The Effect of Pretest Exercise on Baseline Computerized Neurocognitive Test Scores

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Background: Baseline neurocognitive assessment plays a critical role in return-to-play decision making following sport-related concussions. Prior studies have assessed the effect of a variety of modifying factors on neurocognitive baseline test scores. However, relatively little investigation has been conducted regarding the effect of pretest exercise on baseline testing.

Purpose/Hypothesis: The aim of our investigation was to determine the effect of pretest exercise on baseline Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) scores in adolescent and young adult athletes. We hypothesized that athletes undergoing self-reported strenuous exercise within 3 hours of baseline testing would perform more poorly on neurocognitive metrics and would report a greater number of symptoms than those who had not completed such exercise.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: The ImPACT records of 18,245 adolescent and young adult athletes were retrospectively analyzed. After application of inclusion and exclusion criteria, participants were dichotomized into groups based on a positive (n = 664) or negative (n = 6609) self-reported history of strenuous exercise within 3 hours of the baseline test. Participants with a positive history of exercise were then randomly matched, based on age, sex, education level, concussion history, and hours of sleep prior to testing, on a 1:2 basis with individuals who had reported no pretest exercise. The baseline ImPACT composite scores of the 2 groups were then compared.

Results: Significant differences were observed for the ImPACT composite scores of verbal memory, visual memory, reaction time, and impulse control as well as for the total symptom score. No significant between-group difference was detected for the visual motor composite score. Furthermore, pretest exercise was associated with a significant increase in the overall frequency of invalid test results.

Conclusion: Our results suggest a statistically significant difference in ImPACT composite scores between individuals who report strenuous exercise prior to baseline testing compared with those who do not. Since return-to-play decision making often involves documentation of return to neurocognitive baseline, the baseline test scores must be valid and accurate. As a result, we recommend standardization of baseline testing such that no strenuous exercise takes place 3 hours prior to test administration.

Keywords: sport-related concussion; exercise; neurocognitive assessment; ImPACT

An estimated 1.6 to 3.8 million sports-related concussions (SRCs) occur in the United States annually.[16] Furthermore, the occurrence of SRC increased at an annual rate of approximately 7.0% in collegiate athletes from 1988 to 2004.[12] More recent studies have shown an SRC incidence rate of 0.24 per 1000 athlete-exposures among high school athletes and 0.447 per 1000 athlete-exposures among National Collegiate Athletic Association (NCAA) athletes.[18,26] While some of this increase may be attributed to better monitoring for and recognition of SRC, the rates may also reflect a true increase in the incidence of SRC.[5]

In light of the increasing incidence of concussion and the potential consequences of premature return to play (RTP) following SRC, the Concussion in Sport Group has recommended a multidimensional approach to concussion management, including resolution of self-reported symptoms, return to baseline neurocognitive and balance functioning, and completion of a graduated program of exertional physical activity (without symptom recurrence) prior to RTP.[21] Although current guidelines do not mandate neurocognitive or any other baseline testing, such baseline tests can aid in determination of neurocognitive status and other recovery parameters (eg, symptoms, postural stability) as well as RTP decisions. However, if such baseline tests are to be used effectively by clinicians, knowledge is needed

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regarding factors that affect baseline test scores. Factors such as age,[10] sex,[3] education level,[6] amount of sleep during the night before,[20] prior concussions,[2] and learning disabilities or attention-deficit/hyperactivity disorder (ADHD)[8,27] have all been shown to affect neurocognitive test scores. Age,[10] sex,[3] education level,[6] and prior concussions[2] are likely to apply most as modifying factors between groups with regard to the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) baseline scores and neurocognitive recovery. The amount of sleep prior to testing[20] and the presence of learning disabilities or ADHD[8,27] are likely to add intertest variability at the individual level.

