The Sport Concussion Assessment Tool: a systematic review

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OBJECTIVE Over the last 2 decades, sport-related concussion (SRC) has garnered significant attention. Even with increased awareness and athlete education, sideline recognition and real-time diagnosis remain crucial. The need for an objective and standardized assessment of concussion led to the eventual development of the Sport Concussion Assessment Tool (SCAT) during the Second International Conference on Concussion in Sport in 2004, which is now in its third iteration (SCAT3). In an effort to update our understanding of the most well-known sideline concussion assessment, the authors conducted a systematic review of the SCAT and the evidence supporting its use to date.

METHODS English-language titles and abstracts published between 1995 and October 2015 were searched systematically across 4 electronic databases and a review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines adapted for the review of a heterogeneous collection of study designs. Peer-reviewed journal articles were included if they reported quantitative data on any iteration of the SCAT, Standardized Assessment of Concussion (SAC), or modified Balance Error Scoring System (mBESS) data at baseline or following concussion in an exclusively athlete population with any portion older than 13 years of age. Studies that included nonathletes, only children less than 13 years old, exclusively BESS data, exclusively symptom scale data, or a non–SCAT-related assessment were excluded.

RESULTS The database search process yielded 549 abstracts, and 105 full-text articles were reviewed with 36 meeting criteria for inclusion. Nineteen studies were associated with the SAC, 1 was associated with the mBESS exclusively, and 16 studies were associated with a full iteration of the SCAT. The majority of these studies (56%) were prospective cohort studies. Male football players were the most common athletes studied. An analysis of the studies focused on baseline differences associated with age, sex, concussion history, and the ability to detect an SRC.

CONCLUSIONS Looking toward the upcoming Concussion in Sport Group meeting in fall 2016, one may expect further revision to the SCAT3. However, based on this systematic review, the authors propose further, in-depth study of an already comprehensive concussion test, with acute, diagnostic, as well as long-term use.

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KEY WORDS sideline assessment; Sport Concussion Assessment Tool; Standardized Assessment of Concussion; modified Balance Error Scoring System; sport-related concussion

Over the last 2 decades, sport-related concussion (SRC) has emerged as a major public health problem with many stakeholders.[4,42,56] The Centers for Disease Control and Prevention estimate up to 3.8 million instances of SRC in any given year.[17,27] Even with increased awareness and attempts at athlete education,[7,26] sideline recognition and real-time diagnosis by team physician or training staff remains crucial.[17,36,39]

Recognition and diagnosis of SRC based on symptoms alone may be challenging given the variability in symptom reporting.[40] Due to the subjective nature of symptom endorsement, athletes may fail to disclose or purposefully hide symptoms from sideline staff to remain in the game.[20,25] The need for an objective and standardized assessment of concussion, including brief screening of neurocognitive and neurological functions in addition to

symptom assessment, led to the development of the Standardized Assessment of Concussion (SAC) in 1997.[31–33] During the Second International Conference on Concussion in Sport in 2004, the SAC was combined with a standardized symptom scale (the Post-Concussion Symptom Scale [PCSS]), sport-specific orientation questions (i.e., modified Maddocks' questions), on-field markers of concussion (e.g., amnesia, loss of consciousness), and guidelines for a systematic, stepwise return to play to create the first iteration of the Sport Concussion Assessment Tool (SCAT).[34] While the primary purpose of the SCAT was to standardize sideline diagnosis of concussion, it also served as a tool for patient education.[34]

At the third meeting of the Concussion in Sport Group,[35] the SCAT underwent revisions to include the additions of: 1) the Glasgow Coma Scale (GCS); 2) alternate word lists for the immediate and delayed recall portion of the SAC; and 3) a modified version of the Balance Error Scoring System (mBESS, consisting of 3 stances performed on a hard surface).[35] Although the SCAT2 was more labor intensive and required greater time to administer, it was designed for both sideline and serial use to track an athlete's recovery during subsequent clinical assessments.[21,35] In the most recent revision (SCAT3), published in 2013,[14] additional physical/objective signs (i.e., blank/vacant look, cervical stability assessment) were added with the option of using either foam stances or a timed tandem gait task for postural stability assessment. The SAC and PCSS remained unchanged in the SCAT3 from its original iteration.[14] In addition, a SCAT3 version tailored to children (age < 13 years) was introduced, the Child-SCAT3.[36]

Prior to the release of the SCAT3, the SCAT2 became widely used by certified athletic trainers and team physicians.[21,39] Administration of the SCAT2 had been made more efficient with the advent of smartphone and tablet versions.[5] Because few generalizable studies have been conducted to empirically support the use of the SCAT2, questions were raised regarding its sensitivity and specificity, which may have led to the creation of the SCAT3.[15,40]

Although Guskiewicz et al. presented a concise review of the evidence base upon which the SCAT3 was created,[14] it has been 3 years since this review and 8 years since the release of the SCAT2. Further, both the National Football League (NFL) and the National Hockey League (NHL) have used versions of the SCAT league-wide for sideline assessment of suspected concussion.[39] Given the increased use of the SCAT, we performed a systematic review of the current literature related to the SCAT and its objective components. The a priori objectives of the systematic review were to: 1) concisely summarize all published data on the 3 iterations of the SCAT, as well as its major components (the SAC and mBESS); 2) present aggregate normative data for the major components of the SCAT broken down by age and sex; and 3) identify areas for improvement for the next iteration of the SCAT.

Methods

Literature Search

Titles and abstracts in the English language published between 1995 and October 2015 were searched systematically across the electronic databases PubMed, PsychInfo, The Cumulative Index to Nursing and Allied Health Literature (CINAHL), and Embase. To complete the search, the reference lists from review articles were assessed for pertinent studies that may have been overlooked. Key words and search terms included brain concussion, mild traumatic brain injury, Sideline Concussion Assessment Tool, standardized assessment of concussion, concussion resolution index, balance error scoring system, and neurocognitive or neuropsychological testing. In addition, variations and acronyms of these terms (i.e., BESS, SCAT, SAC, mTBI) were included in search syntax. An example of the search syntax is available in Fig. 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[38] were adapted to review a heterogeneous collection of literature.

Inclusion and Exclusion Criteria

A priori inclusion criteria were: 1) peer-reviewed journal articles published after 1995; 2) individuals greater than 13 years of age; 3) outcomes (primary or otherwise) reported included a quantitative analysis of the SCAT, SCAT2, SCAT3, or a major objective component of these assessments (defined as the SAC or mBESS); and 4) the data reported were obtained at baseline or postconcussion.

