# Exertion Testing in Youth with Mild Traumatic Brain Injury/Concussion

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**ABSTRACT**

DEMATTEO, C., K. A. VOLTERMAN, P. G. BREITHAUPT, E. A. CLARIDGE, J. ADAMICH, and B. W. TIMMONS. Exertion Testing in Youth with Mild Traumatic Brain Injury/Concussion. *Med. Sci. Sports Exerc.*, Vol. 47, No. 11, pp. 2283–2290, 2015. **Purpose**: The decision regarding return to activity (RTA) after mild traumatic brain injuries/concussion is one of the most difficult and controversial areas in concussion management, particularly for youth. This study investigated how youth with postconcussion syndrome (PCS) are affected by exertion and whether standardized exertion testing using the McMaster All-Out Progressive Continuous Cycling Test can contribute to clinical decision making for safe RTA. **Methods**: Fifty-four youth (8.5–18.3 yr) with a previously confirmed concussion participated in the study. Each participant performed exertion testing on a cycle ergometer and completed a Postconcussion Symptom scale at the following time points: before exertion (baseline), 5 and 30 min, and 24 h after exertion. A modified Postconcussion Symptom scale was administered at 2-min intervals during exertion. **Results**: Participants had a mean ± SD symptom duration of 6.3 ± 6.9 months after the most recent concussive injury, with a median of 4.1 months (range, 0.7–35 months). Sixty-three percent of participants had symptoms during exertion testing. Symptom profile (number and severity) significantly affected perception of exertion at 50% peak mechanical power. During acute assessment of symptoms (30-min after exertion), headache ($P$ = 0.39), nausea ($P$ = 0.63), and dizziness ($P$ = 0.35) did not change. However, both the number and severity of symptoms significantly improved over 24 h, with 56.8% of youth showing improvements. The time from the most recent injury had a significant effect on the symptom score at baseline, 30 min after exertion, and 24 h after exertion. **Conclusions**: Exertion testing has an important role in the evaluation of symptoms and readiness to RTA, particularly in youth who are slow to recover. Overall, controlled exertion seemed to lesson symptoms for most youth. **Key Words:** RETURN TO PLAY, HEAD INJURY, BRAIN CONCUSSION, POSTCONCUSSION SYNDROME, CHILDREN, ADOLESCENTS

Mild traumatic brain injuries, also referred to as concussions, are common and debilitating events for children and adolescents (hereafter referred to as youth) that can interfere with performance and participation in home, school, and community activities. Moreover, youth who have experienced a concussion are twice as likely to have a subsequent head injury of similar type within 12 months (36) whereas more than 30% of high school athletes report having sustained multiple head injuries (6,32).

Postconcussion syndrome (PCS) is a constellation of physical (e.g., headache, dizziness, fatigue), cognitive (e.g., memory dysfunction, poor attention, lack of concentration), emotional (e.g., anxiety, depression), and behavioral (e.g., impulsivity, poor judgment) symptoms (37). The recovery time frame after concussion is influenced by many factors such as age, sex, severity of injury, and history of concussions (3,15,18,28). Most athletes who incur a sport-related concussion will recover within 7–10 d (30), yet there is concern that young athletes may require more time to recover from concussion than their adult counterparts (2,4,29). A recently published prospective epidemiologic study (3) revealed that 14% of youth were symptomatic 3 months after concussion, with 2.3% remaining symptomatic after 1 yr. Yeates et al. (38,39) further classified PCS into four longitudinal trajectories: 1) no postconcussive symptoms, 2) moderate persistent postconcussive symptoms, 3) high acute/resolved postconcussive symptoms, and 4) high acute persistent postconcussive symptoms. Cognitive deficiencies associated with concussion usually resolve after 1–3 months in most youth (1,5).

One challenge in preventing these prolonged symptoms and multiple injuries, particularly in young athletes, lies in the safe return to sport and other activities. The Zurich consensus on concussion in sport (30) provides a protocol for return to play designated for adult athletes, with special recommendations related to children. Because of differences in physiological responses and recovery time after concussion, it is recommended that the youth adopt a more cautious and conservative approach than adults (9,13,19,30,34). More recently,

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pediatric specific guidelines regarding return to activity (RTA) and return to school after concussion have been developed (7,8) and are available through the CanChild Web site (www.canchild.ca). This RTA protocol outlines six successive recovery steps, beginning with step 1, "no activity and complete rest" and progressing through to step 6, "return to activity, sport or game play" (8).

