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1 **Article category:**

2 Original research article

3

4 **Sub-discipline:**

5 Sports Medicine (Injury screening)

6

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8 There was no specific funding for the research study, though the research was supported by
9 World Rugby, which employs some of the author group, as described in Competing Interests

10 **Competing interests:**

11 Three of the authors (RT, EF, MH) are full-time and part-time employed by World Rugby in
12 roles of research and medicine. JP and GF have served as independent advisors on a
13 working group on concussion administered by World Rugby, for which expenses are
14 covered.

15 **Ethics approval and consent to participate**

16 The research plan for this study was approved by the World Rugby Institutional Ethics
17 committee (REF 19007). Players had provided written informed consent for all data
18 gathered as part of the World Rugby Concussion management programme to be used for
19 research in a de-identified manner

20 **Availability of data and material**

21 Original participant data belongs to the players and the clubs/unions that generate such
22 data. This may be provided upon request to third parties. World Rugby (the corresponding
23 author) may facilitate the provision of that data, in terms of permissions and contacts,
24 though there is not a single point of contact, since the data are generated globally from
25 multiple teams and Unions.

26 **Author' contributions and declaration**

27 MR conceived the study. MR, RT and EF designed the study. RT and MH performed the
28 analyses. All authors made substantial contributions to the study design, data processing
29 and interpretation. RT drafted the article and all other authors revised it critically for
30 important intellectual content. RT is the guarantor. All authors had full access to all of the
31 data in the study and can take responsibility for the integrity of the data and the accuracy of
32 the data analysis. The manuscript has not been published elsewhere and is not being
33 considered for publication elsewhere.

34 **Sport Concussion Assessment Tool: baseline and clinical reference limits for concussion**
35 **diagnosis and management in elite rugby union**

36

37

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44

45

46

47 **Abstract**

48

49 **Objectives**

50

51 Rugby Union has adapted the Sports Concussion Assessment Tool (SCAT) into an abridged
52 off-field concussion screen and the complete SCAT is used during diagnostic screens
53 performed after head impact events. No firm guidelines exist as to what should be
54 considered “abnormal” and warrant further evaluation. This study evaluates SCAT
55 performances in 13479 baseline SCAT assessments, and proposes clear reference limits for
56 each sub-component of the SCAT5. Baseline reference limits are proposed to guide
57 management of baseline testing by identifying abnormal sub-modes, enhancing the clinical
58 validity of baseline screens, while clinical reference limits are identified to support
59 concussion diagnosis when no baseline is available.

60

61 **Design**

62 Cross sectional census sample

63 **Methods**

64

65 13 479 baseline SCATs from 7 565 elite adult rugby players were evaluated. Baseline
66 reference limits were identified for each sub-mode as the sub-mode result achieved by
67 approximately 5% of the population, while clinical references limits corresponded to the
68 sub-mode score achieved by as close as possible to 50% of the cohort.

69

70 **Results**

71

72 Players reported symptoms 35% (95% CI 1.29 – 1.42) more frequently during SCAT5 than
73 SCAT3 baseline assessments (mean 1.4 ± 2.7 vs 1.0 ± 2.4). Ceiling effects were identified for
74 many cognitive sub-tests within the SCAT. Baseline and Clinical reference limits
75 corresponding to the worst performing 5th percentile and 50th percentile were described.

76

77 **Conclusion**

78

79 Targeted baseline re-testing should be repeated when abnormal sub-modes are identified
80 according to proposed baseline reference limits, while a more conservative clinical
81 reference limit supports concussion diagnosis during screens in diagnostic settings.

82

83 **Keywords:**

84 Concussion, SCAT, Rugby Union, neurological screening, concussion management, injury

85

86 **Practical implications**

87

- 88 • SCAT5 screening should remain part of the overall management of sports related
- 89 concussion
- 90 • The clinical utility of baseline screening can be enhanced if clinicians view such
- 91 screening as a means to identify abnormalities as part of annual medical screening
- 92 • Clinicians who undertake regular baseline screening should use pre-identified
- 93 reference limits to identify abnormal tests that warrant further investigation, either
- 94 repeating tests or investigating contributing factors described here
- 95 • In the clinical setting, the application of clinical reference limits that correspond to
- 96 sub-test scores achieved by half the cohort provide a more conservative method of
- 97 identifying abnormal tests and removing players with suspected concussions
- 98

99

100

101 **List of abbreviations**

102 SCAT – Sports Concussion Assessment Tool

103 HIA - Head Injury Assessment

104

105

106 **Introduction**

107

108 The Sports Concussion Assessment Tool (SCAT) was first developed in 2004 using tests from
109 eight existing tools by the Concussion in Sport Group, as a standardised assessment tool for
110 acute concussion ¹.

