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Reliability and Validity of the Sport Concussion Assessment Tool–3 (SCAT3) in High School and Collegiate Athletes

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Background: The Sport Concussion Assessment Tool–3 (SCAT3) facilitates sideline clinical assessments of concussed athletes. Yet, there is little published research on clinically relevant metrics for the SCAT3 as a whole.

Purpose: We documented the psychometric properties of the major SCAT3 components (symptoms, cognition, balance) and derived clinical decision criteria (ie, reliable change score cutoffs and normative conversation tables) for clinicians to apply to cases with and without available preinjury baseline data.

Study Design: Cohort study (diagnosis); Level of evidence, 2.

Methods: High school and collegiate athletes (N = 2018) completed preseason baseline evaluations including the SCAT3. Re-evaluations of 166 injured athletes and 164 noninjured controls were performed within 24 hours of injury and at 8, 15, and 45 days after injury. Analyses focused on predictors of baseline performance, test-retest reliability, and sensitivity and specificity of the SCAT3 using either single postinjury cutoffs or reliable change index (RCI) criteria derived from this sample.

Results: Athlete sex, level of competition, attention-deficit/hyperactivity disorder (ADHD), learning disability (LD), and estimated verbal intellectual ability (but not concussion history) were associated with baseline scores on ≥1 SCAT3 components (small to moderate effect sizes). Female sex, high school level of competition (vs college), and ADHD were associated with higher baseline symptom ratings (d = 0.25-0.32). Male sex, ADHD, and LD were associated with lower baseline Standardized Assessment of Concussion (SAC) scores (d = 0.28-0.68). Male sex, high school level of competition, ADHD, and LD were associated with poorer baseline Balance Error Scoring System (BESS) performance (d = 0.14-0.26). After injury, the symptom checklist manifested the largest effect size at the 24-hour assessment (d = 1.52), with group differences diminished but statistically significant at day 8 (d = 0.39) and nonsignificant at day 15. Effect sizes for the SAC and BESS were small to moderate at 24 hours (SAC: d = −0.36; modified BESS: d = 0.46; full BESS: d = 0.51) and became nonsignificant at day 8 (SAC) and day 15 (BESS). Receiver operating characteristic curve analyses demonstrated a stronger discrimination for symptoms (area under the curve [AUC] = 0.86) than cognitive and balance measures (AUCs = 0.58 and 0.62, respectively), with comparable discrimination of each SCAT3 component using postinjury scores alone versus baseline-adjusted scores (P = .71-.90). Normative conversion tables and RCI criteria were created to facilitate the use of the SCAT3 both with and without baseline test results.

Conclusion: Individual predictors should be taken into account when interpreting the SCAT3. The normative conversion tables and RCIs presented can be used to help interpret concussed athletes' performance both with and without baseline data, given the comparability of the 2 interpretative approaches.

Keywords: head injuries/concussions; clinical assessments/grading scales; athletic training; Sport Concussion Assessment Tool–3 (SCAT3)

Concussions are common among high school and collegiate athletes, with approximately 1.6 to 3.8 million concussions occurring in sport and recreational activity annually in the United States.[15,26] An evaluation of athletes' subjective symptoms, cognitive impairments, and other injury sequelae is widely recognized as important to guiding clinical management decisions,[9,36] and sports medicine professionals are increasingly using formal tools to assess these factors in their athletes. The Sport Concussion Assessment Tool–3 (SCAT3) represents one such tool and is freely available to facilitate sideline screening of athletes' symptoms, cognition, and balance, with space on the form reserved for recording other relevant factors (eg, signs of acute neurological impairment).[36] Developed at the 2012 International Conference on Concussion in Sport in Zurich, the SCAT3 was modified from the SCAT[34] and SCAT2.[35] The primary update between the SCAT2 and SCAT3 was the addition of space to record qualitative information about athletes' backgrounds, injuries, signs of a concussion, and a neck examination. The major

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components of the SCAT3 discussed here (ie, symptom, cognitive, and balance assessment) were not altered in the recent revision, and therefore, findings citing either version are comparable.

Several studies have examined the performance of individual subtests that compose the SCAT3 (eg, Standardized Assessment of Concussion [SAC] and Balance Error Scoring System [BESS])[18,32,33] as well as close variants of those subtests (eg, other postconcussive symptom checklists),[46] but there remains a gap in the published literature on the psychometric properties of all SCAT3 subtests in a variety of athletes. Furthermore, although investigations of these factors have contributed to scientific knowledge on sports concussions, they have been difficult to translate into clinical practice. For example, although sex,[10,16,28,37,52,53] education level,[37] age,[44] concussion history,[7,53] and depression and anxiety ratings[44] have been associated with baseline performance on ≥1 components of the SCAT2 (or baseline symptoms on similar checklists), it is unclear to what extent these relationships are clinically significant and therefore whether such athlete-specific factors should affect decisions for individual cases. To our knowledge, only one study on the SCAT2 has presented data (normative tables and reliable change parameters for collegiate rugby players) that could readily be applied clinically; yet, it is unknown to what extent these findings extend to other populations.[44] We aimed to document a host of clinically useful information about performance of the SCAT3 using one of the largest and most heterogeneous samples to date.