However, part of our a priori inclusion criteria was modified. For the purpose of this review, we allowed for the inclusion of athletes younger than age 13 years (e.g., studies with an age range of 5–23 years). These studies were considered important as a large number of athletes included were older than 13 years of age. We did not include studies in which the athletes were all younger than 13 as the Child-SCAT3 has since been created for this age group.

Six exclusionary criteria were applied: 1) the investigation did not perform any testing with a version of the SCAT, SAC, or mBESS (e.g., only computerized or traditional paper and pencil neuropsychological testing, EYE-TRAC Advance, King-Devick, or simple reaction time task); 2) only the BESS was assessed and reported alone, because the mBESS is used in the SCAT (3-stance firm surface only), rather than the full BESS, which utilizes foam and firm surface stances; 3) solitary assessment of the PCSS or other similar symptom scales were excluded due to heterogeneous content and rating formats, and concussion symptom scales were reviewed thoroughly elsewhere;[1] 4) nonathlete (e.g., motor vehicle accident–related concussion, healthy adults) and mixed (athlete plus nonathlete) populations were excluded to ensure a focus on sport-related concussion; 5) the type of publication was a conference abstract (without full data set), review article, editorial, or letter to the editor; and finally 6) we excluded the GCS component of the SCAT due to its overwhelming evidence in the traumatic brain injury (TBI) population and paucity in athletic populations.

Data Extraction

Following compilation of online search results, record titles and abstracts were screened by one of the authors (A.T.H.) with oversight by the first author (A.M.Y.K.).
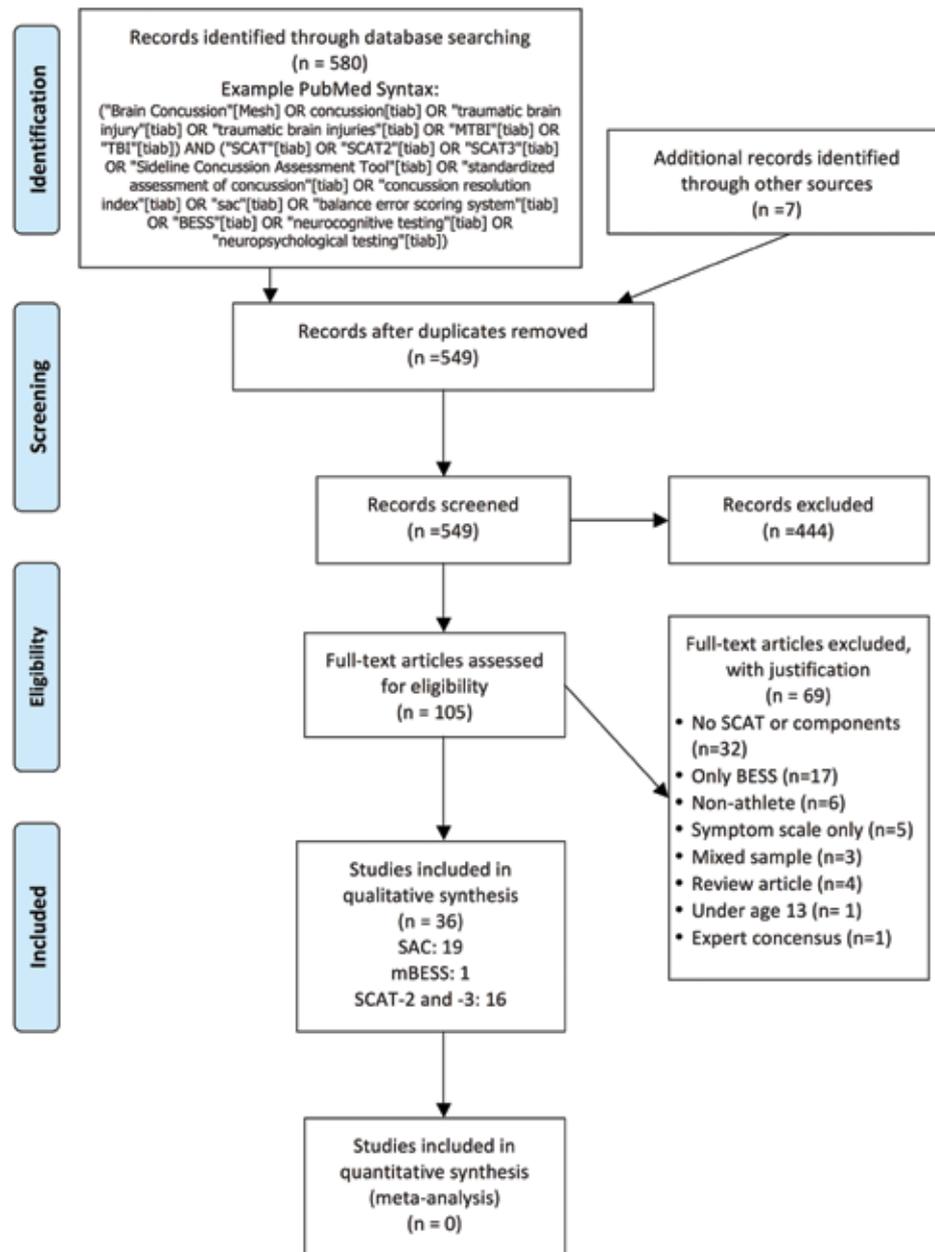
FIG. 1. Flow chart of the systematic review process.

Those articles determined to have potential to meet inclusion and exclusion criteria were passed through to full-text review by 4 authors (A.T.H., B.H.Z., S.L.Z., and A.M.Y.K.). The first author (A.M.Y.K.) reviewed all included and excluded studies for an added level of verification. Disagreements on the inclusion of a study were settled by joint discussion among senior authors (A.M.Y.K., S.L.Z., A.K.S., and G.S.S.). Fig. 1 illustrates the literature review process. Following full-text review, the authors extracted data into evidence tables, which were used for the synthesis within the results section.

Results

Of the 36 included articles, the majority were cohort studies (n = 22), of which 20 were prospective and 2 were retrospective. Twelve cross-sectional studies and 2 case series were reviewed. Eighteen articles examined athletes exclusively at baseline, 1 examined athletes following concussion, and 17 reported both baseline and postconcussion data. All studies meeting criteria for review are listed in Table 1.

