Effect of a High-Intensity Intermittent-Exercise Protocol on Neurocognitive Function in Healthy Adults: Implications for Return-to-Play Management After Sport-Related Concussion

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Context: Determination of return to play (RTP) after sport-related concussion (SRC) is critical given the potential consequences of premature RTP. Current RTP guidelines may not identify persistent exercise-induced neurocognitive deficits in asymptomatic athletes after SRC. Therefore, postexercise neurocognitive testing has been recommended to further inform RTP determination. To implement this recommendation, the effect of exercise on neurocognitive function in healthy athletes should be understood. Objective: To examine the acute effects of a high-intensity intermittent-exercise protocol (HIIP) on neurocognitive function assessed by the Symbol Digits Modality Test (SDMT) and Stroop Interference Test. Design: Cohort study. Setting: University laboratory. Participants: 40 healthy male athletes (age 21.25 ± 1.29 y, education 16.95 ± 1.37 y). Intervention: Each participant completed the SDMT and Stroop Interference Test at baseline and after random allocation to a condition (HIIP vs control). A mixed between-within–subjects ANOVA assessed time- (pre- vs postcondition) -by-condition interaction effects. Main Outcome Measures: SDMT and Stroop Interference Test scores. Results: There was a significant time-by-condition interaction effect (P < .001, η² = .364) for the Stroop Interference Test scores, indicating that the HIIP group scored significantly lower (56.05 ± 9.34) postcondition than the control group (66.39 ± 19.6). There was no significant time-by-condition effect (P = .997, η² < .001) for the SDMT, indicating that there was no difference between SDMT scores for the HIIP and control groups (59.95 ± 10.7 vs 58.56 ± 14.02). Conclusions: In healthy athletes, the HIIP results in a reduction in neurocognitive function as assessed by the Stroop Interference Test, with no effect on function as assessed by the SDMT. Testing should also be considered after high-intensity exercise in determining RTP decisions for athletes after SRC in conjunction with the existing recommended RTP protocol. These results may provide an initial reference point for future research investigating the effects of an HIIP on the neurocognitive function of athletes recovering from SRC.

Keywords: fatigue, Stroop test, SDMT

Determination of return to play (RTP) after sport-related concussion (SRC) is critical given the potential consequences of premature RTP, including lower neurocognitive function and an increased risk of further concussive/severe brain injury.1 Current best RTP practice involves both comparing preseason with postconcussive computerized neurocognitive scores at rest and employing a monitored, graded RTP protocol1 during which the athlete subjectively reports symptom status. This approach faces a number of challenges. First, reliance on patient-reported symptoms may not be appropriate, as neurocognitive deficits persist in otherwise asymptomatic athletes post-SRC, with tests such as the Stroop Interference Test and Symbol Digits Modality Test (SDMT) sensitive to these deficits.2 Second, exercise induces neurocognitive deficits in asymptomatic athletes who were previously concussed but subsequently cleared to RTP after completion of the recommended protocol.3 This suggests that a period of exercise-induced cerebral dysfunction and vulnerability persists beyond the symptomatic period, making such athletes more vulnerable to injury should they RTP at this point.2 Therefore, as neurocognitive tests are sensitive to subtle neurocognitive deficits after the resolution of concussive symptoms,2 it has been proposed that neurocognitive tests be conducted immediately after sports-specific exercise3 that mimics the high-intensity exercise of field sports where concussions are common. The computer dependence and time requirement of neurocognitive testing may limit its applicability in assessing the acute effects of exercise.4 On the other hand, the Stroop Interference Test5,6 and
SDMT\textsuperscript{7,8} are commonly used in concussion research and assessment, reliable,\textsuperscript{5} inexpensive, quick to administer, and suitable for serial neurocognitive testing\textsuperscript{5}; as such, they may be suitable to assess the acute effect of exercise on neurocognitive function after SRC.

As exercise induces findings similar to SRC, such as decline in computerized neurocognitive testing\textsuperscript{3} and the manifestation of concussive-like symptoms,\textsuperscript{9} in healthy athletes, the acute effect of exercise on neurocognitive function in healthy subjects should be understood to facilitate appropriate RTP decisions after SRC. This study aimed to investigate the effect of a high-intensity intermittent-exercise protocol (HIIP) on neurocognitive function as assessed by the SDMT and Stroop Interference Test. Whereas moderate-intensity exercise positively affects neurocognitive function,\textsuperscript{10,11} high-intensity exercise negatively affects neurocognitive function.\textsuperscript{12–14} Therefore, we hypothesized that the HIIP would have a negative effect on test scores.

