00	0.00	61.00	61.00	1.93	3.25
Males only	9.87	12.47	7.00	0.00	51.00	51.00	1.72	2.45
Females only	20.25	24.94	8.50	0.00	61.00	61.00	1.31	–0.17

Note. PCSS = Post-Concussion Symptoms Scale. Baseline: $N = 702$ (523 males, 179 females); postconcussion: $N = 55$ (47 males, 8 females).

TABLE 3
Sample characteristics for "low symptoms" and "high symptoms" groups ($N = 55$)

	Low symptoms group (N = 17)		*High symptoms group (N = 38)*		
Variables	*M*	*SD*	*M*	*SD*	*p*
Age (years)	19.47	1.33	20.11	1.41	.123
Education (years)	13.12	1.41	13.50	1.35	.343
Hours tested post injury	62.79	33.16	59.56	34.17	.745
	N	%	*N*	%	
Gender					.223
Male	16	94.1	31	81.6	
Female	1	5.9	7	18.4	
Sport[a]					.250
High impact	4	23.5	15	39.5	
Low impact	13	76.5	23	60.5	
Concussion history					.336
0	7	41.2	21	55.3	
1	5	29.4	12	31.6	
2 or more	5	29.4	5	13.2	

Note. [a]High-impact sports include football, hockey, and soccer; low-impact sports include basketball and lacrosse.

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(using independent-samples t tests) between the low and high symptom groups for age (p = .123), education (p = .343), and hours tested post injury (p = .745). Using chi-square analyses, there were also no significant differences between groups for gender (p = .223), sport (p = .250), and concussion history (p = .336).

Calculating the neurocognitive composite score

In order to derive the neurocognitive composite score, the 21 baseline neurocognitive test indices were converted to standard scores (using the mean and *SD* of our athlete sample at baseline) so that all measures were on the same metric. Independent-samples t tests revealed that 12 of the 21 neurocognitive indices were significantly different for males and females, so sex-specific means and standard deviations were used to calculate all of the standard scores. All standard scores were calculated so that higher scores would indicate better performance. An EFA was then performed on the 21 test indices. Factors were extracted using principal components analysis with varimax rotation and Kaiser normalization. Test indices with component loadings greater than 0.4 on the first factor were used to derive the final neurocognitive composite score (Rabinowitz & Arnett, 2013).

RESULTS

Aim 1: Conduct a factor analysis to determine the factor structure of the PCSS at baseline

Four distinct factors—or symptom clusters—emerged from the EFA, accounting for 48.2% of the variance with a Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy of 0.85. Three of the 22 PCSS items (headache, sleeping more than usual, and numbness/tingling) were not included in the final factor solution because the rotated component loadings were less than the *a priori* established cutoff of 0.4. The four symptom clusters were: (a) a cognitive factor (27.5% of the variance); (b) a physical factor (8.0% of the variance); (c) an affective factor (6.8% of the variance); and (d) a sleep factor (5.9% of the variance). Table 4 lists all 22 PCSS items and their associated factor loadings for each symptom cluster, and the retained final factor solution is presented in Table 5.

TABLE 4
Baseline PCSS symptoms and factor loadings

PCSS symptoms	*Factor 1: Cognitive*	*Factor 2: Physical*	*Factor 3: Affective*	*Factor 4: Sleep*
Headache[b]	.381	.302	.139	–.042
Nausea	.030	.674[a]	.079	.191
Vomiting	–.041	.692[a]	.116	.186
Balance problems	.261	.586[a]	.129	–.108
Dizziness	.363	.605[a]	–.005	.140
Fatigue[c]	.434	.164	.139	.517[a]
Trouble falling asleep	.118	.105	.117	.706[a]
Sleeping more than usual[b]	.376	.271	.168	–.143
Sleeping less than usual	.066	.163	.068	.823[a]
Drowsiness[c]	.415	.248	.021	.456[a]
Sensitivity to light	.219	.417[a]	.031	.286
Sensitivity to noise	–.075	.532[a]	.173	.266
Irritability[c]	.424	.142	.435[a]	.048
Sadness	.139	.127	.847[a]	.111
Nervousness	.166	.110	.728[a]	.105
Feeling more emotional	.185	.125	.832[a]	.076
Numbness or tingling[b]	.242	.320	.056	.031
Feeling slowed down	.619[a]	.193	.137	.225
Feeling mentally "foggy"	.567[a]	.109	.150	.323
Difficulty concentrating	.717[a]	–.009	.251	.282
Difficulty remembering	.744[a]	.038	.113	.099
Visual problems[c]	.408	.457[a]	.061	.028

Notes. PCSS = Post-Concussion Symptoms Scale. N = 702 (523 males, 179 females).
[a]Item met factor loading criteria (>0.4). [b]Item eliminated from solution as it did not meet factor loading criteria. [c]Item cross-loaded on two factors.