Standardized Assessment of Concussion
General Results

Nineteen studies were found that met inclusion criteria and were associated with the SAC alone or discussed the SAC and other tests unrelated to the SCAT. Participant athletes were assessed primarily at baseline (n = 9086) with fewer having been assessed after concussion (n =

TABLE 1. All studies meeting criteria for inclusion

Authors & Year	Study Design	Level of Evidence*	Test
Galetta et al., 2015	Prospective	1b	SAC
Wang et al., 2015	Prospective	1b	SAC
Galetta et al., 2013	Cross-sectional	4	SAC
McCrea et al., 2013	Prospective	1b	SAC
Zimmer et al., 2013	Cross-sectional	4	SAC
Gysland et al., 2012	Prospective	1b	SAC
Sabin et al., 2011	Retrospective	2b	SAC
Hunt & Ferrara, 2009	Cross-sectional	4	SAC
Miller et al., 2007	Case series	4	SAC
Valovich McLeod et al., 2006	Prospective	1b	SAC
Valovich McLeod et al., 2004	Prospective	1b	SAC
McCrea et al., 2003	Prospective	1b	SAC
Valovich et al., 2003	Prospective	1b	SAC
Daniel et al., 2002	Prospective	1b	SAC
McCrea et al., 2002	Prospective	1b	SAC
Barr & McCrea, 2001	Prospective	1b	SAC
McCrea, 2001	Prospective	1b	SAC
McCrea et al., 1998	Case series	4	SAC
McCrea et al., 1997	Prospective	1b	SAC
King et al., 2014[24]	Cross-sectional	4	mBESS
Schneider et al., 2010	Cross-sectional	4	SCAT
Shehata et al., 2009	Cross-sectional	4	SCAT
Baker et al., 2015	Retrospective	2b	SCAT2
Glaviano et al., 2015	Cross-sectional	4	SCAT2
Putukian et al., 2015	Prospective	1b	SCAT2
Snyder & Bauer, 2014	Cross-sectional	4	SCAT2
Zimmer et al., 2015	Cross-sectional	4	SCAT2
King et al., 2013	Prospective	1b	SCAT2
Weber et al., 2013	Prospective	1b	SCAT2
Echlin et al., 2012	Prospective	1b	SCAT2
Jinguji et al., 2012	Cross-sectional	4	SCAT2
Valovich McLeod et al., 2012	Cross-sectional	4	SCAT2
Echlin et al., 2010[10]	Prospective	1b	SCAT2
Hanninen et al., 2015	Cross-sectional	4	SCAT3
King et al., 2015	Prospective	1b	SCAT3
Vernau et al., 2015	Prospective	1b	SCAT3

* Using the Oxford Center for Evidence-Based Medicine Levels of Evidence (http://www.cebm.net/ocebm-levels-of-evidence/).

943). The vast majority of athletes studied were male (Fig. 2B). Of the 19 athlete studies, 12 were conducted with football players, and the remaining populations described were composed of athletes from multiple sports including hockey, rugby, soccer, and volleyball (Fig. 2A). Summary information for studies utilizing the SAC can be found in Table 2.

Effect of Age

The effects of age on the SAC have been reported in the literature.[11,18,33] In one of the initial studies of the SAC, McCrea et al.[33] found no age effect on SAC scores between male high school and college football players. Similarly, Hunt and Ferrara[18] found that SAC scores in 198 male high school football players did not significantly increase from 9th to 12th grade. Most recently, however, Galetta et al. found that increasing age was associated with significantly increased SAC scores ($p < 0.001$, linear regression model) for a group of 332 athletes from various sports. Notably, the cohort ranged in age from 5 to 23 years.[11]

Effect of Sex

Various authors have commented on the potential association of sex and SAC score.[19,50,51,57,58] As a number of the early studies utilizing the SAC in an athlete population were conducted on exclusively male football teams,[29,31–33] sex differences were first reported in 2006 during a psychometric evaluation of the SAC. Valovich McLeod et al. demonstrated that in a multisport athletic population aged 9–14, males performed significantly worse on the SAC than females (26.22 vs 27.50; $p = 0.035$).[51] Similar findings were reported in a 2012 publication of SCAT2 normative data by Valovich McLeod et al.,[50] who found males performed worse than females (26.4 vs 26.9; $p = 0.004$) on the SAC in a high school–aged, multisport cohort (mean age approximately 15 years). In a similar study, Jinguji et al.[19] found comparable sex associations and further attributed them to particular subtests of the SAC. Specifically, females in all age groups (13–19 years old) performed significantly better on SAC components assessing concentration ($p = 0.01$). Additionally, females outperformed males within the same age group (13–15 or 16–19 years old) on the immediate memory component ($p = 0.02–0.04$).

Despite these early reports, more recent studies with athletes have been inconsistent in demonstrating a relationship between sex and SAC scores. Zimmer et al.,[58] in a study of SAC scores across various collegiate sport teams, reported no sex differences on the SAC. Yet, in a second study of college athletes by Zimmer et al.,[57] females performed significantly better (27.63 vs 26.97; $p = 0.004$) than males.

Detecting Concussion

The use of the SAC to detect SRC began in the 1990s with a series of studies of high school and college football players. From 1997 to 2003, there were 8 peer-reviewed articles examining SAC performance in football players after a concussion with comparisons to individual baseline or control players.[3,6,28,29,31–33] All of these studies demonstrated a significantly decreased total SAC score when compared with individual baseline or uninjured controls. The largest sample of concussed collegiate athletes (n = 94) was presented by McCrea et al.[29] in 2003. Immediately after injury, all football players scored an average of 2.94 points below baseline (95% CI −4.39 to −1.50). In most of these similar studies, players were reevaluated with the SAC at 48 hours postinjury and were found to have SAC scores that were not significantly different from baseline.[28,29,33]

