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ORIGINAL INVESTIGATION

The Dynamic Exertion Test for Sport-Related Concussion: A Comparison of Athletes at Return-to-Play and Healthy Controls

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Purpose: To describe the Dynamic Exertion Test (EXiT) by comparing physiological, performance, and clinical outcomes between athletes medically cleared following sport-related concussion (SRC) and healthy controls. ***Methods:*** One hundred four (female = 41, 39.4%) participants (14–21 y of age) including 52 medically cleared for return to play at 21.48 (15.40) days following SRC and 52 healthy athletes completed the EXiT involving (1) 12-minute aerobic component and (2) 18-minute dynamic component including 2 functional movement and 5 change-of-direction (COD) tasks. Physiological (heart rate and blood pressure), clinical (endorsed symptoms and rating of perceived exertion), and performance (COD-task completion time and errors) outcomes were collected throughout EXiT. Participants also completed the Postconcussion Symptom Scale and vestibular/ocular motor screening before EXiT. Independent-samples *t* tests were used to compare groups on resting heart rate and blood pressure, COD-task completion time, and Mann–Whitney *U* tests on Postconcussion Symptom Scale, vestibular/ocular motor screening, and EXiT symptoms, rating of perceived exertion, and errors. ***Results:*** COD-task completion time and resting systolic blood pressure and heart rate were similar between groups ($P > .05$). SRC reported greater rating of perceived exertion during the aerobic component ($P < .05$) and lower total dizziness ($P = .003$) and total symptoms ($P = .021$) during EXiT and had lower near point of convergence distance ($P < .001$) and total symptoms ($P = .007$) for vestibular/ocular motor screening than healthy athletes. ***Conclusion:*** Physiological, performance, and clinical EXiT outcomes were equivocal between athletes at medical clearance following SRC and healthy controls. The multidomain EXiT may help to inform safe return-to-play decision making post-SRC.

Keywords: mild traumatic brain injury, neurological injury, medical clearance, sport performance

The determination of an athletes' readiness to return to play (RTP) after sport-related concussion (SRC) remains a significant health concern for scientific and medical communities.[1,2] Medical clearance to RTP should constitute a multifaceted clinical assessment of neurocognitive, vestibular/oculomotor impairments, symptoms, and the completion of an exertion-based staged protocol that systematically increases exercise intensity, duration, and sport specificity across subsequent 24-hour stages.[2,3] Despite the wide acceptance that SRC management should be individualized, the staged protocol has several critical limitations that reduces its effectiveness for health care professionals. Exercise prescription factors including exercise type, duration, and intensity are ambiguously described, which can lead to highly variable approaches between clinicians,[4] sport types,[5] and sex.[5,6] Protocol advancement is reliant on self-reported symptoms, which athletes may deliberately hide or underreport;[3,7] a considerable proportion of organized and unorganized sports are noncompliant.[8] There is currently a need for a standardized RTP assessment in accordance with exercise prescription guidance with objective outcomes and generalizable to a physically active population.

Current approaches to evaluate exertional tolerance as part of RTP decision making are based on aerobic exercise with stationary equipment (eg, treadmill running, stationary cycling) and do not account for other functional systems that may be affected from SRC.[2] A plethora of evidence exists to suggest that postconcussion vestibular and ocular impairments may recover on varying trajectories[9,10] and mediate symptom provocation during exercise.[11–13] Even among healthy athletes, concussion-associated symptoms have reportedly increased following a bout of push-ups, sit-ups, and sprints,[12] but not during maximal treadmill running.[14] In addition, a recent retrospective analysis identified 25/65 (38.46%) patients experienced symptom provocation during dynamic (medicine ball dynamic movements and change of direction drills), but not aerobic (treadmill, cycle ergometer, or elliptical) exercise within 30 days of SRC.[13] From these findings, healthcare professionals should consider exercise with challenges to the vestibular system to potentially identify underlying impairments that may be undetected during exercise with minimal head–body movements.

Recently, the Gapski-Goodman Test was suggested to determine physical readiness to RTP by incorporating a standardized high- and low-intensity stationary cycling and a series of plyometric tasks.[15] Notably, despite all athletes being asymptomatic for at least 7 days and having completed the staged RTP progression, 111/759 (14.6%) of athletes experienced symptom worsening and were subsequently withheld from sport. The Gapski-Goodman Test has similar limitations to the staged progression, including lack of adequate information to justify task intensity and ; successful completion is overly reliant on symptom reporting. A standardized, dynamic exercise assessment to objectively determine physical readiness for RTP is indicated[15] and may be able to increase accuracy of RTP readiness by identifying false negatives who were cleared from typical RTP progressions.

