Accuracy of Components of SCAT to Identify Children With Concussion

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abstract

BACKGROUND: The Sport Concussion Assessment Tool version 3 (SCAT3) and its child version (ChildSCAT3) are composite physical and neuropsychological scoring systems used to assess athletes after sport-related concussion. Based on limited validation data, we aimed to evaluate the ability of SCAT3 and ChildSCAT3 to differentiate children aged 5 to 16 years with concussion from controls.

METHODS: Prospective observational study of children in the emergency department with concussion (CONC group) and 2 control groups ([1] upper-limb injury [ULI] and [2] Well children) with equal-sized subgroups in 3 age bands of 5 to 8, 9 to 12, and 13 to 16 years. ChildSCAT3 was used for participants aged 5 to 12 years, and SCAT3 was used for participants aged 13 to 16 years. Differences between study groups were analyzed by using analysis of variance models, adjusting for age and sex.

RESULTS: We enrolled 264 children (90 CONC, 90 ULI, and 84 Well) in equal-sized age bands. The number and severity of child- and parent-reported symptom scores were significantly higher in the CONC group than either control group ($P < .001$). Mean double (ChildSCAT3 $P < .001$) and tandem stance errors (both $P \leq .01$) were also significantly higher, and immediate memory was significantly lower for the CONC group ($P < .01$). No statistically significant group differences were found for orientation and digit backward tasks. There were no significant differences between ULI and Well control groups.

CONCLUSIONS: Overall, SCAT3 and ChildSCAT3 can differentiate concussed from nonconcussed patients, particularly in symptom number and severity.

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Drs Davis and Babl made substantial contributions to the conceptualization and design of the study and critically revised the manuscript for important intellectual content; Dr Dionisio, Ms Davenport, and Ms Baylis made substantial contributions to the acquisition of data and critically revised the manuscript for important intellectual content; Mr Hearps analyzed and interpreted the data and critically reviewed the manuscript for important intellectual content; Drs Oakley, Anderson, and Bressan made substantial contributions to the acquisition and interpretation of data and critically reviewed the manuscript for important intellectual content; Ms Thompson made substantial contributions to the analysis and interpretation of data and drafted the article; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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WHAT'S KNOWN ON THIS SUBJECT: The Sport Concussion Assessment Tool (SCAT3) and its child version are composite physical and neuropsychological scoring systems and are widely used and recommended to assess athletes after sport-related concussion. However, validation data of SCAT3 in children are limited.

WHAT THIS STUDY ADDS: SCAT3 and its child version can differentiate concussed from nonconcussed injured and uninjured children, particularly in terms of symptom number and severity. However, some neuropsychological subtests do not differentiate concussed patients and controls.

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Concussion is a complex pathophysiological process that affects the brain and is induced by biomechanical forces.[1] In the United States over the 2001–2005 period, children aged 8 to 19 years had an estimated 502 000 emergency department (ED) visits for concussion, with approximately half for sport-related concussion.[2] Only recently, however, have researchers begun to develop pediatric concussion assessment tools.[3–10]

The Sports Concussion Assessment Tool (SCAT) was first introduced at the Second International Conference on Concussion in Sport as a standardized tool to assess sport-related concussion.[11] At the Fourth International Conference on Concussion in Sport, a child-specific version of SCAT was conceived (ChildSCAT3) for children <13 years of age, with SCAT3 for those aged >12 years.[1,12] The ChildSCAT3 includes age-appropriate modification of the standardized assessment of concussion (SAC) and inclusion of a parent symptom report.[12] Recently, the ability of SCAT3 to discriminate between high-school athletes with and without concussion has been investigated.[13,14] To our knowledge, only 2 studies have considered the psychometric properties of ChildSCAT3, although neither considered concurrent validity.[15,16]

The aim of the current study was to determine if SCAT3 and ChildSCAT3 can differentiate children with and without concussion during acute presentation to the ED.

METHODS

Study Design and Participants

In this prospective observational study, we recruited children with and without concussion in the ED of The Royal Children's Hospital (RCH) in Melbourne, Australia, between May 2014 and April 2015. The RCH is a tertiary referral pediatric hospital and the sole pediatric trauma center in the state of Victoria. It has an annual census of 82 000 ED presentations. We recruited the following 3 groups of children aged 5 to 16 years: children with concussion and 2 control groups with (1) upper-limb injuries (ULIs) and (2) Well children (siblings of ED patients). Groups were stratified into equal-sized age bands of 5 to 8, 9 to 12, and 13 to 16 years.

Inclusion Criteria

The concussion group (CONC) included children clinically diagnosed with concussion by emergency physicians as per the Zurich Consensus Statement.[1] No limits on duration of loss of consciousness or amnesia were set to define concussion. Additional inclusion criteria included the following: Glasgow Coma Score of 15 at the time of assessment and injury sustained <24 hours from assessment.

