Effects of Exertional Exercise on the Standardized Assessment of Concussion (SAC) Score

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ABSTRACT
The Standardized Assessment of Concussion (SAC) was developed for use by athletic trainers, physicians, and other allied health professionals as a means of evaluating and quantifying mental status immediately following head injury. The purpose of this study was to examine the effects of exertional exercise on the SAC score compared with resting baseline measurements. Fifty-six healthy high school athletes (age range, 14-19 years) took part in 2 randomized testing sessions (rested versus postexercise). Paired t tests revealed no significant differences in mean SAC score (rest = 26.82 versus exerted = 26.38) between conditions (t1,55 = 1.73, P = .09). In addition, no significant differences were observed in any of the 4 component parts of the SAC. However, variability in individual scores fluctuated between testing conditions, suggesting that exertion may influence the efficacy of the SAC in this particular group of interscholastic athletes.

The Centers for Disease Control and Prevention (CDC) estimates that 1.6 to 3.8 million sport-related mild traumatic brain injuries occur in the United States each year.1 Common signs and symptoms of concussion include loss of consciousness, amnesia, headache, dizziness, nausea, balance impairment, and confusion. These injuries are relatively easy to detect when the athlete loses consciousness or experiences amnesia. Unfortunately, more than 90% of head injuries result in no observable loss of consciousness and 72% result in no amnestic symptoms with only slight disorientation, making diagnosis and treatment more difficult.2

Neurocognitive testing has been shown to be an effective tool in the sideline evaluation of concussion. The Standardized Assessment of Concussion (SAC) was developed by McCrea et al3 for use by athletic trainers, physicians, and other health professionals as a means of evaluating and quantifying mental status immediately following head injury. Previous investigators have validated the SAC as an accurate and reliable test for determining the presence of concussion.4-7 It is important to note that the SAC differs from the many commercially available neuropsychological test batteries that are designed to be used for the ongoing management of sport-related concussion.

Baseline neurocognitive tests are essential when the same postinjury tests are used to aid in the diagnosis of concussion.8 This allows the examiner to control for inherent differences in test performance among participants. Although baseline testing for the SAC is traditionally done with the athlete in a rested state, postinjury on-field evaluation is often performed immediately after physical activity or exercise. This difference in testing condition may affect the test results, in which case the testing timeline would need to be reevaluated.

Conflicting literature exists regarding whether exercise is facilitatory (beneficial) or inhibitory (detrimental) for neuropsychological function.9-14 Several studies have shown that short duration, high-intensity anaerobic exercise improves performance on cognitive tasks,10,13,14 whereas others have demonstrated a detrimental effect on neurocognitive function following anaerobic exer-
The variation in both the exercise intervention and the neurocognitive task administered in each of these studies makes it difficult to draw any definitive conclusions. Regardless, the research indicates that the SAC score may be affected by the level of exertional activity prior to traumatic head injury.9-14

Only 2 studies have examined the effects of exertion on concussion evaluation tools. Leclerc et al15 studied the effects of a 4-minute treadmill run at 80% of age-predicted maximal heart rate and performance on the McGill Abbreviated Concussion Evaluation (ACE) in collegiate athletes. The results were inconclusive in that scores from pretest to posttest did not change. Covassin et al9 studied the effects of a ramped treadmill run until volitional exhaustion and performance on the Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) (ImPACT Applications Inc, Pittsburgh, Pa) scores in 102 recreational athletes. Their results demonstrated a significant decrease in verbal memory scores following the exercise intervention.

Although the ImPACT test is used to measure neuropsychological function in injured and uninjured athletes, its length (approximately 25 minutes) and administration (computerized) make it an impractical sideline assessment tool. The SAC, although not as thorough, is a quick, easy, and widely used mental status examination designed to measure immediate neurocognitive effects of sport-related concussion. However, despite several studies validating the SAC as a reliable tool for evaluating concussion, there have not been any studies reporting the differences in test results at rest and following exercise. Therefore, the purpose of this study was to examine the effects of exertional exercise on the SAC score compared with resting baseline measurements. A better understanding of the effects of exertion on the SAC instrument will prove useful in providing clinicians with the most appropriate environment for establishing the baseline measurement and the timing of the postinjury concussion assessment. We hypothesized that the overall total SAC score would not significantly change following an acute bout of exertional exercise compared with resting baseline scores. This hypothesis is based on the previous work by Leclerc et al15 involving the McGill ACE, which reported no significant change in scores between testing conditions (rest versus exertion). The components of the McGill ACE are similar to those found as part of the SAC.

