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Version: Accepted Version

Article:

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Abstract: Objectives: To establish normative reference data for the SCAT3
in professional Rugby Union players.
Design: A cross sectional study in professional Rugby Union players
competing in national and international professional competitions between
2015 and 2016.
Methods: The SCAT3 was administered pre-season or prior to tournaments.
Data was collected electronically using a custom tablet application.
SCAT3 subcomponents distributions were described and normative ranges
determined using percentile cut-offs for average, unusually low/high, and
extremely low/high scores. The association between player characteristics
and performance in SCAT3 subcomponents was also investigated in
exploratory analyses.
Results: A total of 3,611 professional Rugby Union players were included.
The most common baseline symptom was fatigue (14%). The symptom score
median (md) was 0 (interquartile range (IQR) = 0-1). Symptom severity md
was 0 (IQR = 0-1). The md of the SAC score was 28 (IQR = 26-29). The md
of the MBESS was 2 (IQR = 0-4). The Tandem gait md was 11.1 s (IQR =
10.0-12.7 s). Upper limb coordination was normal in 98.4%. Younger age
and lower educational level were associated with worse performance on
delayed recall and reverse month sub-components of the SCAT3 (p<0.0001).
No statistically significant differences in SCAT3 subcomponents were
evident across gender.
Conclusions: Representative normative reference values for the SCAT3
among professional Rugby Union players are provided. Baseline performance
on concentration and delayed recall tests may be lower in younger
athletes or in those with lower educational level.

Cover Letter

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17th July 2017

Dear Dr Waddington,

Thank you very much for the opportunity to respond to the helpful peer review for our research examining baseline SCAT3 values for professional Rugby players. We are pleased that the reviewers' considered the study to be interesting and well conducted. We have edited the manuscript according to the reviewers' minor corrections. Please find detailed responses to each feedback point attached.

Yours Sincerely

Dr Gordon Fuller

SPORT CONCUSSION ASSESSMENT TOOL - THIRD EDITION NORMATIVE REFERENCE VALUES FOR

PROFESSIONAL RUGBY UNION PLAYERS

RESPONSE TO MINOR CORRECTIONS

We would like to thank the reviewers' for their very helpful suggestions to improve the quality of our manuscript. We have made appropriate changes in response to each suggestions as outlined below:

- *Abstract: Methods - p.1, line 9 should read "..cut-offs for average, unusually low/high" rather than "..cut-offs for average, usually low/high".*
  Corrected as suggested.

- *Introduction: p.2, line 6 should perhaps read "…sequelae include game and practice time loss and "possible" increased risk of injury.." and include a reference for such as there is much debate regarding this risk factor.*
  Corrected as suggested. Reference added.

- *Introduction: p.2, line 16 should read "..clinical signs (neck examination); cognitive function…" rather than "cognitive dysfunction"*
  Corrected as suggested.

- *Introduction:* p.2, line 24 .."a better understanding of normal variation and factors influencing different levels of neurocognitive performance." This sentence is a bit clunky and non-specific - suggest re-word to briefly further explain what is meant by "different levels" and outline what some of these factors may be.
  Sentence edited.

- *Methods: p.4, line 14-16 "Classifications were defined based on the direction of the scoring for the SCAT3 component:….are referred to as high; and….are denoted as low" is not entirely clear. I understand it pertains to the reverse scoring on MBESS & symptoms but needs to be stated more clearly.*
  Sentence edited as suggested.

- *Whilst the database is extensive for this cohort study there does not appear to be any exclusion criteria and therefore includes all those with various background factors that may compromise SCAT baseline performance such as history of significant learning difficulties or other neuro history, or previous concussion history. This should be acknowledged as a limitation and this point is outlined further in my discussion of the score ranges in the Results section below.*
  We have added this to the limitations section of the discussion to acknowledge this point.

- *Results: p.5, line 23 "The educational index…ranged from 0.51-0.23" - This measure is outlined in the Methods but the reader unfamiliar with this tool does not know what this translates to in terms of years of schooling or the like - can an equivalence with years of schooling or categories e.g. primary school only, high school, college be made?*
  The equivalent schooling stages have been added as suggested.

- *Results: p.5, line 20. There is an explanation that over the period of recruitment some players had up to 7 repeat assessments for various reasons. This would suggest that some, if not all of the players, had done the SCAT numerous times previously. Although there is brief mention of the potential of practice effects to have contributed to the finding in younger players in the Discussion the lack of control for number of previous SCAT administrations should be outlined as a study limitation.*
  We have further emphasised this as a limitation.

- *Results: p.6, line 1 Table 1. Is there possibly some erroneous data in here? Under the "Ranges" column it seems that some athletes scored 0/5 on the Orientation, concentration and delayed recall components, and some only got 3/15 on the immediate memory component? These are incredibly impaired performances for a healthy adult sample of elite athletes who report very few symptoms & very low symptom severity? Is it the same 1 or 2 athletes with these very poor performances? This needs more investigation.*
  The poor scores were concentrated in a very small number of players (n=2). Unfortunately we are unable to definitively determine whether these were true or erroneous measurements. To highlight this point we have added a sentence to the limitations section of the discussion.

- *Results: p.6, line 4 reads "..distributions of severity and number of individual symptoms are shown in Figure 1". I wondered if it should be "Distributions of severity and % of individual symptoms endorsed are shown in Figure 1"?*
  Thank you – this has been corrected as suggested.

- *In Figure 1 perhaps the X-axis should be labelled "% symptoms endorsed" as it would appear to relate to that rather than severity.*
  This has been changed as suggested to improve clarity.

- *Discussion: p.6, line 9 "…with only 32.4% and 57.9% respectively of players displaying no errors". If this is the case for the single leg stance & tandem gait items in a very fit elite athlete population then there is some discussion warranted in the conclusions regarding the efficacy of this as a marker deemed to be sensitive to concussion.*
  We have added a sentence to the discussion to address this point.

- *p.6, line 17 "the normative classification ranges…are presented in Table 2". There is very little discussion of these findings or the implications in the Discussion.*

Thank you for this point. We have discussed this briefly in the discussion, however unfortunately, due to word count restrictions we are unable to elaborate on this discussion further.

- *p.10, line2 "…baseline complaints were much less frequently endorsed in the Rugby Union sample, but with higher severity to that normally expected in ice hockey players". I am not sure "higher severity" is an accurate interpretation or term to use when the mean severity index was1.61 and the median was 0.0, both of which are so very low - suggest the authors re-frame this sentence.*
  We have edited the this sentence to address the reviewer's concerns.

- *Discussion: p.10, line 14 "Study conduct and reporting is consistent with consensus guidelines for observation studies" - which ones? This should be outlined more formally in the "Methods".*
  STROBE guidelines have been stated and a reference added.

- *Discussion: p.10, lines 15-20. Whilst the authors have generally done a good job of outlining the study limitations, I suggest they include those itemised above and also that this study was undertaken predominantly in professional athletes and they cannot be certain to what extent the findings pertain to those at amateur levels of the game.*
  We have added the helpful and pertinent suggestions about other limitations to the discussion and have added a sentence highlighting the potential for limited generalisability to the amateur level.