The ULI group included children with isolated ULIs sustained <24 hours from assessment, including fractures, dislocations, and soft tissue injuries (such as lacerations).

Uninjured, Well children were children who had attended the ED as siblings of patients.

Exclusion Criteria

Patients were excluded if they had a Glasgow Coma Score of <15 at the time of assessment; had major lower-limb injuries or multiple injuries that prevented the patients from completing SCAT3 or ChildSCAT3; had significant pain or distress; were affected by sedative medication, drugs, or alcohol; were in need of operative interventions; had baseline significant neurologic disabilities or major congenital abnormalities; or were non–English speaking.

Recruitment, Consent, and Study Procedures

Families of children in the 3 study groups were identified from the Hospital Administration System after triage and approached once the children had been assessed by the treating clinician. In the case of the Well siblings, research assistants checked on occupied patient bays to identify possible sibling participants. The recruitment of younger children with concussion in the 5 to 8 years old age band was difficult because of low numbers and sharing with the concurrently running TakeCARe (Concussion Assessment and Recovery Research) study.[17]

Written consent was obtained from a parent or guardian. Additionally, verbal assent was obtained from participants aged 5 to 12 years and written consent from participants aged 13 to 16 years.

In addition to demographic information, we elicited information about previous head injuries, past medical history, mechanism of injury, injuries identified, as well as concussion symptoms and signs. The SCAT3 or ChildSCAT3 was administered by trained and supervised research assistants while a patient was in the ED. The ChildSCAT3 allows the completion of the symptom checklist to be (1) self-rated (child), (2) via clinician interview, or (3) self-rated and clinician monitored; SCAT3 allows completion to be (1) self-rated, (2) via clinician interview, (3) self-rated and clinician monitored, or (4) self-rated with parental input. In the current study, the ChildSCAT3 symptom report was generally completed via research (clinician) interview for younger children (aged 5–8 years) and self-rated (with or without researcher monitoring) for older children (aged 8–12 years), although some older children required completion via researcher (clinician) interview. The SCAT3 symptom report was either self-rated or self-rated with monitoring by the researcher.

The ChildSCAT3 was used to assess participants aged 5 to 12 years in all

study groups, whereas the 13 to 16 years old age band was assessed with SCAT3. The tandem gait component of each tool was omitted; this was deemed to be not feasible within the ED because of space constraints.

Ethics approval was granted by the RCH Human Research Ethics Committee (study ID number 32331).

Measures

SCAT3 and ChildSCAT3

The SCAT3 is a composite clinical, physical, and cognitive tool used to assess acute sports concussion, and it is recommended for use by the Zurich Consensus Statement in sport.[1] SCAT3 is used for children aged ≥13 years whereas the ChildSCAT3 is designed for use within the age group of 5 to 12 years. Both measures take ∼20 minutes to perform.

The SCAT3 and ChildSCAT3 include the following: (1) symptom assessment, the Postconcussion Symptom Scale (PCSS),[18] and Health and Behavior Inventory (HBI),[19] respectively; (2) cognitive assessment (attention and new learning) by using the SAC and the SAC child version (SAC-C); (3) neck examination; (4) balance assessment (modified balance error scoring system [BESS]); and (5) coordination examination.

Symptom Evaluation (PCSS and HBI)

SCAT3 incorporates the 22-item PCSS and uses a 7-point Likert scale to indicate the number and severity of relevant symptoms. ChildSCAT3 includes both a parental and child report form of the HBI and uses a 4-point scale. The maximum (worst) symptom count score is 22 for SCAT3 and 20 for ChildSCAT3, and the maximum symptom severity score is 132 for SCAT3 and 60 for ChildSCAT3.

Cognitive Assessment (SAC and SAC-C)

The SAC and SAC-C incorporate orientation, immediate memory, concentration, and delayed-recall scores. The orientation scale consists of 5 questions (4 in ChildSCAT3) with a score of 1 for each correct answer (maximum [best] score is 5 for SCAT3 and 4 for ChildSCAT3).

Immediate memory is tested by participant free recall of a list of 5 words over 3 trials (maximum [best] score is 15).

A concentration score is derived on the basis of a digits-backward task and recall of months of the year (SCAT3) or days of the week (ChildSCAT3) in reverse order. The participant is given 2 opportunities to provide the number series correctly and only advances to the next series if correct. Participants are then asked to recall months of the year or days of the week in reverse order, with 1 point assigned if entirely correct.

For delayed recall, participants recall a 5-word list given during the initial memory testing at completion of the balance and coordination examination (maximum [best] score is 5).

Neck Examination

The neck examination involves an assessment of range of motion, tenderness, and upper and lower limb sensation and strength.