A key in determining what information is most useful is to consider how the SCAT3 is used in clinical practice. In fact, there appear to be 2 primary approaches to interpret concussion test data: compare concussed athletes' performance to their own preinjury baseline data or evaluate postinjury scores in their own right (ie, in comparison with published normative data). There is neither academic consensus nor well-supported practice guidelines regarding the relative utility of these approaches in the context of sport-related concussions (SRCs). Although incorporating baseline testing into concussion management decisions is widely believed to be superior, numerous testing and athlete-related factors (eg, poor testing environment, athletes' motivation) can hamper the quality and diminish the added value of baseline information.[2,6,22,39,48,49] Given that obtaining baseline scores requires extensive resources[39,49] and that the existing literature is equivocal regarding its added value,[13,50,51] normative comparison appears to be another justifiable interpretative approach.

The purpose of this study was to advance knowledge on the clinical utility of the SCAT3 by providing a comprehensive summary of the test's properties and performance in a novel sample of male and female high school and collegiate athletes. In particular, the aims of the study were to (1) evaluate the individual predictors of baseline performance for each SCAT3 component using a number of variables, (2) derive normative (raw score to percentile) conversion tables stratified on the most essential variables discovered in those analyses (age and sex), and (3) extract reliable change index (RCI) cutoffs using test-retest reliability and other properties of the SCAT3. We then discuss the strengths and limitations of the SCAT3 and how the findings can be applied to clinical cases both with and without preinjury baseline data.

METHODS

Participants

As part of an ongoing study on SRCs, 2148 athletes from 9 high schools and 4 colleges competing in contact and collision sports in southeastern Wisconsin were enrolled in the study between August 2012 and October 2014.[41] Those participants who completed the SCAT3 at preseason testing (N = 2018) were included in the analyses of baseline data. Data from those athletes who were concussed during the study period (n = 166) and their noninjured controls

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TABLE 1
Participant Characteristics[a]

	Baseline Sample (N = 2018)	Concussed (n = 166)[b]	Control (n = 164)	*P* Value (Concussed vs Control)
Male sex	76.9	83.7	82.9	.844
Race				.493
White	83.5	85.9	84.5	
Black	11.9	12.3	11.8	
Asian	1.3	1.2	0.6	
Native American/Alaska Native	0.5	0.0	0.0	
Native Hawaiian/Pacific Islander	0.6	0.0	1.2	
Unknown/other	2.2	0.6	1.9	
Level of competition (high school)	40.3	39.8	39.0	.891
Age, y	17.80 ± 1.92	17.47 ± 1.99	17.65 ± 1.82	.396
ADHD	7.7	10.5	5.0	.066
LD	3.5	3.7	3.1	.775
GPA	3.28 ± 0.52	3.24 ± 0.54	3.30 ± 0.49	.299
WTAR standard score	101.46 ± 12.64	100.95 ± 12.79	100.92 ± 12.03	.986
No. of prior concussions	0.65 ± 0.94	0.94 ± 1.01	0.46 ± 0.77	<.001
Sport				>.999
Football (men's)	48.8	65.7	65.2	
Soccer (men's)	16.6	12.0	12.2	
Soccer (women's)	15.6	10.8	11.6	
Field hockey (women's)	1.8	0.6	0.6	
Wrestling (men's)	3.7	2.4	1.8	
Lacrosse (men's)	5.3	3.0	3.0	
Lacrosse (women's)	2.0	1.2	0.6	
Rugby (women's)	2.5	1.8	1.8	
Ice hockey (men's)	2.6	0.6	0.6	
Ice hockey (women's)	1.2	1.8	2.4	
Baseline SCAT3 performance				
Symptom severity score	5.33 ± 6.81	6.53 ± 10.19	5.90 ± 7.40	.538
SAC total score	27.08 ± 1.90	26.84 ± 2.09	27.06 ± 1.81	.335
mBESS total score	3.12 ± 2.50	3.37 ± 2.34	3.06 ± 2.68	.148
fBESS total score	12.39 ± 4.90	12.94 ± 4.52	12.10 ± 5.26	.306

[a]Values are reported as mean ± SD or %. ADHD, attention-deficit/hyperactivity disorder; fBESS, full Balance Error Scoring System; GPA, self-reported cumulative grade point average; LD, learning disability; mBESS, modified Balance Error Scoring System; SAC, Standardized Assessment of Concussion; SCAT3, Sport Concussion Assessment Tool–3; WTAR, Wechsler Test of Adult Reading.