With substantial risks of repeat injury during the vulnerable brain recovery time, accurate assessment of postinjury readiness for RTA is vital, particularly for children with persisting symptoms. Readiness for RTA does not mean full clearance for return to contact sport but refers to a progressive increase in the amount of daily, noncontact physical activity—moving beyond step 1, "no activity and complete rest." One dilemma often encountered by clinicians is determining whether PCS symptoms reflect the concussion pathophysiology or are caused by factors secondary to the concussion (e.g., depression) (22). Kutcher et al. proposed that if acute postconcussive symptoms are exacerbated with exertion and improved by rest, then the individual has not had sufficient time to heal from the pathophysiology associated with concussion. PCS symptoms that are exacerbated by minimal activity and not improved by rest may be a representation of psychological symptoms due to frustration, prolonged inactivity, and delayed return to usual occupations (22).

Existing evidence suggests that exertion testing in young adults can help both diagnostically and in return to sport decisions (25). Thus, it is possible that information obtained from exertion testing can potentially be applied to clinical practice to resolve the previously described dilemma and contribute to RTA decision-making. Leddy et al. (23,24) have used the Buffalo Concussion Treadmill test, which uses a modified Balke protocol to monitor physiological recovery by identifying patients with symptom exacerbation from concussion to determine whether controlled exercise was safe for patients experiencing PCS (24). However, in the absence of pediatric-specific evidence in concussion management, clinicians must extrapolate from the adult literature while carefully evaluating the pediatric population for their unique response to techniques such as exertion testing.

The decision regarding RTA after concussion is one of the most difficult and controversial areas in concussion management, particularly for the youth. This study uniquely focused on youth with concussion from sport and other causes. In addition, testing was done within a follow-up clinic environment, as opposed to a laboratory setting, in attempts to better address the following clinical decision making objectives: 1) to examine how youth with PCS are affected by exertion, specifically investigating how exertion testing is related to the onset of concussion symptoms, and 2) to determine whether standardized exertion testing using the McMaster All-Out Progressive Continuous Cycling can help contribute to decision making as part of the process to start a safe and progressive RTA protocol in youth with PCS. We hypothesized that exertion testing in youth with persisting symptoms after a concussion will improve self-reported symptoms, both severity and the number of reported symptoms, in most youth and will help distinguish which youth are ready to increase their activity level.

## METHODS

**Participants.** A convenience sample of 54 youth (32 males and 22 females) was recruited between May 2012 and March 2013 from the Acquired Brain Injury (ABI) clinic at McMaster Children's Hospital during routine follow-up. Assent and consent were obtained from the participant and their guardian, respectively. This study was approved by the Hamilton Integrated Research Ethics Review Board.

Inclusion criteria included the following: 1) children 7–18 yr of age, 2) a confirmed diagnosis of mild traumatic brain injury/concussion by a physician, 3) and a transient resolution of self-reported symptoms at rest for a minimum of 24 h before clinic, as determined during the clinic appointment with the ABI team. Children with a single or multiple concussions were included in the study. Exclusion from the study was based on the following criteria:1) the brain injury resulted in admission to the pediatric critical care unit or required neurosurgery, 2) seizures experienced at the scene or history of a seizure disorder, 3) history of premorbid motor delay, 4) any preexisting medical or neurological condition, and 5) presence of headache or dizziness at time of recruitment. Participant characteristics are provided in Table 1.

**Outline of study protocol.** This study used a cross-sectional design with youth participating in testing on one occasion. Participants completed testing during a regularly scheduled ABI clinic visit, unless specifically requested by the family to come another day. Upon enrollment in the study, basic anthropometrics (height, body mass, and body mass index (BMI)) were assessed. Participants then completed two parts: 1) exertion testing on a cycle ergometer using the previously described McMaster All-Out Progressive Continuous Cycling Test (33) and 2) assessment of participants' symptoms before, during, and after exertion according to the Postconcussion Symptom Scale (PCSS) questionnaire. A member of the Child

TABLE 1. Participant characteristics, exertion results, and injury variables.