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To address this critical need in SRC management, we developed the Dynamic Exertion Test (EXiT) to inform RTP decision making at our outpatient concussion clinic as part of routine clinical care. The EXiT combines brief aerobic and dynamic, multi-planar exercises based on American College of Sports Medicine (ACSM) exercise prescription guidelines with evaluations of physiological, performance, and clinical outcomes. The purpose of the current study was to describe the EXiT and compare concussed athletes medically cleared for RTP with healthy athletes.

Methods

Design and Participants

We employed a case-control study design comprised of athletes upon medical clearance to RTP after SRC receiving care at an outpatient concussion clinic (CONCUSS), and healthy male and female athletes within the local community (CONTROLS). Participants were 14–21 years of age and fulfilled ACSM's recommendations for weekly moderate (30 min of moderate-intensity exercise 5 d/wk) or vigorous (20 min of vigorous exercise 3 d/wk) physical activity (preinjury physical activity for CONCUSS participants). CONCUSS participants were diagnosed with a SRC by a neuropsychologist. SRC was operationally defined as a result of direct or indirect force applied to the head or body during sport participation that induced a constellation of signs, symptoms, or impairments upon clinical evaluation based on current consensus criteria,[1] within 14 days of injury and completed EXiT at the medical clearance evaluation for RTP.

Individuals were excluded if self-reported a separate recent (≤6 mo) concussion, 2 or more prior concussions (excluding current injury), previously diagnosed brain surgery or moderate or severe traumatic brain injury (Glasgow Coma Scale of <13), current neurological disorder (seizure disorder, epilepsy, brain tumors, or malformations) or oculomotor condition, currently taking antidepressant or beta blocker prescription medication, pregnant, incapable of treadmill running at speeds up to 11.27 (7.0 mph) and 13.67 km/h (8.5 mph) for females and males, respectively (based on assessment parameters), and any exclusionary criteria from the ACSM's Participation Activity Questionnaire. In addition, exclusion criteria for the CONCUSS group included: concussions incurred outside sport participation (ie, car crashes, falls, or other accidents), diagnosed with SRC > 14 days from injury, and medical clearance (visit when they were enrolled in study) occurred >90 days from injury. As part of standard clinical care, patients were considered eligible for medical clearance after any injury-related medications or therapeutic exercises were discontinued; however, medications unrelated to the head injury (learning disability, contraceptives, etc) that were taken prior to SRC were permitted. Based on a previous investigation of the Gapski-Goodman Test,[15] a sample size estimation conducted with G*Power (version 3.0.10; Franz Faul, Universität Kiel, Kiel, Germany) determined that 50 participants in each group would provide 80% power, based on a 2-tailed, independent samples *t* test with equal group sizes and variances between groups.[16]

Measures

The Dynamic EXiT. The EXiT is a 30-minute clinical assessment with aerobic and dynamic components and required the use of a motorized treadmill (WOODWAY USA, Waukesha, WI), 6 agility training cones (10 cm height), basketball, metronome, and a stopwatch. The aerobic component is comprised of a high-intensity interval protocol that alternates between slow and fast treadmill running speeds based on the 60% and 90% of the superior category (90th percentile) for aerobic capacity among 13- to 29-year-old male and female sex.[17] These target intensities were then used in ACSM's metabolic running equation to determine horizontal running speed:

$$VO_2 = 0.2 \times S + (0.9 \times S \times G) + 3.5 \text{ mL/kg} \cdot \text{min},$$

where VO_2 is oxygen consumption (in milliliters oxygen per kilogram per minute), S is the horizontal running speed (in meters per minute), and G is the percentage grade of the treadmill.[18,19] Subsequently, slow and fast treadmill running for female sex (7.2 km/h [4.5 mph; 3.14 metabolic equivalent of tasks; METs] and 11.27 km/h [7.0 mph, 6.36 METs]), and male sex (8.85 km/h [5.5 mph; 5.21 METs] and 13.67 km/h [8.5 mph, 7.5 METs]) were included in a 1:1 work to rest ratio.[19,20] Participants completed a 2-minute warm-up (female: 4.5 mph and male: 5.5 mph), followed by 30-second intervals of fast and slow running speeds (male: 8.5/5.5 mph and female: 7.0/4.5 mph) for 10 minutes. Participants were instructed to use support handles as necessary to maintain safety excessive pulling for 10 or more seconds or additional rest periods for greater than 10 seconds were counted as errors.