[b]n = 33 concussed participants enrolled in the study after an injury and therefore did not have baseline SCAT3 data; these participants and their controls were included in analyses where possible to maximize the statistical power and because comparisons of concussed participants with and without baseline data revealed no differences in demographics or postinjury performance measures.

(n = 164) were also included in the analyses. Participants' characteristics are summarized in Table 1. The baseline sample was 48.8% football, 16.6% men's soccer, 15.6% women's soccer, and 19.1% other sports (field hockey, wrestling, lacrosse, rugby, ice hockey) (Table 1). The concussed sample was 65.7% football, 12.0% men's soccer, 10.8% women's soccer, and 11.4% another sport. The acute injury characteristics of the concussions included in this sample were as follows: 6.1% loss of consciousness, 10.4% posttraumatic amnesia, and 9.8% retrograde amnesia.

Adult athletes and parents of minor athletes completed written informed consent forms, and minor participants completed assent forms. The athletes were compensated $30 for participating in baseline testing and $50 for each follow-up assessment. All procedures were approved by the institutional review board of the Medical College of Wisconsin.

Study Protocol and Measures

Preseason baseline evaluations were composed of a demographic and health history interview and examination with several assessment measures, including the SCAT3,[36] the Wechsler Test of Adult Reading (WTAR),[17] and the Brief Symptom Inventory–18 (BSI-18).[12] The SCAT3 consists of the symptom checklist, the SAC,[32] and the modified BESS (mBESS).[47] The SCAT3 and all 6 forms of the SAC are included in the Appendix (available online at http://ajsm.sagepub.com/supplemental). The symptom checklist requires athletes to rate themselves on 22 common postconcussive symptoms (each scaled from 0-6; maximum score range, 0-132), where higher scores indicate more symptoms. The SAC is a brief cognitive screening tool that assesses orientation, immediate memory and delayed recall, and concentration (score range, 0-30; higher scores reflect better performance). The BESS assesses postural stability by recording stability errors while participants assume 3 positions for 20 seconds each (10 errors maximum per trial). Although the SCAT3 form only requires participants to complete these stances on a firm surface (ie, mBESS; score range, 0-30 errors), we also completed the trials on a foam surface to obtain full BESS (fBESS) scores (score range, 0-60). The WTAR word-reading test estimates verbal intellectual ability. The BSI-18 global severity index (GSI) is a self-reported measure of current general distress. Testing sessions were administered in quiet settings with minimal distractions and lasted about 90 minutes.

Concussed athletes were re-evaluated within 24 hours of injury and at days 8, 15, and 45 after injury. Matched noninjured controls were re-evaluated as soon after identification as possible and then 7, 14, and 44 days later. SAC form A was used at baseline with forms B, C, D, and E used for these follow-up assessments, respectively. Control athletes were selected to match concussed athletes on school, sport team, WTAR performance, grade point average (GPA), and age. The operational definition of a "concussion" used in this study was based on that of the United States Department of Defense: "mTBI is defined as an injury to the brain resulting from an external force and/or acceleration/deceleration mechanism from an event such as a blast, fall, direct impact, or motor vehicle accident which causes an alteration in mental status typically resulting in the temporally related onset of symptoms such as headache, nausea, vomiting, dizziness/balance problems, fatigue, insomnia/sleep disturbances, drowsiness, sensitivity to light/noise, blurred vision, difficulty remembering, and/or difficulty concentrating."[21]

Statistical Analysis

Analyses of the SCAT3 symptom severity score (sum of all item-level 0-6 ratings) were performed on the log-transformed measure because of a high degree of positive skew in the variables, but descriptive statistics are presented on untransformed scores for interpretability. The participants' performance on the SCAT3 subtests was evaluated using independent-samples (concussed vs control) t tests for each measure and time point (P values were adjusted for multiple comparisons using the false discovery rate control method).[4] Receiver operating characteristic (ROC) curves were computed (for the 24-hour time point) for both raw postinjury and postinjury-minus-baseline scores to reveal the overall discriminative ability for each SCAT3 measure for these 2 clinical interpretive approaches. Area under the curve (AUC) values for the raw versus baseline-adjusted version of each measure were compared using the method previously described for AUCs from dependent samples.[19]

Predictors of baseline performance were explored for the symptom severity score, SAC (total score and subscale scores), and BESS (mBESS and fBESS) using Pearson correlations (for continuous predictors) and independent-samples t tests (for dichotomous predictors). Degrees of freedom were adjusted in which the Levene test indicated heteroscedasticity. The false discovery rate control method was applied to adjust these P values for multiple comparisons.