**METHOD**

**Participants**

A total of 56 (31 male, 25 female) high school student athletes ages 14 to 19 were recruited from a large metropolitan high school (Table 1).

For inclusion in the study, participants had to be healthy and free from injury at the time of the study and have no prior history of traumatic head injury (ie, concussion). All athletes had a complete and current Delaware Interscholastic Activities Association physical examination by a qualified health professional. Prior to testing, all participants completed and signed the approved consent form. Those participants who were minors had additional parental consent, as well as informed assent.

**Test Procedures**

The testing consisted of 2 sessions (A and B) separated by ≥1 week. On reporting to the school’s fitness center for the first session, participants were asked to complete 2 questionnaires to determine inclusion status. The Concussion and General Health History

**TABLE 1**

<table>
<thead>
<tr>
<th>Participant Descriptive Information</th>
<th>MIN</th>
<th>MAX</th>
<th>MEAN</th>
<th>SD</th>
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<tbody>
<tr>
<td>Age (y)</td>
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<td>19</td>
<td>16.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>150</td>
<td>193</td>
<td>171.1</td>
<td>10.0</td>
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<tr>
<td>Mass (kg)</td>
<td>45</td>
<td>136</td>
<td>69.4</td>
<td>16.5</td>
</tr>
<tr>
<td>Heart rate (bpm)a</td>
<td>173</td>
<td>207</td>
<td>186.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Treadmill time (min)b</td>
<td>9:56</td>
<td>16:30</td>
<td>11:17</td>
<td>1:12</td>
</tr>
</tbody>
</table>

a Maximum heart rate achieved during treadmill protocol
b Length of treadmill protocol
Questionnaire screened for current musculoskeletal injuries and prior history of concussion. The Physical Activity Readiness Questionnaire screened for cardiovascular risk factors. Individuals with current musculoskeletal injuries, prior history of concussion, or cardiovascular risk factors were excluded from participation. Participants were asked to refrain from exercise for 6 hours prior to each of the testing sessions. After the participant’s inclusion status was confirmed, a coin flip was used to randomize the order of the 2 testing sessions (described below as session A and session B). A total of 31 participants completed the rest condition first, whereas the remaining 25 participants completed the exertional condition initially.

**Session A.** A certified athletic trainer administered the SAC with the participant in a rested, nonexertional state. The “Neurological Screening” component of the SAC was not used. As a result, the time that elapsed between the “Immediate Memory” component and the “Delayed Recall” component was approximately 5 minutes. The test was administered in a quiet and climate-controlled room. Alternate forms A, B, and C of the SAC were used to minimize practice effects. Previous research has demonstrated the equivalence of these 3 forms. The version of the form used during the first testing session was chosen at random and was not used again during the second testing session. The participant’s overall total SAC score was recorded and used in the data analysis.

**Session B.** During this session, the participant completed an exercise task to volitional exhaustion on a treadmill (Nautilus Inc, Vancouver, Wash) prior to administration of the SAC (Figure 1). A modified ramp protocol described by Covassin et al was used. It began at a speed of 2.5 mph at a 0% incline. The speed increased 0.5 mph per minute until 6.0 mph was reached. Once 6.0 mph was achieved, the incline of the treadmill increased 3% per minute until volitional exhaustion occurred. A Polar heart rate monitor (Polar Electro Inc, Lake Success, NY) was used to obtain the heart rate every minute. Heart rate was monitored continuously throughout the treadmill protocol (Table 1). In addition, rating of perceived exertion was tracked using the Borg scale (Figure 2). The test ended when the participant achieved one of the following criteria: a rating of ≥19 (maximal exertion) on the Borg scale or a heart rate >90% of their age-predicted maximal heart rate.