The sensitivity and specificity of the SAC has been reported sparsely. Barr and McCrea reported that a 1-point drop on the SAC was 94% sensitive and 76% specific for
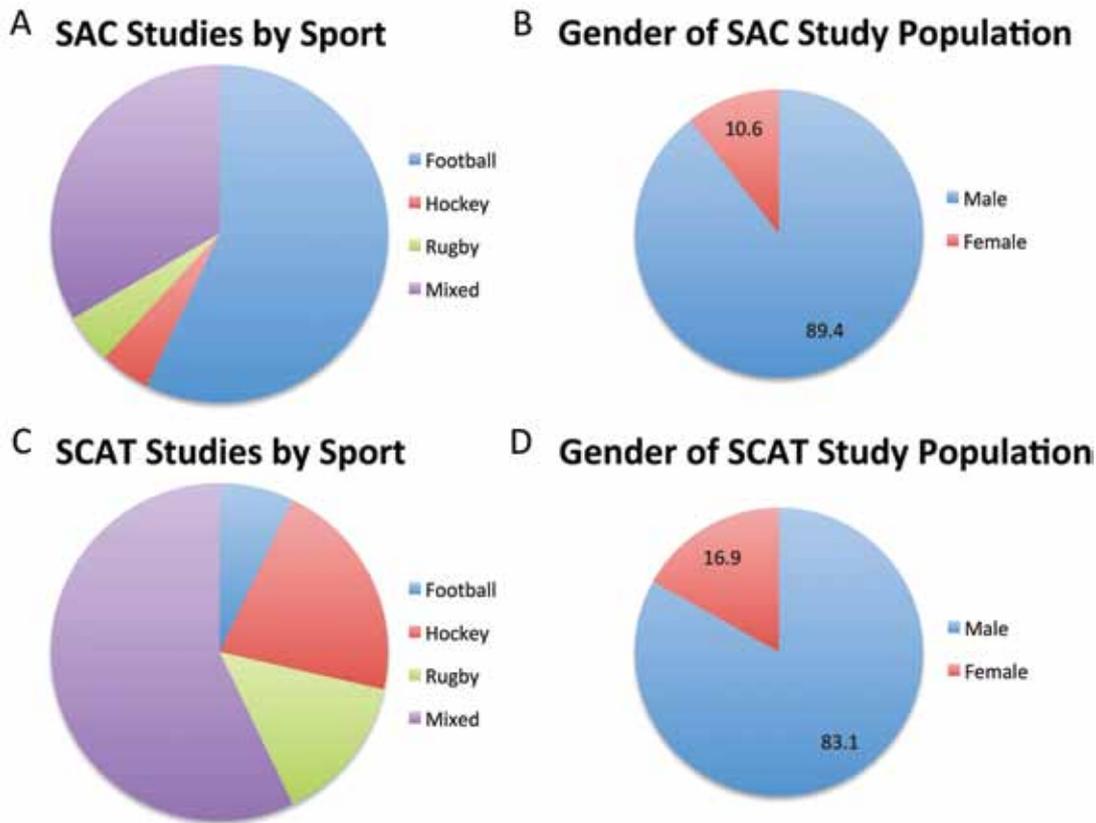
FIG. 2. Graphic representation of themes in study population demographics for the SAC **(A and B)** and SCAT **(C and D)**.

concussion in a mixed sample of high school and collegiate football players.[3] The authors also presented receiver operating characteristic (ROC) curves and found the area under the curve (AUC) to range from 0.911 ± 0.028 (SEM) to 0.939 ± 0.021 (SEM) depending on whether a regression analysis or a 90% reliable change index, respectively, was used.[3] Similarly, McCrea reported a single point drop on the SAC to be 95% sensitive and 76% specific for diagnosing sideline SRC immediately after a head impact in a mixed high school and collegiate sample.[28] However, in a more recent study of an age-diverse population (age 5–23), the ROC curve constructed based on baseline and postinjury SAC scores of 12 concussed athletes was found to have an AUC of 0.68, utilizing a logistic regression model accounting for age, markedly lower than the previous study.[11]

Only more recently has the SAC been evaluated outside of the realm of football, in other sport and nonathlete populations. In a recent study of 32 rugby players (27 male), Putukian et al. found no difference between postinjury and baseline SAC scores when tested 0.52 ± 1.18 (SD) days after concussion (p > 0.1).[41]

Recently, authors have used the SAC in conjunction with more complex methods of concussion detection. Wang and coauthors[54] compared 18 concussed football players to 19 controls and tested them with the SAC and MRI to detect cerebral blood flow at baseline and multiple time points following SRC. Their data demonstrated that decreased cerebral blood flow may persist following symptom resolution and normalization of the SAC score.

Modified Balance Error Scoring System
General Results

Only 1 study was found that met all inclusion criteria and was associated solely with the mBESS in a sports population (or discussed the mBESS and other tests that do not comprise the SCAT). Typically, however, the mBESS is discussed within the context of the SCAT2 or SCAT3. The following results contain data from studies reported in Tables 2 and 3.

Effect of Age

Age appeared to have a variable association with mBESS scores. In Snyder and Bauer's cohort of 761 student athletes aged 9–18, athletes in the younger age group (age 9–10) incurred more errors on the mBESS than those athletes in either the 15–16 or 17–18 age group.[47] Furthermore, in a separate study of high school athletes, mBESS scores improved by grade from 9th to 12th, with 10th, 11th, and 12th graders performing significantly better than 9th graders (p = 0.002).[50]

Effect of Sex

Sex differences on the mBESS in athletes at baseline have also been described. Snyder and Bauer also found no sex difference on the mBESS in their youth and high school athlete sample.[47] In contrast, 3 studies suggested that females perform better than males on the mBESS. Valovich McLead and coauthors found that high school female athletes outscored high school male athletes (27.3 vs 26.6;

TABLE 2. Summaries for included studies of major SCAT2 and SCAT3 components

Authors & Year	Study Type	Study Question/Purpose	No. Baseline/Concussed	% Male	Sport	Age (yrs)*	Relevant Conclusion
SAC							
Galetta et al., 2015	Prospective	Would adding a vision-based test of rapid number naming increase identification of concussed athletes on the sideline at youth & collegiate levels	332/12	81.3	Multiple	5–23	SAC alone is a poor indicator of concussions in youth populations
Wang et al., 2015	Prospective	How does sports-related concussion affect cerebral blood flow & neurocognitive test scores	19/18	100	Football	17.8 ± 1.5	SAC scores demonstrated significant impairment (vs preseason baseline levels) at 24 hrs but returned to baseline levels at 8 days
Zimmer et al., 2013	Cross-sectional	What are the sport & team differences in baseline performance on the SAC	437/0	62.5	Multiple	17–27	Total SAC scores did not differ across sports or teams
Galetta et al., 2013	Cross-sectional	Is there a relation btwn SAC & KD test scores at baseline	27/0	100	Ice hockey	21–40	Lower scores for SAC Immediate Memory & SAC overall score were associated w/ worse times to complete KD at baseline
McCrea et al., 2013	Retrospective	What is the incidence of prolonged symptoms following sport-related concussion	166/570	88.9	Mixed	16.41–17.69	Prolonged recovery group performed poorer than the typical recovery group & control group on the SAC but SAC scores were not predictors of prolonged recovery
Gysland et al., 2012	Prospective	What is the relationship btwn subconcussive impacts & concussion history on clinical measures of neurological function	46/0	100	Football	19.65 ± 1.16	No clinically meaningful changes on SAC were found following repetitive subconcussive head impacts
Sabin et al., 2011	Prospective	What is the relationship btwn reports of non-concussion-induced headache after contact sport participation & scores on common concussion assessment measures	105/0	100	Football	~16.3	SAC was not significantly different btwn the headache & nonheadache group
Hunt & Ferrara, 2009	Cross-sectional	Are there differences btwn high school athletes on neuropsychological tests among grade levels at baseline	198/0	100	Football	13–19	SAC improved as a function of age
Miller et al., 2007	Case series	Does repetitive, subconcussive microtrauma associated w/ participation in a full season of collision sport affect neurocognitive test scores	58/0	100	Football	NR	No differences were found in overall SAC score btwn preseason, midseason, & postseason scores
Valovich McLeod et al., 2006	Prospective	What is the test-retest reliability & reliable change indices of cognitive tests (SAC)	50/0	48	Multiple	9–14	Only a weak relationship btwn performance on the SAC & the selected neuropsychological tests was found; SAC should be used w/ a more complex neuropsychological assessment battery