SPORT CONCUSSION ASSESSMENT TOOL - THIRD EDITION NORMATIVE REFERENCE VALUES FOR

PROFESSIONAL RUGBY UNION PLAYERS

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1   **SPORT CONCUSSION ASSESSMENT TOOL - THIRD EDITION NORMATIVE REFERENCE VALUES FOR**

2   **PROFESSIONAL RUGBY UNION PLAYERS**

3   **ABSTRACT**

4   **Objectives:** To establish normative reference data for the SCAT3 in professional Rugby Union players.

5   **Design:** A cross sectional study in professional Rugby Union players competing in national and

6   international professional competitions between 2015 and 2016.

7   **Methods:** The SCAT3 was administered pre-season or prior to tournaments. Data was collected

8   electronically using a custom tablet application. SCAT3 subcomponents distributions were described and

9   normative ranges determined using percentile cut-offs for average, unusually low/high, and extremely

10   low/high scores. The association between player characteristics and performance in SCAT3

11   subcomponents was also investigated in exploratory analyses.

12   **Results:** A total of 3,611 professional Rugby Union players were included. The most common baseline

13   symptom was fatigue (14%). The symptom score median (md) was 0 (interquartile range (IQR) = 0-1).

14   Symptom severity md was 0 (IQR = 0-1). The md of the SAC score was 28 (IQR = 26-29). The md of the

15   MBESS was 2 (IQR = 0-4). The Tandem gait md was 11.1 s (IQR = 10.0-12.7 s). Upper limb coordination

16   was normal in 98.4%. Younger age and lower educational level were associated with worse performance

17   on delayed recall and reverse month sub-components of the SCAT3 (p<0.0001). No statistically

18   significant differences in SCAT3 subcomponents were evident across gender.

19   **Conclusions:** Representative normative reference values for the SCAT3 among professional Rugby Union

20   players are provided. Baseline performance on concentration and delayed recall tests may be lower in

21   younger athletes or in those with lower educational level.

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1 **Background**

2 Concussion is a common and high profile injury in contact and collision sports.[1] Rugby Union has a

3 relatively high reported incidence of concussion, recently estimated at 15.8 concussions per 1000

4 player-match-hours.[2] Concussion can result in a diverse range of symptoms (somatic, cognitive,

5 behavioural or emotional) and physical signs such as loss of consciousness and ataxia. Short term

6 sequalae include game and practice time loss and possible increased risk of injury.[3] A minority of

7 patients suffer from a post-concussion syndrome of persistent symptoms lasting several weeks.[4]

8 Identification of concussion, with appropriate subsequent management, is important to prevent or

9 ameliorate these deleterious consequences.[5] Given the diverse array of presenting symptoms and signs

10 a standardised multi-modal diagnostic approach has been recommended. The International Consensus

11 Conference for Concussion in Sport therefore developed the Sports Concussion Assessment Tool (SCAT)

12 to standardise evaluation of sports related concussion, track player recovery and serve as a tool for

13 player education. The current third iteration of the SCAT (SCAT3) includes an immediate or on-pitch

14 assessment (comprising observable signs of concussion, Glasgow Coma Scale score (GCS), and

15 Maddock's Score); and an off-field evaluation consisting of six domains examining symptoms (symptom

16 checklist and grading), clinical signs (neck examination); cognitive function (standardized assessment of

17 concussion (SAC)); postural stability (modified balance error scoring system (MBESS) and/or tandem

18 gait); and coordination (finger-to-nose task).[6]

19 Given the non-specificity of concussive symptomatology, and variability in neurocognitive function

20 amongst athletes, baseline SCAT3 testing can be useful for interpreting an individual's post-injury test

21 scores.[7] However, such information is not always available and normative data from a representative

22 reference population can provide a distribution against which post-injury SCAT3 scores can be

23 compared.[8] Normative values may also provide a better understanding of normal variation and factors

24 influencing neurocognitive performance. The SCAT3, or its individual components, has been investigated

1   in a number of settings, but there are no previous studies reporting baseline SCAT3 values in Rugby

2   Union. The aim of this study was to describe baseline SCAT3 data using a large sample of professional

3   Rugby Union players. Specific objectives were to characterise the distribution of SCAT3 sub-component

4   scores; establish normative reference data for the SCAT3 in Rugby playing adults; and evaluate the

5   influence of player characteristics on SCAT3 scores.

6

7   **Methods**

8   A cross sectional study was performed to establish normative values for the SCAT 3 in Rugby Union

9   players. All adult professional players undergoing pre-season, or pre-tournament, baseline SCAT3 testing

10   between 2015 and 2016 and using the electronic CSX data collection system was studied.[9] This

11   represented the majority of all eligible male players in domestic and international competitions globally

12   (included competitions are listed in the web appendix). Data from 3 international Women's sevens

13   teams was additionally available. Where players underwent repeat testing, their earliest result was

14   retained in the primary analysis to minimise learning effects. Players with incomplete data on SCAT3

15   components were excluded from available case analyses.

16   The SCAT3 was administered individually to every player before or after team practice prior to the

17   commencement of the relevant competition season or tournament. Testing was performed in a single

18   session, in a distraction-free environment with the athlete in a resting state, in accordance with

19   standard instructions.[6] The SCAT3 was administered by an accredited, appropriately trained team

20   physiotherapist or physician. Maddock's score, GCS and observable signs were excluded from

21   consideration as these domains are intended for immediate on-field assessment, rather than office or

22   off-field assessment, and represent match specific variables not testable at baseline. The English version

23   of the SCAT3 was used for all athletes. Results were collected immediately using CSX, a bespoke tablet

1   software application designed for real time data collection. Data was instantaneously uploaded to a

2   secure CSX server.[9]

3   Statistical analyses proceeded in four stages. Firstly, the demographic features of the sample were

4   described. Secondly, descriptive statistics were calculated for each subcomponent of the SCAT3, and

5   separately for male/female and under-20/over-20 year's subgroups. Distributions of continuous

6   variables were visualised using density histograms and summarised using mean (M), median (Md),

7   standard deviation (SD), interquartile range (IQR), and range. Distributions of categorical variables were

8   evaluated using density histograms and percentages.

9   Thirdly, normative ranges for each SCAT3 variable were determined. Cut-offs were selected based on

10   distribution percentiles consistent with previous SCAT3 normative value studies and followed

11   conventions used in cognitive assessments (e.g. Wechsler intelligence quotient classifications).[10, 11] The

12   below/above average cut-off was defined as close as possible to the 25th and 75th percentile ranks.

13   Unusually low/high scores corresponded to the 10th and 90th percentile ranks, and extremely low/high

14   scores aimed for the 2nd and 98th percentile ranks. Classifications were defined based on the direction

15   of scoring for abnormality in each SCAT3 component: Increasing symptom scores and number of errors

16   on the MBESS (reverse scored) are referred to as high; and performance on cognitive testing is denoted

17   as low.