**Methods**

**Participants**

Forty male university athletes participated in the study (age 21.25 ± 1.29 y, education 16.95 ± 1.37 y). Participants were excluded if they had previously taken the SDMT or Stroop Interference Test or were color-blind, injured, previously concussed, or taking medication that might affect their neurocognitive ability. Participants refrained from exercise and alcohol and caffeine consumption for 24 hours before testing. Approval was granted by the relevant research ethics committee.

Participants were required to attend on 2 separate occasions. Initially they underwent a familiarization session with demonstration of the HIIP protocol. After a 2- to 5-day interval, participants returned for SDMT and Stroop Interference testing. Twenty participants each were randomly assigned to the control (age 21.24 ± 1.25 y, education 17 ± 1.41 y) and HIIP (age 21.05 ± 1.33 y, education 16.89 ± 1.33 y) groups. They were directly matched across groups by their field sports, which included Gaelic football, hurling, and rugby.

**Procedures**

The SDMT and Stroop Interference Test were administered at baseline. Participants in the intervention group completed a 5-minute dynamic warm-up followed by the HIIP. The HIIP was discontinued when participants reported 18 on the Borg rating-of-perceived-exertion scale. Within 15 seconds of completion, the SDMT or Stroop Interference Test was readministered (in a random order). After this, participants completed further HIIP circuits until they again reported 18 on the Borg scale and then completed the other of the 2 tests. Control participants were administered the tests at the same time as the intervention participants. Tests were administered in a random order.

The HIIP (Figure 1) consisted of a 5-m forward sprint, a 90° angle change of direction, another 5-m forward sprint, and then a 5-m buckpedal. This was

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**Figure 1** — The high-intensity intermittent-exercise protocol.
repeated 4 times before completing 5 two-legged jumps over hurdles (30-cm height) and then turning and repeating another 5 times. Participants then performed side-stepping exercises over the hurdles before 4 lateral shuffles back and forth of 5 m each. Participants were instructed to complete these drills as quickly as possible. This protocol would relate to the third rehabilitation stage (sport-specific exercise) on the RTP guidelines after SRC. Circuit time was recorded using infrared timing gates (Brower, USA). After circuit completion, participants rested for 30 seconds before repeating the circuit. Heart rate was monitored using a Polar heart-rate monitor.

The Stroop Interference Test assesses frontal-lobe executive function because of the inhibitory control it requires. It consists of a list of printed color names that are different from the color in which they are printed. Participants were given 45 seconds to state aloud the ink color rather than the printed word. The score was calculated as the number of correct responses in 45 seconds. The SDMT assesses the parietal- and frontal-lobe functions of attention and information-processing speed. This pen-and-paper task involved the pairing of numbers to symbols in a series of boxes in lines of 15. The score was calculated as the number of correct responses in 90 seconds. In both tests, higher scores represent better neurocognitive function.

**Statistical Analysis**

The main aim of the study was investigated using a mixed between-within analysis of variance to assess any time-(precondition vs postcondition) -by-condition (HIIP vs control) interaction effect. The dependent variables analyzed were Stroop Interference Test and SDMT scores. Effect sizes (partial-eta squared) were calculated and ranked using the Cohen classification (.01 = small, .06 = moderate, .14 = large effects). Paired-sample t tests compared the first and final HIIP circuit completion times and resting and post-HIIP heart rates. SPSS statistical analysis software (SPSS version 17.0) was used for all analyses, with the level of statistical significance set at P < .05.

**Results**

Regarding the primary aim of the study, there was a significant time-by-condition interaction with a large effect size for the Stroop Interference scores (Lambda = 0.64, F1,38 = 21.77, P < .001, η2 = .364), indicating that the HIIP resulted in significantly lower Stroop Interference Test scores (Table 1). There was a significant main effect for time for the Stroop Interference Test scores (Lambda = 0.61, F1,38 = 23.9, P = .001, η2 = .386), indicating that there was a significant increase postcondition. There was no significant effect for condition for the Stroop Interference Test scores (F1,38 = 1.96, P = .169, η2 = .049), indicating that there was no significant difference between conditions. There was a significant main effect for time for the SDMT (Lambda = .829, F1,38 = 7.84, P = .008, η2 = .171), indicating that there was a significant increase postcondition (Table 1). However, there was no significant time-by-condition interaction effect (Lambda = 1.0, F1,38 = 0.000, P = .997, η2 = .000), indicating that the HIIP did not have any effect different than rest. There was no significant effect for condition for the Stroop Interference Test scores (F1,38 = 0.645, P = .427, η2 = .017), indicating that there was no significant difference between conditions.