Two minutes after the participant completed the treadmill task, the SAC was administered in a quiet and climate-controlled room. The brief time span was designed to mimic the time between initial injury and postinjury sideline assessment. The version of the SAC used during the second session was chosen at random from the 2 remaining forms that were not used during the first session. The participant’s overall total score was recorded and used in the data analysis.

**Data Analysis**
A two-tailed dependent t test was used to determine whether differences in SAC scores existed between the 2 testing sessions. Additional t tests were used to examine whether differences existed between any of the 4 component parts (ie, orientation, immediate memory, concentration, delayed recall) of the SAC; in both the nonexertional and exertional states. To minimize the risk of type II error, a Bonferroni correction was used. An alpha level of 0.01 was used to determine statistical significance for all analyses.

Individual difference scores were calculated by subtracting overall total SAC score at rest from overall total SAC score following exertion. Specificity refers to the probability that an individual without the condition will be correctly classified as not having the condition. It is calculated by adding the total number of participants who scored below a given value and dividing by the total number of participants. Higher specificity values indicate a more accurate and reliable assessment tool. Our specificity calculations were based on the previous study by McCrea.5

Power was calculated using means and standard deviations from the McCrea study. Using values from McCrea et al, the power was calculated to be 0.80 for all analyses.
Crea’s control group and the minimum difference needed to indicate a positive test result, we calculated statistical power involving 56 participants to be 0.93.

RESULTS

Standardized Assessment of Concussion Scores
Standardized Assessment of Concussion scores ranged from 16 to 30. There were no significant differences in the overall total SAC score between the exerted and rest conditions ($t_{1.55} = 1.73, P = .09$). The mean SAC score for the exerted condition was $26.38 \pm 2.28$, whereas the mean score for the rest condition was $26.82 \pm 1.90$. Additional analysis involving the 4 component parts of the SAC also demonstrated no significant differences between conditions for orientation ($t_{1.55} = 1.30, P = .20$), immediate memory ($t_{1.55} = 0.32, P = .75$), concentration ($t_{1.55} = -0.14, P = .89$), or delayed recall ($t_{1.55} = 2.55, P = .01$) (Table 2).

Difference Scores
To examine variability in individual participant’s scores between conditions, difference scores were calculated. As reported previously by McCrea and by Barr and McCrea, these difference scores were determined by subtracting resting scores from exertional scores. Difference scores ranged from $-6$ to $+3$ and are provided in Table 3. Specificity values are also displayed in Table 3.

DISCUSSION
The main finding in the current study was that an acute bout of exertional exercise did not significantly affect SAC scores. These findings are in agreement with Leclerc et al, who reported no significant change in score on the McGill ACE following 4 minutes of treadmill running at 80% of age-predicted maximal heart rate. The McGill ACE is similar to the SAC in that it is designed to be a brief neurocognitive test as part of the sideline assessment and contains tasks assessing memory orientation, immediate memory, concentration, and delayed recall. Our findings are also consistent with several other studies that demonstrated no change in performance of various cognitive tasks following exertion.

However, the findings of the current study differ from those of Covassin et al, who reported a significant decrease in verbal memory scores on the ImPACT test following a similar exercise intervention. It is important to note that although we did not find a significant change in score for any of the 4 component parts that comprise the SAC, we did observe a decrease in delayed recall score during the postexertion SAC test that approached significance (rest = 4.21, exertion = 3.91, $t = 2.55, P = .01$). These conflicting findings can most likely be attributed to differences between the SAC and the ImPACT tests. The SAC is designed to be a quick diagnostic tool (mental status examination) for use on the sideline. The immediate memory component consists of just 5 words that the participant is asked to repeat 3 times. The participant is then asked to recall these same words at the end of the test, approximately 5 minutes later. The ImPACT test is a longer, more thorough neuropsychological test designed for the ongoing management of sport-related concussion. For the immediate memory portion of the ImPACT, the participant is shown a series of 12 words and then asked to discriminate between these words and other words not shown. This procedure is performed a second time at the end of the test battery (approximately 15 minutes) and is used to determine the delayed recall score. The immediate memory and delayed recall components incorporated...
in both the SAC and ImPACT tests, although similar in nature, do not measure the same mental construct, likely accounting for the differences in scores between the 2 tests.