18   Fourthly, the association between player characteristics and performance in SCAT3 subcomponents

19   were investigated in exploratory analyses. Categorical background variables were chosen based on *a*

20   *priori* hypotheses or previously suggested interactions, and included: (i) gender (male versus female), (ii)

21   age (<20 versus >20 years, corresponding to professional youth and adult age groups), and (iii)

22   educational level of the player's country of origin (United Nation's educational index,[12] categorised into

23   5 equal groups, lowest ≤0.7, highest >0.9). Categorical variables were tested in relation to non-normal

24   continuous variables using the Mann–Whitney U-test or Kruksall-Wallis H test. Associations between

1   categorical variables were examined using Pearson chi^2 tests. Proportions were compared using 2-

2   sample z tests. Normality of continuous variables was assessed using frequency histograms and the

3   Kolmogorov–Smirnov and Shapiro–Wilk tests. Bonferroni's correction for multiple comparisons was

4   employed using a conventional family wise type 1 error rate of 0.05, applied to all hypothesis tests used

5   simultaneously in this step of the analysis. The adjusted p-value considered statistically significant was

6   consequently 0.003. Statistical analyses were carried out in Stata version 14.1 (StataCorp, College

7   Station, USA). As the study population consisted of a census sample of consecutive cases determined by

8   World Rugby data collection procedures, the final sample size was fixed and formal sample size

9   calculations were not performed.

10   A study protocol with an *a priori* investigation plan was developed prior to analysis. The investigation

11   plan received ethical approval from the University of Sheffield. Study participants provided written

12   consent for the use of anonymised data.

13

14   **Results**

15   A total of 3,611 individual professional Rugby Union players were included in the study between 2015

16   and 2016. All eligible players underwent SCAT3 testing. Incomplete balance and coordination testing

17   was performed on one player due to concurrent injury, their data were excluded from relevant available

18   case analyses. The Tandem gait test is an optional component of the SCAT3 and was performed in 87.1%

19   (n= 3,144) players in the sample. All other data were complete. Of the included athletes, 781 had a

20   further baseline SCAT 3 assessment during the study period on between one (580 players) and seven (1

21   player) occasions. Repeat assessments occurred due to transfer between clubs and additional

22   assessments for national teams at international level World Rugby competitions. The study sample was

23   overwhelmingly male (n=3,573, 98.9%) and aged over 20 years (n=3,181, 88.1%). The educational index

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1   of countries of player origin ranged from 0.51 to 0.93 (corresponding to limited completion of secondary

2   schooling and University level education respectively).

3   Baseline results for each SCAT3 components across the whole study sample are summarised in Table 1.

4   The majority of the sample were asymptomatic (n=2,622, 72.6%). The most commonly reported

5   complaints were: fatigue or low energy (n = 508, 14.1%) and neck pain (n = 417, 11.5%). Distributions of

6   severity and % of individual symptoms endorsed are shown in Figure 1. The SAC showed a left skewed

7   distribution with 14.8% (n=534) reaching the maximum score of 30 and a median score of 28.0

8   (interquartile range 26.0-29.0, range 9.0-30.0). The MBESS showed a heavily right skewed distribution

9   with 25.1% (n=908) athletes completing their balance assessment without errors. The double-leg stance

10   of the MBESS was performed without error in the majority of athletes (96.4%, n=3,480). However, there

11   was greater variability in single-leg stance and tandem stance tests, with only 32.4% and 57.9%

12   respectively of players displaying no errors. Upper limb coordination was performed normally in virtually

13   all athletes (98.39%, n=3,552). Tandem gait time was approximately normally distributed, with a mean

14   time of 11.38 seconds. Overall, only 169 athletes (4.7%) were both asymptomatic and performed all

15   components of the SCAT3 perfectly.

16   Density histograms summarising variable distributions are presented in the web appendix. With the

17   exception of Tandem gait, tests were not normally distributed. Percentile cut-offs were determined to

18   best correspond to the pre-specified normative ranges (broadly normal, above/below average,

19   unusually high/low, extremely low/high). The normative classification ranges for the SCAT3 sub-scores

20   are presented in Table 2.

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22   Baseline SCAT3 results stratified by gender and age are presented separately in the web appendix. There

23   were no statistically significant differences in baseline scores across gender (p>0.01 on all hypothesis

24   tests). There were statistically significant differences of small magnitude in all SCAT3 components,

1   except coordination (p=0.39), between under- and over-20s. However, these differences appeared to be

2   clinically important for only delayed recall (26.7% achieving full score v 43.27%, p<0.001) and reverse

3   month score (83.95% correct v 92.55, p<0.001). Educational level was also significantly associated with

4   all SCAT3 subcomponent scores, but differences were generally not clinically relevant. However, notably

5   worse performance on delayed recall (26.9% achieving top score in lowest educational index group v

6   44.4% in highest educational index group) and reverse month score (78.57% v 92.13%) was apparent in

7   players from countries with an educational index of ≤0.70, p<0.001. Performance of the finger-nose test

8   (100.0% error free v 82.0%) and MBESS (md 1 error, IQR 0-2 v md 1 error, IQR 0-3) was slightly better in

9   this sub-group, p<0.001.

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Discussion

In this sample of 3,611 professional Rugby Union players the most common baseline SCAT3 symptom was fatigue (14%). With the exception of Tandem gait, sub-component test scores were not normally distributed. The symptom score median (md) was 0 (interquartile range (IQR) = 0-1). Symptom severity md was 0 (IQR = 0-1). The md of the SAC score was 28 (IQR = 26-29). The md of the MBESS was 2 (IQR = 0-4). The Tandem gait md was 11.1 s (IQR = 10.0-12.7 s). Upper limb coordination was normal in 98.4%. Representative normative reference values for the SCAT3 were calculated. Age and educational level were associated with worse performance on delayed recall and reverse month sub-components of the SCAT3. No significant differences in SCAT3 subcomponents were evident across gender.

The SCAT should not be used by itself to make, or exclude, a diagnosis of concussion, but provides useful information that will helpfully inform a medical evaluation.[7] The importance of background data is highlighted by the imperfect baseline SCAT3 results reported here; with only 4.68% of study participants being both asymptomatic, and performing the SAC, MBESS and upper limb coordination tests without error. The very high level of errors observed in the single leg and tandem stance tests (only 32.4% and 57.9% respectively of players displaying no errors) may call into question their utility in concussion assessment. Expert assessment is clearly important to interpret the SCAT in the context of pre-existing non-specific symptoms and signs.

Statistically significant differences in distributions of SCAT3 sub-component results were detected in different age and educational level sub-groups. Notwithstanding correction for multiple comparisons, the majority of these positive findings are likely to be artefacts secondary to the large sample size and did not appear to be of clinical significance e.g. negligible differences in median Tandem gait times <1 second. Interestingly, delayed recall and months backwards performance scores were lower in under-20 players and those from countries with a lower educational index. This could represent genuinely worse performance or could, in the case of under-20s, suggest an exposure or practice effect, in that younger

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1   players are likely to have been tested less often with the SCAT3. In either case, physicians may wish to

2   modify their interpretation of these subcomponent results in such players.

3   The large study sample, comprising players of different ages and genders, and from a wide range of

4   countries, educational levels, and playing positions should ensure excellent external validity within

5   professional Rugby Union. Unfortunately, it was not possible to include players from French

6   competitions due to national data protection issues, and differences in normative SAC results are

7   possible in the formal French translation. All testing was with the English SCAT3 version, and

8   extrapolation of results to other SCAT translations to other languages is similarly not possible. However,

9   word choice for immediate and delayed recall are designed to maintain the original denotation and

10   connotation of items, and major differences seem unlikely. Generalisability to amateur Rugby Union,

11   and to other sports, is less certain. The reported variability according to age and educational level could

12   suggest different normative ranges depending on the demographic characteristics of participants in

13   individual sports.