In contrast, relatively little research has been conducted into the effect of pretest strenuous exercise on neurocognitive baseline testing in athletes. Covassin et al[4] investigated the effect of maximal exercise in recreational (nonvarsity) college-age athletes and showed a lowered verbal memory score following exercise. In that study, "maximal exercise" was measured by a treadmill test of increasing speed and incline until volitional exhaustion was reached. During the process, oxygen consumption and heart rate were monitored to verify the intensity of the exercise. Of note, the study had a limited sample size (N = 54), and the exercise was prescribed and may not have reflected the duration and intensity of routine exercise undertaken by athletes prior to baseline testing.

Leclerc et al[17] evaluated the effect of a treadmill test (4 minutes at 80% of maximal heart rate) on the McGill Abbreviated Concussion Evaluation (a baseline neurocognitive test) in varsity collegiate athletes. The investigators found no significant differences in pre- and postexercise scores. Furthermore, meta-analyses of the effect of exercise on cognitive testing in general (not sports-specific) have shown a small positive effect (0.097-0.2) of exercise on cognitive test results.[1,15] However, these meta-analyses involved a wide range of populations, categories of exercise, and cognitive tests assessed and, as a result, are less generalizable to the population of young adult and adolescent athletes undergoing ImPACT baseline testing.

A more recent study by Hall et al[11] investigated the effect of self-reported strenuous exercise 3 hours prior to baseline ImPACT testing in NCAA Division I collegiate athletes. "Strenuous exercise" is a partly defined parameter assessed in the medical history section of ImPACT; the subject is asked to report whether he or she has engaged in strenuous exercise in the 3 hours prior to taking the ImPACT test. Hall et al analyzed strenuous exercise as one of several potential modifying factors and found no significant effect on neurocognitive or total symptom scores.

Given the paucity of literature and the importance of obtaining accurate baseline neurocognitive test results for comparison in the event of an SRC, the purpose of this investigation was to determine whether strenuous exercise (as listed as a parameter in ImPACT) prior to baseline neurocognitive testing in young adult athletes is associated with differences in ImPACT test results. The secondary purpose of this study was to make an evidence-based recommendation as to whether strenuous exercise should be restricted prior to baseline neurocognitive testing.

METHODS

ImPACT

ImPACT is a computerized neurocognitive test designed specifically for SRC. ImPACT provides information regarding demographics, neurocognitive indices, and self-reported concussion symptoms. The demographics section contains a questionnaire regarding the athlete's age, sex, education level, number of prior concussions, hours of sleep prior to testing, whether any strenuous exercise occurred within 3 hours of testing, current medications, and neuropsychiatric, neurosurgical, and seizure histories. The neurocognitive assessment consists of 6 sections that produce composite scores of verbal memory, visual memory, visual motor (processing) speed, reaction time, and impulse control (the latter index serving as a test validity check and reflects the number of unforced errors). Self-reported concussion symptoms are assessed by the Post-Concussion Symptom Scale (PCSS). The PCSS covers 22 self-reported concussion symptoms, each rated on a 7-point (0-6) Likert scale. ImPACT has been shown to be reliable[9,13,23] and valid[14,24] for the assessment of SRCs.

Participant Selection

The student-athletes selected for this study were chosen from a regional sports concussion center database of 18,245 subjects who had undergone baseline testing from 2009 to 2015. The inclusion criteria consisted of (1) age between 14 and 23 years; (2) participation in middle school, high school, or collegiate athletics (defined as grades 6-16); (3) English as the student-athlete's primary language; and (4) complete and valid baseline ImPACT data. The validity of the ImPACT neurocognitive data was determined by ImPACT's internal algorithms.[19] Patients with invalid baseline ImPACT neurocognitive data (n = 225) were included only to determine the frequency of invalid baselines and were otherwise excluded from analysis for the primary outcome of interest. Of the initial 18,245 subjects, 14,351 met the inclusion criteria. Exclusion criteria consisted of (1) failure to specify whether strenuous exercise occurred prior to testing (n = 1967); (2) failure to complete demographics in fields used to match groups (n = 3267); (3) self-reported history of ADHD, learning disability, autism spectrum disorder, or dyslexia (n = 1043); (4) self-reported history of special education, speech therapy, or having repeated a grade (n = 688); (5) self-reported treatment for alcohol abuse (n = 10); and (6) self-reported use of antidepressants, antipsychotics, stimulants, antiseizure medications, benzodiazepines, or opioids (n = 103). After application of inclusion and exclusion criteria, a total of 7273 participants were selected for inclusion in this study, of whom 664 (9.13%) had undergone strenuous exercise prior to baseline testing and 6609 had not.