111 Rugby Union has adapted and implemented the SCAT into an abridged off-field concussion
112 screening tool for the professional game (Head Injury Assessment). The complete SCAT5 is
113 used during diagnostic screens performed within three hours of the head impact event
114 (HIA2 screen) and after two nights' rest (HIA3 screen) ².

115 World Rugby requires mandatory completion of a baseline SCAT in professional players,
116 usually performed in the pre-season, with subsequent diagnostic results evaluated relative
117 to these uninjured baseline results.

118 A number of sporting organisations have abandoned compulsory baseline testing for use in
119 concussion diagnosis, instead using only normative data ³. The time required to complete
120 baseline assessments, the possibility that their use may not improve the sensitivity or
121 specificity of concussion diagnosis, and the difficulty of confirming player effort during
122 baseline testing ^{1,4,5}, are practical and theoretical considerations for those involved in sports
123 concussion diagnosis and management.

124 In the absence of a baseline performance, screen results may be compared to normative
125 data derived from a sport-, sex- and age-matched population ⁶. In research published to
126 date, including in rugby players ^{6,7}, SCAT performances have typically been categorised into
127 ranges as per the Wechsler classification ⁸, but without commitment to clinically relevant
128 cut-offs that indicate when a concussion diagnosis should be made.

129 While diverging views on the merits of baseline testing for SRC exist, baseline testing is a
130 clinically useful annual interaction between players and team doctors, offering ancillary
131 benefits. One must consider, therefore, whether baseline utility can be improved. This
132 might be achieved by enhancing the validity of baseline SCAT tests through content
133 modification, or by changing the baseline SCAT process to improve clinical utility. Unusually
134 poor sub-mode performances may indicate poor effort or an underlying issue at baseline,
135 perhaps triggering repeat testing. This approach is not unique, with computerised cognitive
136 tests also using normative data to trigger repeat testing and ensure engagement ⁴.

137 The primary aim of this study was to analyse SCAT baseline performance in a large (n =
138 13479, from 7565 players) cohort of professional rugby players to identify clear baseline
139 reference limits that indicate abnormal sub-mode performance, and thus require re-testing
140 at baseline. A secondary aim was to apply the baseline cohort data to identify a distinct

141 clinical reference limit to support concussion diagnosis during the HIA1, HIA2 and HIA3
142 phases in the event that baseline data are absent for a player after a head impact during
143 play.

144 We propose a baseline reference limit that corresponds to the sub-test score or
145 performance achieved by the worst-performing 5% of the cohort, while the clinical
146 reference limit is proposed to be the sub-mode score attained by as close as possible to 50%
147 of the cohort.

148 Finally, we apply the baseline limits to propose an approach to abnormal sub-component
149 results that will optimize the baseline SCAT collection process (Appendix A). This is intended
150 to improve player effort and baseline validity by ensuring that results falling outside of
151 expected ranges are subject to scrutiny at baseline, rather than later.

152 **Methods**

153
154 A cross sectional study was performed using data from the World Rugby Head Injury
155 Assessment (HIA) database, which contains baseline and diagnostic concussion screen
156 results from the professional game. In order to use the HIA process, a competition must
157 adhere to mandatory competition player welfare standards [[World Rugby Player Welfare
158 Site](#)] that ensures a standardised approach to concussion detection and management as
159 well as data collection. The source population thus comprises the majority of eligible
160 professional male players in domestic and international competitions, as well as
161 International Women's squads that underwent mandatory baseline SCAT
162 assessment between 2015 and 2019.

163
164 The SCAT assessments were administered prior to commencement of the relevant
165 competition season or tournament, according to methods described previously⁶. A total of
166 14803 baseline screens from 7630 players were present in the database.

