AN EXPLORATORY FACTOR ANALYSIS OF THE COGNITIVE ITEMS OF THE

SPORT CONCUSSION ASSESSMENT TOOL 5

by

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LIST OF ABBREVIATIONS

Abbreviation	Description
ADD	Attention Deficit Disorder
ADHD	Attention Deficit Hyperactivity Disorder
ANAM	Automated Neuropsychological Assessment Metrics
CISG	Concussion in Sport Group
EFA	Exploratory Factor Analysis
ImPACT	Immediate Post-Concussion Assessment and Cognitive Testing
NCAA	National Collegiate Athletic Association
PCSS	Post-Concussion Symptom Scale
SAC	Standardized Assessment of Concussion
SAS	Statistical Analysis Software
SCAT	Sport Concussion Assessment Tool
SRC	Sport-Related Concussion

ABSTRACT

Objective: To assess the construct validity of baseline Sport Concussion Assessment Tool 5 (SCAT5) cognitive items in a healthy sample of NCAA Division I student-athletes from a single institution.

Design: Cross-sectional.

Setting: NCAA Division I University.

Participants: Deidentified data were analyzed for 657 (n = 301 male; 19.2 ± 1.4 years old) healthy NCAA Division I student-athletes who provided consent for use of their pre-participation SCAT5 results during the 2017-2018 and 2018-2019 academic years for research purposes. No individuals were excluded from our analyses.

Independent Variables: Baseline cognitive item scores [Orientation Total (0-5), Immediate Memory (0-30), Delayed Recall (0-10), Digits Backwards Total (0-4), Months in Reverse Order (0/1)] were taken from SCAT5 data.

Outcome Measures: Factor models identified through exploratory factor analysis (EFA) with and without oblique varimax rotation. Items with factor loadings ≥ 0.30 were retained in the factor model.

Main Results: Exploratory Factor Analysis performed with and without rotation produced similar 2-factor models with positive correlations. Factor 1 (Verbal Recall) consisted of the Immediate Memory and Delayed Recall items and Factor 2 (Working Memory) included the Orientation, Digits Backwards, and Months in Reverse Order items.

Conclusions: The SCAT5 cognitive items demonstrate a 2-factor model. These findings provide interpretive value to clinicians working with collegiate athletes by showing how these item scores relate to one another in their assessment of cognition. In conjunction with clinical judgment, these results may be used to determine if re-testing is warranted to assess the possibility of sandbagging or to identify individuals to be referred for further cognitive testing. Furthermore, a comparison of rotated and unrotated EFA results suggest that changes to the scoring methods for Digits Backwards and Months in Reverse Order items could reduce overlap in their assessment of cognition. Future research should investigate the consistency of this model within other populations, with post-injury assessments, and when all SCAT5 items are included.

Key words: baseline, cognition, collegiate, concussion, factor analysis, memory

1. INTRODUCTION

1.1. Background & Significance

Construct validity, also termed factorial validity, describes the degree to which a test measures one or more underlying traits (i.e. constructs or factors) that it is designed to measure.[1] One way to assess construct validity is through exploratory factor analysis (EFA), a statistical technique that groups items based on underlying similarities.[2] In an EFA, if correlations are high between the test items, then those items can be grouped together as items that target the same underlying construct. Conversely, if correlations are not high between test items, it could be possible that the items are not related. Factor analysis is used to determine how well the items of a test are grouping together. Recognizing and understanding if and how test items are grouped together can provide interpretive value when assessing individuals with that measure.

The Sport Concussion Assessment Tool 5 (SCAT5) is the most up-to-date version of the SCAT and was created to be a multimodal tool to assess a patient for concussion.[3,4] As a standardized assessment tool for sport-related concussion (SRC), the SCAT5 contains several cognitive items that assess memory function.[5] These include the Orientation, Immediate Memory, Delayed Recall, Digits Backwards, and Months in Reverse Order tasks which are cognitive tests in the Standardized Assessment of Concussion (SAC).[6]

There are multiple memory components that work together to organize and retrieve information including aspects of working memory and long-term memory. Working memory is the capacity to maintain and manipulate a limited amount of information for a short time and may or may not require access to previous memories and

information.[7,8] The maintenance component of working memory is considered a short-term storage system for a limited amount of information for a short time.[8] Another aspect of working memory is the manipulation of information.[8] Tasks that require working memory function include mathematics, mentally reordering lists, and making mental connections between ideas.[9] Long-term memory differs from working memory in that it is the ability to retrieve previously stored information when it is no longer occupying the current stream of thought.[8]

Although the SAC was originally designed to evaluate four cognitive constructs (orientation, immediate memory, concentration, and delayed recall),[6] it may be more likely that one or more components of memory are underlying constructs of these SCAT5 cognitive items as they have evolved over time. Determining construct validity of these items can help identify whether or not common themes exist within this measure. Identifying the constructs assessed by the SCAT5 cognitive items can help to improve understanding and interpretation of assessment item scores. This holds clinical significance for sports medicine professionals and licensed physicians as it provides interpretive insight which can be used to increase the utility and efficacy of the measure.

1.2. Statement of the Problem

Research has shown the SCAT (all versions) to be reliable in identifying the presence of SRC in an individual,[10-15] but information concerning the construct validity of the cognitive items is lacking. Previous factor analysis studies of SCAT items are limited to the symptom checklist,[16-18] while other items within the SCAT (e.g., cognition items) have not been assessed. Currently, the SCAT5 cognitive items are used as separate

assessments at baseline and post-injury, but data on the relationship of these items are lacking. Factor analysis of the SCAT5 cognitive items is able to identify the underlying construct(s) of these items. This would provide additional insight as to how these items relate to one another which can be used to improve clinical interpretation and decision-making when evaluating individuals with this assessment.

1.3. Specific Aim

The specific aim of this study is to evaluate the construct validity of the SCAT5 through factor analysis of the Orientation, Immediate Memory, Delayed Recall, Months in Reverse Order, and Digits Backwards tasks assessed in a healthy National Collegiate Athletic Association (NCAA) Division I athletic population.

1.4. Research Hypotheses

1. Factors identified by EFA will not reflect the four separate cognitive constructs of orientation, immediate memory, concentration, and delayed recall.
2. Two factors will be produced by EFA:
   a. One factor consisting of the Orientation and Delayed Recall items due to the similarity of these items to require retrieval of previously stored information that is not actively being rehearsed.
   b. Another factor consisting of the Months in Reverse Order and Digits Backwards items due to the similarity of these items to require manipulation of a limited amount of information that is actively being rehearsed.

c. The Immediate Memory item will not load on either of the other delineated factors due to its uniqueness in purely assessing immediate recall of a limited amount of information.

1. Independent Variable

1. *Scores on memory items on the SCAT5*: individual scores on the SCAT5 will vary based on personal health history and cognitive ability.

   a. Orientation assessment: consists of five questions: "What month is it?", "What is the date today?", "What is the day of the week?", "What year is it?", and "What time is it right now?" (within one hour). Each question is scored categorically, with zero corresponding to "incorrect" and one corresponding to "correct"; minimum and maximum scores for this item are zero and five, respectively.

   b. Immediate Memory: measured with a 10-word list. Three trials are administered for this test item with a maximum score of 30. There are three 10-word lists.

   c. Delayed Recall: requires the individual to recall the same 10-word list they were given for the Immediate Memory task. This task should be conducted approximately 20 minutes after the Immediate Memory with a maximum score of 10.

   d. Digits Backwards: conducted with 8 possible strings of digits that increase in length (3 to 6 digits) with each correct recitation. Participants are given two opportunities to correctly recite each length of digits strings

backwards. Upon error for one string of digits, an entirely new string of digits of the same length is read out loud. Each string of digits is scored with zero or one. A zero corresponds with two incorrect responses from different strings of the same length and a one corresponds with a correct response. A maximum total score of four can be given for this item.

e. Months in Reverse Order: A zero is given if the participant is unable to correctly recite the months of the year in reverse order, and a 1 is given if the patient is able to complete the task correctly.