Within 60 seconds of completing the aerobic component, participants started the dynamic component, which consists of 2 functional movement tasks (*dynamic circuit* and *ball toss*) and 5 change of direction tasks (*box drill shuffle*, *box drill carioca*, *zigzag*, *pro agility*, and *arrow agility*) to the best of their ability (see Supplementary Material S1 [available online] for Task Description and Interpretation). The dynamic circuit is a 3-exercise circuit comprised of squat jumps, side-to-side pushups, and ball rotations completed for 3 sets of 10 repetitions in synchronization with a metronome. During the ball toss task, the participant begins by standing 2.5 m from administrator and facing same direction; after the administrator calls "left" or "right," the participant jumps and rotates 180° in the "left," or "right" direction and catches a basketball tossed by the administrator, then tosses the ball back before returning to the starting position for the next trial. Errors were counted during instances when participant drops the basketball or tosses ball outside of the administrator's reach (uncatchable) or commits to (moves one foot off ground) jump turn in the wrong direction. Following the functional tasks, participants complete 2 trials of box drill shuffle, box drill carioca, zigzag, pro agility, and arrow-agility directional change tasks (30-s rest between trials), which were hand timed via stopwatch by the administrator. The lowest (fastest) completion time (of 2 trials) of each change of direction task was analyzed except for arrow agility task due to the secondary cognitive task introduced during the second trial, thus both trials were analyzed. Headache, dizziness, and nausea symptoms and rating of perceived exertion (RPE) on a 6 to 20 Borg scale are recorded prior to and following the warm-up (postwarm-up) and the fifth (midpoint) and tenth (end) intervals of the aerobic component and following the completion of each task of the dynamic component. A preliminary analysis of these outcomes indicated stable percentage of maximal HR following the aerobic (intraclass correlation coefficient = .805) and dynamic (intraclass correlation coefficient = .649) components and change of direction task completion time (intraclass correlation coefficient = .806–.956), across repeated assessments among healthy individuals.[21]

Demographics and Anthropometrics. Participants self-reported demographic (eg, age, sex, sport) and medical history (eg, concussion, migraine, and motion sensitivity) using a standardized clinical intake form. Bodyweight (in kilograms) was measured using a digital scale (Health-o-Meter; Sunbeam Products Inc, McCook, IL) and height (in centimeters) with a wall-mounted stadiometer (Seca, Chino, CA) among CONTROLS and were identified in the electronic medical record for CONCUSS participants. Weight and height measurements were used to calculate body mass index (BMI; in kilograms/meter square).[22]

Concussion Symptoms. Concussion-associated symptoms were assessed using the Postconcussion Symptom Scale (PCSS),[23] a self-report survey comprising 22 items (eg, headache, dizziness, fogginess, sleep) rated on a 0 (none) to 6 (severe) Likert scale. Total symptom severity score was the primary PCSS outcome.

Vestibular/Ocular Motor Symptoms and Impairment. The vestibular/ocular motor screening (VOMS) involves participants rating their headache, dizziness, nausea, and fogginess on a 0 (none) to 10 (severe) Likert scale prior to (pretest) and following a series of head and eye movements including: smooth pursuits, saccades (horizontal and vertical), near point of convergence, vestibular ocular reflex (horizontal and vertical), and visual motor sensitivity subtests.[24] In addition, the VOMS includes an

average of 3 measurements of near point of convergence distance (in centimeters). Total symptoms across each VOMS item and the total VOMS scale, as well as near point of convergence distance (in centimeters) were primary VOMS outcomes.

Procedures

Concussion diagnosis and medical clearance to resume unrestricted sport participation was determined by a multifaceted clinical evaluation utilizing cognitive, vestibular, ocular, and clinical interview results. Since EXiT is part of routine clinical practice at our outpatient concussion clinic to determine medical clearance to RTP, CONCUSS participants that completed EXiT (and subsequent medical clearance) were introduced to the study and (if enrolled) provided consent/assent to use information from the electronic medical record. CONTROLS participants completed study procedures at a research facility with similar environmental conditions and were further instructed to (1) avoid ingesting food, alcohol, or caffeine and tobacco products within 4 hours of assessment; (2) avoid vigorous exercise the day prior to and day of assessment; (3) wear clothing and footwear to permit athletic movements; and (4) drink plenty of fluids the 24-hour period before assessment. All participants completed PCSS and VOMS prior to EXiT. Resting physiological measures (blood pressure [BP] and heart rate [HR]) were obtained with participant seated with back supported and feet placed flat on the floor. Pre-EXiT measurements were collected following a 5-minute resting period whereas post-EXiT measures were collected upon returning to the private examination room (approximately 3–5 min). CONCUSS participants completed EXiT on a 4.5-mm polyvinyl chloride (PVC) composite (Rexcourt; Shaw Industries, Atlanta, GA) administered by a physical therapist, and CONTROLS on an 8-mm rubber flooring (Rubber Flooring Incorporated, Costa Mesa, AZ) administered by a certified athletic trainer. Informed consent was obtained from all participants, and procedures were approved by the University of Pittsburgh Institutional Review Board in accordance with the Code of Ethics of the World Medical Association.