14   Development of the SCAT has been an iterative process with a further version, the SCAT5, recently

15   introduced following the 5th International Consensus Conference on Concussion in Sport.[13, 14] The

16   instrument remains largely unchanged, including the same sub-components, ensuring the relevance of

17   the currently reported results. A major change is an optional increase in the number of words in the

18   immediate recall test from 5 to 10 to avoid ceiling effects. The heavily left skewed distribution, and high

19   proportion of players with a perfect score (67.74%) evident here, suggests this change could help

20   improve discrimination. A further change is provision of a larger number of number strings for the digits

21   backwards test. This could lead to a decreased level of baseline performance if learning effects are

22   counteracted.

23   The normative ranges in the present study are broadly similar to those previously reported,[10, 15-18] but

24   small and potentially clinically important differences were evident in cut-offs. For example, 24 points or

1   lower on the SAC was also defined as unusually low in a recent study of male professional ice hockey

2   players. Conversely, the normal expected range for MBESS (and constituent balance tests) were slightly

3   different in the two populations (normal expected errors 0-4 in Rugby Union v 0-3 in Ice hockey).

4   Interestingly, baseline complaints were much less frequently endorsed in the Rugby Union sample, but

5   with slightly higher severity to that normally expected in ice hockey players.[10]

6   The interaction between age and SCAT scores has been examined in a number of previous

7   investigations. Yengo-Khan reported in a recent systematic review that the literature is inconclusive,

8   with published studies limited by focusing on either adolescents or adults in isolation, or having used

9   large age groupings.[19] There is sparser data regarding gender effects, with a suggestion of worse

10   performance by males on the SAC and MBESS.[19] This was not observed in the current study, but in

11   common with previous studies there was a gross over-representation of male athletes. To our

12   knowledge the influence of educational level on SCAT3 performance has not been previously examined.

13   This study has a number of strengths. It is the largest reported sample of baseline SCAT3 data in the

14   literature, and is the first study to report normative values for Rugby Union, or professional female

15   athletes. The CSX data collection system allowed immediate data collection with minimal missing data.

16   Study conduct and reporting is consistent with STROBE consensus guidelines for observational studies.[20]

17   Conversely, there are some limitations. Sample size in the female gender sub-group is small leading to

18   underpowered hypothesis tests and possible type II error. Certain player characteristics, potentially

19   influencing SCAT3 values, e.g. previous concussions, neurological conditions, learning difficulties and

20   musculoskeletal injuries, were not evaluated. Level of schooling was crudely assigned based on the

21   educational index of each player's country of origin, rather than individual educational record, which

22   could introduce an ecological inference fallacy.[21] A small number of players within the study population

23   had repeated baseline SCAT3 testing. Although, the earliest assessment was used to minimise learning

24   effects, it is possible that previous testing had occurred with the potential for improved performance.

Very poor scores were observed in certain SCAT3 tests e.g. immediate recall of 3/15. Although such scores were concentrated in a tiny minority of players (n=2), suggesting genuine results, we cannot exclude measurement error. Finally, intra- and inter-observer variability was not assessed.

Conclusion

This study provides representative normative reference values for the SCAT3 for professional Rugby Union players. Notable variability was evident in individual SCAT3 sub-component scores in healthy athletes, and normative ranges should therefore help distinguish normal background levels from abnormal scores related to concussive injury. Of note, performance on concentration and delayed recall tests may be lower in normal younger athletes or in those with lower educational level.

Practical Implications

- The SCAT3 assessment tool is helpful to diagnose sports related concussion and track player recovery. However, background symptoms and signs may make interpretation challenging.
- Expected baseline values for the SCAT3 from a representative sample may help interpretation where athlete specific values are absent.
- Baseline performance on SCAT3 concentration and delayed recall tests may be lower in younger athletes or in those with lower educational level.

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Table 1. Summary of the distribution of SCAT3 component scores.

SCAT3 Subcomponent	Scale	n*	Mean	SD	Median	IQR	Range
Symptom Score	0-22 points	3,611	0.98	2.38	0.0	0.0-1.0	0.0-22.0
Symptom Severity	0-132 points	3,611	1.61	4.34	0.0	0.0-1.0	0.0-85.0
Standardised Assessment of Concussion	0-30 points	3,611	27.2	2.34	28.0	26.0-29.0	9.0-30.0
Orientation	0-5 points	3,611	4.87	0.37	5.0	5.0-5.0	0.0-5.0
Immediate Memory	0-15 points	3,611	14.41	1.14	15.0	14.0-15.0	3.0-15.0
Concentration	0-5 points	3,611	3.86	1.08	4.0	3.0-5.0	0.0-5.0
Digits backwards	0-4 points	3,611	2.94	1.01	3.0	2.0-4.0	0.0-4.0
Months in reverse order	0-1 points	3,611	0.92	0.28	1.0	1.0-1.0	0.0-1.0
Delayed recall	0-5 points	3,611	4.00	1.09	4.0	3.0-5.0	0.0-5.0
Coordination score	0-1 points	3,610	0.98	0.13	1.0	1.0-1.0	0.0-1.0
M-BESS	0-30 errors	3,610	2.68	2.77	2.0	0.0-4.0	0.0-20.0
Double leg stance	0-10 errors	3,610	0.05	0.31	0.0	0.0-0.0	0.0-5.0
Single leg stance	0-10 errors	3,610	1.83	1.93	1.0	0.0-3.0	0.0-10.0
Tandem stance	0-10 errors	3,610	0.8	1.22	0.0	0.0-1.0	0.0-10.0
Tandem gait	seconds	3,144**	11.39	2.39	11.1	10.0-12.7	5.2-29.9

*Data missing on coordination and balance for one subject due to concomitant injury preventing testing **Tandem gait optional

Table 2. Normative ranges for SCAT3 components in professional Rugby Union players.