The underlying neurophysiological changes caused by exertion and that may affect cognition remain unclear. Shibuya et al.\textsuperscript{19,20} found decreases in cerebral oxygenation during supramaximal exercise and speculated that exhaustive exercise can decrease cerebral function. Ogoh et al.\textsuperscript{21} studied cerebral blood flow following exercise. Their results suggested that dynamic cerebral autoregulation becomes less effective in response to rapid decreases in blood pressure during the initial 10 minutes of recovery from dynamic exercise. Others have examined the effects of exercise-induced dehydration on cognitive function with mixed results. Cian et al.\textsuperscript{22} observed that dehydration impaired cognitive abilities, whereas Patel et al.\textsuperscript{23} found no differences in neurocognitive function between dehydrated and euhydrated states. Further studies are needed before any definitive conclusions can be made about the neurophysiological changes during exercise and the effects these may have on cognition.

The current study suggests that exertional state does not affect SAC score and, therefore, reliable baseline and postinjury scores can be collected from the athlete both preactivity and postactivity. Although the recommended strategy is to obtain baseline scores during physical activity,\textsuperscript{4,5} this may not always be feasible in the high school setting, where a single athletic trainer is responsible for assessing many athletes. The potential ability to effectively use the SAC under different exertional conditions is important because the postinjury assessment is typically performed with the athlete in an exerted state, whereas baseline testing is most easily and efficiently done at rest.

Although we did not observe a significant difference in mean scores between conditions, we did find variability in individual participant scores. Only 16% (9 of 56) of the participants had no change in score, whereas 46% (26 of 56) showed a decrease of \( \geq 1 \) point when tested following exertion. Barr and McCrea\textsuperscript{4} and McCrea\textsuperscript{5} studied the efficacy of the SAC and reported that only 24% of uninjured controls decreased in total SAC score by \( \geq 1 \) point between testing sessions. These findings led them to conclude that a drop of \( \geq 1 \) point is 76% specific in correctly classifying injured and uninjured participants. However, the findings of the current study revealed that a drop of \( \geq 1 \) point between scores collected at rest and postexertion was only 54% specific. This can be interpreted as 54 of 100 from such a population would be correctly categorized as not having a concussion. Conversely, a 54% specificity value results

\begin{table}[h]
\centering
\caption{Standardized Assessment of Concussion Score Between Conditions (N = 56)}
\begin{tabular}{llll}
\hline
 & MEAN & SD & t & P \\
\hline
Total score & & & & \\
Rest & 26.82 & 1.90 & & \\
Exerted & 26.38 & 2.28 & 1.73 & .09 \\
Orientation & & & & \\
Rest & 4.93 & 0.26 & & \\
Exerted & 4.84 & 0.42 & 1.30 & .20 \\
Immediate memory & & & & \\
Rest & 14.39 & 1.00 & & \\
Exerted & 14.32 & 1.22 & 0.32 & .75 \\
Concentration & & & & \\
Rest & 3.29 & 1.30 & & \\
Exerted & 3.30 & 1.19 & -0.14 & .89 \\
Delayed recall & & & & \\
Rest & 4.21 & 0.91 & & \\
Exerted & 3.91 & 1.12 & 2.55 & .01 \\
\hline
\end{tabular}
\end{table}

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in 46 of 100 incorrectly classified as having a concussion and suggests that although exertion does not significantly affect the mean SAC score, it does increase the variability in individual participant scores, leading to an increase in false-positive results. It should be noted that a false-positive test score on the SAC would result in a more conservative approach to treatment and return-to-play consideration. Although athletic trainers and parents may appreciate more conservative measures, a high misclassification rate might not be acceptable to coaches and players eager to return to competition. It is also interesting to note that 21 of 56 participants (37%) increased their SAC score postexertion. This may be another indication of and lends support to the fact that variability in SAC scores due to exertion can result in both increases and decreases in neurocognition. Although our study did not include participants with concussions, this finding is something that clinicians should be aware of. We are careful to suggest that this could potentially lead to a false-negative SAC score compared with baseline, indicating no concussion when in fact there may be one. Therefore, it is our recommendation that in the event that baseline and postinjury SAC scores are collected under different exertional conditions, clinicians should shift from using the SAC quantitatively to using it more qualitatively. Specifically, we suggest placing less emphasis on the numerical SAC score and more emphasis on using the components of the SAC to acutely evaluate neurocognition (ie, orientation, memory, concentration).