BESS

Participants are asked to complete a modified version of the BESS. This includes double leg stance, single leg stance (SCAT3 only), and tandem leg stance components. The number of errors or deviations from the stance is recorded. The maximum (worst) number of errors is 20 for children aged ≤12 years and 30 for children aged ≥13 years. Tandem gait is included in ChildSCAT3 and is optional in SCAT3 in addition to (or instead of) the modified BESS, but it was not included in the current study because of space restrictions during assessment in the ED.

Coordination Examination

Upper-limb coordination is tested by a finger-to-nose task. Five correct repetitions of finger to nose in <4 seconds are scored as 1 point.

Statistical Methods

Sample Size

Sample size analysis (α level of .05 and power of 80%) determined that 3 study groups of $n = 30$ were required to detect a mean difference of 0.75 SD between the concussed and the control groups on SCAT3 scales for the subgroup of children aged ≥13 years. This allowed for the inclusion of a continuous age covariate in analysis of covariance (ANCOVA) models, with $N = 90$ and a medium-to-large size of effect, partial η squared (η_p^2) = 0.11. We elected to double the group size for children completing the ChildSCAT3 to explore separate analyses for children in age bands 5 to 8 years and 9 to 12 years, maintaining the same power and effect size and an overall medium effect size of $\eta_p^2 = 0.06$ with $N = 180$. As such, a total sample size of 270 was proposed.

Analysis

Demographic characteristics and medical histories were compared among groups; analysis of variance models were used for continuous variables, and Fisher's exact test was used for categorical variables to accommodate low cell frequency. The test elements that participants were unable to complete were explored, and reasons for missing items were reported. Analyses were conducted on valid data.

To determine concurrent validity of SCAT3 and ChildSCAT3, group differences in scale outcomes were modeled by using negative binomial ANCOVA (allowing for positive skew), adjusting for mean-centered participant age (continuous) as well as participant sex. Observed group means and SDs were presented with the group main effect *P* value.

Post hoc Tukey tests explored specific differences among groups after significant omnibus results. Between-group effect size (Cohen's *d*) quantified the standard differences between each group combination. This ANCOVA modeling was also applied to individual SCAT3 and ChildSCAT3 items, highlighting concurrent validity for SCAT3 symptoms.

Concussion differentiation was also supported by exploring the discriminant validity of SCAT3 and ChildSCAT3 scales. The area under the curve (AUC) statistic from receiver operating characteristic (ROC) curve analyses was used to assess the ability of scales to discriminate between CONC and combined control groups, in which AUC >0.7 indicates acceptable discrimination.[20] ROC curves were also plotted to assist in AUC interpretation.

The relationships between child- and parent-reported ChildSCAT3 items were explored. Spearman correlations were used to determine correlation (because of the ordinal nature of items), and weighted Cohen's κ investigated agreement between participants and their parents. Stata version 13.1 (Stata Corp, College Station, TX) was used for all analyses. An α level of .05 was deemed statistically significant.

RESULTS

We approached a total of 286 children to complete recruitment for the 3 study groups with 3 age bands. A total of 19 eligible potential participants refused inclusion within the study, 7 because of child refusal and 12 because of parent refusal. Three participants were excluded after enrollment, 2 because of incomplete consent and 1 because of enrollment within the incorrect age band.

A total of 264 participants were enrolled into the CONC (n = 90), ULI (n = 90), and Well groups (n = 84), and 30 subjects were in each age band of 5 to 8, 9 to 12, and 13 to 16 years, with the exception of the 13 to 16 years old Well group (see Table 1). Recruitment within the Well group age band of 13 to 16 year olds was slowest, and we ceased recruitment after 24 participants.

Demographics and Medical History

As illustrated in Table 1, there was a significant association between study group and sex (P < .001), with the Well group composed of fewer boys (36%) compared with the ULI (50%) and CONC groups (70%). Further significant results showed a difference in the proportion of the sample previously hospitalized and/or having had a computed tomography and/or MRI scan (P = .008) and having a history of a learning disability (P = .030), psychiatric disorder (P = .035), or a family history of either (P = .020). No significant group differences were found for age, medications, or previous concussions. Between-group analysis was also conducted for the SCAT3 and ChildSCAT3 subsamples and yielded similar results. For the younger group, significant differences were found for sex (boys: CONC 60%, ULI 43%, Well 37%; P = .032) and family medical history (CONC 25%, ULI 23%, Well 9%; P = .039). For children aged ≥13 years, significant differences in sex (boys: CONC 90%, ULI 63%, Well 33%; P < .001), history of headaches and/or migraines (CONC 10%, ULI 3%, Well 21%; P = .035), or learning disability (CONC 7%, ULI 0%, Well 0%; P = .019) were identified.

A small portion of the present sample (n = 45, 17%) were unable to complete 1 or more items from the SCAT3 or ChildSCAT3. Of these, 29% did not understand, 7% refused to continue, 4% were unable to continue, and 4% were too unwell. The remaining had multiple reasons (18%), reasons for an inability to continue were unknown or unclear (36%), or data for this variable were missing (2%). An inability or refusal to complete at least 1 subtest occurred in 29 (32%) of the 5 to 8, 5 (5.5%) of the 9 to 12, and 11 (13.3%) of the 13 to 16 year age bands. The distribution of these reasons did not significantly differ between study or age groups (all P > .05).