| Component	Scale	Broadly normal		Above/below average		Unusually low/high		Extremely low/high	
		Cut-off	%	Cut-off	%	Cut-off	%	Cut-off	%
Symptom Score	0-22 points	<1	72.61	1-3	17.73	4-9	7.73	≥10	1.94
Symptom Severity	0-132 points	<1	72.61	1-4	16.56	5-16	8.66	≥17	2.19
SAC	0-30 points	≥27	67.80	25-26	20.58	21-24	10.19	<21	1.45
•Orientation	0-5 points	5	87.95	NA	NA	4	11.33	≤3	0.72
•Immediate Memory	0-15 points	15	67.74	14	18.58	11-13	12.07	≤10	1.61
•Concentration	0-5 points	4-5	65.18	3	22.99	2	9.42	≤1	2.41
•Digits backwards	0-4 points	3-4	67.30	2	24.20	1	7.26	0	1.25
•Months in reverse order	0-1 points	1	91.53	NA	NA	0	8.47	NA	NA
•Delayed recall	0-5 points	4-5	73.91	3	16.79	2	6.32	0-1	2.99
Coordination score	0-1 points	1	98.39	NA	NA	NA	NA	0	1.61
MBESS	0-30 errors	0-4	79.44	5-6	10.96	7-10	7.78	≥11	1.83
•Double leg stance	0-10 errors	0	96.40	NA	NA	NA	NA	≥1	3.60
•Single leg stance	0-10 errors	0-2	70.17	3-4	20.78	5-7	7.59	≥8	1.47
•Tandem stance	0-10 errors	0-1	78.42	2	12.22	3-4	7.95	≥5	1.42
Tandem gait	seconds	≤12.7	75.00	12.8-13.9	15.00	14.0-17.2	8.00	>17.3	2.00
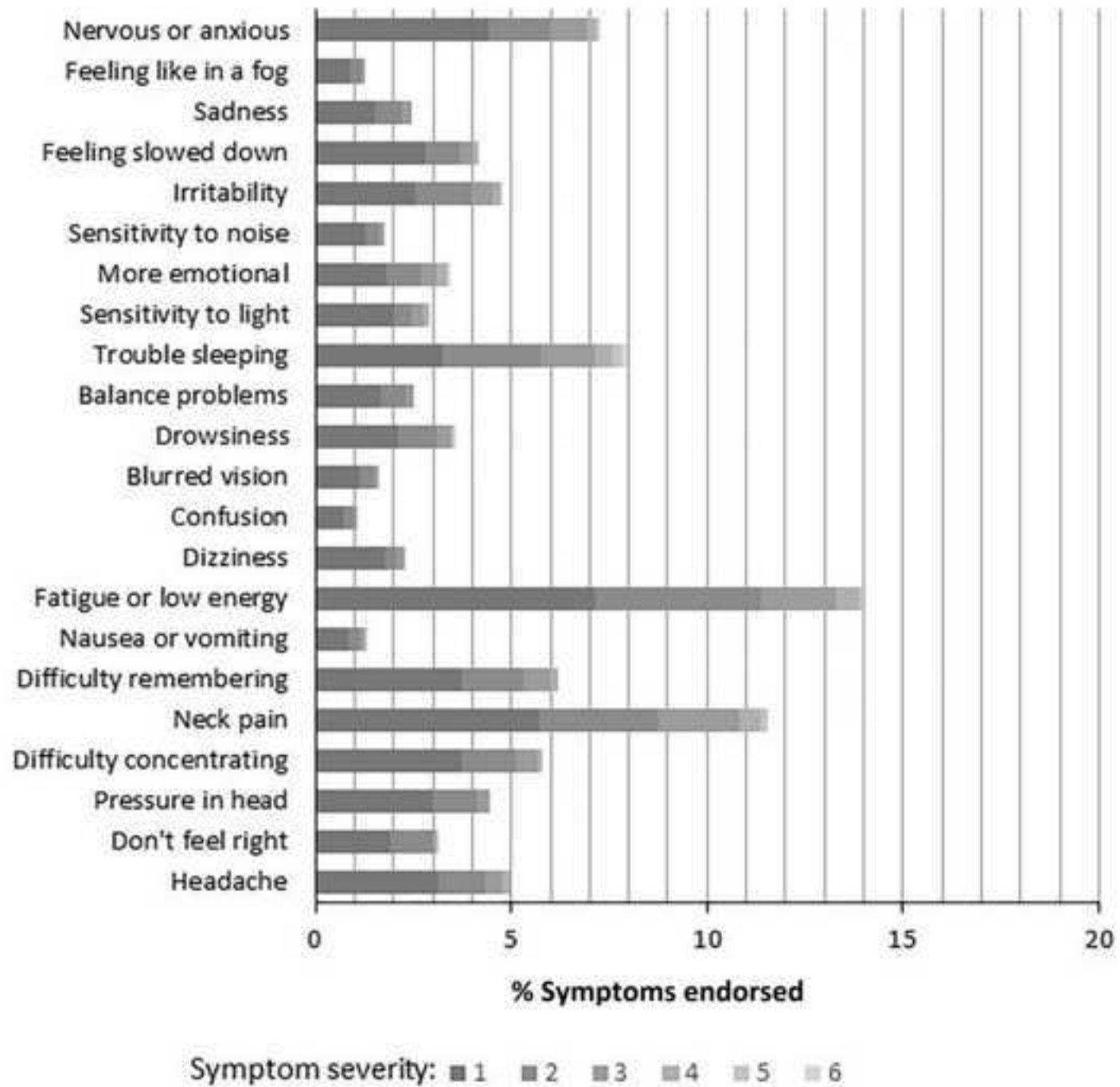
Figure 1. Frequency and severity of baseline symptoms.

SPORT CONCUSSION ASSESSMENT TOOL - THIRD EDITION NORMATIVE REFERENCE VALUES FOR PROFESSIONAL RUGBY UNION PLAYERS

WEB APPENDIX

Included competitions

Players from the following competitions between 2015 and 2016 were included in the study:

Domestic teams competing in:
- The RFU Premiership (England)
- The RFU Championship (England)
- Super Rugby (Southern hemisphere)
- ITM cup (New Zealand)
- Currie Cup (South Africa)
- Pro 12 (Northern Hemisphere)
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National teams competing in:
- World Rugby World Cup
- World Rugby under 20 championship
- World Rugby Sevens championships

Players from the domestic French Top 14 competition and French national team were excluded due to national information governance legislation. The sample represented the large majority of all eligible professional Rugby Union players globally.