TABLE 2. Summaries for included studies of major SCAT2 and SCAT3 components

Authors & Year	Study Type	Study Question/Purpose	No. Baseline/ Concussed	% Male	Sport	Age (yrs)*	Relevant Conclusion
SAC (continued)							
Valovich McLeod et al., 2004	Prospective	Would serial administration of SAC elicit a learning effect	49/0	49	NR	9–14	SAC scores remained stable across all trials
McCrea et al., 2003	Prospective	What are the acute effects of concussion & the continuous time course to recovery following concussion	1537/79 (56 controls)	100	Football	18–22	SAC scores were worse immediately after concussion & normalized by postinjury Days 2–3
Valovich et al., 2003	Prospective	Does repeated administration of the SAC demonstrate a practice (learning) effect	32/0	Unknown	Multiple	15–18	No practice effect was found w/ SAC
Daniel et al., 2002	Prospective	Can SAC be used to identify subtle TBIs & monitor clinical improvement	298/21	100	Football	17–24	SAC is a useful tool but is not intended to discern finer cognitive problems or other sequelae of concussions
McCrea et al., 2002	Prospective	What are the neurocognitive effects of mTBI immediately & during recovery	2385/91	100	Football	15–20	There was a significant decrease in SAC scores immediately after injury & a gradual slope of the cognitive recovery curve later after injury
Barr & McCrea, 2001	Prospective	What is the sensitivity & specificity of SAC immediately following sports concussion	1313/50	100	Football	14–22	A 1-point drop on SAC from baseline is 90% sensitive & 76% specific for concussion; SAC is a valid instrument in detecting immediate effects of mTBI
McCrea, 2001	Prospective	What is the efficacy of SAC on the sport sideline to detect abnormalities that result from concussion	1325/63	100	Football	High school 16.26 ± 0.83, college 19.84 ± 1.30	A 1-point decrease on SAC is 95% sensitive & 76% specific; SAC is a valid tool to assist in detecting immediate effects of concussion
McCrea et al., 1998	Case series	What is the clinical utility of SAC in detecting concussions	568/33	100	Football	NR	No significant difference btwn high school & college players' SAC scores
McCrea et al., 1997	Prospective	What is the feasibility & clinical validity of SAC	141/6	100	Football	14–18	Concussed players scored significantly below the nonconcussed controls & below their own baseline performance
mBESS							
King et al., 2014[24]	Prospective	Would alterations to BESS, such as modified conditions (mBESS) &/or instrumentation, improve the ability to correctly classify TBI status in patients w/ mTBI	13/13	100	Mixed	Concussed 16.3 ± 2, control 16.7 ± 2	Instrumented mBESS provides enhanced diagnostic ability

KD = King-Devick; NR = not reported.
* Age presented as range or mean ± SD when range unavailable.

TABLE 3. Summaries of included investigations of the SCAT, SCAT2, and SCAT3

Authors & Year	Study Type	Study Question/Purpose	No. Baseline/Concussed	% Male	Sport	Age (yrs)*	Relevant Conclusion
Baker et al., 2015	Retrospective	Using SCAT2, what were predictors of increased return to school	0/73	77	Mixed	13–19	Worse SCAT2 total score & symptom-related scores are associated w/ difficulty returning to school
Glaviano et al., 2015	Cross-sectional	What are the normative SCAT2 values in this school's athlete population	361/0	54	Mixed	12–18	Age differences in concentration support the use of a separate instrument for children <12 yrs old
Hanninen et al., 2015	Cross-sectional	What are the normative SCAT3 values for hockey players	304/0	100	Ice hockey	16–40	Total scores of SCAT3 components had no statistically significant association w/ age, yrs of education, history, or number of past concussions
King et al., 2015	Prospective	What is the role of KD & SCAT3 in evaluating concussions w/out observable symptoms in rugby players	104/52	100	Amateur rugby	18–28	SCAT3 (& KD) helped identify cognitive impairments in players w/out clinically observable symptoms postmatch
Putukian et al., 2015	Prospective	How useful is the SCAT2 in detecting concussion	263/32	66.9	Mixed	20 ± 1.74	The SCAT2 total composite score & each sub-component are useful in the assessment of concussion; SCAT2 used in full is better than components alone
Vernau et al., 2015	Prospective	Do KD & SCAT2 scores correlate w/ memory in youth hockey players	108/108	100	Ice hockey	6–18	There is no association btwn KD times & SCAT2 memory scores in youth hockey players
Snyder & Bauer, 2014	Cross-sectional	Establish normative data & assess how clinical setting impacts SCAT2 score	761/0	86.2	Mixed	9–18	Younger age associated w/ lower scores on total SCAT2 & across all components; test setting may influence total score
Zimmer et al., 2015	Cross-sectional	What are the normative SCAT2 data in this population of athletes	477/0	62.5	Mixed	18–23	There is no statistically significant association btwn sexes on the total SCAT2
King et al., 2013	Prospective	Can KD be used in addition to SCAT2 for evaluation of concussion	37/22	100	Rugby	22.0 ± 4.0	Findings provide evidence in support of KD as a sideline tool to complement the many other SRC assessment tools
Weber et al., 2013	Prospective	What are the effects of dehydration on performance on sideline concussion tests	32/0	100	Wrestling	20 ± 1.4	In the absence of an obvious deteriorating condition warranting prompt emergency medical care, the authors recommend evaluating athletes w/ a suspected concussion only after they have been properly rehydrated
Echlin et al., 2012	Prospective	Is the SCAT2 a valid & sensitive tool to assist physicians in diagnostic & return-to-play decision making	45/45	100	Ice hockey	18.2 ± 1.2	The power of the study to make definitive conclusions on the validity of neuropsychological paradigms (SCAT2) was limited by small sample size
Jinguji et al., 2012	Cross-sectional	What are representative baseline SCAT2 values in a high school athlete population	214/0	72.4	Mixed	13–19	Females performed better than males overall on SCAT2; there is baseline variability among age groups, sexes, & sports
Valovich McLeod et al., 2012	Cross-sectional	What are representative baseline SCAT2 values in a high school athlete population	1134/0	76.9	Mixed	14–18	Males score lower than females on SCAT2; older athletes perform better on SAC & BESS; athletes w/ a history of concussion score worse on SCAT2