2. Dependent Variable

1. *Factors of the SCAT5*: Factors are the underlying hypothetical themes of a test that are represented by its correlated items.[1] We will examine this through exploratory factor analysis methods. Valid factors will be determined by these criteria:

    a. Factors will be retained as identified by comparison of the Kaiser criterion, Scree plot, total variance explained, and parallel analysis.[19]

    b. Three items that reach a minimum factor loading of ≥0.30 and/or two items reach a strong factor loading (i.e. >0.70) while being relatively uncorrelated with all other items.[2]

    c. Items that cross-load (e.g. factor loading ≥0.30 on more than one factor) will be included on the factor with their highest loading.

1.7. Operational Definitions

1. *Concussion[3]*: a complex pathophysiological process affecting the brain, induced by biomechanical forces.

2. *Sport-related concussion (SRC)*: a concussion that occurred during sport participation that was diagnosed by a qualified healthcare professional.

3. *Working Memory[8]*: the capacity to maintain and manipulate a limited amount of information through active rehearsal.

4. *Long term memory[8]*: the capacity to recall information from the past when the information is no longer occupying the current stream of thought.

3. Assumptions

1. All clinicians who administered the SCAT5 were competent in test administration.

2. The sample data collected accurately represent SCAT5 scores of the generalized population.

3. All participants gave full effort during testing sessions.

4. All participant data were entered accurately before deidentification.

1.9. Delimitations

4. Data were obtained only from current NCAA Division I student-athletes at a single University.

5. Only the five cognitive items of the SCAT5 (i.e. Orientation, Immediate Memory, Delayed Recall, Months in Reverse Order, Digits Backwards) were included in this study.

6. Limitations

1. Data were collected from athletes who participate in cheer, dance, and varsity sports offered at a single university. The varsity sports include: Baseball, Basketball (men's and women's), Cross Country (men's and women's), Football, Golf (men's and women's), Women's Soccer, Softball, Women's Tennis, Track & Field (men's and women's), and Volleyball.

2. Data were collected from NCAA Division I student-athletes aged 17 – 26 years old.

3. The SCAT5 was not administered by the same clinician for every athlete.

4. The nature of exploratory factor analysis is complex, with few absolute guidelines and many options for analysis and interpretation.[20]

5. Factor retention and rotational scheme decisions are based on practical, rather than theoretical, considerations.[2]

1.11. Summary

One way to establish meaningful validity of a test is measuring a test's construct validity. This can be done by performing factor analysis to determine what underlying themes are present among test items. Determining construct validity is helpful because it shows whether or not a test (i.e., SCAT5) assesses what the developers had hoped to

assess. The SCAT5 is a commonly used cognitive tool for baseline and sideline

assessment of SRC and contains five cognitive tests (i.e., Orientation assessment,

Immediate Memory, Delayed Recall, Digits Backwards, and Months in Reverse Order)

that assess memory function. The structure and organization of memory is complex and

multifaceted as it involves multiple components including working memory and long-

term memory. Currently, construct validity research is lacking on the cognitive items of

the SCAT5. Therefore, measuring construct validity through factor analysis of the five

cognitive items will help fill this existing gap in research by identifying the relationship

of these items to one another.

2. REVIEW OF LITERATURE

2.1. Introduction

"Statistics are not scary; they are your friend" (Missy A. Fraser, Ph.D., oral communication, September 2019). Put simply, statistical analyses are the calculations that we make to obtain objective, replicable data for real-world application. Statistics are infused throughout athletic training, other healthcare professions, and athletics more than clinicians may be aware. Without statistics, it can be difficult to make objective determinations concerning evaluations and assessments. Measurement can be simple; but there is a depth to measurement and statistics that allow us to create, refine, understand, critically analyze, and validate evaluative tools and tests that are used in clinical settings.

2.2. Construct Validity and Factor Analysis

Construct validity is defined as the degree to which a test measures the theoretical trait or construct that it was designed to measure.[1] In other words, it is the ability of items of a test to accurately identify the underlying theme(s) of a test. For example, tests that seek to assess an individual's personality need to have construct validity in order to be able to properly identify that individual's personality type. Typically, a personality test will attempt to differentiate between 2 or more types of personalities; therefore, the test questions, also called items, should be written in such a way that the patient's answers make it possible to determine their personality type. The personality test will demonstrate strong construct validity if an individual answers all of the questions that would label them as Personality X and the test determines that they are Personality X. It would demonstrate poor construct validity if the patient answers all of the questions that would

label him/her as Personality X and the test determines that he/she is Personality Y.

Evaluating for construct validity can be done by measuring the strength of correlation

between items of a test.[1]

Construct validity can also be termed *factorial validity*, which is determined

through factor analysis.[21] *Factor analysis* is a statistical technique commonly used to

reduce a set of observed variables (items) into a fewer number of independent subsets.[2]

The independent subsets are grouped by underlying similarities (latent variables) among

the observed variables.[22] These groupings are termed *factors* or *constructs*.[2] In other

words, factors are discovered through mathematic and statistical programs that

consolidate large groups of test items that share one or more unnamed, underlying themes

into smaller groups.

Exploratory factor analysis (EFA) is used to group large data sets of correlated

variables together to describe and summarize data for the purpose of discovering the

latent construct, or underlying theme, among a set of variables.[2] This approach is used as

an "exploratory" method to generate theory for why variables might group together (i.e.

find a latent construct),[22] and is generally used for the development of assessment tools

that seek to identify underlying processes (e.g. personality, intelligence, function).[2] The

EFA protocol can be summarized into five steps: determining the suitability of data (e.g.

sample size, sample normality), choosing a factor extraction method (e.g. principal

components, maximum likelihood, least squares), choosing factor extraction criteria (e.g.

Kaiser criterion, Scree plot), choosing a factor rotation method (orthogonal or oblique),

and interpretation of the factors.[19]

2.3. Sport-Related Concussion

It is estimated that 1.6 million to 3.8 million sport-related concussion (SRCs) occur in the United States each year.[23] A SRC is a mild traumatic brain injury sustained during sport participation. It is caused by biomechanical forces (contact or non-contact), results in deficits across a wide range of domains (i.e., clinical symptoms, physical signs, cognitive impairment, neurobehavioral features and sleep/wake disturbance), and requires a multi-faceted approach to evaluation and management.[3] Following concussion, there is a complex pathophysiological cascade that occurs resulting in microstructural damage to brain tissue.[24] Studies have shown that domains such as cognitive and emotional response,[25] balance,[26] and vestibular/ocular function[27] are all disrupted as a result of concussion; therefore, diagnosis of acute SRC involves careful and thorough assessment. Although SRC assessments should cover a wide range of domains,[28] this review of literature is primarily focusing on memory, an aspect of cognitive function.

2.4. Memory

Several of the early discoveries about the nature of memory came from the circumstances of patient H.M., who was studied extensively after undergoing an experimental surgical procedure to remove his hippocampus to treat his severe epilepsy.[29,30] The surgery left H.M. unable to recall information or activities once attention was diverted to a new topic and yet he was still able to recall memories and recognize faces from before his surgery.[30] Studies on H.M. led to the future discoveries of multiple memory systems and how they are organized. These insights and decades of subsequent research has supported that working memory and long-term memory function

independently from one another. The processes involved in the performance of working memory tasks are beyond the scope of this paper; but it should be noted that working memory tasks require various areas of the brain to coordinate the maintenance and manipulation of incoming new information, often requiring interaction with previously stored information as well.[7,31]

Working memory has undergone several changes in theory and definition as more was discovered about memory function.[31,32] Working memory function is accessed when a limited amount of information is actively rehearsed and kept at the forefront of the mind.[8] Because working memory function requires new information to be actively rehearsed, working memory has a maintenance component that allows for storage of a finite amount of information for a short amount of time.[8] New information competes for full control of attention during working memory tasks as the brain works to manipulate this information in order to solve a problem or make connections.[7] Reliance on working memory is required to perform mental tasks such as mathematics, reordering list items, transforming instructions into plans, considering alternatives, and mentally relating information for the purpose of making connections between items or ideas.[9]