Density histograms illustrating the distribution of SCAT3 component scores.
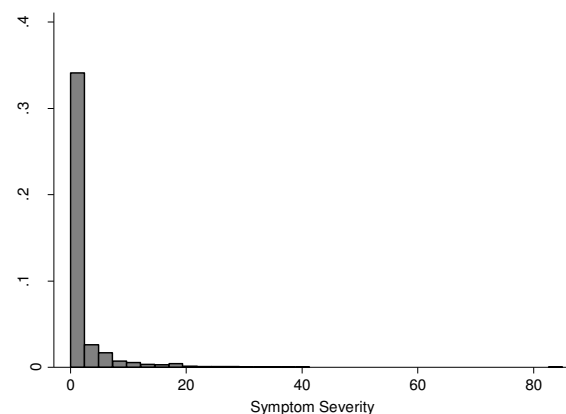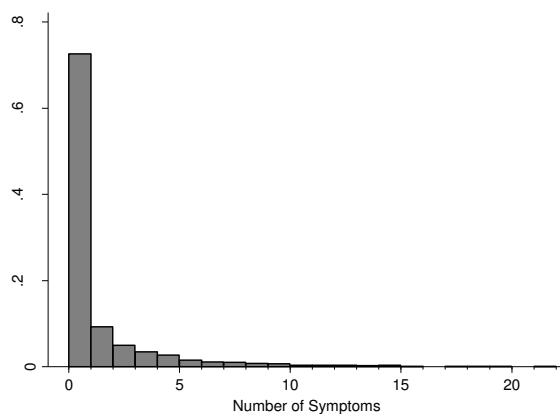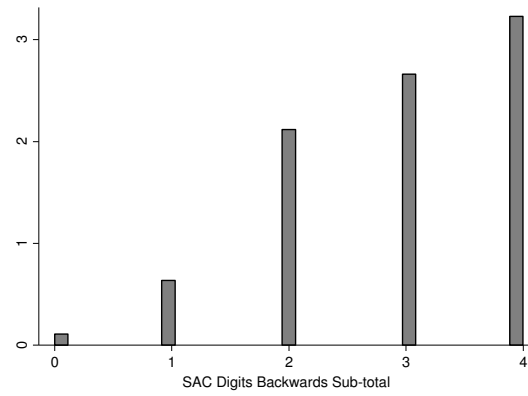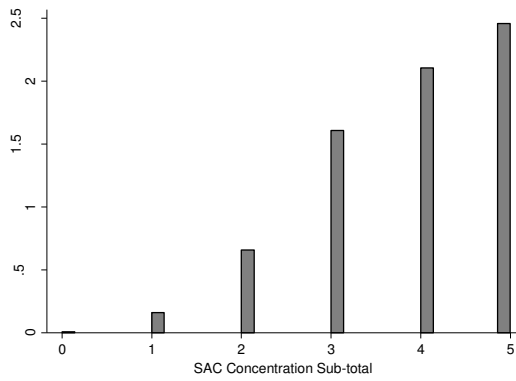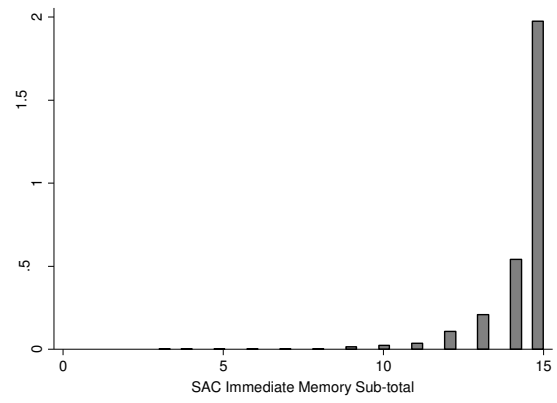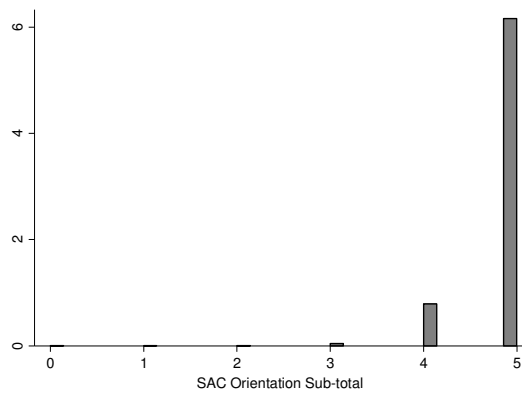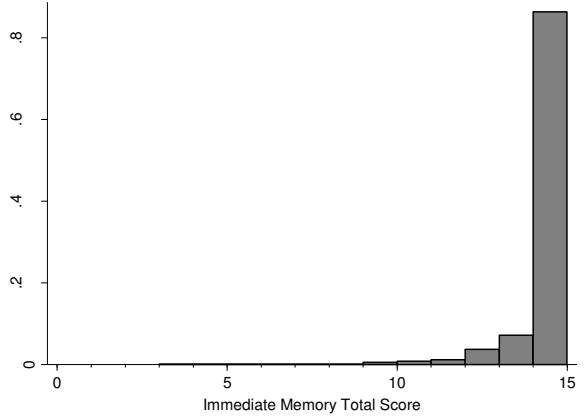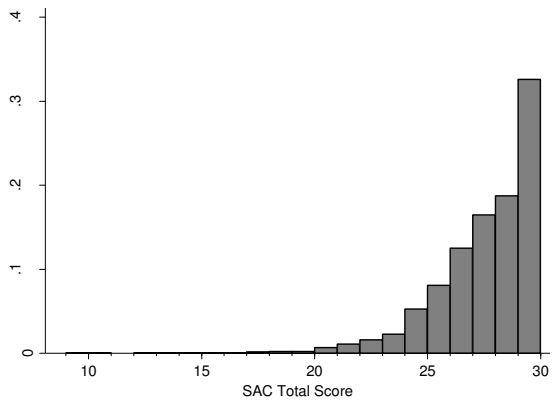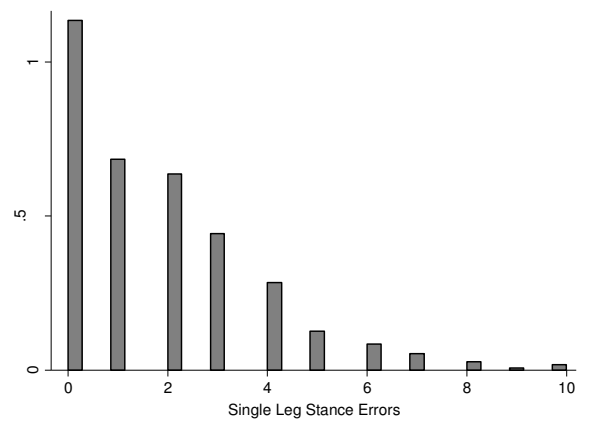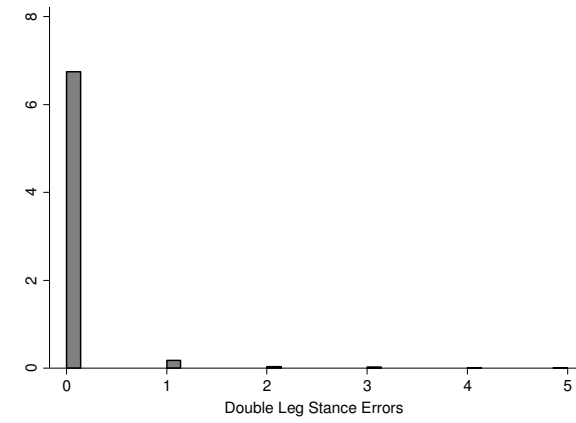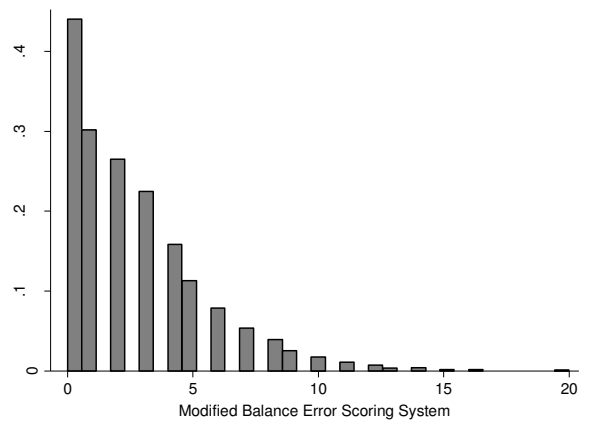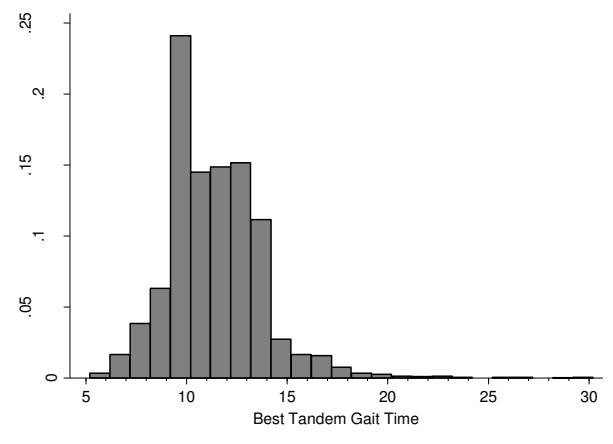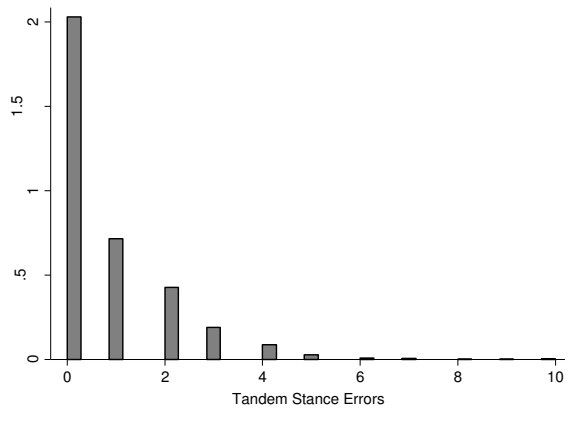
Baseline SCAT3 component scores stratified by age