SCAT3 and ChildSCAT3 Subscale Group Contrasts

Calculated SCAT3 and ChildSCAT3 subscale means were compared among the CONC, ULI, and Well groups by using ANCOVA models, adjusting for participant age (continuous) and sex. For the majority of these scales, results indicated significant differentiation between CONC, Well, and ULI groups, with CONC having poorer outcomes. Symptom number and severity scores significantly differentiated the CONC group from the ULI and Well groups for the SCAT3 (ages ≥13 years, all d > 1.52, all P < .001) and the child- and parent-reported ChildSCAT3 (d range = 0.88–1.28, all P < .001, see Supplemental Table 2). Similar group mean differences (between CONC and ULI and Well groups) were found in immediate memory (SCAT: both d > 0.52, P = .038; ChildSCAT3: both d > 0.31, P = .023), tandem leg stance errors (SCAT: both d > 0.79, P = .013; ChildSCAT3: both d > 0.44, P = .010), and the BESS (SCAT: both d > 0.76, P = .011; ChildSCAT3: both d > 0.61, P < .001). For the younger group, significant mean differences were found on the SAC ($d_{\mathrm{CONC/WELL}}$ = 0.37, P = .024) and double leg stance errors (both d > 0.56, P < .001). Post hoc analyses showed that significant results were driven by pairwise comparisons between CONC and at least 1 of the control groups (Well or ULI); no significant differences were found between the control groups.

SCAT3 and ChildSCAT3 Symptom Item Group Contrasts

For participants aged ≥13 years (SCAT3), on 19 of 22 symptom items, there were significant mean differences between the CONC group and at least 1 control group by using ANCOVA models (adjusting for age [continuous] and sex; Supplemental Table 3). The greatest effect sizes were seen in the items "drowsiness" ($d_{CONC/ULI}$ = 1.44, $d_{CONC/WELL}$ = 1.79), "pressure in head" ($d_{CONC/ULI}$ = 1.84, $d_{CONC/WELL}$ = 1.34), and "headache" ($d_{CONC/ULI}$ = 1.81, $d_{CONC/WELL}$ = 1.87). Fifteen items showed a high significance ($P \leq .001$). Items "trouble falling asleep," "blurred vision," and "nervous or anxious" did not yield a significant difference in means (Ps > .05).

Results from ROC curve analyses indicated that SCAT3 and ChildCSAT3 symptom number and severity acceptably differentiated between CONC and combined control groups (all AUC >0.7) as shown in Figs 1 and 2. Additionally, the SCAT3 tandem stance (AUC = 0.73) and BESS (AUC = 0.72) adequately differentiated between groups. Figures 3 and 4 illustrate poor classification ability of the remaining SCAT3 and ChildSCAT3 subscales.

Child-reported items of the ChildSCAT3 showed similar results, with 17 of 20 symptom items showing a significant difference between the CONC and ULI groups and 12 showing a further significant difference between the CONC and Well groups (a total of 18 significant tests, see Supplemental Table 4). The items "I have problems finishing things" and "I daydream too much" did not show a mean difference among groups (P = .102 and .051, respectively). Generally, the child-reported items did not display the magnitude group differences that were seen in children aged ≥13 years, with the largest sizes of effect seen in "I feel sick to my stomach" ($d_{CONC/ULI}$ = 0.70, $d_{CONC/WELL}$ = 0.89),

TABLE 1 Demographics of Participants Who Had Sustained Concussions, Had ULI Only, or Were Well Visitors to the ED