Conversely, long-term memory is accessed when information needs to be recalled after attention has been diverted from the learning episode, especially with increased passage of time.[8] Studies on patient H.M. led to a greater understanding of the differences between the separate organization of working and long-term memory in the brain.[30] It was originally believed that working memory was necessary for assimilating information into long-term memory through the active rehearsal of information, but later studies found that this was not completely true. Rather, it was observed that storage of

information in long-term memory can happen separately from the working memory

system by using other portions of working memory that still may be intact.[32]

2.5. Sport Concussion Assessment Tool (SCAT)

In the most recent consensus statement published by the International Concussion

in Sport Group (CISG), multimodal assessments (e.g. Sport Concussion Assessment

Tool) have been recommended as the best option for sideline assessment of SRC.[33] The

Sport Concussion Assessment Tool (SCAT) was first introduced at the 2nd International

Conference on Concussion in Sport in Prague, 2004.[34] At its inception, it was intended to

be a standardized tool that could be used for the education and assessment of SRC on the

sideline and for the sub-acute phases of recovery.[34] The SCAT combines several clinical

evaluation components of cognitive function into one tool and is now in its fifth version.[5]

The SCAT5 is designed to assess individuals age 13 years and older who are

suspected of having sustained a SRC.[5] It has multiple sections to collect patient

demographic information as well as to assess a patient for concussion. Components of the

SCAT5 that are pertinent to this paper are also modified components of the Standardized

Assessment of Concussion (SAC) measure, which is a brief cognitive screening tool that

includes Orientation, Immediate Memory, Delayed Recall, Digits Backwards, and

Months in Reverse Order tasks.[6] For the purposes of this paper, these five items will be

referenced as components of the SCAT5 with the understanding that they are also

modified items of the SAC.

2.6. Cognitive Items of the SCAT5

Memory assessment is an important evaluation component for those suspected to have sustained a SRC as memory function has been shown to be impaired following mild traumatic brain injury (i.e., concussion).[35] Within the SCAT5, memory function is evaluated with five cognitive items: Orientation, Immediate Memory, Delayed Recall, Months in Reverse Order, and Digits Backwards.[4] Months in Reverse Order and Digits Backwards are further categorized into a sub-category called "Concentration". This is due to these being higher order executive function memory tasks as they also require manipulation of information in order to successfully perform the task.

The SCAT5 contains a five-question Orientation section that assesses working memory regarding day and time.[3] The five questions include: "What month is it?", "What is the date today?", "What is the day of the week?", "What year is it?", and "What time is it right now?" (within one hour). No verbal cues or assistance is provided to the participant to answer these questions. In order to correctly answer these questions, there may be a need to either draw on previously stored information regarding these questions or to manipulate contextual information about their day and/or circumstances. Each question is scored categorically, with zero corresponding to "incorrect" and one corresponding to "correct". The minimum and maximum scores for this item are zero and five, respectively. In an item analysis of the SAC items in healthy adults (age [mean $\pm$ SD] = 21.4 $\pm$ 1.7 years), Ragan et al.[36] found that the Orientation assessment questions held an unacceptable difficulty rating ($P > 0.92$) and were lacking as a discriminatory measure (point bi-serial correlation < 0.1) This finding suggests that the Orientation assessment is not able to appropriately differentiate between individuals with greater and

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lesser abilities; individuals with greater ability should score better than individuals with lesser ability. In support of this finding, collegiate student-athletes are able to score an average of 4.94 out of 5 for their baseline Orientation assessment.[11] Additionally, Hanninen et al.[12] found 91% (n = 277) of their participants were able to score perfectly on this test item at baseline.

In previous versions of the SCAT, Immediate Memory and Delayed Recall were performed with a 5-word list.[13,37] At baseline, high school and collegiate student-athletes have been found to consistently be near perfect for both Immediate Memory (14 out of 15) and Delayed Recall (4 out of 5) when performed with the 5-word list.[11,38] In a separate study of collegiate student-athletes' baseline ability on the SCAT, 96.4% of participants were able to immediately recall all five words and 36.9% of participants were able to recall all five words after a delay.[15] These results suggest that this task was too easy, which leads to an inherent ceiling effect that limits the chances of identifying the presence of concussion in individuals.[36,39,40] A ceiling effect is produced when individuals with greater memory capacity are not challenged with the 5-word list and thus are typically able to remember all five words at baseline and following a head injury. To improve the validity of the test and reduce the ceiling effect, the test difficulty had to be increased, which could be accomplished by increasing the difficulty of words or by adding additional words.[41]

In 2016, the CISG added three 10-word Immediate Memory lists to the SCAT5.[42] Norheim et al.[37] established its clinical validity in a collegiate student-athlete population at baseline. When using the 10-word list, participants recalled an average of 20.57 (out of 30) words over three trials for the Immediate Memory task and an average of 6.59 (out of

10) words for the Delayed Recall task. No participants achieved a perfect Immediate Memory score and only 5% of participants achieved a perfect Delayed Recall score compared to 60% and 40% of participants achieving perfect Immediate Memory (15 out of 15) and Delayed Recall (five out of five) scores with the 5-word list, respectively.

The Months in Reverse Order task has been used in various ways to assess cognitive function.[43] As a component of the SCAT5, Months in Reverse Order is included as an assessment item of concentration. As a test of attention,[44] the Months in Reverse Order task can be argued to be an assessment of working memory function by requiring an individual to access previously stored information (i.e. months of the calendar in chronological order) and interpreting it in a typically unrehearsed version (i.e. backwards order). This task is performed by assessing the participant's ability to recite the months of the year in backwards order (i.e. "December, November…February, January).[4,43] At least 92% of collegiate student-athletes are able to successfully complete this task, indicating relatively low difficulty with this task.[15] The use of a dichotomous grading system may be a reason for the high rate of completion of this task, regardless of how long it takes. In contrast, time to successfully complete the task may provide more sensitive information about an individual's ability. Although it has been found that healthy, cognitively intact adults should complete this task without error and within 20 seconds,[45,46] this has not yet been established in a collegiate student-athlete population.

The Digits Backwards task is another test that assesses working memory in individuals.[47,48] Updated versions of the SCAT over time have added more lists and rows in order to combat participant memorization of the lists with repeated assessments.[3,49] On the SCAT5, there are six lists (A – F) each with eight strings of digits for test

administration.[4] In a sample of collegiate student-athletes, 51% of participants were able to correctly recite six-digit strings at baseline, indicating that a small majority of this population is able to achieve a perfect score (four out of four) on this task.[15]

2.7. Concussion Assessment-Related EFA Studies

Factor analytic methods provide helpful information for the interpretation of assessment outcomes within psychological and medical research. When applied to concussion research, factor analysis studies can help guide the assessment, management, and treatment of concussions.[16-18] Exploratory factor analysis methods conducted on the Post-Concussion Symptom Scale (PCSS) in a sample of high school and collegiate student-athletes found that concussion symptom factors are different from baseline to post-injury.[16] Another EFA performed with symptom severity scores from the SCAT3 in a sample of high school and college student-athletes helped determine that symptoms reported after an acute (24-48 hours) concussion injury demonstrates a unidimensional structure.[17] Additionally, EFA studies performed on popular neurocognitive assessment tools (e.g., Immediate Post-Concussion Assessment and Cognitive Testing [ImPACT], Automated Neuropsychological Assessment Metrics [ANAM]) resulted in novel and simple ways to interpret the outputs of these measures.[50-53] These results are just a few examples of how EFA has helped reveal if any underlying factors can be identified in assessment tools commonly used in clinical practice. Depending on the assessment being analyzed, EFA results can provide a suggestion for the most appropriate method to interpret scores.