| | Total Sample ($n$ = 54) | 24-h Follow-up ($n$ = 37) | $P$ Value |
|---|---|---|---|
| Males/females | 32/22 | 20/ 7 | — |
| Age (yr) | 14.8 (2.3) | 14.8 (2.3) | 1.00 |
| Height (cm) | 163.7 (12.5) | 161.6 (12.0) | 0.42 |
| Height (percentile) | 56.8 (30.8) | 53.7 (30.7) | 0.63 |
| Body mass (kg) | 60.7 (19.5) | 56.7 (13.8) | 0.25 |
| Body mass (percentile) | 65.4 (28.4) | 61.7 (27.9) | 0.54 |
| BMI ($kg \cdot m^{-2}$) | 22.1 (4.7) | 21.4 (3.6) | 0.38 |
| BMI (percentile) | 64.3 (26.8) | 61.9 (27.0) | 0.68 |
| $HR_{peak}$ (bpm) | 186.0 (14.0) | 183.8 (14.2) | 0.47 |
| PMP (W) | 174.9 (53.7) | 164.9 (49.6) | 0.36 |
| Relative PMP ($W \cdot kg^{-1}$) | 2.94 (0.71) | 2.97 (0.73) | 0.85 |
| PMP (% predicted) | 85.6 (15.4) | 84.7 (16.2) | 0.79 |
| Exercise duration (s) | 575.4 (114.4) | 572.1 (125.2) | 0.90 |
| Number of previous concussion | 1.0 (0–5) | 1.0 (0–5) | 0.65 |
| Time from most recent injury (months) | 4.1 (0.7–35.3) | 4.4 (0.7–35.3) | 0.50 |

Data are presented as mean (SD) or median (range). Height, body mass, and BMI percentiles were calculated according to Ogden et al. (32).

Health and Exercise Medicine Program team at McMaster Children's Hospital conducted all exertion testing and administration of PCSS and was blinded to the nature and details of the participant's injury. Total time commitment for the study was approximately 1 h per participant.

**Exertion testing.** Exertion testing was performed with a progressive continuous exercise test on an electronically braked cycle ergometer (Lode Corival, The Netherlands). Participants began cycling between 25 and 85 W (according to age, height, body mass, and estimated level of fitness) and were instructed to pedal at 60 rpm. Progression in the test was achieved by a consistent increase in work rate every 2 min until the participant reached exhaustion. The test was terminated when the participant experienced the following: 1) a drop in pedaling rate below 50 rpm for 3 s, 2) volitional exhaustion, or 3) onset of concussion-like symptoms (excluding fatigue).

Exertion time and whether the exercise was terminated due to symptom exacerbation were recorded. When a participant could not complete two full minutes of exercise at the final stage, peak mechanical power (PMP) was prorated on the basis of the period they were able to complete. PMP was then normalized to body mass (relative PMP) as an indicator of fitness. PMP was also expressed as the percentage predicted (PMP % predicted) on the basis of our laboratory's reference data for healthy children of similar age and sex. HR was measured continuously using a Polar HR monitor (Polar Electro Oy, Kempele, Finland) fastened around the chest, and participants were also asked to rate their perceived exertion (RPE) using the Borg 6–20 categorical scale. $HR_{peak}$, HR at 50% of PMP ($HR_{50}$), the ratio between RPE peak and $HR_{peak}$ (RPE:$HR_{peak}$), and the ratio between RPE and HR at 50% PMP (RPE:$HR_{50}$) were subsequently assessed.

**Symptom assessment.** The primary outcome measure in this study was the onset of participant symptoms during and after exertion testing, measured as a change in both the total number of symptoms and total symptom severity from preexertion (baseline) values as assessed by PCSS. The PCSS is a 5-min, 22-item standardized symptom scale that is used to rate symptoms from 0 (none) to 6 (severe) and was completed by the participant at the following time points: 1) immediately before exertion (baseline), 2) 5 min after exertion, 3) 30 min after exertion, and 4) 24 h after exertion. Families were contacted by e-mail survey to obtain the 24-h postexertion PCSS. In addition to individual and total symptom scores, the 22 PCSS symptoms were also categorized into four symptom domain scores (cognitive–sensory, sleep–arousal, vestibular–somatic, and affective) as presented in the study of Kontos et al (21).

A modified PCSS, composed of seven common concussive symptoms (headache, nausea, vomiting, balance problems, dizziness, fatigue, and drowsiness) most indicative of changes in brain function (11), was administered by the tester at 2-min intervals during the exertion testing, as safety monitoring was an important consideration in the study. The tester asked the participants to rate each of the seven symptoms from 0 (none) to 6 (severe). Except fatigue, if any symptoms presented during exertion (that were not present at baseline) or worsened in severity compared with their baseline PCSS score or if the youth asked to stop, the testing was terminated immediately. The time of symptom onset and the level of exertion at onset were recorded.

**Adverse outcomes protocol.** If a participant continued to experience concussive symptoms 30 min after exertion, an assessment was performed by a physician in the ABI clinic. If symptoms continued to persist after 24 h, an urgent follow-up appointment in the ABI clinic was booked.

**Statistical analysis.** Analysis of data was carried out using the Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL). All analyses were defined *a priori* and were completed after study conclusion. Statistical significance was established at $P < 0.05$. All data were checked for normality using the Shapiro–Wilk test.