	CONC (n = 90)		ULI (n = 90)		Well (n = 84)		P[a]
Age							
Mean (SD)	10.85	(3.20)	11.00	(3.20)	10.54	(3.24)	.62
Median (IQR)	11.50	(7.66–13.48)	11.04	(8.21–13.89)	10.04	(7.42–13.32)	.60
Boy, n (%)	63	(70.0)	45	(50.0)	30	(35.7)	<.001
Any previous concussions, n (%)							
No	67	(74.4)	71	(78.9)	74	(88.1)	.09
Yes	17	(18.9)	10	(11.1)	5	(6.0)	—
Unknown	6	(6.7)	9	(10.0)	5	(6.0)	—
Hospitalized, CT, or MRI, n (%)							
No	71	(78.9)	70	(77.8)	79	(94.0)	.008
Yes	5	(5.6)	5	(5.6)	1	(1.2)	—
Unknown	14	(15.6)	15	(16.7)	3	(3.6)	—
Acute concussion characteristics							
Loss of consciousness, n (%)							
No	55	(61.11)	—	—	—	—	—
Yes	24	(26.67)	—	—	—	—	—
Suspected	5	(5.56)	—	—	—	—	—
Unknown	6	(6.67)	—	—	—	—	—
Vomiting, n (%)							
No	63	(70.00)	—	—	—	—	—
Yes	27	(30.00)	—	—	—	—	—
PTA, n (%)							
No	47	(52.22)	—	—	—	—	—
Yes	37	(41.11)	—	—	—	—	—
Unknown	6	(6.67)	—	—	—	—	—
Seizure, n (%)							
No	83	(92.22)	—	—	—	—	—
Yes	3	(3.33)	—	—	—	—	—
Unknown	4	(4.44)	—	—	—	—	—
Past medical history							
Headaches and/or migraines, n (%)							
No	71	(78.9)	70	(77.8)	75	(89.3)	.051
Yes	6	(6.7)	5	(5.6)	5	(6.0)	—
Unknown	13	(14.4)	15	(16.7)	3	(3.6)	—
Learning disability, ADHD, dyslexia, or seizures, n (%)							
No	75	(83.3)	72	(80.0)	78	(92.9)	.030
Yes	6	(6.7)	3	(3.3)	2	(2.4)	—
Unknown	9	(10.0)	15	(16.7)	3	(3.6)	—
Psychiatric disorder, n (%)							
No	78	(86.7)	71	(78.9)	78	(92.9)	.035
Yes	5	(5.6)	4	(4.4)	2	(2.4)	—
Unknown	7	(7.8)	15	(16.7)	3	(3.6)	—
Family history of above, n (%)							
No	56	(62.2)	57	(63.3)	68	(81.0)	.020
Yes	21	(23.3)	18	(20.0)	11	(13.1)	—
Unknown	13	(14.4)	15	(16.7)	4	(4.8)	—
Medications, n (%)							
None	69	(76.7)	70	(77.8)	70	(83.3)	.48
ADHD and/or anxiety	1	(1.1)	1	(1.1)	0	(0.0)	—
Antibiotics	1	(1.1)	2	(2.2)	1	(1.2)	—
Antidepressants	2	(2.2)	0	(0.0)	0	(0.0)	—
Asthma	4	(4.4)	5	(5.6)	6	(7.1)	—
Insulin	0	(0.0)	3	(3.3)	0	(0.0)	—
Other	4	(4.4)	1	(1.1)	4	(4.8)	—
Unknown	4	(4.4)	7	(7.8)	3	(3.6)	—

ADHD, attention-deficit/hyperactivity disorder; CT, computed tomography; IQR, interquartile range; PTA, posttraumatic amnesia. —, not applicable.

[a] Analysis of variance for continuous variables and Fisher's exact test for categorical variables. Age presented as median (IQR), was tested using the Kruskal-Wallis test.

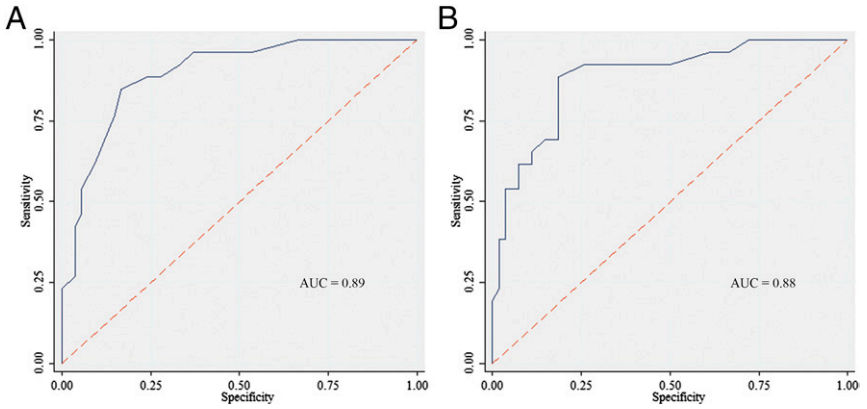

FIGURE 1

ROC curves (with AUC) examining the ability of SCAT3 subscales to distinguish concussed from control patients (control groups were collapsed because of statistical equivalence). A, SCAT3 symptom number. B, SCAT3 symptom severity.

"I get tired easily" ($d_{CONC/ULI}$ = 0.84, $d_{CONC/WELL}$ = 1.01), "I get tired a lot" ($d_{CONC/ULI}$ = 0.86, $d_{CONC/WELL}$ = 1.05), "I feel dizzy" ($d_{CONC/ULI}$ = 0.89, $d_{CONC/WELL}$ = 1.12), and "I have headaches" ($d_{CONC/ULI}$ = 1.27, $d_{CONC/WELL}$ = 1.25).