167 For the present analysis, we excluded baseline SCATs performed post-exercise, and thus
168 analysed 13479 resting SCAT assessments (5757 SCAT3 and 7722 SCAT5) from 7565
169 players. We recognise that there may be learning effects in players with multiple tests.
170 These potential effects will be evaluated in subsequent research studies. We chose to
171 include all resting baseline tests to maximize the external validity of the study, since the
172 annual requirement to perform these SCATs means that most players will perform multiple
173 SCATs in their careers.

174
175 Descriptive data for each sub-component are presented as means, standard deviations,
176 medians and ranges. Distributions of continuous variables were visualised using density
177 histograms and summarised using mean (M), median (Md), Standard deviation (SD),
178 interquartile range (IQR) and range.

179 The research plan for this study was approved by the World Rugby Institutional Ethics
180 committee (REF 19007). Players had provided written informed consent for all data
181 gathered as part of the World Rugby Concussion management programme to be used for
182 research in a de-identified manner

183 Patients or the public were not involved in the design, or conduct, or reporting, or
184 dissemination plans of the research.

185 Descriptive statistics for each sub-test were presented as Means, Standard Deviation,
186 Medians and Interquartile Ranges (IQR). A baseline reference limit was identified as that
187 score that was achieved by approximately the worst-performing 5% of players in the cohort.
188 That is, the 5th/95th percentile guided the identification of a sub-test result that would
189 achieve as close to 5% abnormal results as possible.

190 A clinical reference limit was identified using a similar method, but at the 50th percentile,
191 rather than the 5th/95th percentile. Classifications were defined based on direction of
192 scoring for abnormality in each sub-test, with higher symptom scores and modified Balance
193 Error Scoring System (mBESS) errors referred to as abnormally high, and lower cognitive test
194 performances referred to as abnormally low.

195 A modification in SCAT5 compared with SCAT3 involved the method of assessing symptoms.
196 In SCAT5, a player is handed the symptom sheet to read aloud, and instructed to 'rate
197 his/her symptoms based on **how he/she TYPICALLY feels**'. These have been termed 'trait'
198 symptoms⁹. During SCAT3, and when the SCAT is applied post-injury, the instruction to
199 players is to identify '**how they feel now**', so-called 'state' symptoms¹⁰. We explored
200 whether this change affected symptom results by calculating proportion ratios, with 95%
201 confidence limits calculated according to the delta method. The proportion ratio was
202 calculated as the proportion of players reporting a symptom during SCAT5, divided by the
203 proportion of players reporting that symptom during SCAT3 assessments. Effect sizes for
204 proportion ratios were judged on the following threshold values: trivial – PR <1.11; small
205 ≥ 1.11 PR <1.43; moderate ≥ 1.43 PR <2.00; large ≥ 2.00 PR <3.30; very large ≥ 3.30 PR <10.00;
206 and extremely large PR ≥ 10.00 ¹¹. Z-scores were produced for each comparison to test
207 against the null hypothesis that no difference would exist in symptom reporting frequency
208 between the two SCAT modalities. Statistical significance was accepted at $P < 0.05$.

209 All Statistical analyses were conducted using SPSS (V.23 for Windows, IBM Corp, Armonk,
210 NY, USA). Statistical significance was accepted at $\alpha < 0.05$.

211

212 **Results**

213

214 The sub-component scales, cases, means, standard deviation, medians, interquartile ranges
215 and 5th/95th percentiles for each SCAT components are shown in the supplementary
216 materials (Table 1 supplementary material).

217

218 65.2% of players were asymptomatic during baseline testing. Five or more symptoms were
219 reported by 9.1% of players, indicative of an “unusually high” number, while
220 the 95th percentile corresponded to seven symptoms.

221

222 The percentage of baseline assessments in which each symptom was reported is shown in
223 Table 1. To support clinical management and insight, symptoms are grouped into categories
224 of Physical, Cognitive, Vestibulo-ocular and Psychological ^{3,12}.

225

226 Table 1 here *

227

228 Fatigue, neck pain, trouble sleeping and nervous/anxious were the most commonly
229 reported symptoms, accounting for 52.0% of all symptoms reported.

230

231 Symptom endorsement was higher during SCAT5 (1.4 ± 2.7) than SCAT3 (1.0 ± 2.4).
232 Players report at least one symptom 35% more frequently during the SCAT5 assessment
233 than the SCAT3 assessment (proportion ratio 1.35, 95% CI 1.29 – 1.42, $P < 0.001$, Figure 1). All
234 individual symptoms were reported more frequently in SCAT5 than SCAT3 (proportion ratios
235 = 1.12 – 1.55), although effects were small to moderate in size.