To provide relevant characteristics related to injury and/or symptoms, proportions of participants were calculated for descriptive purposes. Student's *t*-tests were used to compare demographic variables between sexes. An investigation of participant characteristics (e.g., age, sex) and injury variables (e.g., number of previous concussions, cause of most recent injury, time from most recent injury) associated with PCSS scores (total number of symptoms and total symptom severity) was conducted through multiple regression analyses at baseline and at 5 min, 30 min, and 24 h after exertion. To investigate predictors of exertion measures (e.g., PMP, relative PMP, PMP percent predicted, $HR_{peak}$, $HR_{50}$, RPE:$HR_{peak}$, and RPE:$HR_{50}$), separate multiple regression analyses were conducted with injury variables and baseline PCSS scores.

To assess the acute effects of exertion on changes in symptoms over time (up to 30 min after exertion), a separate Friedman test was used for total symptom severity, each of the four symptom domain scores, total number of symptoms, and each of the PCSS items (28 tests). *Post hoc* analyses using a Wilcoxon signed-rank test with Bonferroni adjustment was used when differences were significant. To assess the effects of exertion on changes in PCSS scores from baseline to 24 h after exertion, a separate Wilcoxon signed-rank test was then conducted with the same variables (28 tests). Participants were then categorized into three groups (worsened, improved, and no change) according to change in severity from baseline score. To examine differences between participant groups for changes in total symptom severity from baseline to 5 min, baseline to 30 min, and baseline to 24 h after exertion, separate one-way ANOVA were conducted to determine differences in age, sex, number of previous concussions, cause of most recent injury, and time from most recent injury.

## RESULTS

Thirty-seven of the 54 participants who completed the exertion testing responded to the 24-h postexertion follow-up survey and thus were included in the 24-h analysis.

**Participant characteristics.** Mean age of participants was 14.8 yr (range, 8.5–18.3 yr). At least one previous concussion was reported in 65% ($n$ = 35) of the participants, whereas 20% ($n$ = 11) of participants report having incurred more than three. The cause of injury by sex is depicted in Figure 1. Sixty-five percent of youth were still experiencing some symptoms at 3 months and onwards after injury. Twenty percent of youth were within the first month after injury. Time from most recent injury was the only significant difference ($P$ = 0.02) between participants included and excluded in the 24-h analysis (mean (range), 7.5 (0.7–35.3) and 3.9 (0.8–8.0) months, respectively).

**Multiple regression analyses.** At baseline, the model for total number of symptoms ($r^2$ = 0.35) was significant ($F$ = 5.21, $P$ = 0.001). Age ($\beta$ = −0.53, $P$ = 0.07), sex ($\beta$ = 0.88, $P$ = 0.51), number of previous injuries ($\beta$ = 0.42, $P$ = 0.36), and cause of most recent injury ($\beta$ = −0.12, $P$ = 0.50) were not significant predictors, whereas time from most recent injury ($\beta$ = 0.41, $P$ < 0.001) was significant. The model for total symptom severity ($r^2$ = 0.42) was also significant ($F$ = 6.83, $P$ < 0.001). When predicting total symptom severity, both age ($\beta$ = −2.43, $P$ < 0.01) and time from most recent injury ($\beta$ = 1.31, $P$ < 0.001) were significant whereas sex ($\beta$ = 3.70, $P$ = 0.34), number of previous injuries ($\beta$ = 0.83, $P$ = 0.62), and cause of most recent injury ($\beta$ = −0.22, $P$ = 0.68) were not significant predictors.

Five minutes after exertion, the model for total number of symptoms ($r^2$ = 0.28) was significant ($F$ = 2.65, $P$ < 0.01). Time from most recent injury was the only significant predictor ($\beta$ = 0.49, $P$ < 0.001). The model for total symptom severity ($r^2$ = 0.29) was significant ($F$ = 3.99, $P$ < 0.01) at 5 min after exertion. Both age ($\beta$ = −0.34, $P$ < 0.01) and time from most recent injury ($\beta$ = 0.43, $P$ = 0.001) were significant predictors of severity of symptoms. Thirty minutes after exertion showed similar results; the model for total number of symptoms ($r^2$ = 0.30) was significant ($F$ = 4.18, $P$ < 0.01), with time from most recent injury being the only significant predictor ($\beta$ = 0.50, $P$ < 0.001), and a significant model for total severity of symptoms ($r^2$ = 0.28; $F$ = 3.87, $P$ < 0.01) with both age ($\beta$ = −0.15, $P$ = 0.04) and time from most recent injury ($\beta$ = 0.48, $P$ < 0.001) as significant predictors. At 24 h after exertion, the model for total number of symptoms ($r^2$ = 0.31) was significant ($F$ = 2.75, $P$ < 0.05), with time from most recent injury ($\beta$ = 0.24, $P$ = 0.02) significantly contributing to the model. The model for total symptom severity ($r^2$ = 0.52) was also significant ($F$ = 6.64, $P$ < 0.001); however, at 24 h after exertion, time from most recent injury ($\beta$ = 1.44, $P$ < 0.001) was the only significant predictor.