Test-retest reliability was computed on the control sample using Pearson correlations, Spearman correlations, and intraclass correlations (2-way, mixed, absolute agreement). RCIs were computed using Pearson-based reliability coefficients and the formula for the standard error of the difference recommended in the 2004 review of this topic by Maassen[29] (S_{diff}; equation 5).

RESULTS

Overall SCAT3 Performance

Table 2 displays descriptive statistics and group differences for the concussed and control groups on the SCAT3 components at each assessment. Across symptom, SAC, and BESS measures, the groups were well matched at baseline but manifested significant group differences after injury. The symptom checklist manifested the largest effect size at the 24-hour assessment (d = 1.52), with group differences diminished albeit still significant at day 8 (d = 0.39) and nonsignificant by day 15 (d = 0.12). Effect sizes for the SAC and BESS were small to moderate at 24 hours (SAC: –0.36; mBESS: 0.46; fBESS: 0.51) and became nonsignificant at day 8 (SAC) and day 15 (BESS).

ROC Curves

To evaluate the degree to which it was justifiable to derive both normative tables and reliable change parameters, we examined the ROC curves between concussed and control athletes for single postinjury scores versus baseline-adjusted scores. The 24-hour time point was selected because the largest group-level effect sizes across all SCAT3 components were observed at this time point. Table 3 displays a summary of the ability for each SCAT3 component (at 24 hours) to discriminate between concussed and control athletes (ie, AUC). Discrimination was good for the symptom score (0.86-0.88) but poor for the SAC and BESS (0.55-0.62). For each measure, the AUC values for the raw 24-hour score were compared statistically to those of the baseline-adjusted score using a method described by Hanley and McNeil[19] for comparing AUC values from the same sample. All comparisons were nonsignificant (ie, taking baseline data into account did improve discrimination). For example, selecting raw and baseline-adjusted cutoff scores for symptom severity in which they would be matched at 90% specificity (ie, $\geq$11 for raw symptom scores and change scores of 5), the sensitivity of the raw versus baseline-adjusted measures was 0.73 and 0.76, respectively (McNemar test, P = .344).

Derivation of Normative Conversion Tables

Exploring Predictors of Baseline SCAT3 Performance. Table 4 displays a summary of the major demographic predictors of baseline SCAT3 performance. Symptom severity scores were higher for female versus male athletes (t(2016) = 5.62, P < .001), high school versus collegiate athletes (t(2016) = 7.21, P < .001), and participants with versus without attention-deficit/hyperactivity disorder (ADHD)

TABLE 2
Descriptive Statistics and Concussed Versus Control Group Differences for SCAT3 Components[a]

	Concussed (n = 166)	Control (n =164)	*t* Value	*P* Value	*d* Value
Symptom severity					
Baseline	6.53 ± 10.19	5.90 ± 7.40	0.62	.566	0.07
24 hours	24.91 ± 18.25	4.50 ± 5.06	13.80	**<.001**	**1.52**
Day 8	7.44 ± 14.32	3.21 ± 5.14	3.52	**.003**	**0.39**
Day 15	3.16 ± 6.95	2.46 ± 4.22	1.07	.458	0.12
Day 45	1.87 ± 4.18	2.97 ± 5.38	−1.86	.162	−0.23
SAC					
Baseline	26.84 ± 2.09	27.06 ± 1.81	−0.97	.458	−0.11
24 hours	25.54 ± 2.68	26.38 ± 1.90	−3.27	**.005**	**−0.36**
Day 8	27.14 ± 1.99	27.38 ± 1.67	−1.15	.458	−0.13
Day 15	26.74 ± 1.99	26.95 ± 1.91	−0.95	.458	−0.11
Day 45	26.96 ± 1.95	27.03 ± 1.80	−0.33	.746	−0.04
mBESS					
Baseline	3.37 ± 2.34	3.06 ± 2.68	1.45	.329	0.12
24 hours	4.16 ± 2.96	2.90 ± 2.54	4.54	**<.001**	**0.46**
Day 8	3.34 ± 2.74	2.50 ± 2.33	2.96	**.011**	**0.33**
Day 15	2.76 ± 2.35	2.55 ± 2.41	0.75	.535	0.09
Day 45	3.10 ± 2.55	2.73 ± 2.82	0.70	.540	0.14
fBESS					
Baseline	12.94 ± 4.52	12.10 ± 5.26	1.03	.458	0.17
24 hours	13.85 ± 5.45	11.28 ± 4.55	4.08	**.004**	**0.51**
Day 8	11.98 ± 5.02	10.39 ± 4.42	2.91	**.011**	**0.34**
Day 15	10.78 ± 4.67	10.37 ± 4.85	0.78	.535	0.09
Day 45	11.04 ± 4.63	10.62 ± 5.15	1.10	.458	0.09