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TABLE 3. Summaries of included investigations of the SCAT, SCAT2, and SCAT3

Authors & Year	Study Type	Study Question/Purpose	No. Baseline/Concussed	% Male	Sport	Age (yrs)*	Relevant Conclusion
Echlin et al., 2010[10]	Prospective	What is the incidence of concussion & recurrent concussion during 1 regular season	67/21	100	Ice hockey	16–21	Singular results of SCAT2 should not be considered independent decision-making tools
Schneider et al., 2010	Cross-sectional	What are representative baseline SCAT2 values in a youth hockey player population	4193/0	92.5	Ice hockey	9–17	There was a tendency of higher total symptoms reported in individuals w/ previous concussion
Shehata et al., 2009	Cross-sectional	What are baseline SCAT data in this population of athletes	260/0	73.1	Mixed	17–32	Women scored higher in all baseline cognitive tests on the SCAT compared w/ men; previously concussed athletes scored better than non-concussed in all cognitive tests besides delayed recall

* Age presented as range or mean ± SD when range unavailable.

$p < 0.001$) on the mBESS.[50] Jinguji et al. reported a similar relationship of female performance superiority (26.85 vs 25.43; $p = 0.01$) in a separate cohort of high school athletes.[19] Glaviano et al. also found females recorded fewer errors than males (total score 27.2 vs 26.6; $p = 0.0043$) on the mBESS in a group of athletes aged 12–18.[13]

Detecting Concussion

In a group of 32 collegiate athletes, Putukian et al. provided the first evidence that mBESS scores decline from baseline following concussion (26.13 vs 24.54; $p < 0.05$).[41] In an effort to improve concussion detection with the mBESS, King et al.[24] added instrumentation in the form of an inertial sensor (accelerometer and gyroscope). The instrumented mBESS was found to be significantly better at detecting concussion (AUC = 0.81, 95% CI 0.64–0.990) than the noninstrumented mBESS (AUC = 0.64, 95% CI 0.42–0.86).

Sport Concussion Assessment Tool

General Results

Sixteen studies met inclusion/exclusion criteria and were associated with the first, second, or third edition of the SCAT alone or discussed the SCAT (2 or 3) and other tests unrelated to the SCAT. Of these 16 studies, 11 assessed the SCAT2, 3 used the SCAT3, and only 2 assessed the original SCAT. Of the excluded studies, 2 studies had a mixed population of both athletes and nonathletes and 1 study used entirely nonathletes. As with the SAC, the majority of participants were assessed at baseline rather than postconcussion (8360 vs 353, respectively). A large fraction of athletes were studied at baseline in an attempt to establish normative data. Two studies have been conducted to establish SCAT[45,46] normative data, 5 for the SCAT2,[13,19,47,50,58] but only 1 for the SCAT3.[16] These studies have reported on variations of the SCAT across ages, sex, and with concussion history. The majority of these studies used mixed sports populations (Fig. 2C), and the athletes studied were > 85% male (Fig. 2D).

Effect of Age

Despite a wide age range (17–32 years of age), the first normative study of the original SCAT, by Shehata et al., did not include an analysis of variation of the SCAT by age.[46] In the largest study to provide normative SCAT data, Schneider et al.[45] administered a baseline SCAT to over 4000 youth hockey players. Although the authors did not report the effect of age on SCAT scores quantitatively, they did report that a greater percentage of older female hockey players (age 15–17) reported higher total symptoms at baseline compared with the younger female players (age 9–10).

The association between the SCAT2 and age was first described by both Jinguji et al.[19] and Valovich McLeod et al.[50] in their publications of normative SCAT2 data. Jinguji et al. divided their group of high school athletes into 2 age cohorts (13–15 and 16–19). The authors found a trend toward the younger age group reporting fewer symptoms (19.14 vs 20.32; $p = 0.06$) and performing better than the older group on the delayed recall portion of the SCAT2.

Additionally, the younger group recorded a higher total SCAT2 score (89.37 vs 88.66; p value not reported), but none of these findings reached statistical significance.[19] Valovich McLeod et al. reported normative data from a large cohort of 1134 high school athletes from various sports. The total SCAT2 score was found to increase each grade from 9th to 12th with both the 11th and 12th graders scoring significantly better than 9th graders (88.7 vs 89.0 vs 86.9, respectively; p = 0.001). Secondary analysis of component scores found this difference was likely related to significantly better SAC (p < 0.001) and mBESS (p = 0.002) scores for 10th, 11th, and 12th graders compared with 9th graders.[50]

Following these initial normative data publications, Snyder and Bauer published SCAT2 normative data of 761 athletes with a wider age range of 9–18 years. A significant positive, linear association between age and total SCAT2 scores was found (p < 0.001).[47] These differences were attributed specifically to the balance and cognitive components in which younger athletes (ages 9–10) performed significantly worse than older athletes (aged 17–18). However, when the authors controlled for test setting and sex, only total SCAT2 score and the balance component were significantly associated with age, with younger athletes performing worse.[47] In contrast, Glaviano et al. gave the baseline SCAT2 to 361 middle and high school athletes and found that although the total SCAT2 score did not vary with age (p = 0.21), specific SCAT2 component scores appeared age dependent.[13] Specifically, the authors found that 12-year-olds performed worse on the concentration component compared with 15- and 18-year-olds (3.3 vs 3.9 vs 4.2, respectively; p = 0.01), yet no other statistically significant differences related to age were found.[13]