Although there have been EFA studies on the symptom checklists and computerized neurocognitive assessment tools, there are currently no EFA investigations on the SCAT5 or its items. These previous studies have provided additional insight for the interpretation of these assessment tools in order to improve the care that clinicians provide to their patients. As the SCAT5 continues to be widely used internationally, additional information for the interpretation of baseline SCAT5 results will be beneficial in the assessment and care of student-athletes. It is not enough that concussion baseline testing is done; it is also necessary for clinicians to continue growing in their interpretive skills of the assessments that they administer.[3,54]

2.8. Summary

Test validity is a vital component for the production of useful and applicable clinical assessment tools. Construct validity is the degree to which a test measures the theoretical construct or theme that it was intended to measure. To determine construct validity of a test, exploratory factor analysis can be used to produce correlations among test items to identify any underlying themes, or factors.

Previous concussion assessment-related factor analysis studies have been performed on concussion symptom checklists and computerized neurocognitive assessment tools. These studies have resulted in novel interpretive strategies and unique insight into commonly used concussion assessment tools. As more information becomes available on sport-related concussion, more research is warranted for the management and treatment of patients with this condition.

Sport-related concussion can cause deficits in many domains of cognitive function, including memory. Memory function has been described to be complex and multi-faceted. Working memory and long-term memory are divisions of memory that may or may not work in conjunction with one another depending on the task at hand. Clinical concussion assessment tools such as the SCAT5 contain memory function assessments.

The SCAT5 is a commonly used multimodal assessment tool for concussion that assesses cognition across five tasks: Orientation, Immediate Memory, Delayed Recall, Months in Reverse Order, and Digits Backwards. These tasks are sensitive for acute identification of SRC when compared to baseline values,[11,14,38,55] but evidence for the construct validity of these five tasks is lacking. Based on the understanding of memory as presented above, factor analysis of the five cognitive items on the SCAT5 is appropriate to identify if these tasks provide overlap in their assessment. Understanding the underlying constructs of these SCAT5 components can show how these items relate to one another. This novel insight can be used to assist clinical decision-making during baseline and post-injury assessments with this tool.

3. METHODS

3.1. Study Design

This cross-sectional study utilized a convenience sample of SCAT5 scores from NCAA Division I University varsity, cheer, and dance athletes. The SCAT5 scores used for this study were collected as part of a larger, ongoing concussion study. The SCAT5 test scores were collected as part of a battery of neurocognitive tests for the purpose of establishing baseline measures as part of pre-participation requirements for varsity athletics. Data were collected by a research team trained in the administration of all involved tests. This study analyzed baseline scores from the Orientation, Immediate Memory, Delayed Recall, Months in Reverse Order, and Digits Backwards tasks of the SCAT5. All data were deidentified for this study prior to being shared with the primary investigator. Approval from the University Institutional Review Board was obtained prior to data collection.

3.2. Participants

This study utilized a clinical convenience sample of 657 healthy NCAA Division I university varsity, cheer, and dance athletes. Varsity sports represented in this sample include: Baseball, Basketball (men's and women's), Cross Country (men's and women's), Football, Golf (men's and women's), Women's Soccer, Softball, Women's Tennis, Track & Field (men's and women's), and Volleyball. No participants were excluded from analysis based on demographic characteristics (e.g. sex, age, sport participation, attentional or learning disability, concussion history).

Participants' consent to use their baseline data for research was obtained prior to undergoing preseason baseline concussion testing. Any athletes that were <18 years old at the time of baseline testing were contacted after they turned 18 years old to gain consent to use their baseline data. Per University protocol, completion of baseline testing was mandatory before clearance to participate in their sport, but participants' consent for this study did not influence playing time or eligibility.

3.3. Data Collection

Baseline SCAT5 data were collected as part of a mandatory pre-participation neurocognitive testing battery for the student-athletes. Other testing measures included in the testing battery were CNS Vital Signs, the NeuroCom Sensory Organization Test, and the Senaptec Sensory Station. Upon arrival to their testing session, all participants began with an intake form before undergoing baseline testing. Based on participants' responses on the intake form, any participant that was feeling less than 75% of normal, had slept at least three hours less than normal, had exercised three hours prior to testing, did not wear their corrective vision for testing that day, or did not take their normal ADD/ADHD or headache/migraine medication that day were not permitted to test that day. Tests were then administered in a randomized order for all participants approved for testing that day. Student-athletes diagnosed with an attentional disorder, learning disability, or both were scheduled for one-on-one testing sessions. Baseline testing lasted about two hours for groups of three to six individuals.

The baseline testing process began with the use of the SCAT3 which used the 5-word list for Immediate Memory and Delayed Recall tasks. When the SCAT5 became

available, student-athletes were retested with the 10-word lists on the SCAT5. Retest

values of participants that were retested for any part of the SCAT5 were used for analysis

purposes. Baseline retests of the SCAT5 are noted on the form. Athletes are required to

retest at baseline when their original scores are deemed by the clinicians to not be

representative of full ability. Poor performance on concussion baseline tests may be the

result of fatigue, misinterpretation of the directions, and/or diminished effort. Clinically,

it is best practice to retest an athlete in these instances to obtain a baseline score that more

closely exemplifies their abilities.

3.4. SCAT5 Cognitive Items

The Orientation section consists of five questions: "What month is it?", "What is

the date today?", "What is the day of the week?", "What year is it?", and "What time is it

right now?" (within one hour). The questions are asked one at a time and scored as a

categorical variable (correct or incorrect). If the question is answered correctly, a one is

scored for the question; if the question is answered incorrectly, a zero is scored for the

question. The score for each question is summed for a total score, which is scored as a

continuous variable ranging from zero to five.

The Immediate Memory task requires the participant to recite as many words as

possible immediately after the test administrator has read a list of words out loud to the

participant. This task is performed with a 10-word list to prevent a ceiling effect.[43] There

are three separate lists (Lists G, H, & I) available for this task. The proctors randomly

selected a list for each person. This task is performed with three trials, and the number of

words correctly recalled in each trial is recorded and summed to obtain the total score.

This task is scored as a continuous variable with a range from zero to 30 for the total score.

The Delayed Recall task requires the participant to recall as many words as they can remember from the same 10-word list they were read earlier for the Immediate Memory task. Delayed Recall was performed approximately 20 minutes after the completion of the Immediate Memory task. This task is scored as a continuous variable with total scores ranging from zero to 10.

The Months in Reverse Order task is scored as a categorical variable. A zero is scored if the patient is unable to correctly recite the months of the year in reverse order. A one is scored if the patient is able to correctly recite the months of the year in reverse order.

The Digits Backwards test item contains six possible lists (Lists A, B, C, D, E, & F), each with eight possible strings of digits for test administration. This test item begins with 3-digit strings and increases to 6-digit strings. With the successful recitation of one string of numbers, the participant is required to successfully recite an increasingly longer string of numbers in the reverse order that is read to them by the proctor. If the participant incorrectly recites a digit string, a different digit string of the same length is given for a second attempt. A zero or one is scored for each string of digits, with zero corresponding with two consecutive incorrect responses and one corresponding with a correct response. The Digits Backwards task ends when the participant either completes the task without two consecutive errors or incorrectly recites the strings for two consecutive trials. This task is scored as a continuous variable with a range of total score between zero and four.

3.5. Data Cleaning

Participant that were missing demographic or SCAT5 cognitive data were deleted from the analysis. Participants that were not tested or retested for Immediate Memory and Delayed Recall scores used with the 10-word list from the SCAT5 were removed for final analysis. Any participant that was retested during baseline assessment had multiple rows so a final data row containing only necessary demographic and final accepted scores was created to prevent duplicate analysis of data. Six-hundred fifty-seven participants remained after data cleaning procedures.

3.6. Statistical Analysis

Descriptive analysis of demographic characteristics (e.g. sex, sport, age, concussion history) and exploratory factor analysis (EFA) of the Orientation, Immediate Memory, Delayed Recall, Months in Reverse Order, and Digits Backwards task scores were conducted with Statistical Analysis System (SAS), Version 9.4 (SAS Institute Inc., Cary, NC).