[a]Values are reported as mean ± SD unless otherwise indicated. Bolded values indicate statistically significant difference between groups after adjusting for multiple comparisons ($P < .05$). n values range from 131 to 166 for the concussed group and 127 to 164 for the control group. fBESS, full Balance Error Scoring System (firm and foam surface trials); mBESS, modified Balance Error Scoring System; SAC, Standardized Assessment of Concussion; SCAT3, Sport Concussion Assessment Tool–3.

TABLE 3
Area Under the Curve Values at the 24-Hour Assessment With and Without Baseline Data[a]

	24-Hour Score	24-Hour – Baseline Score (RCI)	*P* Value
Symptoms	0.86	0.88	.897
SAC	0.58	0.56	.901
mBESS	0.62	0.56	.745
fBESS	0.62	0.55	.714

[a]fBESS, full Balance Error Scoring System (firm and foam surface trials); mBESS, modified Balance Error Scoring System; RCI, reliable change index; SAC, Standardized Assessment of Concussion.

($t(2011) = -3.70$, $P = .009$), with learning disability (LD) showing only a trend toward higher symptom ratings ($t(2008) = -1.99$, $P = .068$) (effect sizes for this symptom score fell in the small to medium range; d = 0.24-0.32). The symptom severity score was also significantly associated with BSI-18 GSI scores ($r = 0.54$, $P < .001$) and, to a minor but statistically significant degree, with the WTAR standard score and number of prior concussions (r = 0.05 and 0.07, respectively; P = .044 and .002, respectively).

SAC total scores were lower for participants who were male ($t(849.74) = 5.40$, $P < .001$), had ADHD ($t(174.27) = 4.08$, $P < .001$), and had LD ($t(73.24) = 5.13$, $P < .001$). SAC performance was also moderately positively associated with WTAR scores ($r = 0.35$, $P < .001$) but was unrelated to the number of prior concussions ($r = 0.03$, $P = .325$) and BSI-18 GSI scores ($r = -0.01$, $P = .621$). Within SAC subtests, small to medium size effects were found for immediate memory with LD ($d = -0.44$), concentration with ADHD and LD ($d = -0.36$ to -0.56), and delayed recall with ADHD and LD ($d = -0.27$ to -0.34). WTAR performance was moderately associated with immediate memory ($r = 0.23$, $P < .001$) and concentration ($r = 0.34$, $P < .001$) but only weakly with orientation and delayed recall (r = 0.06 and 0.07, respectively; $P < .05$ for both).

BESS performance was poorer for male athletes (mBESS only: $t(2016) = -2.66$, $P = .016$; fBESS: $P = .174$), high school athletes (mBESS/fBESS: $t(1627.23)/t(1663.08) = 4.14/3.60$, P = .002/.001), and those with ADHD (mBESS/fBESS: $t(172.43)/t(2011) = -2.90/-3.25$, P = .009/.004) and LD (fBESS only: $t(2008) = -2.30$, $P = .036$; mBESS: $P = .081$). Lower WTAR performance and high BSI-18 GSI scores were significantly associated with errors on the BESS, but the effects were small (mBESS/fBESS: $r = -0.07/-0.05$ for WTAR and 0.06/0.06 for BSI-18 GSI; $P < .03$ for all). Concussion history was unrelated to BESS performance (mBESS/fBESS: $r = -0.02/-0.03$, P = .335/.230).

Development of Normative Performance Tables. The aforementioned analyses of sex and level of competition had consistent effects on SCAT3 performance. Interaction

TABLE 4
Summary of Select Predictors of SCAT3 Performance[a]