Data Processing and Statistical Analysis

The EXiT physiological outcomes included resting systolic and diastolic BP, and percentage of age estimated maximum HR (220 age) were calculated and analyzed from resting raw values.[18] Commission errors and completion time for both trials of the arrow agility task and the fastest time for remaining change of direction tasks were analyzed. Endorsed headache, dizziness, and nausea symptoms were subtotaled within aerobic and dynamic components, and subsequently combined to create individual symptom severity scores (eg, headache severity score) and an EXiT total symptom score.

The CONCUSS and CONTROLS participants that completed all EXiT components within assessment's description outlined prior to data collection were analyzed. Independent samples t tests were conducted for continuous (eg, age, BMI, etc), and chi-squared (χ^2) with odds ratio values for nominal demographic variables (eg, sex, sport type, number of previous concussion[s], etc) were conducted to ensure group equivalency. Preliminary screening of physiological, performance, and clinical outcomes was conducted, and statistical outliers were removed from analysis. Based on results of Shapiro–Wilk tests, we conducted independent sample t test for physiological (HR and BP, change of direction task completion time, Mann–Whitney U tests for symptoms (endorsed on PCSS, VOMS, and EXiT), RPE, and errors due to nonnormality. Moreover, Levene test was used to facilitate interpretation of t tests, and violations in homogeneity of variances underwent a Welch t test. A priori $P = .05$ was set for statistical significance, and analyses were conducted with SPSS (version 26; IBM Corp, Armonk, NY).

Results

Descriptive Data

Of 61 enrolled participants in the CONCUSS group, 3 (4.91%) were 22 years of age or older, 2 (3.28%) had modified aerobic component, and 4 (6.56%) patients attempted EXiT during an earlier visit and experienced symptom provocation and passed EXiT on a return visit (range: 3–10 d between visits), and were excluded from analysis (Figure 1). Participants with additional rest periods may affect EXiT performance, so we removed 15 participants who did not complete EXiT with the same activity-rest duration as the CONCUSS group from the analysis. Fifteen (16.3%) completed EXiT with additional rest or did not have complete EXiT results. A total of 104 participants, including 52 (female = 17, 32.7%) CONCUSS and 52 CONTROLS (female = 24, 46.2%) participants were analyzed. The CONCUSS group was younger (mean difference [MD], 95% confidence interval: −1.37, −2.20 to −0.53) and had a greater BMI (MD, 95% confidence interval: 2.18, 0.43 to 3.91) than CONTROLS (Table 1). Participants were also more likely to be in the CONCUSS group if self-reported a history of migraine/headache ($P = .017$) or a previous concussion injury ($P = .004$). Among the CONCUSS group, the interval between SRC onset to medical diagnosis and clearance evaluations were 5.31 (3.41) (range: 1–14) and 21.48 (15.40) (range: 7–90) days, respectively. The CONCUSS group exhibited lower near point of convergence distance (37.69 vs 64.78, $U = 1990.500$, $z = 4.888$, $P < .001$) and total symptoms