236

237 Figure 1 here *

238

239 85.2% of players scored perfectly (five out of five) for Orientation questions, while 99.9% of
240 players answered at least three questions correctly (equating to 9,992 per
241 10,000 assessments).

242

243 Date was most frequently answered incorrectly (12.7%) followed by Month, Time and
244 Day (all 0.8%), with Year least frequently incorrect (0.1%).

245

246 Given the change in Immediate Memory assessment from the SCAT3 (a five-word list) to the
247 SCAT5 (a ten-word list was added as an option), Immediate Memory performance was
248 evaluated separately for SCAT3 and SCAT5 assessments (Figure 1, Supplementary material).

249

250 When using the five-word list ($n = 8437$), 65.9% of players scored 15 out of 15 (Median 15,
251 IQR 14 – 15), with only 2.9% of players scoring fewer than twelve (Figure 1, Supplementary
252 material). The ten-word list ($n = 5042$) results were more normally distributed (Mean 21.5,
253 Median 21, IQR 19 to 24, Table 1 supplementary material). The 5th percentile for the 10-
254 word list corresponded to a score of 15 out of 30.

255 -
256 The mean concentration score was 4.1 ± 1.0 (out of a maximum of five), with 44.2% of
257 players scoring perfectly. The 5th percentile corresponded to a score of two out of 5, with
258 91.7% of players achieving a score of three out of five. Months in reverse was correctly
259 answered in 91.7% of baseline assessments.

260
261 Delayed Recall was assessed using either the five- or ten-word list. A similar ceiling effect
262 was observed using the five-word list, with 97.5% of players scoring two or more out of
263 five. Using the ten-word list, the 5th percentile corresponded to a score of four out of ten,
264 with 96.6% of players recording at least four correct answers.

265
266 99.9% of players completed the tandem gait test in under 17 seconds. The 95th percentile
267 corresponded to a time of 13.3 seconds.

268
269 Errors during double leg balance were rare, with 97.4% of players performing the
270 assessment without any errors. An average of 1.9 errors were made during the single leg
271 balance assessment, with 29.9% of players performing without error. The 95th percentile
272 corresponded to six errors.

273
274 Tandem stance errors averaged 0.8, with a 95th percentile at three errors. Collectively, total
275 errors ranged between zero and 22, with a mean of 2.8 and a 95th percentile corresponding
276 to eight errors.

277
278 A schematic summary of the identified baseline and clinical reference limits for each sub-
279 mode in the SCAT5 is shown in Figure 2. The baseline reference limit (top panel) is derived
280 from the 5th and 95th percentiles, and is that score at which as close as possible to 5% of
281 players achieve an abnormally poor result. The clinical reference limit corresponds a sub-
282 mode score as close as possible to the 50th percentile.

283
284 Figure 2 here *

285
286 The baseline and clinical reference limits are further summarized into clinical guidelines in
287 Table 2 of the supplementary material, showing the sub-component result that would
288 warrant further investigation (during baseline) and which would support a diagnosis of
289 concussion (during diagnostic settings such as World Rugby's HIA1 off-field screen and the
290 HIA2 and HIA3 assessments).

291
292 **Discussion**

293
294 This study used a large dataset of baseline SCAT3 and SCAT5 assessments in professional
295 rugby players to identify reference limits for each sub-component in the SCAT assessment.

296 We propose that the baseline reference limits identified here will enhance the clinical utility
297 of the SCAT baseline testing. Any scores outside of the baseline reference limits indicate
298 that re-testing be undertaken and, if abnormalities persist, further clinical evaluation. In
299 addition, during rugby matches when no player baseline is available, the identified
300 clinical reference limits may be used to support concussion diagnosis and to guide return-to-
301 play decisions.