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TABLE 5
Final factor solution: Baseline PCSS factors and their associated items

Factor 1: Cognitive	*Factor 2: Physical*	*Factor 3: Affective*	*Factor 4: 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 Symptoms Scale.

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Aim 2: Identify premorbid/preinjury characteristics that are predictive of postconcussion symptom reporting in the acute injury period following concussion

Analysis 1: PCSS-related variables

Preliminary correlation analyses (Pearson's point biserial correlations) revealed no significant relationships between any of the baseline PCSS-related predictor variables (e.g., the cognitive, physical, affective, and sleep symptom clusters) and the dichotomized postconcussion total symptom score. Next, logistic regression was used to examine whether the four PCSS baseline symptom clusters could identify athletes classified in the low and high postconcussion symptoms groups. After controlling for concussion history, a test of the full model with the four predictor variables (i.e., the symptom clusters) was statistically significant, $\chi^2(4, N = 55) = 12.49$, $p < .05$, indicating that the baseline symptom clusters, as a set, reliably distinguished between athletes with low and high postconcussion total symptom scores (Nagelkerke's $R^2 = .29$). Classification results indicated that 29.4% of the athletes with low total symptom scores and 94.7% of the athletes with high total symptom scores were correctly classified, with the model correctly predicting 74.5% of the cases. According to the Wald criterion, both the physical and affective symptom clusters made a significant contribution to the prediction of the total symptom score (Table 6), such that an athlete is less likely to fall within the high symptom group for each one unit increase in physical symptoms at baseline, but is more likely to fall within the high symptom group for each one unit increase in affective symptoms at baseline.

Analysis 2: Demographic variables

Logistic regression was used to examine whether the four demographic predictor variables could identify athletes classified in the low and high

TABLE 6
Logistic regression for premorbid/preinjury characteristics predicting dichotomized postconcussion PCSS scores

Predictor variable	*β*	*SE β*	*Wald's $\chi^2(1)$*	*p*	*e^{β} (odds ratio)*
Analysis 1: PCSS symptom clusters					
Constant	1.06	0.81	1.69	.194	2.88
Cognitive symptoms	–0.10	0.21	0.24	.623	0.90
Physical symptoms	–0.91	0.43	4.38	.036	0.40
Affective symptoms	1.15	0.53	4.68	.031	3.17
Sleep symptoms	–0.06	0.17	0.13	.714	0.94
Analysis 2: Demographic variables					
Constant	–19.67	10.26	3.67	.055	0.00
Sex (female vs. male)	3.67	1.56	5.52	.019	39.30
Previous concussions	–0.67	0.47	2.06	.151	0.51
Height	0.25	0.15	2.64	.104	1.29
Weight	0.01	0.01	0.88	.347	1.01
Analysis 3: Neurocognitive variables					
Constant	10.70	5.26	4.14	.042	44,162.17
NC composite	–0.12	0.05	5.10	.024	0.89
WTAR	0.02	0.04	0.14	.706	1.02

Note. PCSS = Post-Concussion Symptoms Scale; NC = neurocognitive; WTAR = Wechsler Test of Adult Reading.

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postconcussion symptoms groups. After controlling for concussion history, a test of the full model with the four demographic predictor variables was statistically significant, $\chi^2(4, N = 54) = 12.51$, $p < .05$, indicating that these variables, as a set, reliably distinguished between athletes with low and high postconcussion total symptom scores (Nagelkerke's $R^2 = .29$). Classification results indicated that 47.1% of the athletes with low total symptom scores were correctly classified, and 89.2% of the athletes with high total symptom scores were correctly classified, with the model correctly predicting 75.9% of the cases. According to the Wald criterion, sex was the only demographic variable that significantly contributed to the prediction of the postconcussion total symptom score (Table 6). Specifically, female athletes are more likely to fall within the high postconcussion total symptom score group than male athletes.