It is well documented that the SAC is not intended for use as a stand-alone tool for sideline concussion assessment but instead should be part of a larger framework for examining athletes with head injuries, allowing implementation of proper injury management strategies, and permitting more informed decisions on return to play. The National Athletic Trainers’ Association position statement, Management of Sport-Related Concussion, recommends using a combination of brief screening tools (eg, SAC, Balance Error Scoring System, symptom checklist) designed to identify deficits caused by injury and postinjury recovery and protect players from the potential risks associated with prematurely returning to competition and sustaining a repeat concussion. More recently, Broglio et al reported that findings from multiple assessment techniques, such as self-reported symptoms, postural control, and neurocognitive performance, should be incorporated into a concussion assessment protocol. No single assessment technique should be used to the exclusion of the others or the physical examination.

The mean SAC score demonstrated by participants in this study is similar to those seen in previous studies in middle school, high school, and collegiate athletes. A practice effect was not observed in this study and is in agreement with previous research using repeated SAC testing.

**Table 3**

<table>
<thead>
<tr>
<th>Difference Score</th>
<th>No. of Participants</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>0.04</td>
</tr>
<tr>
<td>1</td>
<td>13</td>
<td>0.14</td>
</tr>
<tr>
<td>0</td>
<td>9</td>
<td>0.44</td>
</tr>
<tr>
<td>-1</td>
<td>10</td>
<td>0.54</td>
</tr>
<tr>
<td>-2</td>
<td>8</td>
<td>0.71</td>
</tr>
<tr>
<td>-3</td>
<td>4</td>
<td>0.86</td>
</tr>
<tr>
<td>-4</td>
<td>3</td>
<td>0.93</td>
</tr>
<tr>
<td>-5</td>
<td>0</td>
<td>0.98</td>
</tr>
<tr>
<td>-6</td>
<td>1</td>
<td>0.98</td>
</tr>
</tbody>
</table>

*Exertional SAC score minus the resting SAC score.*

**Limitations**

The main limitation of this study is the lack of a true control group. It would have been ideal to include a group that had the SAC administered twice under the same conditions to compare with the experimental group. We also acknowledge that a treadmill test to volitional exhaustion in a controlled environment does not use the same functional strategies seen during actual competition and practice. Participants were instructed to give maximal effort during both testing sessions, but this could not be assured. We acknowledge that the generalizability of our study is limited in that our exertional protocol may be applicable to only a certain subset of athletes who participate in high-intensity sports. The variability in exertional levels seen across and within sports makes it difficult to control for in the laboratory setting; therefore, the
recommendations presented here must be carefully applied to the athletic population as a whole. In addition, variables such as hours of sleep and participant fitness levels were not controlled for in this study. Hydration status also was not controlled for, but it has been shown to have no effect on SAC score.  

**CONCLUSION**

This study examined the effects of an acute bout of exertional exercise on neurocognitive function in an attempt to help sports medicine professionals administer and interpret SAC scores and make return-to-play decisions. We did not find a significant difference between mean SAC scores following a graded treadmill test in healthy individuals. Variability in individual scores fluctuated between testing conditions, suggesting that exertion may influence the efficacy of the SAC. Further studies should be conducted to examine the effects of exertion on cognitive function by using protocols directly related to sport-specific activity and the fatigue associated with it.

**REFERENCES**

29. Valovich TC, Perrin DH, Gansneder BM. Repeat administration elicits a practice effect with the balance error scoring system but not with the standardized assessment of concussion in high school athletes. *J Athl Train.* 2003;38:51-56.