	Sex			Level of Competition			ADHD			LD		
	Female (n = 467)	Male (n = 1551)	*d* Value	High School (n = 813)	College (n = 1205)	*d* Value	Yes (n = 154)	No (n = 1859)	*d* Value	Yes (n = 71)	No (n = 1939)	*d* Value
No. of symptoms[b]	1.38 ± 0.80	1.12 ± 0.79	**0.32**	1.33 ± 0.78	1.08 ± 0.80	**0.32**	1.36 ± 0.78	1.17 ± 0.80	**0.25**	1.37 ± 0.75	1.17 ± 0.80	0.26
Symptom severity[c]	1.61 ± 0.97	1.32 ± 0.96	**0.30**	1.58 ± 0.96	1.26 ± 0.96	**0.33**	1.67 ± 1.00	1.37 ± 0.97	**0.31**	1.61 ± 0.94	1.38 ± 0.97	0.24
SAC total	27.46 ± 1.72	26.96 ± 1.94	**0.28**	27.01 ± 1.87	27.12 ± 1.92	−0.06	26.42 ± 2.08	27.13 ± 1.88	**−0.36**	25.68 ± 2.36	27.13 ± 1.86	**−0.68**
Orientation	4.94 ± 0.24	4.91 ± 0.31	0.11	4.89 ± 0.33	4.94 ± 0.27	**−0.14**	4.90 ± 0.35	4.92 ± 0.29	−0.08	4.89 ± 0.36	4.92 ± 0.29	−0.10
Immediate memory	14.54 ± 0.77	14.34 ± 0.92	**0.24**	14.34 ± 0.89	14.42 ± 0.89	−0.09	14.38 ± 0.89	14.39 ± 0.89	−0.02	13.93 ± 1.27	14.41 ± 0.87	**−0.44**
Concentration	3.53 ± 1.04	3.35 ± 1.15	**0.16**	3.35 ± 1.12	3.43 ± 1.13	−0.07	3.03 ± 1.09	3.43 ± 1.12	**−0.36**	2.80 ± 1.08	3.42 ± 1.12	**−0.56**
Delayed recall	4.45 ± 0.80	4.35 ± 0.90	**0.12**	4.42 ± 0.83	4.33 ± 0.91	**0.10**	4.12 ± 1.10	4.39 ± 0.86	**−0.27**	4.06 ± 1.05	4.38 ± 0.87	**−0.34**
BESS												
Modified	2.85 ± 2.48	3.20 ± 2.50	**−0.14**	3.40 ± 2.63	2.93 ± 2.39	**0.19**	3.75 ± 2.85	3.06 ± 2.46	**0.26**	3.83 ± 3.10	3.09 ± 2.47	**0.26**
Full	12.12 ± 4.76	12.47 ± 4.94	−0.07	12.87 ± 5.08	12.06 ± 4.75	**0.16**	13.61 ± 5.37	12.28 ± 4.84	**0.26**	13.70 ± 5.56	12.34 ± 4.87	**0.26**

[a]Comparisons are bolded where $P < .05$ after adjusting for multiple comparisons. Five and 8 subjects were missing data on ADHD and LD status, respectively. ADHD, attention-deficit/hyperactivity disorder; BESS, Balance Error Scoring System; LD, learning disability; SAC, Standardized Assessment of Concussion; SCAT3, Sport Concussion Assessment Tool–3.
[b]Number of symptoms endorsed.
[c]Sum of 0-6 symptom ratings.

effects between sex and level of competition (for each of the SCAT3 components) were nonsignificant ($F(1,2014) = 0.33$-1.19, $P = .29$-$.56$). Normative performance tables stratified by sex and level of competition, derived from only those athletes without ADHD or LD, are available in the supplementary material (see Appendix Tables A1-A4, available online). Normative tables were also derived for male participants with ADHD (stratified by level of competition) because of adequate sample sizes in this cohort (see Appendix Tables A5 and A6, available online). Common clinical guidelines for interpreting percentiles are presented in Table 5. Although baseline BSI-18 GSI ratings had a moderate effect on SCAT3 symptom scores, because premorbid level of distress would not be measurable in the context of a postinjury evaluation in which these normative tables would be most sensibly applied, this variable was not considered for stratification in these normative tables.

Derivation of RCIs

Table 6 displays the test-retest reliability, mean practice effects observed (rounded to the nearest whole raw score value), and reliable change criteria derived from controls. Although the time interval of preseason baseline to the first (24-hour) postinjury assessment (mean, 196 days; range, 4-771 days) is likely of most clinical utility for clinicians employing a baseline testing model of an SRC evaluation, we also present the reliability and associated RCIs for a shorter interval (7 days) to illustrate the effect of more rapid repeat testing on performance stability. Practice effects were observed for the SAC and fBESS for the 7-day but not the longer retest interval, suggesting that unless clinicians apply RCIs for scores from 2 examinations performed within a very short (1-week) window of time, they need not account for practice effects in their interpretation of change scores (assuming the use of different SAC forms at repeat testing as was done in this study).[i]

TABLE 5
Common Guideline for Interpreted Performance Level by Percentile

Percentile	Level
≥98	Very superior
91-97	Superior
75-90	High average
25-74	Average
9-24	Low average
2-8	Borderline
<2	Impaired

DISCUSSION

We characterized the psychometric properties and derived clinical interpretation information for the 3 subtests of the SCAT3 using a large sample of high school and collegiate athletes. An evaluation of the predictors of baseline performance revealed that athletes who are female, attend high school (vs college), have a history of ADHD, or report more psychological distress report more severe concussive symptoms at baseline. Baseline cognitive performance was lower among athletes who are male or have a history of ADHD or LD. Athletes who are male, attend high school (vs college), or report a history of ADHD or LD showed more baseline balance problems. Derived normative conversion tables and reliable change criteria may be applied to clinical cases.