Analysis 3: Neurocognitive variables

The EFA of the neurocognitive variables revealed that 14 of the 21 indices had component loadings of 0.4 or greater on Factor 1; therefore, these 14 indices were used to derive the neurocognitive composite. Table 7 lists the retained neurocognitive test indices and their associated component loadings. The final neurocognitive composite variable was found to be highly reliable (14 items; $\alpha = .82$).

TABLE 7
Retained neurocognitive test indices and their associated component loadings

Test index	*Component 1 loadings*
ImPACT	
Verbal memory composite	.62
Visual memory composite	.58
Visual motor speed composite	.65
Reaction time composite	.52
BVMT–R	
Total immediate recall	.53
Total delayed recall	.50
HVLT–R	
Total immediate recall	.54
Total delayed recall	.55
Symbol Digit Modalities Test	
Total correct	.66
Incidental memory	.46
Stroop	
Word time	.41
Color–word time	.56
Comprehensive Trail Making Test	
Trial 1 (Trail 2 or 3)	.47
Trial 2 (Trail 4 or 5)	.48

Notes. ImPACT = Immediate Post-concussion Assessment and Cognitive Testing; BVMT–R = Brief Visuospatial Memory Test–Revised; HVLT-R = Hopkins Verbal Learning Test–Revised.

As before, logistic regression was used to examine whether the baseline neurocognitive variables could identify athletes classified in the low and high postconcussion symptoms groups. After controlling for concussion history, a test of the full model with both neurocognitive predictors was statistically significant, $\chi^2(2, N = 50) = 6.69$, $p < .05$, indicating that these variables, as a set, reliably distinguished between athletes with low and high postconcussion total symptom scores (Nagelkerke's $R^2 = .18$). Classification results indicated that 26.7% of the athletes with low total symptom scores were correctly classified, and 88.6% of the athletes with high total symptom scores were correctly classified, with the model correctly predicting 70.0% of the cases. According to the Wald criterion, only the neurocognitive composite score reliably predicted the postconcussion total symptom score, with the data showing that an athlete is less likely to fall within the high postconcussion total symptom score group for each one unit increase in the baseline neurocognitive composite score (Table 6).

DISCUSSION

The purpose of the present study was to better characterize athlete symptom reports in our sample at baseline, as well as determine what impact premorbid/preinjury characteristics have on the presence and severity of postconcussion symptoms in the acute injury period following concussion. In order to better characterize symptom reports in our sample (Aim 1), a factor analysis was conducted on the PCSS at baseline. The results revealed that the PCSS at baseline is composed of cognitive, physical, affective, and sleep symptom clusters. To date, Kontos, Elbin, et al. (2012) appear to be the only other group that has examined the PCSS factor structure at baseline. Our results are remarkably consistent with their findings with respect to the structure of the affective and sleep symptom clusters, but the items associated with the cognitive and physical symptom clusters differed. Specifically, we found a more homogeneous "cognitive" symptom cluster (i.e., symptoms include feeling slowed down, feeling mentally foggy, difficulty concentrating, and difficulty remembering) and "physical" symptom cluster (i.e., symptoms include nausea, vomiting, balance problems, dizziness, sensitivity to light and noise, and visual problems) at baseline as compared

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to Kontos et al.'s "cognitive–sensory" and "vestibular–somatic" symptom clusters. Interestingly, Kontos, Elbin, et al.'s (2012) factor analysis of the PCSS at baseline utilized 30,455 athletes (high school and college), whereas our factor analysis of the PCSS at baseline utilized 702 athletes (college only). Additional differences between our study and Kontos, Elbin, et al.'s (2012) study that may account for the discrepant factors are that we used a different item loading criterion (>0.4) than they did (>0.5), and how we handled multiple factor loadings differed—in our study, if an item cross-loaded (>0.4) on two or more factors, the item was assigned to the factor with the highest loading; in their study, if an item cross-loaded (>0.4) on two or more factors, the item was only kept "if the main loading was above 0.6 and the difference between the main and highest cross-loading was +0.2 or greater" (Kontos, Elbin, et al., 2012; p. 2378). Nevertheless, our intention was to determine the factor structure of the PCSS in our athlete sample at baseline, and our findings resulted in four relatively homogeneous symptom clusters.