Participants completed on average 6.58 (± 0.81) circuits of the HIIP with an average heart rate of 188.03 ± 7.03 beats/min, or 94.6% ± 3.5% of maximum predicted heart rate at completion, versus 63.12 ± 6.91 beats/min at rest (Table 2). Circuit completion times increased significantly (P < .001) from the initial to final circuit (51.09 ± 2.61 vs 54.23 ± 2.12 s, respectively).

**Discussion**

There is a need to understand the effect of exercise on neurocognitive capacity in healthy individuals to facilitate future research examining the effect of exercise on neurocognitive function in athletes after SRC. The hypothesis of the current study that a HIIP would have a negative effect on neurocognitive function in healthy adults was

**Table 1** Precondition and Postcondition Stroop Interference Test (SIT) and Symbol Digit Modalities Test (SDMT) Scores, Mean ± SD, and Effect Sizes of Main and Interaction Effects

<table>
<thead>
<tr>
<th></th>
<th>Group</th>
<th>Main Effect</th>
<th>Time-by-Exercise Interaction</th>
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<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Exercise</td>
<td>Condition</td>
</tr>
<tr>
<td>Test</td>
<td>Pre (SD)</td>
<td>Post (SD)</td>
<td>Pre (SD)</td>
</tr>
<tr>
<td>SIT</td>
<td>54.89 ± 15.36</td>
<td>66.39 ± 19.6</td>
<td>55.76 ± 10.48</td>
</tr>
<tr>
<td>SDMT</td>
<td>53.06 ± 11.5</td>
<td>58.56 ± 14.02</td>
<td>55.86 ± 7.51</td>
</tr>
</tbody>
</table>

Note: ES indicates effect size (partial eta-squared value).

*a* Difference between high-intensity intermittent-exercise and control conditions, *b* Difference between precondition and postcondition, *c* Group differences for precondition and postcondition.
of the current study demonstrate that in healthy athletes needs to be understood. The results from neurocognitive testing, the effect of exercise on such tests is assessed by the Stroop Interference Test, whereas the SDMT assesses both frontal- and parietal-lobe activity. The HIIP resulted in fatigue as evident as assessed by the Stroop Interference Test but not the SDMT. This partially supports previous studies that found that high-intensity exercise negatively affects neurocognitive function. The HIIP resulted in fatigue as defined as an exercise-induced decline of performance, indicated by the significant increase in lap completion times. Therefore, the results from this study may only be applicable to high-intensity-exercise protocols that induce fatigue. It must also be noted that although all participants were varsity athletes, they may have had differing levels of fitness, which might have affected their response to the HIIP and affected the results.

The baseline neurocognitive-test scores in the current study are similar to previously reported scores for the SDMT and Stroop Interference Test. The results of the current study support previous research that found the Stroop Interference Test sensitive to the effects of fatigue. They also support previous studies demonstrating that fatigue does not affect processing speed and reaction-time elements of computerized neurocognitive function, which correlate highly with SDMT scores. These results may be explained by the transient-hypofrontality hypothesis, which states that exercise of a sufficient intensity may require frontal-lobe resources, impairing frontal executive function. Previous studies have demonstrated that exercise intensities resulting in greater than 60% and 80% maximum heart rate lead to impaired frontal-lobe executive function. This suggests that the observed 94% maximum heart rate in the current study may impair frontal-lobe executive function, which is assessed by the Stroop Interference Test, whereas the SDMT assesses both frontal- and parietal-lobe activity.

Currently, RTP decisions incorporating neurocognitive scores at rest and a monitored, graded RTP protocol do not detect exercise-induced neurocognitive deficits in otherwise asymptomatic athletes after SRC. Therefore, it is recommended that determination of RTP after SRC be further informed by postexercise neurocognitive testing. To accurately determine RTP using postexercise neurocognitive testing, the effect of exercise on such tests in healthy athletes needs to be understood. The results of the current study demonstrate that in healthy athletes SDMT scores should improve when tested post-HIIP in comparison with pre-HIIP testing, while Stroop Interference Test scores should remain unchanged. Clinically, this indicates that an HIIP should not result in SDMT and Stroop Interference Test scores falling below baseline in healthy athletes. However, residual dysfunction from concussion may become apparent after such exercise. These results may provide an initial reference point for future studies investigating the effects of an HIIP on the neurocognitive function of athletes recovering from SRC.

### Conclusion

High-intensity exercise negatively affects aspects of neurocognitive function, specifically the frontal executive function as measured by the Stroop Interference Test. In addition to the currently recommended RTP protocol after SRC, the proposed neurocognitive testing immediately after sport-specific exercise should be conducted after high-intensity exercise. Future research should also examine the acute effects of exercise on such neurocognitive test scores in athletes recovering from SRC.

### References