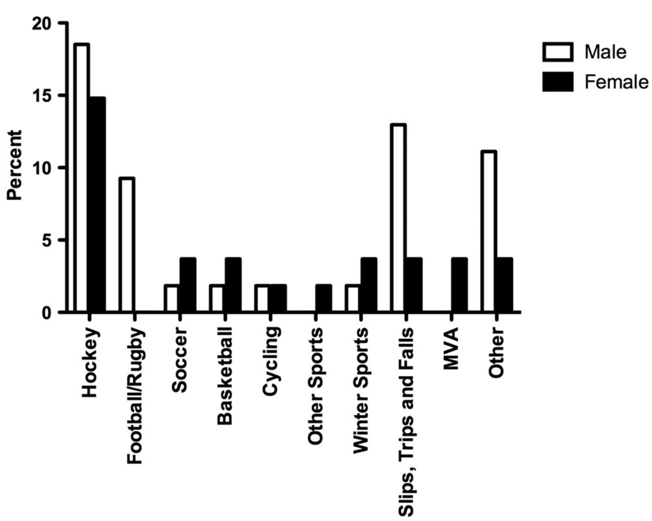


**FIGURE 1—Proportional cause of most recent injury depicted by sex. MVA, motor vehicle accident.**

It was found that injury variables were not significant predictors of exertion measures; PMP ($P$ = 0.96), relative PMP ($P$ = 0.58), PMP % predicted ($P$ = 0.32), $HR_{peak}$ ($P$ = 0.14), $HR_{50}$ ($P$ = 0.47), RPE:$HR_{peak,}$ ($P$ = 0.60), and RPE:$HR_{50}$ ($P$ = 0.86). Baseline PCSS scores were also found not to predict the majority of exertion measures; PMP ($P$ = 0.19), relative PMP ($P$ = 0.56), % of PMP % predicted ($P$ = 0. 29), $HR_{peak}$ ($P$ = 0.68), $HR_{50}$ ($P$ = 0.68), and RPE:$HR_{peak}$ ($P$ = 0.17). However, the model for RPE:$HR_{50}$ ($r^2$ = 0.12) was significant ($F$ = 3.55, $P$ < 0.05), with both total number of symptoms ($\beta$ = 0.003, $P$ = 0.01) and total symptom severity ($\beta$ = −0.001, $P$ < 0.05) as significant predictors.

**Effect of exertion on change in symptoms.** In the total sample ($n$ = 54), results of the Friedman test showed significant acute decreases in total symptom severity ($\chi^2$ = 14.00, $P$ = 0.001), cognitive–sensory domain ($\chi^2$ = 29.5, $P$ < 0.001), sleep–arousal domain ($\chi^2$ = 11.1, $P$ < 0.01) and affective domain ($\chi^2$ = 26.1, $P$ < 0.001) from baseline up to 30 min after exertion. The total number of symptoms also decreased significantly ($\chi^2$ = 8.7, $P$ = 0.01) from baseline up to 30 min after exertion, with nine of 22 individual symptoms scores showing significant improvement at both 5 min and 30 min after exertion. Of note, headache ($P$ = 0.39), nausea ($P$ = 0.63), and dizziness ($P$ = 0.35) did not change as a result of exertion, whereas sadness, feeling more emotional, difficulty concentrating, and difficulty remembering showed the most significant improvements based on $P$ value ($P \leq 0.001$ for all). The effects of exertion on changes in PCSS scores from baseline to 24 h after exertion are presented in Table 2. Participants experienced a significant improvement in all of the symptom domain scores: cognitive–sensory domain ($Z$ = −3.47, $P$ < 0.01), sleep–arousal domain ($Z$ = −2.63, $P$ < 0.01), vestibular–somatic domain ($Z$ = −2.50, $P$ = 0.01) and affective domain ($Z$ = − 2.48, $P$ = 0.01), as well eight of the individual symptom scores. Total symptom severity was also significantly reduced ($Z$ = −3.47, $P$ < 0.01).