This pattern was similarly seen in the parent-reported symptoms of ChildSCAT3, with 18 of 20 items demonstrating significant mean differences between the CONC and at least 1 of the control groups (Supplemental Table 5). Similar to the child report, large effect sizes were found in the items "gets tired easily" ($d_{CONC/ULI}$ = 1.30, $d_{CONC/WELL}$ = 1.21), "gets tired a lot" ($d_{CONC/ULI}$ = 1.46, $d_{CONC/WELL}$ = 1.30), and "has headaches" ($d_{CONC/ULI}$ = 1.87, $d_{CONC/WELL}$ = 1.71), as well as "has difficulty concentrating" ($d_{CONC/ULI}$ = 1.00, $d_{CONC/WELL}$ = 0.67), "has blurred vision" ($d_{CONC/ULI}$ = 0.78, $d_{CONC/WELL}$ = 0.86), "feels faint" ($d_{CONC/ULI}$ = 0.81, $d_{CONC/WELL}$ = 1.11), "feels dizzy" ($d_{CONC/ULI}$ = 1.11, $d_{CONC/WELL}$ = 1.45), and "experiences nausea" ($d_{CONC/ULI}$ = 1.30, $d_{CONC/WELL}$ = 1.21).

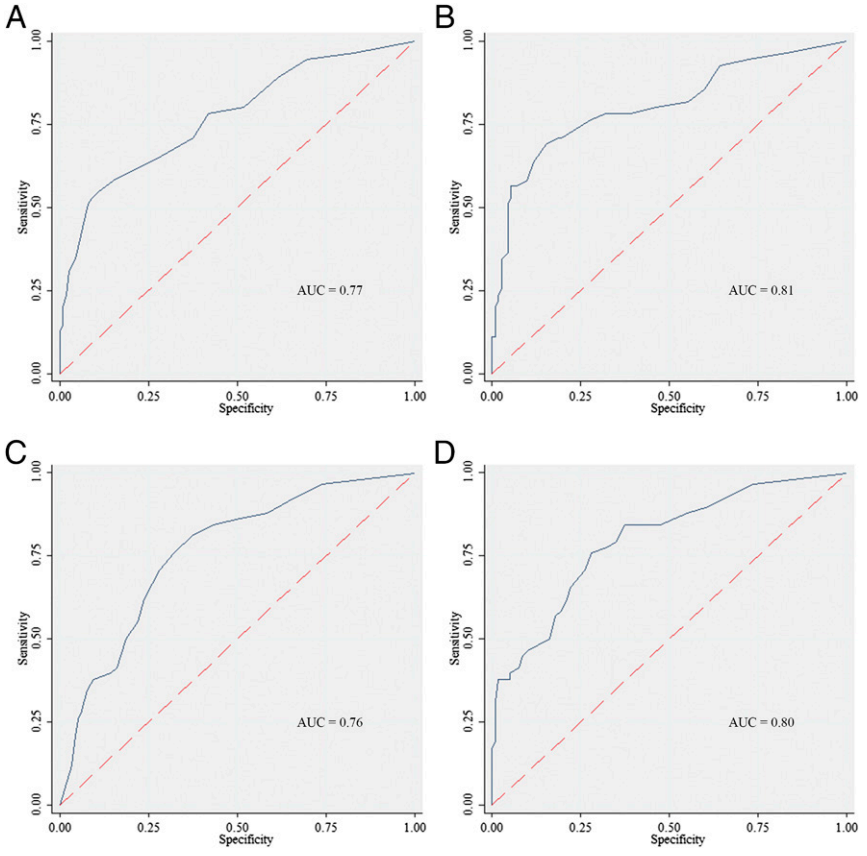

FIGURE 2

ROC curves (with AUC) examining the ability of ChildSCAT3 subscales to distinguish concussed from control patients (control groups were collapsed because of statistical equivalence). A, ChildSCAT3 symptom number (child). B, ChildSCAT3 symptom severity (child). C, ChildSCAT3 symptom number (parent). D, ChildSCAT3 symptom severity (parent).

ChildSCAT3 Symptom Scale Item Correlation and Agreement

Spearman correlations and weighted κ tests showed the degree of relationship and agreement between ChildSCAT3 child and parental symptom reports (see Supplemental Table 6). The strongest correlations were seen in the items "experiences nausea" (r = 0.54), "has headaches" (r = 0.65), and "feels dizzy" (r = 0.66). An additional 9 items showed moderate positive correlations (r = 0.3–0.5), and the remaining 8 items showed weak correlations (r < 0.3). Items showed concordant agreement, with the 3 top-correlated items showing moderate agreement ("experiences nausea" κ = 0.49, "has headaches" κ = 0.58, and "feels dizzy" κ = 0.55). Moreover, items with moderate correlation showed fair agreement (κ = 0.2–0.4), and the remaining items (weak correlation) showed poor agreement (κ < 0.2).