Given that clinical decisions are rarely clear-cut, we hesitate to be too prescriptive about exactly how to apply the data presented here in a clinical setting. We can, however, likely draw a couple of conclusions from the data presented, also with consideration of neuropsychological practice standards. First, the findings do not support a significant added value of baseline testing versus a comparison of postinjury performance to normative data, so at

TABLE 6
Test-Retest Reliability and Reliable Change Scores Derived From Noninjured Controls (n = 164)[a]

	Test-Retest Reliability			Criteria for Significant Change by CI			
	Pearson *r*	Spearman *r*	ICC	80% CI	90% CI	95% CI	Practice Effect
196-day interval[b]							
Symptoms	0.45	0.55	0.43	2.89	3.71	4.42	N/A
SAC	0.41	0.41	0.39	1.66	2.13	2.54	0
fBESS	0.53	0.52	0.52	2.28	2.93	3.49	0
mBESS	0.53	0.45	0.54	1.66	2.14	2.54	0
7-day interval[c]							
Symptoms	0.63	0.62	0.62	1.94	2.49	2.97	N/A
SAC	0.49	0.50	0.42	1.46	1.87	2.23	+1
fBESS	0.66	0.65	0.64	1.71	2.20	2.62	−1
mBESS	0.57	0.52	0.56	1.50	1.93	2.30	0

[a]fBESS, full Balance Error Scoring System; ICC, intraclass correlation coefficient; mBESS, modified Balance Error Scoring System; N/A, not applicable; SAC, Standardized Assessment of Concussion.
[b]Reflects the mean test-retest interval from preseason baseline to the 24-hour assessment point.
[c]Reflects the stability of the measures from the 24-hour to day-8 assessment.

this time, clinicians' choices regarding how to apply these criteria should vary based on their preferred model of practice and resources available for baseline testing. We expect that most clinicians will apply the RCIs provided in the context of interpreting change scores from baseline and will apply the normative tables when baseline data are not available. However, a hybrid model might also be justified. For example, those who administer preseason baseline testing could use the normative tables to provide evidence regarding the validity of baseline performance obtained on their athletes. This would be consistent with clinical trends to consider, attempt to maximize, and formally measure effort and other sources of performance validity.[11,20,38,42] While cutoff scores for questioning performance validity have varied across studies, conventions in the neuropsychological literature are to maintain false-positive rates of ≤10% (corresponding to normative performance of ≤10th percentile for a demographically matched group).[27] Data from a recent study identifying cutoff scores on the SAC that were sensitive to low effort would support a cutoff score for this test of 21 and perhaps somewhat higher.[58]

Overall, the results of this study suggested that the symptom checklist represents the component of the SCAT3 that is most sensitive to the effects of a concussive injury, with the SAC and BESS performing more modestly. It is worth noting that other samples have yielded better performance from the SAC and BESS,[3,31] and therefore, decisions about the utility of these tests should take into account all available literature. Nevertheless, other data from the current study sample found a similar advantage of self-reported symptom data over those derived from computerized neurocognitive tests,[41] and some other studies have similarly found larger effect sizes for symptoms than other performance metrics (eg, neurocognitive testing).[5,23] Further study would be valuable to determine under what conditions or in which concussed populations cognitive and postural stability metrics provide the greatest added value. Nevertheless, the literature consistently supports self-reported symptom burden as a key component of any concussion assessment.

Individual Differences in Baseline SCAT3 Performance

That female athletes in our sample reported more baseline concussion-like symptoms than male athletes is consistent with most of the previous studies with the SCAT/SCAT2 and similar concussion symptom checklists reporting significant sex differences or a similar trend.[10,28,52,53] In addition, our finding of sex differences in baseline cognitive performance was consistent with most of the previous studies with the SCAT2.[16,37] To our knowledge, this is the first study to examine performance on all 3 subtests of the SCAT3 in both high school and collegiate students. When only focused on high school students, previous studies have shown that younger athletes tend to perform worse in baseline cognitive tasks[1,57] and report more severe symptoms than older athletes with preseason baseline assessments using the SCAT.[1] This study found a similar moderate association between level of competition across a wider age bracket.