**Differences between participant groups based on change in severity of symptoms.** Five minutes after exertion, there were no differences in age ($P$ = 0.17), sex ($P$ = 0.10), time from most recent injury ($P$ = 0.25), cause of most recent injury ($P$ = 0.30), and number of previous

TABLE 2. Change in symptom severity 24 h after exertion.

| *n* = 37 | Preexertion (Baseline) | | 24 h after Exertion | | *n* | | | Wilcoxon | |
|---|---|---|---|---|---|---|---|---|---|
| *df* = 1 | Mean (SD) | Range | Mean (SD) | Range | Worsened | Improved | No Change | *Z* | *P* |
| Total symptom severity | 14.01 (16.82) | (0–67) | 7.86 (10.7) | (0–40) | 7 | 21 | 9 | −3.47 | <0.01 |
| Cognitive–sensory domain | 4.80 (6.05) | (0–21) | 2.51 (4.31) | (0–16) | 2 | 17 | 18 | −3.67 | <0.01 |
| Sleep–arousal domain | 3.76 (4.74) | (0–21) | 2.32 (3.40) | (0–14) | 6 | 19 | 12 | −2.63 | <0.01 |
| Vestibular–somatic domain | 2.62 (4.00) | (0–14) | 1.51 (2.23) | (0–9) | 4 | 13 | 20 | −2.50 | 0.01 |
| Affective domain | 2.91 (4.26) | (0–13) | 1.51 (2.38) | (0–8) | 6 | 16 | 15 | −2.48 | 0.01 |
| Average no. of symptoms | 5.95 (5.83) | (0–18) | 4.11 (4.80) | (0–17) | 7 | 21 | 9 | −3.00 | <0.01 |
| Headache | 0.97 (1.19) | (0–4) | 0.78 (1.08) | (0–4) | 5 | 9 | 23 | −1.10 | 0.27 |
| Nausea | 0.27 (0.87) | (0–4) | 0.22 (0.67) | (0–3) | 2 | 4 | 31 | −0.53 | 0.60 |
| Vomiting | 0 (0) | (0) | 0 (0) | (0) | 0 | 0 | 37 | 0 | 1.00 |
| Balance problems | 0.27 (0.65) | (0–3) | 0.03 (0.16) | (0–1) | 0 | 7 | 30 | −2.46 | 0.01 |
| Dizziness | 0.57 (1.19) | (0–4) | 0.22 (0.53) | (0–2) | 0 | 7 | 30 | −2.39 | 0.02 |
| Fatigue | 0.97 (1.54) | (0–6) | 0.76 (1.04) | (0–3) | 5 | 10 | 22 | −0.93 | 0.36 |
| Trouble falling asleep | 1.27 (1.74) | (0–6) | 0.68 (1.55) | (0–6) | 4 | 14 | 19 | −2.44 | 0.02 |
| Sleeping more than usual | 0.35 (0.98) | (0–5) | 0.27 (0.56) | (0–2) | 3 | 4 | 30 | −0.09 | 0.93 |
| Sleeping less than usual | 0.51 (1.17) | (0–6) | 0.32 (1.11) | (0–6) | 1 | 5 | 31 | −1.82 | 0.07 |
| Drowsiness | 0.65 (0.95) | (0–3) | 0.30 (0.81) | (0–3) | 3 | 12 | 22 | −1.79 | 0.07 |
| Sensitivity to light | 0.62 (1.01) | (0–4) | 0.46 (0.93) | (0–4) | 3 | 8 | 26 | −1.23 | 0.22 |
| Sensitivity to noise | 0.30 (0.70) | (0–3) | 0.22 (0.67) | (0–3) | 1 | 3 | 33 | −1.13 | 0.23 |
| Irritability | 0.89 (1.17) | (0–4) | 0.65 (1.14) | (0–4) | 5 | 11 | 21 | −1.27 | 0.02 |
| Sadness | 0.70 (1.33) | (0–4) | 0.35 (0.82) | (0–3) | 3 | 8 | 26 | −1.92 | <0.05 |
| Nervousness | 0.35 (0.82) | (0–3) | 0.14 (0.35) | (0–1) | 2 | 6 | 29 | −1.73 | 0.08 |
| Feeling more emotional | 0.97 (1.66) | (0–5) | 0.38 (0.76) | (0–3) | 2 | 11 | 24 | −2.67 | <0.01 |
| Numbness or tingling | 0.08 (0.36) | (0–2) | 0.03 (0.16) | (0–1) | 0 | 2 | 35 | −1.41 | 0.16 |
| Feeling slowed down | 0.81 (1.43) | (0–5) | 0.46 (0.93) | (0–3) | 1 | 6 | 29 | −2.05 | 0.04 |
| Feeling mentally 'foggy' | 0.65 (1.32) | (0–5) | 0.35 (0.89) | (0–4) | 1 | 8 | 28 | −1.84 | 0.07 |
| Difficulty concentrating | 1.33 (1.74) | (0–6) | 0.51 (0.99) | (0–4) | 0 | 12 | 24 | −3.08 | <0.01 |
| Difficulty remembering | 1.16 (1.64) | (0–5) | 0.51 (1.07) | (0–3) | 1 | 14 | 22 | −3.22 | <0.01 |
| Visual problems | 0.46 (1.10) | (0–5) | 0.24 (0.68) | (0–3) | 1 | 6 | 30 | −1.58 | 0.11 |