DISCUSSION

The current study aimed to investigate whether SCAT3 and ChildSCAT3 could differentiate children with concussion from those who were uninjured and/or those with ULIs during acute presentation to the ED. Overall, SCAT3 and ChildSCAT3 could differentiate concussed from

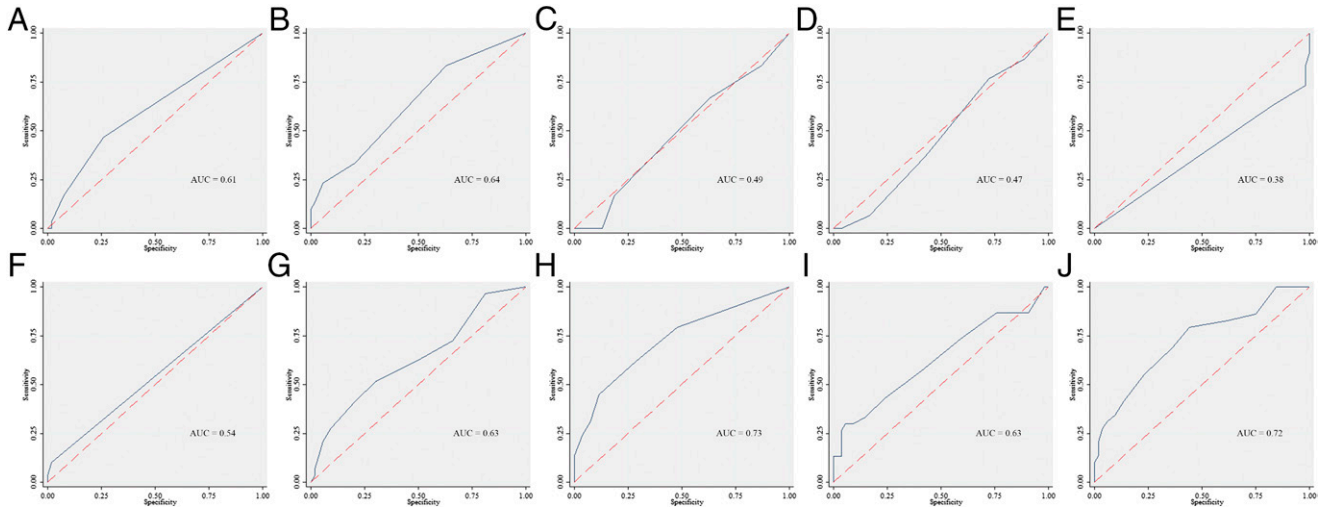

FIGURE 3

ROC curves (with AUC) examining the ability of SCAT3 subscales to distinguish concussed from control patients (control groups were collapsed because of statistical equivalence). A, SCAT3 orientation. B, SCAT3 immediate memory. C, SCAT3 digit backward. D, SCAT3 concentration. E, SCAT3 delayed-recall score. F, SCAT3 double leg stance. G, SCAT3 single leg stance. H, SCAT3 tandem stance. I, SCAT3 SAC. J, SCAT3 BESS.

nonconcussed patients, particularly in terms of symptom number and severity. In fact, the majority of scales on both SCAT3 and ChildSCAT3 could differentiate children with a concussion from those who were uninjured as well as those with ULIs. The number and severity of symptoms reported (both parental and child reports) showed the greatest effect sizes in differentiating between concussed and control groups. In addition, on both SCAT3 and ChildSCAT3, immediate memory, tandem leg stance errors, and BESS subcomponents significantly differentiated concussed and control groups but with smaller effect sizes. At the item level, the majority of symptoms on SCAT3 and parental and child reports of ChildSCAT3 were able to distinguish between the children with concussion and at least 1 control group, although certain items showed greater effect sizes. Given the nonspecific nature of many concussion symptoms,[1] the present findings provide important evidence to support the validity of both SCAT3 and ChildSCAT3 to distinguish children who have experienced a concussion from those with other common pediatric injuries (ie, ULIs) at acute presentation.

The symptom scales include some items that may not be apparent in the acute setting or that take time to evolve (eg, "I have problems