There are multiple methods available to determine the number of factors to extract in the model because none of the available methods have been shown to be more accurate than the others.[19] Therefore, it is recommended that a combination of these methods should be utilized.[19,22] Parallel analysis, Kaiser criterion, Scree plot, and total variance explained are all factor extraction methods that were utilized in order to determine the best factor structure.[19] Parallel analysis compares eigenvalues of a randomly generated data set against actual eigenvalues.[19,21,22] Eigenvalues are considered to be a representation of variance where an eigenvalue less than one indicates that a factor is not

important.[2] Factors with actual eigenvalues that surpass the randomly-generated eigenvalues were retained. The Kaiser criterion (eigenvalues > 1) has been one of the most commonly used methods of factor extraction.[56] Use of the Kaiser criterion leads to retention of factors with eigenvalues greater than 1. The Scree plot is a graphical representation of possible factors to be retained in descending order.[21] On a Scree plot, eigenvalue magnitudes are graphed on the vertical axis while the number of factors are on the horizontal axis. With this method, factors are retained through subjective observation of an "elbow" or leveling out of the plot. The number of factors that are above the point where the plot plateaus determines the number of factors retained in a model. When using total variance explained, an individual is encouraged to retain the number of factors that account for less than 70% of the total variance.[56]

Factor rotation is performed to define a distinct cluster of items in order to simplify the interpretation of each factor.[57] This is done by maximizing high correlations and minimizing low correlations between factors and items, thereby reducing the chance that items will cross-load on more than one factor.[2] This is helpful in delineating factors for labeling. There are two main types of factor rotation: orthogonal and oblique. Orthogonal rotation rotates factors 90° from each other and produces factors that are uncorrelated with each other.[57] In contrast, oblique rotation is a rotation method that does not rotate factors 90° from each other and is used when the factors are considered to be correlated.[57] As it is typically expected that factors have some correlation to one another, oblique rotation should theoretically produce a more accurate solution.[20] If factors are truly uncorrelated, orthogonal and oblique rotation should produce nearly identical

results; therefore, oblique rotation of factors was used in this study as this method is more likely to increase factor interpretation and produce more replicable results.[20]

In this paper, an unrotated EFA model was produced and reported in addition to the traditional rotated EFA model. By choosing not to rotate and correlate the factors, the unrotated results provided additional insight into the items and factors that were identified. This revealed the actual amount of cross-loading between items, portraying how much overlap exists between them. This overlap demonstrates that these items are not as unidimensional as they may seem to be which is important to be aware of in clinical practice.

Items were considered to load on a factor if they reached a factor loading of at least 0.30.[2,20,56] In order for a factor to be considered stable, three or more items with factor loadings ≥ 0.30 need to load under that factor.[20] Additionally, factors with only two items that load strongly (≥ 0.70) without any other items reaching the minimum loading criteria (≥ 0.30) can be considered stable.[2] Factors were excluded if no items reach the minimum loading value of 0.30, less than three items reach minimum loading value of 0.30 but less than 0.70, or less than two items reach a loading value of 0.70. Any items that cross-loaded on more than one factor (i.e. factor loading of ≥ 0.30 on more than one factor) were included on the factor with their highest loading because the greater the loading, the more the item is a pure measure of that factor.[2] Factor loadings are either positive or negative. This indicates the direction of correlation, but does not play a role during interpretation of factors; absolute factor loadings are used when interpreting factors.[57]

Based on varying recommendations for adequate sample size for factor analysis studies, best practice is to obtain the largest possible sample size.[22] Another recommendation for adequate sample size for factor analysis is to maintain a ratio of at least 10 participants to 1 item.[2] Data was collected for 657 individuals; therefore, this study met all recommendations for an adequate sample size for EFA. Based on this value, the research team for the current study feels the power was sufficient to conduct our proposed analyses.

4. MANUSCRIPT

4.1. Abstract

Objective: To assess the construct validity of baseline Sport Concussion Assessment Tool 5 (SCAT5) cognitive items in a healthy sample of NCAA Division I student-athletes from a single institution.

Design: Cross-sectional.

Setting: NCAA Division I University.

Participants: Deidentified data were analyzed for 657 (n = 301 male; 19.2 ± 1.4 years old) healthy NCAA Division I student-athletes who provided consent for use of their pre-participation SCAT5 results during the 2017-2018 and 2018-2019 academic years for research purposes. No individuals were excluded from our analyses.

Independent Variables: Baseline cognitive item scores [Orientation Total (0-5), Immediate Memory (0-30), Delayed Recall (0-10), Digits Backwards Total (0-4), Months in Reverse Order (0/1)] were taken from SCAT5 data.

Outcome Measures: Factor models identified through exploratory factor analysis (EFA) with and without oblique varimax rotation. Items with factor loadings ≥ 0.30 were retained in the factor model.

Main Results: Exploratory factor analysis performed with and without rotation produced similar 2-factor models with positive correlations. Factor 1 (Verbal Recall) consisted of the Immediate Memory and Delayed Recall items and Factor 2 (Working Memory) included the Orientation, Digits Backwards, and Months in Reverse Order items.

Conclusions: The SCAT5 cognitive items demonstrate a 2-factor model. These findings provide interpretive value to clinicians working with collegiate athletes by showing how

these item scores relate to one another in their assessment of cognition. In conjunction with clinical judgment, these results may be used to determine if re-testing is warranted to assess the possibility of sandbagging or to identify individuals to be referred for further cognitive testing. Furthermore, a comparison of rotated and unrotated EFA results suggest that changes to the scoring methods for Digits Backwards and Months in Reverse Order items could reduce overlap in their assessment of cognition. Future research should investigate the consistency of this model within other populations, with post-injury assessments, and when all SCAT5 items are included.

Key words: baseline, cognition, collegiate, concussion, factor analysis, memory

4.2. Introduction

Sport-related concussions (SRCs) affect several domains of neurological and cognitive function (e.g. somatic symptoms, memory, balance, coordination) and require a multimodal approach to evaluation and management.[3] The Sport Concussion Assessment Tool (SCAT) was developed as a standardized, multimodal tool for sideline assessment of SRC.[34] The SCAT is in its fifth version (SCAT5) and is the most widely used sideline concussion assessment tool internationally.[3,58] In addition to assessing symptoms, balance, coordination, and neurological deficits due to SRC, the SCAT5 contains items that assess cognitive function including Orientation, Immediate Memory, Digits Backwards, Months in Reverse Order, and Delayed Recall.[4] These five items were previously published as the Standardized Assessment of Concussion (SAC) and were originally designed to assess an individual's orientation, immediate memory, delayed recall, and concentration.[6]

Currently, there is limited SCAT5 research available,[59,60] but previous versions of the SCAT (i.e. SCAT2, SCAT3) have been determined to be sensitive tools for the diagnosis of SRC in an athletic population.[11,12,14] The most reliable and sensitive items of the SCAT have been the symptom checklist, SAC, and modified Balance Error Scoring System.[10,13] Of these components, the SAC items (Orientation, Immediate Memory, Delayed Recall, Digits Backwards, Months in Reverse Order) have been revised multiple times to address their clinical limitations as the SCAT has evolved over the past decade.[5,34,49] These updates were necessary to improve item difficulty and item discrimination for individuals of varying ability.[36] Most recently, the SCAT5 was revised to include three 10-word lists for Immediate Memory in order to eliminate a ceiling effect identified in the SCAT3.[37] While there is evidence to suggest that the SCAT (all versions) and the original SAC are valid concussion assessment tools,[10,11,14,38,55] no study has sought to investigate the construct validity of these items.