injuries ($P$ = 0.32) among participants whose symptom severity improved ($n$ = 25), worsened ($n$ = 19), or had no change ($n$ = 10). Similarly, at 30 min after exertion, there were no differences in age ($P$ = 0.50), sex ($P$ = 0.95), time from most recent injury ($P$ = 0.40), cause of most recent injury ($P$ = 0.13), and number of previous injuries ($P$ = 0.34) among participants whose symptom severity improved ($n$ = 31), worsened ($n$ = 12), or had no change ($n$ = 11). Of those who completed 24 h follow-up data, 56.8% experienced an improvement in the severity of symptoms (18.9% worsened, 24.3% had no change). At 24 h after exertion, change in symptom severity (Table 3) had no main effect of group for age ($P$ = 0.81), sex ($P$ = 0.64), cause of most recent injury ($P$ = 0.83), and number of previous injuries ($P$ = 0.94). Time from most recent injury, however, showed a trend for significance ($P$ = 0.06).

## DISCUSSION

This study explored how standardized exertion testing is related to the onset of concussion symptoms in youth after concussive injury. We found that overall, both total symptom severity and numbers of symptoms improved after exertion and that improvement lasted for 24 h after testing.

Concussions are debilitating events for youth, producing a spectrum of symptoms that may interfere with participation and performance in home, school, and community activities. In many countries, injuries occurring from sports and recreation are the leading cause of injury in youth (12). In Canada, 66% of head injuries related to sports occur in youth under 20 yr of age and account for 53.4% of all head injuries in those 10–14 yr of age (20). Statistics have also shown that approximately 21.5% of elite youth hockey players are diagnosed with concussion in a typical season (10). It is therefore not surprising that 73% of our participants had incurred sport-related concussions (hockey being the most prominent cause of injury at 33.3%).

A previous study reported that young athletes have an average of 12.8 d until return to play (28). However, a minority of children and adolescents are slow to recover and have symptoms that persist for many weeks (2,3,16,31). These individuals represent a unique challenge to clinicians and are of particular concern, as there is a risk that their symptoms will 1) become chronic and 2) are caused, either in whole or part, by factors not directly related to the pathophysiology of the concussion (i.e., lifestyle restriction) (9,14). Most participants in the present study would be considered within this "slow to recover" population, as 80% of the youth still had symptoms 1 month after concussion and 65% had symptoms lasting longer than 3 months. This could certainly

TABLE 3. Characteristics of participants ($n$ = 37), whose total symptom severity worsened, improved, or showed no change 24 h after exertion.

| | Worsened | Improved | No Change |
|---|---|---|---|
| Males/Females | 3/4 | 11/10 | 6/3 |
| Age (yr) | 15.2 (1.9) (11.6–17.7) | 14.9 (2.3) (11.0–18.3) | 14.4 (2.6) (10.2–17.9) |
| BMI (percentile) | 63.4 (30.7) (3.7–91.6) | 63.9 (26.3) (14.7–96.1) | 56.3 (28.4) (4.8–94.3) |
| No. of previous concussions | 1.6 (1.7) (0–5) | 1.7 (1.6) (0–5) | 1.4 (1.6) (0–4) |
| Time from most recent injury (months) | 3.8 (2.8) (0.8–8.6) | 10.2 (9.6) (1.0–35.3) | 3.9 (3.6) (0.7–12.1) |

Data are presented as mean (SD) and (range). BMI percentile values were calculated according to Ogden et al. (32).

be a factor in the decrease in symptoms that were observed after exertion in the present study.

At both 5 and 30 min after exertion, both the younger age of the participants and closer time to most recent injury were significant factors in predicting an increased severity of symptoms. However, at 24 h after exertion, age was no longer a factor and, as such, time from most recent injury was the only significant predictor of symptom severity; individuals who showed improvements were on average 10.2 (SD, 9.6) months after concussion, whereas those whose symptoms worsened were 3.8 (SD, 2.8) months after concussion. These findings support the emerging data that youth may require extended time to recover, as evidenced by the neurophysiologic and brain imaging studies demonstrating brain changes even after symptoms have cleared (15,27,35). Participants with PCS may have had completely avoided physical activity because of the strong "rest until symptom free" recommendation that is considered best practice after an acute concussion. A number of authors (14,25) have since proposed a different approach for patients with PCS, which includes a conservative yet balanced reintroduction of activity after concussion using individualized and gradual amounts.