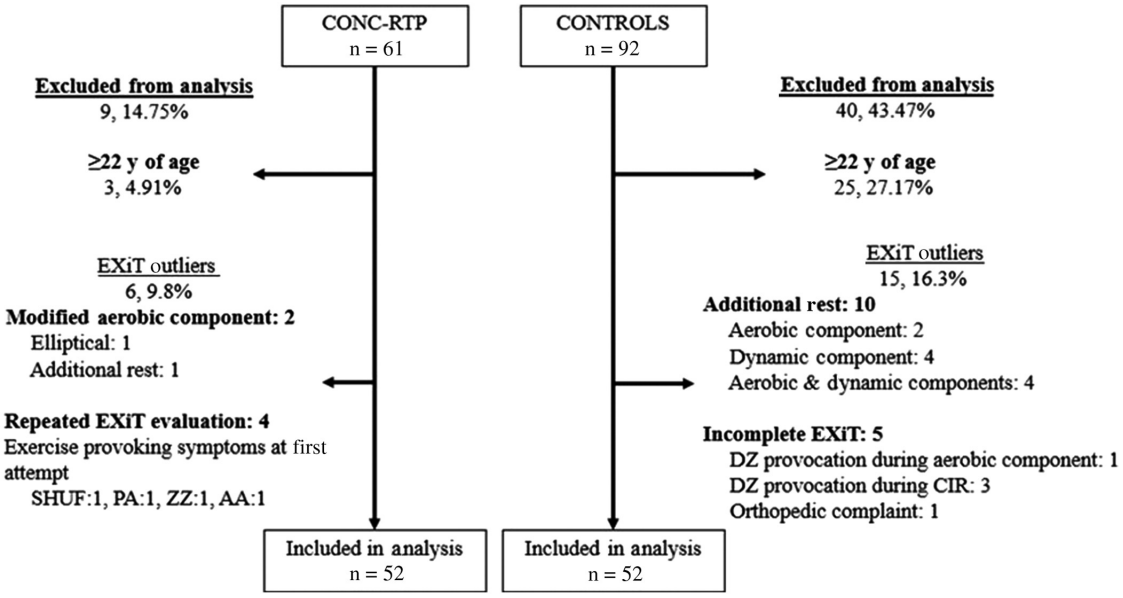

Figure 1 — Frequency of enrolled participants excluded from statistical analyses. Among the CONTROLS group, 10 participants required additional rest periods during aerobic or dynamic components or both; 5 participants discontinued exercise: 1 due to dizziness complaints during aerobic component, 2 due to dizziness complaints during CIR, and 1 self-reported "shin splint" pain after the third interval of the aerobic component. All complaints were resolved within 5 minutes of exercise cessation. AA indicates arrow agility; CIR, dynamic circuit; CONC-RTP, postconcussion at medical clearance to RTP; CONTROLS group, healthy athletes; DZ, dizziness; EXiT, Dynamic Exertion Test; PA, pro agility; RTP, return to play; SHUF, box-drill shuffle; ZZ, zig-zag.

(46.66 vs 56.16, $U = 1542.000$, $z = 2.708$, $P = .007$) for VOMS than CONTROLS (Table 2). PCSS symptom severity, and all other VOMS outcomes were similar between groups ($P > .05$).

EXiT Physiological, Performance, and Clinical Outcomes

Pre-EXiT resting systolic and diastolic BP and HR completion time for all change of direction tasks, and post-EXiT resting systolic BP and HR were similar between groups ($P > .05$; Table 3), but post-EXiT resting diastolic BP was lower among the CONCUSS group ($P = .028$). In addition, CONCUSS had a lower symptom severity (better) score than CONTROLS across aerobic component dizziness ($P = .042$), dynamic component dizziness ($P = .023$), and dynamic component symptom subtotal ($P = .003$; Table 4). Consequently, the CONCUSS group had a lower EXiT total dizziness severity ($P = .003$) and EXiT total symptoms ($P = .021$) (see Supplementary Material S2 [available online]). The CONCUSS group reported lower Pre-EXiT RPE than CONTROLS ($P = .042$) but greater RPE at post warm-up ($P < .001$), midpoint ($P = .001$), and end ($P = .009$) time points of the aerobic component (Table 5), and RPE was similar throughout the dynamic movement component ($P > .05$) (see Supplementary Material S3 [available online]). Finally, after excluding outliers none of the CONCUSS or CONTROLS participants committed errors on the aerobic component (Table 5). CONCUSS committed more errors than CONTROLS during the SHUF task ($P < .001$), but total errors were similar ($P > .05$).

Discussion

The purpose of this study was to describe the EXiT and compare athletes assessed at medical clearance following concussion with healthy, physically active controls. The primary findings indicated that change of direction agility task completion times and resting systolic and diastolic BP and HR between groups were similar except for lower post-EXiT DBP among the CONCUSS group. Aside from more committed errors by CONCUSS on box drill shuffle, errors were similar between groups. The CONCUSS group also reported less dizziness symptoms throughout the entire assessment and greater RPE during the aerobic component. However, RPE ratings were similar between groups during the dynamic movement component. Taken together, the preceding findings support our hypothesis that healthy controls and a group of athletes at medical clearance for RTP following SRC would exhibit similar physiological, performance, and clinical outcomes on EXiT.