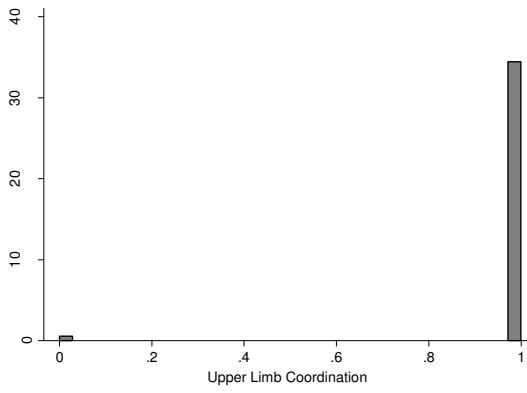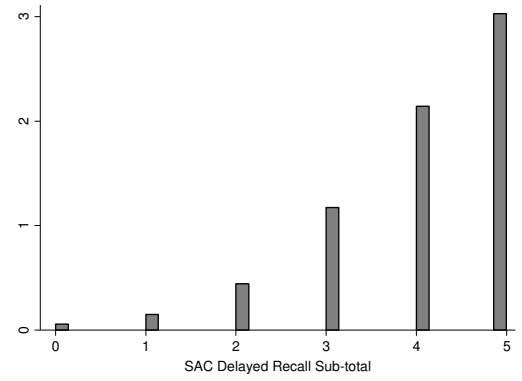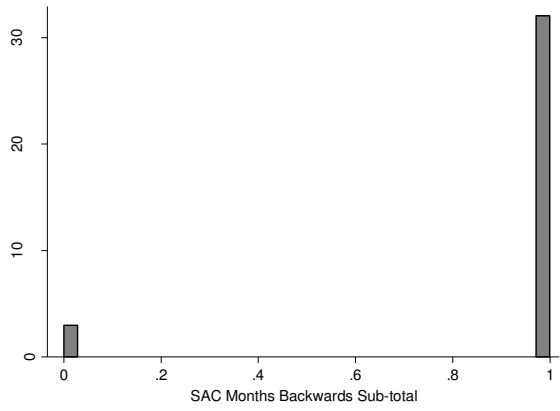| SCAT3 Subcomponent	Scale	n*		Mean		SD		Median		IQR		Range	
Age Group		Over 20	Under 20	Over 20	Under 20	Over 20	Under 20	Over 20	Under 20	Over 20	Under 20	Over 20	Under 20
Symptom Score	0-22 points	3187	424	0.93	1.37	2.34	2.63	0.00	0.00	0.0-1.0	0.0-2.0	0.0-22.0	0.0-22.0
Symptom Severity	0-132 points	3187	424	1.53	2.26	4.30	4.58	0.00	0.00	0.0-1.0	0.0-2.0	0.0-85.0	0.0-26.0
Standardised Assessment of Concussion	0-30 points	3187	424	27.28	26.45	2.29	2.53	28.00	27.00	26.0-29.0	25.0-28.0	9.0-30.0	17.0-30.0
Orientation	0-5 points	3187	424	4.88	4.77	0.35	0.46	5.00	5.00	5.0-5.0	5.0-5.0	0.0-5.0	3.0-5.0
Immediate Memory	0-15 points	3187	424	14.44	14.18	1.12	1.29	15.00	15.00	14.0-15.0	14.0-15.0	3.0-15.0	7.0-15.0
Concentration	0-5 points	3187	424	3.87	3.77	1.08	1.04	4.00	4.00	3.0-5.0	3.0-5.0	0.0-5.0	1.0-5.0
Digits backwards	0-4 points	3187	424	2.95	2.93	1.01	0.87	3.00	3.00	2.0-4.0	2.0-4.0	0.0-4.0	1.0-4.0
Months in reverse order	0-1 points	3187	424	0.93	0.84	0.26	0.37	1.00	1.00	0.0-1.0	0.0-1.0	0.0-1.0	0.0-1.0
Delayed recall	0-5 points	3186	424	4.08	3.73	1.08	1.05	4.00	4.00	1.0-5.0	2.0-5.0	0.0-5.0	0.0-5.0
Coordination score	0-1 points	3186	424	0.98	0.98	0.12	0.14	1.00	1.00	1.0-1.0	1.0-1.0	0.0-1.0	0.0-1.0
M-BESS	0-30	3186	424	2.64	2.97	2.79	2.58	2.00	2.00	0.0-4.0	1.0-4.0	0.0-	0.0-

	errors											20.0	12.0
Double leg stance	0-10 errors	3186	424	0.04	0.13	0.28	0.48	0.00	0.00	0.0-0.0	0.0-0.0	0.0-5.0	0.0-4.0
Single leg stance	0-10 errors	3186	424	1.81	1.95	1.94	1.81	1.00	2.00	0.0-3.0	0.0-3.0	0.0-10.0	0.0-9.0
Tandem stance	0-10 errors	3186	424	0.78	0.89	1.23	1.15	0.00	0.00	0.0-1.0	0.0-2.0	0.0-10.0	0.0-5.0
Tandem gait	seconds	2728**	416**	11.23	12.45	2.33	2.46	10.90	12.20	10.0-12.5	10.9-13.5	5.2-29.9	6.5-26.3

Normative ranges for SCAT3 components in professional Rugby Union players stratified by age

Component	Scale	Broadly normal				Above/below average				Unusually low/high				Extremely low/high			
		Cut-off	Over 20	Cut-off	Under 20	Cut-off	Over 20	Cut-off	Under 20	Cut-off	Over 20	Cut-off	Under 20	Cut-off	Over 20	Cut-off	Under 20
Symptom Score	0-22 points	<1	74.05	≤1	73.11	1-3	16.79	2-4	16.51	4-9	7.28	5-9	11.08	≥10	1.88	8.02	2.36
Symptom Severity	0-132 points	<1	74.05	0-2	75.71	1-4	15.97	3-7	14.15	5-16	7.88	8-16	7.55	≥17	2.10	≥17	2.59
SAC	0-30 points	≥27	68.87	≥26	71.70	25-26	20.24	24-25	17.69	21-24	9.79	20-23	8.49	<21	1.10	<20	2.12
•Orientation	0-5 points	5	89.11	5	79.25	NA	NA	4	18.87	4	10.32	NA	NA	≤3	0.56	≤3	1.89
•Immediate	0-15	15	69.06	14-15	79.95	14	18.10	13	9.43	11-13	11.45	10-12	9.43	≤10	1.38	<10	1.18