302

303 Given that the baseline reference limit is identified at the sub-mode score as close as
304 possible to the 5th/95th percentile, while the clinical reference limits correspond to scores
305 near the 50th percentile, every sub-mode score requirement during clinical settings is more
306 challenging than during baseline (Figure 2). For example, six or more single leg errors
307 constitutes an abnormal baseline test, whereas an abnormal clinical screen at HIA1, HIA2 or
308 HIA3 occurs at two or more errors (Figure 2 and Table 2 Supplementary material). We
309 recognize that this will produce more abnormal clinical tests than previously, since the
310 thresholds have been reduced compared to historical thresholds. However, since baseline
311 testing is now mandatory, the real impact of this change will be small because normative
312 data should rarely be applied. We also deem it to be more conservative, and thus
313 preferable, because fewer false negatives will occur. Thus, despite the risk of increased
314 cases of false positives, we deem the proposed clinical reference limits to be preferred in
315 cases where no baseline screen is present.

316

317 The baseline reference limits that guide re-testing of abnormal baseline screens are based
318 on the premise that these scores are achieved by the worst-performing 5% of players
319 (Figure 2). We then propose specific guidance to evaluate these results (Appendix A), with
320 advice on repeating any abnormal baseline sub-components, followed by clinical steps that
321 may identify contributing factors and possible confounders for persistent abnormal results.

322

323 The process we outline here will also address concerns such as player effort, effective
324 implementation and data reliability, since repeating tests that are identified using the
325 baseline reference limits will ensure greater concentration and performance. This approach
326 also supports concussion education, allows the physician to obtain a better understanding
327 of individual player's medical profiles and ensures more accurate post-injury diagnosis.
328 Player welfare will also be improved with the recommendation to investigate reported
329 baseline 'trait' symptoms. Each sub-component outcome is described briefly.

330

331 We found that symptom endorsement is greater using SCAT5 than SCAT3 (Figure 1),
332 possibly as a result of different instructions for how symptoms should be collected.

333

334 The distinction between a trait and a state symptom is key to the collection and diagnostic
335 utility of valid and reliable baseline SCAT5 symptoms, which should be recorded only

336 if typically present. After a head impact, only symptoms that are new or altered should
337 indicate a concussive event.

338

339 For this reason, symptom reference limits have not been proposed (Figure 2). In return-to-
340 play and diagnostic settings, clinicians should interpret the presence of new symptoms as
341 indicative of a concussion, while symptoms claimed by the player to be typically present
342 (trait symptoms) should be questioned to identify if these symptoms have changed. A 'trait'
343 symptom that has worsened should be interpreted as indicative of a concussion.

344

345 In the general population, a variety of medical conditions may cause concussion-like
346 symptoms. For example, headaches may be cervicogenic in origin, dizziness may be related
347 to viral infection or cardiac disease, and sleep disorders may relate to underlying depression
348 or anxiety¹². The most commonly endorsed symptom, fatigue (19.6% of SCAT5s, Table 1), is
349 often load-related, but the clinician should also consider illness (e.g. anaemia), and
350 psychologically-related fatigue. These may require investigation using tests such as Profile of
351 Mood States (POMS)¹³, medical work-up and endocrinological review considered if mood is
352 unaffected.

353

354 Neck pain, reported in 16.3% of baseline SCAT5 tests, warrants further investigation due to
355 a possible role in prolonged concussion recovery and persistent post-concussion symptoms
356^{14,15}. Cervical muscles are thought to play a significant role in chronic headaches^{16,17}.

357 Mechanical neck pain is common but other causes such as cervical disc pathology, shoulder
358 pathology and medical conditions require exclusion.

359

360 Trouble falling asleep may be considered as a sign of heavy training load and functional
361 over-reaching¹⁸, possible increased use of ergogenic agents such as caffeine and taurine¹⁹
362 or a potential indicator for undiagnosed mental health issues. Sleep hygiene assessment
363 should be considered because quality and quantity of sleep are recognised components of
364 an athlete's recovery and preparation²⁰.

365

366 Finally, anxiety was reported in 9.7% of SCAT5 tests at rest and may be a potential indicator
367 of a mental health condition. This symptom requires further investigation which may
368 include specific neuro-psychological screen or immediate
369 referral for psychological evaluation.

370

371 We found that the use of the ten-word lists at least partly overcomes ceiling effects^{1,21}
372 during Immediate Memory and Delayed Recall sub-tests (Figure 2, supplementary material).
373 This may improve the clinical performance of these sub-components for concussion
374 diagnosis.