This sample yielded new information regarding the association between ADHD and LD on baseline SCAT3 performance. In particular, elevated baseline scores were found among athletes with ADHD or LD compared with those without ADHD or LD. While it is not surprising that athletes with these conditions score lower on the SAC because of cognitive difficulties, it is unclear why they reported more baseline symptoms and rated their symptoms as more severe. ADHD and LD have high comorbidity with mood and behavioral disorders (eg, anxiety disorder, oppositional defiant disorder),[25,30,42,56] so it is possible that these comorbid conditions (rather than ADHD or LD specifically) could result in the higher prevalence of physical and emotional symptoms. Not surprisingly, patients with ADHD also tend to report more baseline difficulties with concentration and other "postconcussive" symptoms that directly overlap with the clinical sequelae of ADHD,[54] which probably leads to an inflation of concussion symptom scores because of criterion contamination among concussion and ADHD measures. In addition, brain abnormalities associated with ADHD may be directly responsible for the increased prevalence of headaches in patients with ADHD.[43]

Concussion history did not predict baseline SCAT3 performance in this sample. While this is not surprising given the complete recovery that is expected for most patients after an SRC,[40] it is inconsistent with some other studies reporting differences in baseline symptoms among cohorts with and without reported histories of multiple concussions.[7,8,14] Given that most participants in our study with concussion histories reported only 1 prior injury, we may have lacked the power to detect what may be a dose-response relationship between repeated concussions and chronic symptoms. On the other hand, this relationship could be accounted for by confounding variables that have yet to be identified. Additional longitudinal studies are needed to explore the effect of repeat concussions on long-term neurological function.

Two Interpretative Approaches

Preliminary analyses of postinjury SCAT3 scores versus baseline-adjusted scores showed equivalent sensitivity and specificity. This finding was consistent with another study of the SCAT3,[44] which found similar and clinically acceptable sensitivity and specificity between these 2 approaches. This is also consistent with most of the limited literature comparing these 2 interpretive models for other concussion assessment measures,[13,51] although findings of equivalence between these approaches have not been universal.[50] Overall, the data supporting the added value of baseline testing are probably too sparse to justify its widespread practice.[24] When baseline data are collected, clinicians must take steps to optimize the validity of these evaluations and should take steps to review their baseline data for questionably valid profiles.

Although the normative performance tables derived were stratified only by sex and level of competition (with additional tables provided for male participants with ADHD), other factors, including a history of LD and estimated verbal intellectual ability (WTAR score), also predicted baseline SCAT3 performance. This implies that clinicians should take these other predictive factors into account and make adjustments in the interpretation of relevant SCAT3 subtests, particularly when athletes are outside the average range on these factors.[50]

There are several limitations to this study. First, the data were collected from high school and collegiate athletes residing in the southeastern Wisconsin area, and most participants were white and male. This may limit our ability to generalize the results to other populations, particularly with regard to our analyses of concussed and control participants (where the female sample was small). Second, as developmental, psychiatric, and injury history variables were ascertained via self-report, it is possible that our normative sample was affected by athletes' awareness and willingness to report this information. Third, despite efforts to minimize extraneous variables, other confounding factors not assessed (eg, possible variability in athlete motivation) could affect the results. Finally, contextual factors such as test group size,[39] the surrounding environment,[45] and the time since last physical exertion[55] can influence performance on aspects of concussion assessments, and therefore, further research is needed to estimate the degree to which the reported results would vary under a variety of testing conditions likely to be relevant in such evaluations.

In summary, this study provided a wealth of data on the psychometric properties of the SCAT3 in a large sample of high school and collegiate athletes. The normative conversion tables and reliable change criteria provided can be readily applied to clinical cases. Future work will be important to document the performance of the SCAT3 in novel samples and to understand how applying differing decision rules influences clinical decision accuracy and the recovery of concussed athletes.

NOTE

i. Supplementary analyses explored whether reliable change cutoffs should be stratified by sex and level of competition and supported the derivation of a single set of reliable change criteria. Specifically, we measured the differences in test-retest reliability coefficients (using Fisher z transformations) and variance (using Levene tests) for each SCAT3 measure (symptom severity score, SAC total score, and fBESS total score) and for every pairwise comparison using the 4 groups by which normative tables were stratified (female high school, female college, male high school, and male college). Reliability coefficients (in the control sample only) were nearly all statistically equivalent (Fisher z test, P values $>.05$), with the exception that the college female control sample demonstrated lower reliability than the other groups on SAC total scores (the sample size for this group was only 12). The groups all demonstrated equivalent variance (Levene test, P values $>.05$) on all 3 SCAT3 measures.

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