As for Aim 2, the goal was to identify premorbid/preinjury characteristics that are predictive of postconcussion symptom reporting in the acute injury period following concussion. We found that, when taken together, the four symptom clusters (physical, cognitive, affective, and sleep) reliably predicted athletes' postconcussion symptom group (low vs. high postconcussion total symptom score), with the model more reliably predicting the high total symptom score group than the low total symptom score group. Moreover, when considering each predictor independently, the physical and the affective clusters made a significant contribution to the prediction of the total symptom score group; for every one point increase in physical symptoms at baseline, athletes were less likely to demonstrate a high total symptom score, and for every one point increase in affective symptoms at baseline, athletes were more likely to demonstrate a high total symptoms score.

To date, relatively few studies have examined baseline symptoms as predictors of postconcussion symptoms, but, as mentioned previously, a study by Cicerone and Kalmar (1997) explored whether premorbid depression influenced postconcussion symptom reporting and found no differences in symptom reporting between those with and those without premorbid depression. On the other hand, Kontos, Covassin, Elbin, and Parker (2012) found that baseline somatic depression was associated with higher symptom scores following concussion. Interestingly, other studies have also found relationships between sports-related concussion and depression-related symptoms (Hutchison, Mainwaring, Comper, Richards, & Bisschop, 2009; Mainwaring, Hutchison, Bisschop, Comper, & Richards, 2010), consistent with the results of the present study. Furthermore, when considering studies outside of the sports-concussion realm, a number of studies on adult and child mTBI populations have shown that preexisting depression and/or anxiety-related symptoms may exacerbate traditional postconcussion symptoms measured after an injury event and possibly lead to persisting postconcussion symptoms in these populations (Binder, 1986; Kashluba et al., 2008; Luis et al., 2003; McNally et al., 2013; Ponsford et al., 2000; Ponsford et al., 2012; Taylor et al., 2010). With respect to physical symptoms, however, our findings were paradoxical in that higher baseline physical symptoms were associated with falling in the low symptoms group postconcussion. Given that this is the first study, to our knowledge, to report such a finding, this particular result is in need of replication before we can begin to speculate as to why higher reports of baseline physical symptoms are associated with lower postconcussion symptom reports. As such, further investigation into the relationship between baseline physical symptoms and postconcussion symptoms seems warranted.

Next, the demographic variables (sex, concussion history, height, and weight), as a set, also reliably predicted athletes' postconcussion symptom group (low vs. high postconcussion total symptom score), with the model more reliably predicting the high total symptom score group than the low total symptom score group. When considering each predictor independently, sex was the only demographic-related variable that made a significant contribution to the prediction of the postconcussion total symptom score. Specifically, female athletes were more likely to fall within the high total symptom score group than male athletes. This is consistent with our hypothesis and is also consistent with the majority of past research that has documented clear sex differences in symptom reporting following concussion (Broshek et al., 2005; Covassin et al., 2012; Ponsford et al., 2012). However, when examining the odds ratio for the sex variable (refer to Table 6), it is unusually large. This is presumed to be because of the low number of female athletes in the overall sample and the disproportionate number of females who fell in the high-symptoms group. Nonetheless, despite the large odds ratio, as noted above, this finding is generally consistent with past literature.

With respect to concussion history, although we hypothesized that athletes with a greater number of previous concussions would be more likely than

athletes with a history of fewer concussions to endorse higher symptoms postconcussion, our results suggested that there is no clear relationship between concussion history and symptom reporting following a subsequent concussion. However, consistent with our findings, there have been a number of previous studies that have drawn similar conclusions—that is, several studies have reported that there are no significant effects of concussion history on symptom reporting (Colvin et al., 2009; Covassin et al., 2008; Iverson et al., 2006). Furthermore, as noted previously, interpretation of past findings is complicated by the fact that there has not been a consistent method for examining the effects of previous concussions on subsequent functioning (i.e., it is unclear how concussion history was defined and/or measured in past studies, and concussion history has been examined in a number of ways, including both dichotomously and continuously), thereby limiting the ability to draw definitive conclusions. Although our findings contribute to the growing evidence that history of concussion may not directly impact symptom reporting following subsequent concussions, more evidence in support of this finding needs to be observed in order to impact clinical decision making.