In youth, repeat injury is a serious issue as the symptomatology associated with a second concussion is exponentially more severe (18). A major challenge in preventing prolonged symptoms and decreasing the risk for multiple injuries is ensuring a safe progressive RTA. It has been suggested that exertion testing can contribute to the prevention of further injury by providing more objective information about the recovery state of the brain (25). It may also illustrate the deconditioned state of the young athlete who has been restricted from activity due to concussion, which in turn could make them more vulnerable to injury. Thus, any exertion performed too soon after concussion could stress the still recovering brain. It has been proposed that if acute postconcussive symptoms are exacerbated with exertion, then the individual has not had sufficient time to heal (15,22,27,30,35). On the other hand, when full exertion can be attained without exacerbation of symptoms, this often serves as an important factor for a safe RTA. The fact that participants who were further from injury had an improvement in symptoms after exertion supports the hypothesis that these youth were ready to introduce more exercise and activity into their lives.

The present study found that 63% percent of youth had symptoms during exertion, but overall, there was a statistically significant improvement in symptom severity both acutely (up to 30 min after exertion) and after 24 h. Significant improvements in the cognitive–sensory, affective, and sleep–arousal symptom domains were recorded during acute symptom assessment and after 24 h compared with those at baseline levels, whereas the vestibular–somatic domain only showed significant improvement after 24 h. Given the importance of education during the childhood years, the effect of the cognitive symptoms of concussion can be catastrophic on a child's academic achievement. The decreased severity in cognitive symptoms after exertion observed in the present study (particularly, difficulty concentrating and difficulty remembering) may prove beneficial in the return to school process and ensure that the child does not fall behind in their education.

Often, youth who are diagnosed with concussion experience significant emotional distress, as they are no longer able to participate in sports and activities. In addition to physical deconditioning, prolonged rest can contribute to depression and anxiety that further interfere with the child's ability to function and participate in sports and other activities (9,23,26). The decreased severity in affective domain symptoms observed after exertion (e.g., sadness and feeling more emotional) suggests a role for controlled exertion testing to help improve the emotional affect of a child as they recover from a concussion.

Although rest is advised for the treatment of acute concussion symptoms, there is no existing evidence showing that prolonged rest in patients with concussion for more than several weeks is beneficial (24). Rather, it is suggested that there should be a stepwise progressive balance of activity with rest (30). The challenge, however, is determining the right amount of activity to promote recovery so as not to exacerbate symptoms. Herein lie the most important aspects of exertion testing. An acceptable level of exercise tolerance can be decided objectively and then used to gradually progress the youth throughout recovery, as tolerated.

The strength of this study lies in its representation of a typical pediatric concussion clinic population. The study cohort was made up of youth of both sexes across a 9-yr age span and included individuals with both single and multiple concussions of different causality. It also demonstrated that, when the primary question is clinical decision making about RTA, standardized exertion testing can be easily incorporated into regular clinic routines without the need for laboratory testing facilities. Additionally, this study provided both subjective and objective results within a real clinical population. Notwithstanding the novelty of our study, several limitations require discussion. A selection bias may also have occurred because of the physical activity and exertion testing required for the study, whereby physically active youth or those involved in sports were more likely to participate. Moreover, there were differences between the population of participants who completed the 24-h follow-up and those who did not respond with respect to time from most recent injury. There were, however, no significant differences in other factors shown to influence concussion outcome, such as age, sex, previous concussion, or symptom severity. A number of variables (e.g., time since previous concussion, number of previous concussions, and cause of previous concussion) were assessed on the basis of a retrospective report by the parent and the participant, which may result in some information not being available or being documented inaccurately. Moreover, it has been suggested that 50% of concussions may go unreported (17), and therefore, it is difficult to obtain a true representation of the number of previous concussions our participants may have incurred. Furthermore, as the study was exploratory, a small convenience sample size was used because power analysis was not completed.

In conclusion, a systematic evaluation of exercise tolerance via standardized exertion testing has an important role in the evaluation of symptoms and readiness as part of progressive RTA protocol, without risk for head injury, in children with PCS. It contributes to more objective and evidence-based decision making for families and clinicians. Controlled exertion seemed to lesson both severity and number of symptoms, with improvements remaining 24 h after exertion. Future longitudinal studies including appropriate power analysis are needed to address the relation between exertion testing and physical performance as well as their correlation with RTA.

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