Data Collection

After informed written consent was obtained (from the student-athlete or parent/guardian), the online version of

TABLE 1
Biopsychosocial Profiles of Pretest
Exercise and Control Groups

	Exercise (n = 664)	Control (n = 1328)	P^a
Age, y, mean ± SD	15.90 ± 1.907	15.90 ± 1.798	.501
Sex, % male	69.1	69.1	≤.999
Education level, y, mean ± SD	9.73 ± 1.788	9.73 ± 1.679	.573
No. of prior concussions, mean ± SD	0.33 ± 0.690	0.31 ± 0.616	.581
Hours of sleep, mean ± SD	7.352 ± 1.4956	7.415 ± 1.3784	.155

[a]Mann-Whitney U test used for continuous variables; chi-square test used for categorical variable.

ImPACT was administered for routine baseline purposes. This test administration was typically done in a controlled group setting and under the supervision of sports medicine personnel trained in ImPACT administration. ImPACT scores, along with self-reported biopsychosocial data (age, sex, years of education, hours of sleep the night before testing, engagement in strenuous exercise within 3 hours of test administration, and history of concussion, psychiatric condition, ADHD, and learning disability), were extracted from a regional sports concussion center database containing deidentified ImPACT test results. Institutional review board exemption was obtained for this study.

Matching

A matching process was used to control for the potential confounders of age, sex, education level, prior concussions, and hours of sleep prior to testing. These factors were chosen for the matching process because they have been shown in prior studies to significantly affect baseline ImPACT results.[2,3,6,10,20] The athletes who had a self-reported history of strenuous exercise within 3 hours of ImPACT test administration (exercise group; n = 664) were randomly matched in a 1:2 ratio to athletes who had self-reported no strenuous exercise prior to testing (control group; n = 1328). Statistical analysis revealed no significant differences between the variables used to match the groups, thus indicating a successful matching process (Table 1).

Statistical Analysis

Continuous variables are reported as mean ± standard deviation, and categorical variables are reported as percentages. When the dataset was tested for normalcy by use of the Shapiro-Wilk test, the data were found to be nonparametric. Because of this, Mann-Whitney U tests were used instead of 2-tailed t tests in the analysis of continuous matching variables and ImPACT composite scores. The comparison of categorical matching variables and the occurrence of invalid results between the matched groups were assessed by use of the chi-square test. Due to unequal group sizes, the Hedges g was used to assess effect sizes.

TABLE 2
ImPACT Composite Scores of Pretest
Exercise and Control Groups[a]

ImPACT Composite Score	Exercise	Control	P^b	Hedges g^c
Verbal memory	84.06 ± 10.532	85.52 ± 9.548	.009	–0.148
Visual memory	74.15 ± 13.398	75.92 ± 12.863	.005	–0.136
Visual motor	36.944 ± 6.675	37.6815 ± 6.773	.051	–0.109
Reaction time	0.6303 ± 0.108	0.6137 ± 0.0851	.001	0.177
Impulse control	6.61 ± 4.880	5.85 ± 4.243	.002	0.170
Total symptom score	4.86 ± 8.253	2.84 ± 6.104	<.0001	0.293

[a]Scores for exercise and control groups expressed as mean ± SD. ImPACT, Immediate Post-Concussion Assessment and Cognitive Testing.
[b]From Mann-Whitney U test.
[c]Cohen d corrected for unequal size between groups.

A significance level of $\alpha = .05$ was selected a priori for all statistical analyses. The final dataset did not contain any individuals with missing data points in the fields used in the analyses. Analysis was performed with IBM SPSS statistics software version 24.0.