Construct validity describes the degree to which a test measures one or more underlying traits (i.e. constructs or factors) that it is designed to measure.[1] Exploratory factor analysis (EFA) assesses construct validity by identifying how test items relate to one another when there is a large set of data.[22] Understanding the relationship of test items to one another provides information that helps facilitate interpretation of a test's results.[57] For example, EFA has proven helpful in the interpretation of various healthcare assessment tools such as concussion symptoms checklists[16-18] and computerized neurocognitive assessment tools.[50-53] Factor analysis has identified differing constructs among various symptoms checklists, suggesting that individuals may report symptoms differently depending on time point of evaluation (e.g., baseline vs. post-injury),

demographic characteristics, and the assessment tool that is used.[16-18] Additionally, factor

analysis has helped to improve the understanding and interpretation of various

concussion test batteries by delineating the specific constructs that each assessment is

evaluating[50,52,53] as well as improving the test-retest reliability of neurocognitive test

results when reliability is analyzed with the constructs rather than domain scores.[51]

Although these studies all helped to improve interpretation of their respective

neurocognitive assessments, only one of these studies analyzed a sideline concussion

assessment tool.[17] As research is lacking for construct validity among sideline assessment

measures for SRC, further investigation is necessary to aid understanding and

interpretation of these measures.

As researchers and clinicians continue to grow in SRC knowledge and

understanding, it is important to continually investigate commonly-used cognitive

assessment tools to improve clinical decision-making.[39,54,61] The SCAT is the world's

most widely used sideline concussion assessment tool.[3,58] The Orientation, Immediate

Memory, Digits Backwards, Months in Reverse Order, and Delayed Recall items (i.e.

cognitive items) on the SCAT5 have previously demonstrated clinical validity for SRC

assessment and recovery;[38,55,62] but evidence is lacking for the construct validity of these

measures. Therefore, the specific aim of this study is to investigate the construct validity

of baseline SCAT5 cognitive items within a sample of healthy collegiate student-athletes

through EFA. As an exploratory study, knowledge of the cognitive requirements for these

items lead us to hypothesize that two factors will appear in the factor analysis. One factor

consisting of the Orientation and Delayed Recall items will be delineated due to their

similarities as assessments of long-term memory and a separate factor consisting of the

Digits Backwards and Months in Reverse Order item will be delineated based on their requirement for manipulating information. Immediate Memory may not factor with any of the other items, showing that it is an independent and unique assessment for the maintenance of information.

4.3. Methods

Study Design

      This cross-sectional study was a part of a larger, ongoing investigation of baseline and post-injury concussion data from a cohort of National Collegiate Athletic Association (NCAA) Division I varsity, cheer, and dance athletes from a single institution. The SCAT5 data obtained for this study were collected during the 2017-2018 and 2018-2019 academic years as part of the University's pre-participation baseline testing protocol. All data were collected by a team of clinicians, researchers, and research assistants trained in the administration and interpretation of all tests.

Participants

      This study used baseline concussion data from a clinical convenience sample of 657 healthy NCAA Division I student-athletes. Participants' provided consent for use of their results for research purposes prior to completing preseason baseline neurocognitive testing. Any athletes that were <18 years old at the time of baseline testing were contacted to gain consent to use their baseline data after they turned 18 years old (n=26). Per University protocol, all athletes were required to complete baseline concussion testing before clearance to participate in their sport; but participants' consent for this study did not influence playing status or eligibility. All participant data were deidentified

and approval from the University's Institutional Review Board was obtained prior to the primary investigator receiving the data.

Data Collection

The SCAT5 data were collected during preseason concussion baseline testing. All testing sessions began with a participant background section which included demographic information, injury history, what percent of normal they were feeling that day (out of 100%), the amount of hours they had slept the night before compared to what is normal for them, and when they last exercised. Those who were feeling less than 75% of normal, had slept at least three hours less than normal, or had exercised three hours prior to testing were not permitted to test that day. Those diagnosed with any attentional disorder, learning disability, or both were scheduled for one-on-one testing sessions. All individuals were healthy at the time of baseline testing.

SCAT5 Cognitive Items

The Immediate Memory item requires the participant to immediately repeat back a list of 10 words that are read out loud to them by the proctor. One of three separate 10-word lists is randomly selected for testing. This task is performed for three trials and the total number of words correctly recalled from each trial is recorded and summed for a total score. Total score ranges from zero to 30. According to the SCAT5 directions, Delayed Recall is assessed by asking participants to recall the list of words used in the Immediate Memory after at least five minutes have elapsed. This task only has one trial and the score for this item ranges from zero to 10. The Digits Backwards item requires participants to repeat back, in reverse order, a string of digits read out loud to them by the proctor. Digit strings begin at three digits in length and increase to six digits in length.

With the successful recitation of one string of digits, the participant is given an increasingly longer string of digits to recite in backwards order. Participants can score between zero and four on this item. The Months in Reverse Order item requires the participant to successfully recite the months of the year in chronologically reverse order (i.e. December, November, October. . .etc.). Participants are given a score of either zero (incorrect) or a one (correct) for this task. The Orientation item contains five questions that seek to assess the participant's awareness and perception of time. These questions assess the participant's knowledge of the year, month, week, day of the week, and time of day. Each question is asked out loud by the proctor and scored with a zero (incorrect) or one (correct). The score for each question is summed into a total score ranging from zero to five.

SCAT5 Testing Procedures

All participants began with the 10-word Immediate Memory task followed by all other SCAT5 items assessed in a randomized order. The symptom checklist was modified during testing to include an additional symptom (ringing in the ears) as it is a common symptom following concussive head injuries.[63,64] This increased the total symptoms to 23 and the total symptom score to 138. The Delayed Recall task was assessed approximately 20 minutes after the completion of the Immediate Memory task. This was the amount of time that passed between these two items due to our testing procedures, allowing us to follow the recommendations of the SCAT5 and to standardize the time elapsed between these two tasks. Prior to the release of the SCAT5, the SCAT3 was used, which includes 5-word lists for Immediate Memory and Delayed Recall tasks. To ensure that all participants would have accurate comparisons if they sustained concussive injuries, all

participants initially assessed with the 5-word list (SCAT3) were retested to obtain

baseline scores with the 10-word list (SCAT5) in the summer of 2017.

Data Cleaning

Any participant that was missing necessary demographic and SCAT5 cognitive

data were deleted from the analysis (n=2). Participants that were not tested or retested

with the 10-word list from the SCAT5 were not included for analysis (n=6). The final

accepted scores were included in all analyses for individuals who required retesting

(n=51). Data cleaning procedures resulted in baseline data for 657 remaining participants.

Data Analysis

All analyses were conducted in SAS 9.4 (SAS Institute, Cary, NC). Exploratory

factor analysis was performed with the following dependent variables from the SCAT5:

Orientation Total score, Months in Reverse Order score, Digits Backwards Total score,

Immediate Memory score, and Delayed Recall score. The Kaiser criterion (eigenvalue >

1),[56] the number of factors above an eigenvalue of one on the Scree plot,[21] the number of

factors that account for less than 70% of total variance,[56] and comparison of actual

eigenvalues with randomly generated eigenvalues in a parallel analysis were conducted

and inspected for agreement to determine the number of factors to be extracted.[19] An

oblique varimax rotation method was used in order to improve accuracy and

interpretability of the results, and an unrotated model was used in order to show a raw

interpretation of EFA results.[20] Items with factor loadings ≥ 0.30 were considered

significantly associated with that factor.[2] A factor was retained when there were at least

two items with factor loadings ≥ 0.70 and/or there were at least three items with factor

loadings ≥ 0.30.[2] The higher the factor loading of an item, the more that item represents

that factor; therefore, items that cross-loaded on more than one factor were included on the factor with their highest loading.[2]

Due to the exploratory nature of this study, it was felt that performing both rotated and unrotated factor analyses would provide unique insight for these items. The unrotated EFA model is not typically reported in studies as the results tend to be more difficult to interpret and replicate.[22,56] Rotation methods are applied in order to maximize high factor loadings and minimize low factor loadings to reduce the occurrence of cross-loading items and produce clearly delineated factors that may be more reproducible.[2] Although it is not typically a primary analysis, it can be argued that an unrotated model is able to provide insight into a test and its items, especially in smaller sets of items. Whereas rotation will maximize high loadings and minimize low loadings, an unrotated model produces a "raw" output of factor loadings that may demonstrate existing overlap (i.e. cross-loading) of items on more than one factor. This allows researchers to identify unique contributions of items and factors.[2]

4.4. Results

Six hundred fifty-seven (n = 301 male, 45.8%; M ± SD age = 19.2 ± 1.4 years old, range: 17 to 26 years old) NCAA Division I varsity, cheer, and dance athletes were included in the analyses. At time of baseline evaluation, 516 (78.5%) participants reported to be feeling 100% normal with an average of 2.6 ± 3.3 (mean ± SD; range: 0 to 23) total symptoms and an average total symptom severity of 3.7 ± 5.4 (mean ± SD; range: 0 to 34). Seventy-two (11.0%) participants had an attentional disorder or learning disability. Additional participant demographics can be found in Table 1.