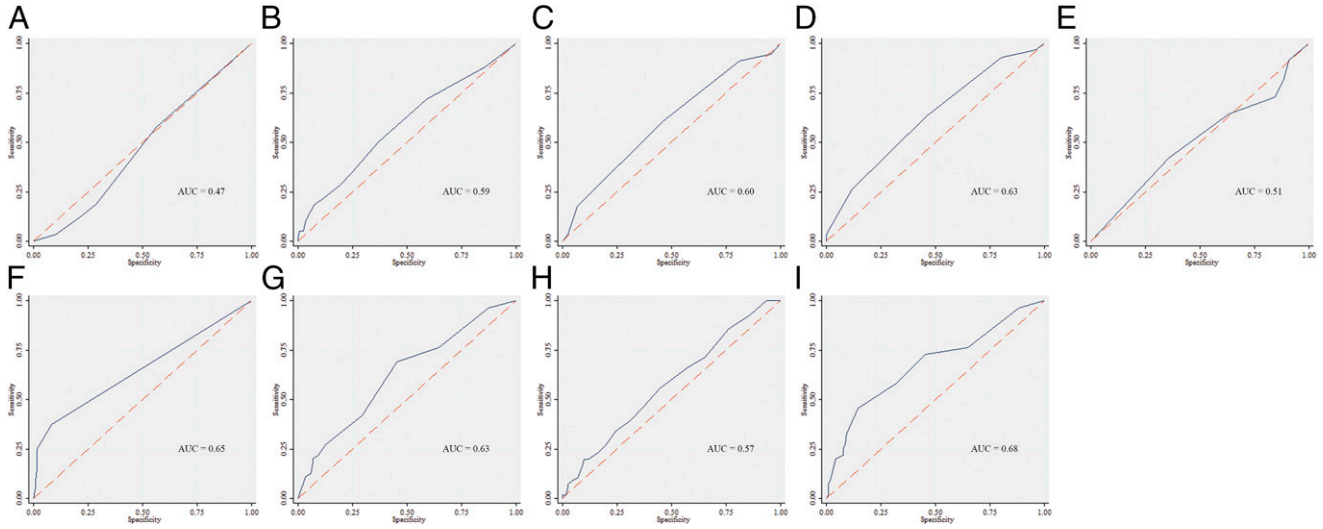

FIGURE 4

ROC curves (with AUC) examining the ability of ChildSCAT3 subscales to distinguish concussed from control patients (control groups were collapsed because of statistical equivalence). A, ChildSCAT3 orientation. B, ChildSCAT3 immediate memory. C, ChildSCAT3 digit backward. D, ChildSCAT3 concentration. E, ChildSCAT3 delayed-recall score. F, ChildSCAT3 double leg stance. G, ChildSCAT3 tandem stance. H, ChildSCAT3 SAC. I, ChildSCAT3 BESS.

finishing things," "I daydream too much," "trouble falling asleep," "blurred vision," and "nervous or anxious") and can manifest over days postconcussion. These items may demonstrate greater utility in the subacute recovery period.

To date, limited research has considered the validity of the SCAT3 and ChildSCAT3 in children despite their widespread dissemination and use. Similarly, few studies have considered the psychometric properties of the ChildSCAT3 such as baseline and normative performance.[15,16] The current study is the first to consider the validity of the ChildSCAT3 to differentiate children with and without concussion. It also builds upon existing validity literature for SCAT3 in teenagers and young adults, further supporting the notion that it can distinguish among concussed and control groups.[13,14] Concordant with the limited SCAT3 literature, our results indicate that the SAC is not useful in the acute differentiation of those with and without concussion (although it may have an important role in monitoring recovery in the subacute period), and further investigation is required.[13,21] Given the pending development of the SCAT5 and ChildSCAT5, the current study provides evidence in support of the ability of the SCAT3 and ChildSCAT3 to differentiate between children with and without a concussion in an acute ED setting.

Our study must be interpreted in the context of some limitations. SCAT3 and ChildSCAT3 were only administered at a single, early time point, and research assistants were not blinded to study aims. Thus, the validity of SCAT3 and ChildSCAT3 to differentiate children with and without a concussion in terms of delayed symptoms remains unknown. In addition, because SCAT is designed to screen several domains, it is not possible or clinically useful to combine the test components into an overall score or provide categorical cutoffs for test components. The representativeness of the present sample may also be influenced by the difficulty of obtaining some subgroups (young CONC and older Well), differences in sex distribution among groups, and recruitment of CONC patients presenting to an ED. Despite these limitations, the current study offers previously lacking insight into the validity of SCAT3 and ChildSCAT3 in differentiating between children with concussion and those without. A natural extension of the current study would include the expansion of recruitment to concussion patients from more diverse sources. We excluded non–English speaking children from this study, and this may have resulted in a cultural bias. Further investigation across different cultures and languages is required.

CONCLUSIONS

The current study supports the use of SCAT as an assessment tool in the acute care setting. It provides valuable insight into the validity of SCAT3 and ChildSCAT3, which will be critical for the development of pending iterations of the tools. Although younger children are less likely to complete every element of the tool, our results indicate that individual components of both SCAT3 and ChildSCAT3 (and the items of both parent and child symptom reports) can acutely differentiate between children with and without concussion. The present findings are of importance because they provide evidence to validate the widespread use of SCAT3 and ChildSCAT3 in pediatric populations.

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ABBREVIATIONS

ANCOVA: analysis of covariance
AUC: area under the curve
BESS: balance error scoring system
CONC: concussion group
ED: emergency department
HBI: Health and Behavior Inventory
PCSS: Postconcussion Symptom Scale
RCH: The Royal Children's Hospital
ROC: receiver operating characteristic
SAC: standardized assessment of concussion
SAC-C: standardized assessment of concussion, child version
SCAT: Sports Concussion Assessment Tool
ULI: upper-limb injury

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