While the studies mentioned above are almost exclusively in high school athletes, Zimmer et al.[57] reported SCAT2 normative data for collegiate athletes. In a population of 477 college athletes from various sports aged 18–23, an average total SCAT2 score of 91.08 ± 5.60 is reported. Although the authors correctly commented that this score alone was greater than that reported in studies of high school students, Zimmer et al. did not provide analysis of their sample by age.[57] To date, Hanninen et al. is the only group to publish normative data for the SCAT3. In their population of 304, mostly Finnish, professional hockey players aged 16 to 40 years old, there was no association of any portion of the SCAT3 with age.[16]

Effect of Sex

The potential for sex effects on each iteration of the SCAT has been well described. For the original SCAT, both Shehata et al.[46] and Schneider et al.[45] found extensive differences between males and females. In a group of 260 collegiate ice hockey, football, and wrestling athletes (age 17–32), Shehata et al.[46] reported a higher symptom score at baseline (6.39 vs 3.52; p value not reported), but a better performance on all baseline cognitive tests for females compared with males. However, no statistical comparative analysis was performed to determine significance.[46] Similarly, Schneider et al. found that sex differences on symptom reporting varied with age group, in which about the same percentage of older females (64.3%, age 13–14)

reported symptoms as the oldest males (64.5%, age 13–14), but younger males (age 11–12) reported more symptoms than same-aged females. Additionally, the authors found that a relatively young group of females (age 11–12) were able to all complete the months-in-reverse task, while only 50% of males up to age 14 could complete it, a result the authors suggested as a sex difference. Again, it is important to point out that no quantitative analysis was conducted to assess for statistical significance.[45]

Sex differences were also a centerpiece of both Valovich McLeod et al.'s and Jinguji et al.'s SCAT2 normative data publications in 2012. Jinguji et al. found that male high school athletes reported slightly fewer symptoms (19.79 vs 19.64; p = 0.38, higher score represented fewer symptoms), but performed significantly worse than females on the SCAT2 overall (88.39 vs 90.81; p < 0.01).[19] This result was reinforced by Valovich McLeod et al. in a large sample of 1134 athletes, with results indicating that high school males performed significantly worse than females on the SCAT2 overall (87.7 vs 88.7; p = 0.03).[50]

Conversely, 3 subsequent studies reported no statistically significant difference in total SCAT2 scores between males and females. Snyder et al. reported no sex difference on the total SCAT2 score (or SAC or mBESS), but did find that females reported significantly more symptoms (and with great severity) at baseline than males across a wide age range (9–18 years old).[47] Similarly, Glaviano et al. found no sex difference in high school athletes on the total SCAT2 score (p = 0.463), but females reported more symptoms (p = 0.007).[13] Finally, Zimmer et al. found no significant main effect of sex on total SCAT2 score or symptoms in a cohort of college athletes.[57]

Concussion History

There have been numerous publications that have examined normative SCAT data stratified by concussion history; results have varied widely. When Shehata et al.[46] investigated the association of previous concussion history and the original SCAT, previously concussed individuals appeared to perform better on all cognitive testing with the exception of the delayed recall component. For example, 61% of previously concussed athletes were able to score 6 digits on the digits-reverse test while only 46% of never concussed athletes were able to equal this level of performance. Similarly, Schneider et al.[45] reported that among 11–12 year olds, 100% of previously concussed athletes were able to complete the months-in-reverse task while only 40.5% of never concussed athletes achieved this. The authors also reported a tendency for previously concussed athletes to report more symptoms with headaches being the most common.

In high school athletes, Valovich McLeod et al.[50] found that previously concussed athletes performed worse on the SCAT2 overall (87.0 vs 88.7; p < 0.001). This difference may be attributable to previously concussed athletes reporting a large total symptom burden (p < 0.001). These differences noted at the high school level do not appear to transfer to the college or professional level as both Zimmer et al.[57] and Hanninen et al.[16] reported no effect of concussion history on SCAT2 performance.

Detecting Concussion

In contrast to the SAC, few studies have assessed the full SCAT and its iterations to determine sensitivity or specificity for detecting concussion on the sideline. Putukian et al.[41] calculated the sensitivity and specificity of the SCAT2 utilizing a prospective cohort study design with 263 collegiate athletes, 32 of whom suffered concussions. A 3.5-point drop from baseline was found to be 96% sensitive and 81% specific (AUC = 0.93) to detect concussion, while using a cutoff score of 74.5 proved to be 83% sensitive and 93% specific (AUC = 0.91). Conversely, in a small study of 11 concussed collegiate ice hockey players, the total SCAT2 score was no different from baseline following concussion.[8] Similarly, in another small study of 10 concussed athletes, the postinjury SCAT3 memory score did not differ significantly from baseline.[53]

Predicting Outcomes with SCAT Sideline Assessment

Several authors have ventured to correlate sideline test scores and eventual outcomes following concussion. Putukian et al.[41] found that in collegiate athletes, a lower total SCAT2 score at the time of injury was correlated with more days to becoming symptom free ($p < 0.05$) and more days until returning to graduated activity ($p < 0.05$). In addition, a greater number of total symptoms was correlated with more days until becoming symptom free ($p < 0.01$) and returning to restricted activity ($p < 0.01$) as well as returning to play ($p < 0.05$). Notably, neither the SAC nor mBESS was significantly predictive of any of these outcomes,[44] which is similar to the findings of McCrea and coauthors.[30] The group aimed to identify predictors of athletes who recover at greater than 7 days and found that in 570 athletes with concussion, 57 (10%) of which had recovery outside of 1 week, the SAC or BESS did not predict a longer recovery, although a graded symptom scale did.

Baker et al.[2] sought to elucidate predictors of difficulty returning to school in 91 student athletes aged 13–19 years old. Student athletes who struggled upon returning to school had significantly worse SCAT2 total scores than athletes who had no difficulty ($p < 0.003$). Athletes who returned to school with difficulty also had significantly more symptoms with significantly worse severity than those who returned to school smoothly. There is no reported literature to date on the ability of the SCAT to specifically predict progression through the graduated return-to-play or learn protocols.

Additional Baseline Testing Considerations

Weber et al.[55] studied the effects of dehydration on SCAT2 performance in 32 collegiate wrestlers. Their total SCAT2 score declined significantly from baseline to postpractice (93.06 vs 87.94; $p < 0.05$) and notably the number of errors recorded on the mBESS increased from 15.72 to 18.81 ($p < 0.05$). Because the athletes' urine specific gravity increased from baseline to postpractice, the authors concluded that euhydration should be a goal prior to performance of sideline concussion tests.