Finally, the baseline neurocognitive variables (neurocognitive composite score and WTAR standard score), as a set, reliably predicted athletes' postconcussion symptom group (low vs. high total symptom score), again with the model more reliably predicting the high total symptom score group than the low total symptom score group. When examining the individual predictors, we found that athletes are significantly less likely to fall within the high symptoms group following concussion if they have higher baseline neurocognitive composite scores. Better cognitive functioning may thus serve as a potential protective factor against the impact of concussion, consistent with notions of cognitive reserve (Stern, 2009). Relatedly, a recent study by Fay et al. (2010) examined cognitive ability as a predictor of postconcussion symptoms. Specifically, these investigators sought to establish whether "cognitive reserve" moderated the relationship between mTBI and postconcussion symptoms in a pediatric population. A neurocognitive composite score, similar to the one derived in this study, served as a proxy of cognitive reserve. The authors examined mTBI participants at 3 weeks post injury and found that those with lower cognitive ability reported greater postconcussion symptoms than those with higher cognitive ability. Thus, findings from our study and the Fay et al. (2010) study are consistent with the notion that better premorbid neurocognitive functioning may serve as a protective factor against the effects of concussion. The findings are also consistent with Rabinowitz and Arnett's (2013) recent finding that athletes with higher and less variable cognitive functioning at baseline are less likely to show declines postconcussion.

Clinical implications

The major study objective was to establish whether there are premorbid/preinjury predictors of postconcussion symptoms in the acute injury period following concussion. Identifying potential risk factors for postconcussion symptom reporting could be important not only for the athlete, but also for the coaching and training staff. First, with respect to athletes, the finding that certain personal characteristics are predictive of symptom reporting following concussion could impact decisions regarding return to play. Additionally, depending on the nature or severity of the injury, this information may have implications for whether or not the athletes choose to continue pursuing the sport, either at the collegiate level or making the transition to become professional athletes. As for the coaching and training staff, having an understanding of who is susceptible to developing greater postconcussion symptoms would likely influence return-to-play decisions from a coaching/management perspective.

Limitations

One limitation of the present study is that postconcussion symptoms are not specific to concussion or brain injury and, in fact, have been documented in other populations who have not sustained such injuries. For example, symptoms traditionally considered to be "postconcussion symptoms" have been reported in healthy adults (Chan, 2001; Lange, Iverson, & Rose, 2010; Wang, Chan, & Deng, 2006), in trauma patients (Meares et al., 2006), in patients with orthopedic injuries and chronic pain (Gasquoine, 2000; Mickevičiene et al., 2004), and in depressed patients (Garden & Sullivan, 2010). It will be important to keep this in mind when interpreting the results, as it is possible that athletes may endorse symptoms that are not due to concussion per se, but instead, are a result of social or environmental factors, or secondary factors (e.g., depression, anxiety, pain, fatigue, etc.). Second, because some athletes may minimize their symptoms because of the concern over return-to-play decisions (Bailey, Echemendia, & Arnett,

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2006; Echemendia & Julian, 2001), the number or severity of symptoms that athletes experience may not be accurately reflected in their PCSS report. However, because symptom reporting is vital to concussion management and return to play decisions, exploring the nature of athletes' symptom reporting is meaningful. Another limitation of the current study is that we did not specifically evaluate headache. Although headache is one of the 22 symptoms listed on the PCSS, it did not meet the factor loading criteria (i.e., the headache symptom did not load >0.4 on any of the factors) and thus was one of the symptom items that was not included in any of the symptom clusters. Importantly, though, headache is one of the most common symptoms that is experienced following concussion (Erlanger et al., 2003; Guskiewicz, Weaver, Padua, & Garrett, 2000; Makdissi et al., 2010); thus, future research should examine the relationship between headache and overall symptom reporting following concussion. Finally, it is important to note that the relatively small number of females included in the postconcussion sample is a limitation; consequently, the findings may not be as representative for females as for males.

Conclusions and future directions

The results of the current study lend support to the notion that premorbid characteristics have an influence on athletes' symptom reporting postconcussion. Specifically, athletes at risk for higher postconcussion symptom reporting include those who endorse low physical and high affective symptoms at baseline. Additionally, female athletes and those with lower overall cognitive ability also appear to be at highest risk for experiencing greater postconcussion symptoms. These findings suggest that there may be additional benefits to having athletes undergo routine baseline evaluations prior to engaging in athletics beyond being able to make direct comparisons with preinjury scores. Given the present findings, it follows that (a) postconcussion interventions should be developed that target athletes who are most susceptible to reporting high symptoms postconcussion, and (b) future studies should continue to examine potential predictors of postconcussion symptom reporting. Although this research is still in the early stages, it seems likely that as predictors of postconcussion symptoms are elucidated, concussion management and return to play decisions will greatly improve.

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