375

376 Clinically abnormal cognitive tests that persist at re-test baseline SCAT indicate further
377 assessments, either via computerised psychometric assessment or formal
378 neuropsychological assessment. In players with a history of previous concussions, post-
379 concussion syndrome should be considered. In all instances medical illnesses need to be
380 considered.

381

382 Numbers of balance errors are higher than previously identified, with a 95th percentile
383 corresponding to six errors for single leg stance, and 4.6% of players making four errors
384 during tandem stance.

385

386 Abnormal balance results that persist on retesting may indicate chronic ankle ligamentous
387 instability, a common complaint in field sport populations ²². Many such athletes regularly
388 strap their ankles, in this case, baseline testing should be repeated under similar conditions.
389 Further lower limb orthopaedic causes should be investigated and if indicated, vestibular-
390 ocular assessment, and a thorough neurological examination is also recommended.

391

392 Among the strengths of this study are its size, among the largest documented number of
393 baseline assessments in athletes, allowing for robust conclusions and normative ranges and
394 reference limits to be created. The method of collection, using the CSx platform, allows
395 immediate data collection with minimal missing data. Study conduct and reporting is
396 consistent with STROBE guidelines for observational studies ²³

397

398 There are some limitations to the present study. The inclusion of multiple tests per player
399 may introduce learning effects, which we acknowledge. However, we chose to include
400 these tests because during the diagnostic screens after head impacts, those same learning
401 effects are present, and thus any normative limits derived from baseline testing should be
402 generated using all tests for external validity. The potential for learning effects will be
403 explored in future research.

404

405 We also cannot account for individual player circumstances and characteristics, including
406 previous concussions and other injuries, and acknowledge that these may affect baseline
407 performances and thus normative ranges. Future research will also explore how head
408 impact events and diagnosed concussions affect subsequent baseline performance. Finally,
409 intra- and inter-observer reliability was not assessed.

410

411 Our recommendation is that individual baseline SCAT be retained as part of the overall
412 management of sports related concussion. We have identified what we propose as
413 reference limits for abnormal sub-test results during baseline and during clinical settings
414 when baseline data are absent. We recommend that the baseline reference limits guide the
415 re-testing of abnormal sub-modes, and possible investigation of persistent abnormal
416 performances. This approach should ensure collection of a more reliable and valid

417 individual baseline SCAT test and allows the clinician to use baseline testing as a screening
418 tool for both concussive and non-concussive related injury.

419

420 Recognising that this new approach will add to the workload of the team medical staff our
421 next analysis will investigate the necessity for annual baseline SCAT by reviewing cases
422 where multiple baseline SCATs are available over time. This analysis will also review the
423 impact of previous concussive events on baseline SCAT modes and identify if exercise and
424 rest influence each SCAT mode. This subsequent analysis will support recommendations
425 regarding the necessity for annual part or full baseline SCAT collection.

426

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429 practitioners for their help in facilitating collection of Sports Concussion Assessment Tool
430 (SCAT) data.

431

432 **References**

433 1. Echemendia RJ, Meeuwisse W, McCrory P, et al. The Sport Concussion Assessment Tool
434 5th Edition (SCAT5): Background and rationale. *Br J Sports Med* 2017;51:848–850.

435 2. Raftery M, Kemp S, Patricios J, et al. It is time to give concussion an operational definition:
436 a 3-step process to diagnose (or rule out) concussion within 48 h of injury: World Rugby
437 guideline. *Br J Sports Med* 2016;50:642–643.

438 3. Harmon KG, Drezner JA, Gammons M, et al. American Medical Society for Sports
439 Medicine position statement: concussion in sport. *Br J Sports Med* 2013;47:15–26.

440 4. Walton SR, Broshek DK, Freeman JR, et al. Valid but Invalid: Suboptimal IMPACT Baseline
441 Performance in University Athletes. *Med Sci Sport Exerc* 2018;50:1377–1384.

442 5. Chin EY, Nelson LD, Barr WB, et al. Reliability and Validity of the Sport Concussion
443 Assessment Tool-3 (SCAT3) in High School and Collegiate Athletes. *Am J Sports Med*
444 2016;44:2276–2285.

445 6. Fuller GW, Govind O, Tucker R, et al. Sport concussion assessment tool-Third edition
446 normative reference values for professional Rugby Union players. *J Sci Med Sport*
447 2018;21:347–351.