The findings of the present study build upon previous work to improve the medical clearance evaluation to RTP.[15] Importantly, we observed no differences in change of direction task completion time between CONCUSS and CONTROLS, suggesting physical performance was equivalent. We also observed fewer symptoms (primarily dizziness) for VOMS and EXiT among CONCUSS participants. These findings support the notion that reported symptoms in isolation during exertion may not be sensitive enough to delineate recovered from unrecovered athletes, but the addition of outcomes such as agility task completion time and changes in HR and BP may provide more objective information to inform RTP decision making. Considering these novel findings, we also acknowledge that performance on hand-timed change of direction tasks may be affected by physical strength characteristics and task familiarity by the athletes,[25,26] and measurement error by the administrator.[27] Collectively, these factors may have contributed to our findings by masking potential differences in performance or physiological responses to EXiT between groups. CONCUSS participants also reported greater effort during the aerobic component, which has been previously observed with treadmill-based assessments among asymptomatic athletes compared to healthy controls.[28] Interestingly, we observed similar effort during dynamic functional exercises and change of direction tasks

Table 1 Frequency (Percentage), Mean (SD), and Comparison Statistics Across Demographic Variables Between CONCUSS (n = 52) and CONTROLS (n = 52) Groups

Variable	CONCUSS	CONTROLS	Sig
Female sex	17 (32.7%)	24 (46.2%)	.160
Age	16.02 (1.87)	17.38 (2.39)	.002[a]
Height, cm	170.93 (9.25)	171.29 (8.12)	.840
Weight, kg	71.20 (18.71)	64.90 (12.09)	.053
BMI	24.18 (5.18)	22.00 (2.94)	.015[b]
Sport			.220
Soccer	16 (30.5%)	15 (28.8%)	
Football	13 (25.0%)	4 (7.8%)	
Ice hockey	7 (13.5%)	4 (7.8%)	
Basketball	3 (5.8%)	10 (19.2%)	
Lacrosse	3 (5.8%)	4 (7.8%)	
Softball	3 (5.8%)	3 (5.8%)	
Wrestling	2 (3.8%)	2 (3.8%)	
Volleyball	1 (2.0%)	3 (5.8%)	
Other[e]	4 (7.8%)	7 (13.5%)	
Sport category[f]			.085
Full contact/collision	45 (86.5%)	39 (75%)	
Limited contact	6 (11.5%)	6 (11.5%)	
Noncontact	1 (2.0%)	7 (13.5%)	
Clinical factors			
Migraine/headache history	13 (25.0%)	4 (7.8%)	.017[c]
Attention-deficit/hyperactivity disorder	3 (5.8%)	1 (2.0%)	.309
Learning disability	2 (3.8%)	0 (—)	.248
Number of previous concussions			.018[d]
0	31 (59.6%)	44 (84.6%)	
1	16 (30.8%)	6 (11.6%)	
2	5 (9.6%)	2 (3.8%)	

Abbreviations: BMI, body mass index; CONCUSS group, outpatient concussion clinic; CONTROLS group, healthy athletes; OR, odds ratio.
[a]Independent-sample t test: $t_{96.43} = -3.239$. [b]Independent-sample t test: $t_{95} = 7.706$. [c]$\chi^2_1 = 5.696$, OR (95% CI): 2.345 (975 to 5.640). [d]$\chi^2_1 = 8.085$, OR (95% CI): 2.625 (1.280 to 5.381). [e]Includes baseball, cheerleading, crew, gymnastics, roller derby, swimming and diving, and track and field. [f]Sport Classification Endorsed by American Academy of Pediatrics.[25]

between groups. Although median perceived effort was rated as "Somewhat hard" (RPE: 12–14) for both groups, differences in RPE cannot be directly explained in the current study but may partially be due to short-term cardiovascular deconditioning secondary to physical activity restrictions following SRC.[29] The duration of rest and activity was individualized to each patient, and it is unknown if duration and intensity of exercise during recovery was sufficient to attain preinjury cardiovascular fitness levels. What is known is the CONCUSS participants underwent a brief 2- to 3-day rest period post-SRC followed by a gradual stepwise return to sport progression as recommended by international consensus.[1,2] Future work should consider the effects of physical deconditioning on structured exercise among concussed populations to better understand the potentially maladaptive autonomic nervous system responses to injury.

Except for more errors by CONCUSS participants during the box drill shuffle, committed errors were similar across the sample throughout the dynamic component. From our findings, most individuals did not incur errors; further work is necessary to determine the relevance of errors for EXiT interpretation. Finally, we observed lower diastolic BP among the CONCUSS group post-EXiT. Potential autonomic nervous system dysfunction is a critical domain of clinical research, and our findings disagree with previous investigations of symptomatic patients with greater diastolic BP following postural repositioning and aerobic exercise.[30] Although all participants had their HR and BP measured within several minutes of completing EXiT, the interval between EXiT completion and resting physiological measurements was not strictly controlled and BP is also affected by age and BMI, and in the current study the CONCUSS group was of lower age and greater BMI than the CONCUSS group. Future work should address these considerations to improve future research examining postexertion autonomic nervous system function following SRC.