Means and standard deviations of the Immediate Memory, Delayed Recall, Orientation, Digits Backwards, and Months in Reverse Order scores can be found in Table 2. Kaiser criterion indicated a two factor model.[56] Inspection of the scree plot shows that two points are above an eigenvalue of 1, agreeing with the Kaiser criterion.[21] Variance explained by Factor 1 and Factor 2 were 31.0% and 22.5%, respectively, accounting for 53.5% of the total variance explained for the data.[56] Finally, a parallel analysis also suggested that two factors would be extracted in the factor analysis.[19] Per previous recommendations, agreement of all factor extraction methods was used to determine the number of factors to extract for factor analysis.[19]

Exploratory factor analysis performed with and without an oblique varimax rotation each produced a similar two-factor model (Table 3). In the unrotated EFA model, the Delayed Recall, Months in Reverse Order, and Digits Backwards Total items reached the minimum loading value of 0.30 for both factors (i.e. cross-loaded); therefore, these items were included on the factor with its largest loading. The rotated EFA model did not contain any items that reached the minimum loading criteria of 0.30 on more than one factor. For both models, Factor 1 consists of two items that may be described as "Verbal Recall" including Delayed Recall and Immediate Memory. Factor 2 consists of three items that may be described as "Working Memory" including Months in Reverse Order, Digits Backwards, and Orientation.

4.5. Discussion

The specific aim of this study was to assess the construct validity of baseline scores of the SCAT5 cognitive items in a healthy sample of NCAA Division I student-

athletes. This is the first known study to perform factor analysis on the SCAT5 to identify the constructs embedded within its cognitive items. The SAC was originally developed to combine the assessment of Orientation, Immediate Memory, Delayed Recall and Concentration (i.e., Digits Backwards, Months in Reverse Order) into one summed score.[6,55] The results of this EFA shows that baseline scores demonstrate a two-factor structure with Factor 1 (i.e., "Verbal Recall") consisting of the Immediate Memory and Delayed Recall items and Factor 2 (i.e., "Working Memory") consisting of the Months in Reverse Order, Digits Backwards Total, and Orientation Total items. These results suggest that the SCAT5 cognitive items comprise a bi-dimensional cognitive assessment tool that measures the constructs of "Verbal Recall" and "Working Memory" rather than the constructs of orientation, immediate memory, concentration, and delayed recall as it was originally designed to assess.[6] This finding may partially be due to the evolution of these items from the original SAC.

Factor 1 consists of the Immediate Memory and Delayed Recall items of the SCAT5. As the results do not demonstrate that the immediate memory or delayed recall constructs of the original SAC are clearly assessed by these items, it was felt that this factor would appropriately be named "Verbal Recall". Interestingly, our results show that these two items are very similar to each other as their factor loadings were each above 0.70, indicating that these items strongly correlate to a common construct. This finding suggests that the Immediate Memory and Delayed Recall items of the SCAT5 may not be assessing separate constructs of immediate memory and delayed recall as originally intended; rather, these items may only be assessing a general recall ability. As the names of the items would suggest, Immediate Memory would likely assess working memory

maintenance and Delayed Recall would assess long-term memory. Instead, the results of this study show these items may not be very different from each other in their assessment of cognition.

At baseline, these two items seem to assess similar recall ability at both the immediate and delayed time points used in this study. There are several possible reasons for this result. First, this may be due to an inherent relationship between these two items, as the athletes were asked to recall the same words during both tests. Therefore, one possibility is that words that were not remembered during Immediate Recall were not learned well enough to be maintained in working memory, which reduces the likelihood of concomitant storage in long-term memory. Second, individuals who are familiar with the structure of baseline testing may be aware that they will need to recall these items at a later time. This could lead them to maintain recall of that information throughout baseline testing or to move that information to long-term memory storage more efficiently. Third, this finding may be due to our use of a healthy sample of athletes with intact recall ability so that performance on these two items are similar at baseline. The time delay and interfering tasks between the Immediate Memory and Delayed Recall tasks were sufficient to separately assess working memory and long-term memory.[8] If the original intent was to assess these two separate constructs, then our results do not demonstrate that these constructs are delineated by these items at baseline. It is possible that a concussed sample may demonstrate different findings, but further research would need to identify the stability of this factor in a concussed sample.

Factor 2 consists of the Digits Backwards, Months in Reverse Order, and Orientation items of the SCAT5. Based on the similar cognitive requirements of these

items (i.e., manipulating information in working memory), it was decided that "Working Memory" would be the most appropriate name for this factor. It is not surprising that the Digits Backwards and Months in Reverse Order items were similarly correlated with one another. The Digits Backwards task involves manipulating and inverting a list of digits and saying it back out loud, requiring working memory function to successfully perform this task.[9] This is supported by previous research that found that tasks similar to the Digits Backwards item utilize components of working memory.[47,48] Similarly, the Months in Reverse Order item requires the manipulation and inversion of a list.[7] In addition to baseline concussion testing, this item has also been used elsewhere to assess working memory.[43]

Interestingly, Orientation loaded strongly with the Digits Backwards and Months in Reverse Order items, providing novel insight into the Orientation item. As this item could require access to information after attention has been diverted away from it and/or require the manipulation of context clues to correctly answer these questions, this item could be argued to be a measure of either long-term memory recall or working memory.[7,8] This study's results suggest that in order to answer the Orientation questions, it may be more likely that individuals resort to using contextual information from their day or week; envisioning a calendar in their mind to identify the date, month, day of the week, or year; or utilizing a mental to-do list in order to identify what time it might be instead of looking at their watch. All of these methods require working memory to identify previously known information and manipulate it to determine the correct answer.

Recognizing the two-factor structure of the SCAT5 cognitive items can guide clinicians in their interpretation of participants' baseline scores. If participants are able to

do well in one item of the construct, it is likely that they would perform well on the other item(s) within that construct. Athletes may intentionally underperform at baseline in hopes of later passing post-injury assessments more easily (i.e., "sandbagging").[65,66] Therefore, knowing which items assess a particular construct may help reduce the possibility that clinicians will accept poor baseline scores by providing an appropriate expectation of how well an individual should perform on items of the same construct. For example, if an individual is able to score a 27 out of 30 (90%) for Immediate Memory but only recalls 2 words (20%) during Delayed Recall, then it is possible that they are purposely underperforming on the latter. If this is not reassessed at baseline to ensure that this is their best performance, then a low Delayed Recall score would be used as a comparison in future post-injury assessments. Furthermore, if individuals continue to score low upon reassessment, then this study's results may be used as a reference to indicate the need for further cognitive testing. Further testing can identify any underlying conditions (e.g., attentional disorders, learning disability, emotional/mood disorders) that may be affecting their results. The scope of this paper does not allow us to investigate these possibilities thoroughly; but due to the strong correlations noted in our data between these two items, we feel that this relationship is plausible. Future studies should investigate the relationship of the Verbal Recall and Working Memory items for individuals that may be giving low effort on the SCAT5 and for individuals that may require further cognitive testing.

From a statistical standpoint, factor rotation is a beneficial component of EFA as it improves the interpretation of factors by reducing the occurrence of cross-loading items.[2] This reduction in cross-loading removes any indication that these items would

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overlap in their assessment of constructs, making it easier to give meaning to the factors. From a clinical perspective, it may be helpful to know the true amount of overlap between items as it would provide additional insight as to how these items assess individuals. For example, the unrotated EFA results show that the Delayed Recall, Months in Reverse Order, and Digits Backwards items cross-load (i.e. factor loading > 0.30 on more than one factor) while the rotated EFA results do not reflect this same overlap. Although small, this cross-loading shows that these items are still related to one another and should not always be considered unidimensional items.