448 7. Fuller GW, Raftery M. Sport Concussion Assessment Tool-Fifth Edition Normative
449 Reference Values for Professional Rugby Union Players. *Clin J Sport Med* 2018; Publish Ahead
450 of Print:1.

- 451 8. Hänninen T, Tuominen M, Parkkari J, et al. Sport concussion assessment tool – 3rd edition
452 – normative reference values for professional ice hockey players. *J Sci Med Sport*
453 2016;19:636–641.
- 454 9. Asken BM, Houck ZM, Bauer RM, et al. SCAT5 vs. SCAT3 Symptom Reporting Differences
455 and Convergent Validity in Collegiate Athletes. *Archives of Clinical Neuropsychology*
456 2019;32:963–11.
- 457 10. Asken BM, Houck ZM, Bauer RM, et al. SCAT5 vs. SCAT3 Symptom Reporting Differences
458 and Convergent Validity in Collegiate Athletes. *Archives of Clinical Neuropsychology*
459 2019;32:963–11.
- 460 11. Hopkins W, 2010. Linear models and effect magnitudes for research, clinical and
461 practical applications. *Sportscience* 2010;14:49–48.
- 462 12. Harmon KG, Clugston JR, Dec K, et al. American Medical Society for Sports Medicine
463 position statement on concussion in sport. *Br J Sports Med* 2019;53:213–225.
- 464 13. McNair DM, Lorr M, Droppleman LF. *Profile of Mood States*. 1971.
- 465 14. Ellis MJ, McDonald PJ, Olson A, et al. Cervical Spine Dysfunction Following Pediatric
466 Sports-Related Head Trauma. *J Head Trauma Rehabil* 2019;34:103–110.
- 467 15. Ellis MJ, Leddy J, Willer B. Multi-Disciplinary Management of Athletes with Post-
468 Concussion Syndrome: An Evolving Pathophysiological Approach. *Front Neurol* 2016;7:136.
- 469 16. Lyngberg AC, Rasmussen BK, Jørgensen T, et al. Has the prevalence of migraine and
470 tension-type headache changed over a 12-year period? A Danish population survey. *Eur J*
471 *Epidemiol* 2005;20:243–249.
- 472 17. Madsen BK, Søgaard K, Andersen LL, et al. Efficacy of strength training on tension-type
473 headache: A randomised controlled study. *Cephalalgia* 2018;38:1071–1080.
- 474 18. Leeder J, Glaister M, Pizzoferro K, et al. Sleep duration and quality in elite athletes
475 measured using wristwatch actigraphy. *J Sports Sci* 2012;30:541–545.
- 476 19. Bonnar D, Bartel K, Kakoschke N, et al. Sleep Interventions Designed to Improve Athletic
477 Performance and Recovery: A Systematic Review of Current Approaches. *Sports Med*
478 2018;48:683–703.
- 479 20. Fullagar HHK, Skorski S, Duffield R, et al. Sleep and athletic performance: the effects of
480 sleep loss on exercise performance, and physiological and cognitive responses to exercise.
481 *Sports Med* 2015;45:161–186.
- 482 21. Echemendia RJ, Broglio SP, Davis GA, et al. What tests and measures should be added to
483 the SCAT3 and related tests to improve their reliability, sensitivity and/or specificity in
484 sideline concussion diagnosis? A systematic review. *Br J Sports Med* 2017;51:895–901.
- 485 22. Attenborough AS, Hiller CE, Smith RM, et al. Chronic ankle instability in sporting
486 populations. *Sports Med* 2014;44:1545–1556.

487 23. Elm von E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational
488 Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.
489 In: Vol 12. 2014:1495–1499.

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491 **Figure titles and legends**

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493 *Figure 1: Proportion ratios (x/\div 95% confidence intervals) for symptoms reported in*
494 *SCAT5 relative to symptoms reported in SCAT3 symptoms. Effect sizes and P-values also*
495 *shown.*

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497 *Figure 2: Schematic representation of the identified baseline (top panel) and clinical (bottom*
498 *panel) reference limits for SCAT5 sub-modes. Baseline reference limits are to be applied at*
499 *baseline testing, indicating abnormal sub-modes that require re-testing. Clinical reference*
500 *limits are applied during screens when baseline data are absent in clinical settings, and*
501 *correspond to a sub-mode score nearest the 50th percentile*

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