Surprisingly, only one report observing a reduction of repeat injury among National Collegiate Athletic Association Division 1 football athletes recovering from SRC prior to and following the

Table 2 Mean (SD) or Median [IQR] and Mann–Whitney *U* Test (Postconcussion Symptom Severity Score and Vestibular-Ocular Motor Screening Symptoms) and Independent-Sample *t* Test (NPC) Between CONCUSS (n = 52) and CONTROLS (n = 52) Groups

	CONCUSS				CONTROLS		
	Initial evaluation		Medical clearance				
Outcome	Mean (SD)	Median [IQR]	Mean (SD)	Median [IQR]	Mean (SD)	Median [IQR]	Sig
Postconcussion Symptom Severity Score	18.48 (16.16)	15.00 [27.50]	1.37 (2.02)	0.00 [2.00]	1.92 (2.56)	1.00 [3.00]	.347
Vestibular-ocular motor screening							
Baseline symptoms	3.16 (4.21)	1.00 [5.00]	0.21 (0.69)	0.00 [0.00]	0.17 (0.65)	0.00 [0.00]	.412
Smooth pursuits	3.34 (4.56)	1.00 [5.00]	0.06 (0.31)	0.00 [0.00]	0.17 (0.65)	0.00 [0.00]	.412
Horizontal saccades	3.44 (4.76)	1.00 [5.00]	0.06 (0.31)	0.00 [0.00]	0.23 (0.76)	0.00 [0.00]	.246
Vertical saccades	3.46 (4.77)	1.00 [5.00]	0.06 (0.31)	0.00 [0.00]	0.15 (0.67)	0.00 [0.00]	.421
Convergence	3.52 (4.86)	1.00 [5.25]	0.06 (0.31)	0.00 [0.00]	0.21 (0.67)	0.00 [0.00]	.155
Horizontal VOR	4.06 (5.16)	1.50 [7.00]	0.06 (0.31)	0.00 [0.00]	0.23 (0.73)	0.00 [0.00]	.153
Vertical VOR	4.04 (5.06)	2.00 [7.00]	0.06 (0.31)	0.00 [0.00]	0.19 (0.72)	0.00 [0.00]	.407
VMS	4.54 (5.43)	3.00 [7.00]	0.06 (0.31)	0.00 [0.00]	0.17 (0.59)	0.00 [1.00]	.258
Total symptoms	26.40 (34.15)	10.50 [40.25]	0.48 (2.51)	0.00 [0.00]	1.69 (4.76)	0.00 [4.00]	.007[a]
NPC, cm	2.78 (5.62)	0.00 [2.75]	0.68 (1.30)	0.00 [0.75]	2.37 (2.17)	0.00 [2.62]	<.001[b]

Abbreviations: CONCUSS group, outpatient concussion clinic; CONTROLS group, healthy athletes; IQR, interquartile range; NPC, near point convergence; VOR, vestibular ocular reflex; VMS, visual motion sensitivity.
[a]75.75 vs 64.97; $U = 2773.50$, $z = 2.337$, $p = .007$; [b]Independent-sample T Test: $t_{95} = -6.03$.

Table 3 Mean (SD) and Independent-Sample *t*-Test Results of Resting Physiological Measures and Agility Task Completion Time (in Seconds) Between CONCUSS (n = 52) and CONTROLS (n = 52) Groups

Outcome	CONCUSS	CONTROLS	Mean difference (95% CI)	*t*	*α*
Resting physiological measures					
Pre-EXiT					
Systolic blood pressure	119.71 (15.10)	115.12 (8.64)	4.60 (–0.20 to 9.40)	1.906	.060
Diastolic blood pressure	72.65 (9.64)	72.31 (5.73)	0.35 (–2.75 to 3.44)	0.223	.824
HR—raw	70.22 (10.26)	67.56 (9.73)	2.66 (–1.25 to 6.57)	1.349	.180
HR—%maximum	34.40 (4.94)	33.35 (4.88)	1.04 (–0.87 to 2.96)	1.080	.283
Post-EXiT					
Systolic blood pressure	127.62 (15.30)	128.63 (14.67)	–1.01 (–6.93 to 4.91)	–0.338	.736
Diastolic blood pressure	72.60 (9.56)	76.64 (8.46)	–4.04 (–7.62 to –0.46)	–2.237	.028[a]
HR—raw	124.96 (19.92)	121.81 (15.46)	3.15 (–3.84 to 10.14)	0.895	.373
HR—%maximum	61.27 (9.80)	60.13 (7.71)	1.14 (–2.32 to 4.60)	0.655	.514
Agility task completion time, s					
Box drill shuffle	22.00 (3.01)	22.21 (3.13)	–0.21 (–1.41 to 0.99)	–0.351	.726
Box drill carioca	14.69 (1.89)	14.09 (1.55)	0.60 (–0.08 to 1.27)	1.750	.083
Zigzag	29.42 (7.85)	29.44 (4.09)	–0.02 (–2.46 to 2.42)	–0.019	.985
Pro agility	7.82 (1.21)	7.97 (0.81)	–0.15 (–0.56 to 0.25)	–0.756	.452
Arrow agility trial 1	40.93 (8.77)	39.19 (3.98)	1.73 (–0.97 to 4.44)	1.29	.206
Arrow agility trial 2	43.42 (9.10)	40.86 (4.58)	2.56 (–0.29 to 5.42)	1.79	.078