Putukian et al.[41] assessed whether anxiety or depression was associated with differences on the SCAT2. Both depressed and anxious patients were found to display worse total SCAT2 scores ($p < 0.001$). However, these differences appeared to be attributable to significantly more symptom reporting by these groups related to their psychiatric diagnoses, given the authors did not find that either diagnosis was related to cognitive (SAC) or balance (mBESS) components.

Discussion

We performed a systematic review of the literature pertaining to the SCAT and its major components (SAC and mBESS). After application of inclusion and exclusion criteria, 36 articles were reviewed in detail. Given the majority of data reported baseline or normative data, we focused on differences associated with age, sex, and concussion history, in addition to the ability to detect a concussion.

Effect of Age

Across the studies that analyzed baseline assessment results by age, the literature appears somewhat inconclusive. However, close examination finds that the studies reporting age differences on both the SCAT2[47] and SAC[11] alone used large age ranges (e.g., 5–23 or 9–18 years old). In studies with more focused age ranges such as a pure high school (13–18 years old)[18] or college[57] population (18–23 years old), or comparing the two,[33] there are few reported differences. This discrepancy suggests that age differences are mainly related to differences between the youngest athletes (age < 12) and oldest athletes (age 15–18 or 18–23), which was confirmed for the SCAT2 by Snyder et al. utilizing post hoc analysis.[47] Given that the Child-SCAT3 is now available for children age < 13 years old, we recommend ensuring the use of this modified version rather than the adolescent/adult SCAT3.

That said, one of the large studies assessing the SCAT2 normative data in high school athletes found significant age differences.[50] The difference was between 9th graders and each of 10th, 11th, and 12th graders on both the total SCAT2 and mBESS; however, differences between the oldest 3 grades did not exist. This may suggest an exposure or practice effect, in that 9th graders are likely being tested with the SCAT2 for the first time, while student athletes in older grades have probably been exposed to the test previously. The study in question did not clarify any possible effect of previous testing. In an effort to obtain accurate age information, we caution future normative studies to recognize this limitation and clarify the testing status of young athletes enrolled in the study, as well as whether alternate forms of the SAC are being used across time intervals.

Effect of Sex

The association of sex and sideline assessment scoring appeared to depend on whether the components are used alone or if one examines the total SCAT2 composite score. While the evidence appears convincing that males perform slightly worse than females on the SAC[19,50,51,57] and mBESS,[13,19,50] it is important to note that these differences do not reliably translate to sex differences on the aggregate SCAT2.[13,47,57] However, drawing firm conclusions on any sideline assessment score association with sex is difficult given the gross overrepresentation of male athletes across

all studies (89.4% SAC, 83.1% SCAT2 and SCAT3). Future studies should continue to report sideline assessment normative data stratified by sex and ideally by sport, and preinjury baseline testing of athletes is preferable.

Concussion History

The current literature was inconclusive regarding whether prior concussion history is associated with differences on baseline sideline concussion assessments. The results ranged from athletes with previous concussions performing worse on the SCAT2 overall,[50] to no difference,[16,57] to paradoxically performing better on all cognitive testing.[45,46] The observation that a larger percentage of previously concussed than never concussed athletes were able to successfully perform the more difficult components of the original SCAT suggests the possibility of an exposure effect, in that athletes who suffered previous concussions were exposed to the SCAT.[45,46] Also, given the exposure effect, it is possible that a test ceiling effect also exists, as is the case with brief cognitive screening examinations. Further research is needed to understand the significance of prior concussion on sideline assessment, as well as to clarify whether separate normative data are needed.

Detecting Concussion

Based on this review, there are important limitations inherent in applying the literature utilizing the SAC to a given concussed athlete. A 1-point decline on the SAC has been reported to be 95% sensitive and 76% specific for detecting concussion.[3,28] However, it is notable that these articles used a population of male high school and college football players exclusively.[3,28] While the specific study population is a strength in applying results to male football players, the generalizability to other sports may be limited. This has been demonstrated as the SAC has been shown to be less efficacious in detecting concussion in a mixed sex and sports sample (mixed sports, AUC = 0.68, vs football, AUC > 0.9).[3,11] Given that only a single prospective investigation of the sensitivity and specificity of the SCAT2[41] (in rugby only) is available and none is available for the SCAT3, this is an area in need of further prospective studies of large, mixed sport and sex cohorts. Finally, it should be emphasized that the reliability and ultimate utility of the SCAT (and its quantitative component parts) are based on valid test results, which require good faith effort on the part of the athlete taking the test at any time point. If an athlete were to give a minimal effort at baseline and a full effort following concussion, the result may be an undetected concussion. While some studies have addressed "sandbagging," or purposeful suboptimal performance on computerized baseline neurocognitive testing,[48] no study to date has addressed this matter with the SCAT.

Review Limitations

One goal of the present review was to aggregate normative data in an attempt to have age- and sex-specific norms compiled from a sport-, geographic-, and setting-diverse population. However, we found this to be difficult due to a wide variation in reporting of age ranges (e.g., 13–15 vs 14–16 vs 13–18), which could not be reliably aggregated. Additionally, the literature reviewed was rarely stratified by age and sex simultaneously, which effectively means utilizing the same norms for both sexes in a given age group. This is problematic given the findings presented above regarding sex differences. Finally, we focused this review solely on the athlete population, which means important literature may not have been assessed due to the exclusion of nonathletes, such as military personnel.

Conclusions and Future Directions

The SCAT and all its iterations have provided the groundwork for major improvements in the acute diagnosis of a concussion. Between all 3 iterations, athletes at all levels are being tested with the SCAT. Although we could not calculate aggregate normative data, one reason may be due to a significant strength of the SCAT, the constant evolution of the test to be more comprehensive and complete.

Looking toward the fifth Concussion in Sport Group meeting in Berlin in 2016, one may expect further revision to the SCAT3. However, based on this systematic review, we believe that further study of this concussion-screening tool is warranted. Based on our review, areas recommended for further investigation include: 1) the ability of the SCAT (as an instrument) and its individual components to detect acute concussion on the sideline (with and without baseline test availability); 2) the utility of the SCAT and its components as serial assessments to monitor recovery, including investigations aimed at assessing the SCAT as a tool for predicting progression through return-to-play protocols; 3) the effects of repeated exposure to the SCAT, including the use of alternate forms of its components, as well as possible ceiling effects on component and total scores; and 4) the effects of age, sex, sport, and concussion history on total SCAT and individual component scores.

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Disclosures

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