Memory	points																
•Concentration	0-5 points	4-5	65.77	4-5	60.85	3	22.62	3	25.71	2	9.01	2	12.50	≤1	2.60	≤1	0.94
•Digits backwards	0-4 points	3-4	67.46	3-4	66.04	2	23.78	2	27.36	1	7.34	1	6.60	0	1.41	NA	NA
•Months in reverse order	0-1 points	1	92.56	1	83.73	NA	NA	NA	NA	0	7.44	0	16.27	NA	NA	NA	NA
•Delayed recall	0-5 points	4-5	75.52	4-5	61.79	3	15.66	3	25.24	2	5.71	2	10.85	0-1	3.11	0-1	2.12
Coordination score	0-1 points	1	98.46	1	97.88	NA	NA	NA	NA	NA	NA	NA	NA	0	1.54	0	2.12
MBESS	0-30 errors	0-4	79.79	0-4	76.65	5-6	10.67	5-6	13.21	7-10	7.69	7-10	8.49	≥11	1.85	≥11	1.65
•Double leg stance	0-10 errors	0	97.14	0	90.80	NA	NA	NA	NA	NA	NA	1	6.84	≥1	2.86	>1	2.36
•Single leg stance	0-10 errors	0-3	82.99	0-3	81.60	4	7.82	4	10.38	5-7	7.66	5-7	7.08	≥8	1.54	≥8	0.94
•Tandem stance	0-10 errors	0-1	79.22	0-1	72.41	2	11.64	2	16.51	3-4	7.60	3	8.02	≥5	1.54	≥4	3.07
Tandem gait	seconds	≤12.5	75.04	≤13.5	75.48	12.6-13.7	14.66	13.6-14.8	14.42	13.8-16.9	8.39	14.9-19.7	7.93	≥17.0	1.91	>19.7	2.16

Baseline SCAT3 component scores stratified by gender

SCAT3 Subcomponent	Scale	n*		Mean		SD		Median		IQR		Range	
Age Group		Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Symptom Score	0-22 points	3573	38	0.99	0.84	2.39	1.65	0.0	0.0	0.0-1.0	0.0-1.0	0.0-22.0	0.0-7.0
Symptom Severity	0-132 points	3573	38	1.61	1.55	4.35	3.51	0.0	0.0	0.0-1.0	0.0-1.0	0.0-85.0	0.0-15.0
Standardised Assessment of Concussion	0-30 points	3573	38	27.18	27.03	2.34	2.24	28.0	27.0	26.0-29.0	26.0-29.0	9.0-30.0	21.0-30.0
Orientation	0-5 points	3573	38	4.87	4.92	0.37	0.27	5.0	5.0	5.0-5.0	5.0-5.0	0.0-5.0	4.0-5.0
Immediate Memory	0-15 points	3573	38	14.41	14.34	1.14	1.05	15.0	15.0	14.0-15.0	14.0-15.0	3.0-15.0	11.0-15.0
Concentration	0-5 points	3573	38	3.86	3.63	1.08	0.94	4.0	4.0	3.0-5.0	3.0-4.0	0.0-5.0	1.0-5.0
Digits backwards	0-4 points	3573	38	2.95	2.68	1.01	0.84	3.0	3.0	2.0-4.0	2.0-3.0	0.0-4.0	1.0-4.0
Months in reverse order	0-1 points	3573	38	0.91	0.95	0.28	0.23	1.0	1.0	1.0-1.0	1.0-1.0	0.0-1.0	0.0-1.0
Delayed recall	0-5 points	3572	38	4.04	4.13	1.09	0.91	4.0	4.0	3.0-5.0	4.0-5.0	0.0-5.0	2.0-5.0
Coordination score	0-1 points	3572	38	0.98	1.00	0.13	0.00	1.0	1.0	1.0-1.0	1.0-1.0	0.0-1.0	1.0-1.0
M-BESS	0-30 errors	3572	38	2.68	2.18	2.78	2.37	2.0	2.0	0.0-4.0	0.0-3.0	0.0-20.0	0.0-9.0

Double leg stance	0-10 errors	3572	38	0.05	0.03	0.32	0.16	0.0	0.0	0.0-0.0	0.0-0.0	0.0-5.0	0.0-1.0
Single leg stance	0-10 errors	3572	38	1.83	1.37	1.93	1.51	1.0	1.0	0.0-3.0	0.0-2.0	0.0-10.0	0.0-5.0
Tandem stance	0-10 errors	3572	38	0.80	0.79	1.22	1.28	0.0	0.0	0.0-1.0	0.0-1.0	0.0-10.0	0.0-4.0
Tandem gait	seconds	3106**	38**	11.41	10.35	2.39	2.08	11.1	10.7	10.0-12.7	8.6-12.0	5.2-29.9	7.2-13.8

Normative ranges for SCAT3 components in professional Rugby Union players stratified by gender

Component	Scale	Broadly normal				Above/below average				Unusually low/high				Extremely low/high			
		Cut-off	% Male	Cut-off	% Female	Cut-off	% Male	Cut-off	% Female	Cut-off	% Male	Cut-off	% Female	Cut-off	% Male	Cut-off	% Female
Symptom Score	0-22 points	<1	72.66	≤1	76.32	1-3	17.66	2	15.79	4-9	7.72	3-6	5.26	≥10	1.96	≥7	2.63
Symptom Severity	0-132 points	<1	72.66	<1	68.42	1-4	16.51	1-4	21.05	5-16	8.65	5-14	7.89	≥17	2.18	≥15	2.63
SAC	0-30 points	≥27	67.75	≥27	71.06	25-26	20.62	24-26	18.42	21-24	10.16	22-23	7.89	<21	1.46	<22	2.63
•Orientation	0-5 points	5	87.91	5	92.12	NA	NA	NA	NA	4	11.36	4	7.89	≤3	0.73	NA	NA
•Immediate Memory	0-15 points	15	67.84	15	57.89	14	18.44	14	31.58	11-13	12.09	12-13	5.26	≤10	1.62	≤11	5.26

•Concentration	0-5 points	4-5	65.29	4-5	55.26	3	22.84	3	36.84	2	9.46	2	5.26	≤1	2.41	≤1	2.63
•Digits backwards	0-4 points	3-4	67.42	3-4	55.26	2	24.04	2	39.47	1	7.28	1	5.26	0	1.26	NA	NA
•Months in reverse order	0-1 points	1	91.49	1	94.74	NA	NA	NA	NA	0	8.51	0	5.26	NA	NA	NA	NA
•Delayed recall	0-5 points	4-5	73.88	4-5	76.32	3	16.77	3	18.42	2	6.33	2	5.26	0-1	3.02	NA	NA
Coordination score	0-1 points	1	98.38	1	100.00	NA	NA	NA	NA	NA	NA	NA	NA	0	1.62	NA	NA
MBESS	0-30 errors	0-4	79.37	0-3	76.32	5-6	10.97	4-5	18.42	7-10	7.81	≥6	5.26	≥11	1.85	NA	NA
•Double leg stance	0-10 errors	0	96.39	0	97.37	NA	NA	NA	NA	NA	NA	NA	NA	≥1	3.61	≥1	2.63
•Single leg stance	0-10 errors	0-3	83.73	0-2	76.32	4	8.17	3	15.79	5-7	7.61	4-5	7.89	≥8	1.48	NA	NA
•Tandem stance	0-10 errors	0-1	78.44	0-1	76.32	2	12.26	2	7.89	3-4	7.87	3	10.53	≥5	1.43	≥4	5.26
Tandem gait	seconds	≤12.7	75.31	≤11.9	73.68	12.7-13.9	14.87	12.0-13.1	15.79	14.0-17.2	7.86	13.2-13.5	7.89	≥17.3	1.96	≥13.8	2.63

*Acknowledgements