As these items are only meant to be screening assessments,[5,6] overlap in their assessment of cognitive constructs may be unavoidable or expected. This overlap may be due to the current scoring methods for these items. Different scoring methods (e.g., awarding partial points for Digits Backwards, recording time to complete Months in Reverse Order) would potentially increase the sensitivity and specificity of these measures by providing more specific information of an individual's cognitive abilities. Additionally, the use of more specific scoring methods could increase variability among these items and possibly alter their factor structure.

Additionally, Immediate Memory and Delayed Recall negatively loaded on the "Working Memory" factor when the factors were not rotated. Negative factor loadings do not affect factor interpretation,[2] but they still indicate the direction of correlation. These negative loadings may have been produced for several reasons. First, it could be due to random chance. Second, it could be due to the fact that these items are scored on a different scale (i.e., the ranges of scores for the Immediate Memory and Delayed Recall tasks are much larger than the other three items). Third, it may be that these items are

more strongly related to a separate factor (i.e., the instrument is not unidimensional). The third reason may be the most likely explanation as these items load much more strongly on the first factor.

Limitations

This study is not without its limitations. First, due to the use of a clinical convenience sample of NCAA Division I student-athletes aged 17 to 26 years old, the results of this study may not be generalizable to other age groups. Nevertheless, the item scores for this sample are similar to previous research in this population, supporting the generalizability of these findings among all collegiate student-athletes. Second, factor analysis was limited to the cognitive items of the SCAT5 because they are the most objective measures on the SCAT5. The objectivity of these items allows for greater generalizability of this study's findings as the assessment of these items hold stable across all individuals. Third, the SCAT5 was not administered by the same clinician for each athlete which may introduce error during data collection. Although a team approach was taken to collect baseline SCAT5 data, all individuals collecting data were thoroughly trained by the University's concussion coordinator who ensured uniform data collection methods. This team approach to baseline and post-injury concussion testing is also reflective of clinical practice as multiple clinicians are often needed for baseline testing due to time and personnel constraints.

Clinical Significance

The two factors identified in this study account for 53.5% of the total variance of the SCAT5 cognitive items, reflecting the complexity of cognition and supporting the need to continue using a multimodal assessment for SRC. Additionally, these findings

suggests that clinicians can expect performance to be similar on items in the same factor, but they should not expect that high performance on items in one factor means that there will be equally high performance on items in the other factor. Clinicians can use these constructs to identify athletes who may be intentionally underperforming on certain items and to identify individuals who may need to be referred for further cognitive testing if they continue to score low on repeated baseline assessments. At this time, scoring for these items should continue to be independent, but understanding the relationship of these items may provide additional insight into an individual's cognitive abilities.

Future Research

Future work should investigate the consistency of this factor structure in acutely concussed individuals. This could be done through another EFA of post-injury SCAT5 scores or with a confirmatory factor analysis comparing baseline to post-injury models. As this study was analyzed with a sample of NCAA Division I university student-athletes, future work could also be done to investigate the factor structure of baseline scores from athletes participating at other levels of competition (e.g., middle school, high school, professional). Furthermore, as these cognitive items are not the only components of the SCAT5, additional factor analyses should be performed on the entirety of the SCAT5. Finally, future investigations should assess whether or not existing overlap in the Verbal Recall and Working Memory unrotated model would be reduced or eliminated with the implementation of different scoring methods (e.g., awarding partial points, recording the time to complete).

4.6. Conclusion

The SCAT5 is a widely used neurocognitive assessment tool in the evaluation and management of SRCs. Although the SCAT5 cognitive items were initially believed to assess four constructs (i.e. orientation, immediate memory, delayed recall, concentration), the present study found that these items demonstrate a two-factor model of "Verbal Recall" and "Working Memory". Understanding the relationship of these items can be used to improve clinical judgment when interpreting SCAT5 scores. Baseline scores that are not consistent with this model may be used to determine if re-testing is warranted to assess the possibility of sandbagging or to identify individuals to be referred for further cognitive testing. Although the rotated EFA results produce two separate factor structures, the unrotated EFA results provide information on the overlapping contributions of items and factors. This information shows that these items are more related than suggested by findings solely based on the rotated EFA. Future research should investigate the consistency of this model within other populations, with post-injury assessments, and when all SCAT5 items are included.

Table 1. Participant Demographic Frequencies for NCAA Division I Student-Athletes (2017-2019)

Demographic Variable	n (%)
Sex	
Male	301 (45.81)
Female	356 (54.19)
Sport Participation	
Baseball	50 (7.61)
Basketball - Men's	19 (2.89)
Basketball - Women's	16 (2.44)
Cheerleading - Men's	12 (1.83)
Cheerleading - Women's	55 (8.37)
Dance Team – Women's	130 (19.79)
Football	165 (25.11)
Golf - Men's	14 (2.13)
Golf - Women's	8 (1.22)
Softball	35 (5.33)
Soccer - Women's	34 (5.18)
Track and Field - Men's	40 (6.09)
Track and Field - Women's	43 (6.54)
Tennis - Women's	10 (1.52)
Volleyball - Women's	26 (3.96)
Level of Education	
Freshman	302 (45.97)
Sophomore	147 (22.37)
Junior	116 (17.66)
Senior	80 (12.18)
5th year senior	6 (0.91)
Graduate	6 (0.91)
Concussion History	
0	509 (77.47)
1	99 (15.07)
2	32 (4.87)
3	8 (1.22)
>3	9 (1.37)
Feeling 100% Normal	
Yes	516 (78.54)
No	141 (21.46)
Attentional Disorder or Learning Disability	
Yes	72 (10.96)
No	585 (89.04)
Psychiatric Disorder	
Yes	23 (3.50)
No	634 (96.53)
Total	657 (100.00)

Note. NCAA = National Collegiate Athletic Association.

Table 2. Baseline SCAT5 Cognitive Item Scores for NCAA Division I Student-Athletes (2017-2019)

Variable	Mean (SD)	Minimum	Maximum
Orientation Total	4.5 (0.2)	3	5
Immediate Memory	21.0 (3.3)	10	30
Delayed Recall	6.2 (1.8)	1	10
Digits Backwards Total	2.9 (1.0)	0	4
Months in Reverse Order*	569 (86.6%)	-	-

Note. n = 657. NCAA = National Collegiate Athletic Association. SCAT5 = Sport Concussion Assessment Tool 5. SD = standard deviation.

*Reported as frequency of those who were able to successfully recite the months of the year in reverse order, n(%)

Table 3. Unrotated and Rotated Factor Structures of SCAT5 Cognitive Items with Cross-Loading Displayed (n=657)

Items	Unrotated EFA Model[a]		Rotated EFA Model[a]	
	Factors[a]		Factors[a]	
	1	2	1[b]	2
Immediate Memory	**0.83**[*]	-0.23	**0.85**[*]	0.10
Delayed Recall	**0.79**[*]	**-0.35**	**0.86**[*]	-0.23
Months in Reverse Order	**0.36**	**0.58**[*]	0.11	**0.68**[*]
Digits Backwards	**0.31**	**0.57**[*]	0.07	**0.64**[*]
Orientation	-0.14	**0.53**[*]	-0.08	**0.55**[*]

Note. Factor loadings ≥ 0.30 are shown in bold. For negative values, absolute values were used determine factor loadings. SCAT5 = Sport Concussion Assessment Tool 5. EFA = Exploratory Factor Analysis.
[*]Item is included in factor structure based on highest factor loading of item across factors
[a]Factor 1 = "Verbal Recall"; Factor 2 = "Working Memory"
[b]Delayed Recall item accounts for greater variability in this factor; entered out of order to match order of Unrotated EFA Model

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