RESULTS

When compared with the control group (matched on age, sex, education level, prior concussions, and hours of sleep prior to testing), athletes with a history of self-reported strenuous exercise within 3 hours of baseline testing had significantly decreased scores on verbal memory (84.06 vs 85.52, $P = .009$, Hedges $g = -0.1476728$) and visual memory (74.15 vs 75.92, $P = .005$, Hedges $g = -0.1356979$). Furthermore, athletes with pretest strenuous exercise had a significantly slower reaction time score (0.6303 vs 0.6137, $P = .001$, Hedges $g = 0.17743062$), a higher impulse control score (6.61 vs 5.85, $P = .002$, Hedges $g = 0.1702001$), and greater total symptom score (4.86 vs 2.84, $P < .0001$, Hedges $g = 0.29298033$). No significant between-group difference was detected in the visual motor score (Table 2). Additionally, a significantly higher frequency of invalid baseline testing (4.46% vs 2.44%, $P = .013$) occurred within the exercise group compared with the control group.

DISCUSSION

For many health professionals, the return of an athlete to his or her baseline neurocognitive status plays an important role in RTP decisions following SRC. This emphasis necessitates the acquisition of valid neurocognitive test baselines. Our aim

was to investigate the effect of self-reported strenuous exercise prior to the administration of baseline neurocognitive testing. Significant differences were noted in verbal memory, visual memory, reaction time, impulse control, and total symptom scores, indicating that strenuous exercise prior to baseline neurocognitive testing may alter baseline test results. However, the effect size of these differences was small, as determined by the Hedges g. Traditionally, effect sizes around 0.2 are considered small, those around 0.5 are considered medium, and those 0.8 or higher are considered large.[7] This stratification of effect sizes comes with the caveat that such interpretation must be conducted in light of the field of study and clinical context. When compared with the effect size of test-retest variability of ImPACT testing, the effect of exercise shows differences in both magnitude and direction of effect sizes. Strenuous exercise prior to baseline testing tends to have a small negative effect on the verbal memory, visual memory, and visual motor composite scores, while the effect size of repeat testing in a similar population at 1 and 2 years is small and positive.[9,23] With regard to the composite scores of reaction time and total symptom score, the effect size of exercise prior to testing is small and positive while the effect size of repeat testing is small and negative.[9,23] Furthermore, strenuous exercise prior to administration of baseline testing was associated with a significant increase in the incidence of invalid baseline tests.

Although our results have very small effect sizes, they may have clinical significance related to the potential for misinterpreting post-SRC ImPACT scores. On average, the group that had reported undergoing strenuous exercise prior to baseline testing obtained lower neurocognitive and greater total symptom scores than the nonexercise group. In an individual with lowered neurocognitive baseline scores secondary to exercise, it may be easier to return to this artificially lowered baseline following SRC. This may lead to possible premature RTP and potentially increased risk for subsequent injury. Furthermore, one may expect that the post-SRC athlete would have been engaging in little to no exercise prior to initiating a progressive RTP exercise protocol. Therefore, if strenuous exercise were to take place prior to baseline testing, it would result in increased variability, complicating the clinical RTP decision making. Furthermore, the current results indicate that strenuous exercise prior to taking a baseline neurocognitive test leads to a higher number of invalid tests. Therefore, despite small effect sizes, the effect of self-reported strenuous exercise on neurocognitive baseline assessment may have meaningful clinical significance.

Our findings are inconsistent with those of Covassin et al[4] and Hall et al[11] in that we found that individuals who had engaged in self-reported strenuous exercise prior to ImPACT baseline test administration had significantly lower verbal memory and visual memory scores and significantly higher scores on reaction time, impulse control, and total symptoms. Covassin et al found a decrease in only verbal memory, and Hall et al found no significant difference in neurocognitive scores. Possible explanations for the differences in findings among the studies include differences in sample size, populations, type of exercise, and covariates controlled. The sample size of the current study was significantly larger

compared with the 2 previous studies (664 in the current study vs 104 in Hall et al and 54 in Covassin et al). This larger sample size may account for our findings of significant differences in multiple scores as opposed to no differences reported by Hall et al or a difference only in verbal memory reported by Covassin et al. Also, populations differed in average age (15.74 years in the current study vs 18.96 years in Hall et al and 21.00 years in Covassin et al). The younger average age of our participants may have magnified the modifying effect of self-reported exercise on neurocognitive test scores.

Another possible explanation for the variation in findings between the current study and that by Covassin et al[4] is the difference in type of exercise undergone by the study participants. In the Covassin et al study, participants underwent a treadmill test until maximal exertion was reached (approximately 15 minutes). The manner of exercise was not reported or controlled in our study, as the only information available to us was whether the subject underwent strenuous exercise within 3 hours of the baseline test. Such variation in type and amount of exercise may have caused the observed difference in results. One possible explanation for the difference in findings between the current study and Hall et al[11] is the number of covariates controlled. The current study accounted for the covariates of age, education level, concussion history, and hours of sleep prior to testing, while the study by Hall et al did not.

Two prior studies have shown the importance of standardization in the administration of baseline neurocognitive testing. Moser et al[22] showed that the administration of ImPACT baseline testing in an unstandardized group setting produced significantly worse scores compared with individually proctored sessions. Further support of standardization was provided by Vaughan et al[25] in a later study showing that proper standardization of the testing environment and training of test administrators negated this effect, resulting in no difference in baseline neurocognitive scores between individual and group test administration. The results of the current study provide an additional aspect for consideration when standardizing baseline neurocognitive testing procedures.

Strengths and Limitations

The primary strength of this study is the matching of pretest exercise and control groups based on sex, age, education level, concussion history, and prior hours of sleep, 5 factors shown to have the potential to affect baseline neurocognitive test scores.[2,3,6,10,20] A second major strength is the large sample of more than 7000 individuals from which randomly matched controls were selected, leading to a decreased potential for selection bias. Finally, the sample size used in this study was significantly larger than those of previous investigations into the effect of pretest exercise on baseline neurocognitive testing.

The results of this study should be interpreted in light of several methodological limitations. The first limitation is that this study relies on self-reported information for biopsychosocial, exercise, and demographic data. As a result, there is a potential for recall bias and inaccuracy.

Furthermore, independent confirmation of the medical histories and medication lists was not available. Second, the definition of strenuous exercise was left to the interpretation of the student-athlete and, therefore, was subject to variability among subjects. Third, ImPACT testing of the subjects in this study was conducted primarily in group settings, which may have been a possible confounder. However, in light of the standardized testing procedures and trained test administrators, we believe that the potential confounding effect was minimized. Fourth, the findings of this study can only speak to self-reported strenuous exercise occurring with 3 hours of baseline neurocognitive testing. We separated subjects into exercise and nonexercise groups using data from the ImPACT demographic section, which contained the binary question as to whether strenuous exercise had occurred within 3 hours of testing. Because of this, these results may not be generalizable to strenuous exercise across other time frames. Fifth, all participants in this study were from a specific region of the country and attended institutions that sponsor baseline neurocognitive testing (or the participants themselves had personal financial means to undergo baseline neurocognitive testing), which may limit the generalizability of the findings.

Recommendations

Given the current results and the reported efficacy of standardizing baseline test administration,[25] we recommend that a similar strategy be taken toward the variable of pretest exercise for baseline neurocognitive testing. We recommend that participants undertake no scheduled practice or strenuous exercise (individually or in groups) prior to baseline testing to minimize or eliminate potential variation in baseline test scores. This elimination of pretest exercise could improve the reliability of baseline testing and aid in the RTP decision-making process by providing accurate scores for postinjury comparison.

CONCLUSION

Participants with a self-reported history of strenuous exercise prior to ImPACT baseline testing had differences in several composite scores compared with participants who did not report pre–baseline testing exercise. Thus, the accuracy of the baseline ImPACT test may potentially be affected for those who have exercised within 3 hours prior to testing. We recommend that clinicians involved in baseline test administration take care to schedule test sessions such that no exercise takes place prior to testing, in order to minimize the potential to confound baseline test results.

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