Abbreviations: CI, confidence interval; CONCUSS group, outpatient concussion clinic; CONTROLS group, healthy athletes; EXiT, Dynamic Exertion Test; HR, heart rate.
[a]Independent-samples t test, $t_{96.4} = -2.67$.

implementation of the staged protocol supported the effectiveness of the currently recommend staged approach.[31] This finding may be due to the concurrent implementation of a more conservative clinical management; consequently, a longer recovery period as 75% of athletes returned to sport within 7 days of SRC in the cohort that did not perform RTP progression, compared to 80% who were withheld for more than 7 days in the cohort who completed the protocol.[31] The current study was unable to determine if EXiT as a standalone exertion assessment is a better approach to inform RTP decisions than a staged protocol. Nevertheless, our findings fulfill an initial step in the standardization and implementation of objective exercise testing to inform return to sport decision making.

Table 4 Median [IQR] and Mann–Whitney *U* Test Results for Endorsed Symptoms Across EXiT Components Between CONCUSS (n = 52) and CONTROLS (n = 52) Groups

	CONCUSS			CONTROLS			
Outcome	Range	Mean (SD)	Median [IQR]	Range	Mean (SD)	Median [IQR]	Sig
Aerobic component							
Pre-EXiT	0–2	0.07 (0.38)	0.00 [0.00]	0–0	0.00 (0.00)	0.00 [0.00]	.155
Postwarm-up	0–3	0.08 (0.39)	0.00 [0.00]	0–0	0.00 (0.00)	0.00 [0.00]	.155
Midpoint	0–2	0.04 (0.28)	0.00 [0.00]	0–0	0.00 (0.00)	0.00 [0.00]	.317
End	0–2	0.04 (0.27)	0.00 [0.00]	0–3	0.13 (0.52)	0.00 [0.00]	.174
Headache	0–8	0.25 (1.29)	0.00 [0.00]	0–0	0.00 (0.00)	0.00 [0.00]	.155
Dizziness	0–0	0.00 (0.00)	0.00 [0.00]	0–3	0.13 (0.52)	0.33 [0.00]	.042[a]
Nausea	0–0	0.00 (0.00)	0.00 [0.00]	0–0	0.00 (0.00)	0.00 [0.00]	1.00
Aerobic component symptoms	0–8	0.25 (1.29)	0.00 [0.00]	0–3	0.13 (0.52)	0.00 [0.00]	.440
Dynamic component							
Dynamic circuit	0–0	0.00 (0.00)	0.00 [0.00]	0–1	0.04 (0.19)	0.00 [0.00]	.155
Ball toss	0–0	0.00 (0.00)	0.00 [0.00]	0–2	0.04 (0.28)	0.00 [0.00]	.317
Box drill shuffle	0–0	0.00 (0.00)	0.00 [0.00]	0–1	0.06 (0.31)	0.00 [0.00]	.155
Box drill carioca	0–0	0.00 (0.00)	0.00 [0.00]	0–2	0.19 (0.14)	0.00 [0.00]	.317
Zigzag	0–1	0.19 (0.14)	0.00 [0.00]	0–2	0.11 (0.42)	0.00 [0.00]	.166
Pro agility	0–0	0.00 (0.00)	0.00 [0.00]	0–2	0.57 (0.31)	0.00 [0.00]	.155
Arrow agility	0–1	0.19 (0.14)	0.00 [0.00]	0–2	0.58 (0.31)	0.00 [0.00]	.552
Headache	0–0	0.00 (0.00)	0.00 [0.00]	0–4	0.07 (0.55)	0.00 [0.00]	.317
Dizziness	0–0	0.00 (0.00)	0.00 [0.00]	0–8	0.25 (1.23)	0.00 [0.00]	.023[b]
Nausea	0–0	0.00 (0.00)	0.00 [0.00]	0–1	0.06 (0.23)	0.00 [0.00]	.080
Dynamic component symptoms	0–1	0.03 (1.06)	0.00 [0.00]	0–8	0.38 (1.28)	0.00 [0.25]	.003[c]
Exertional testing summary							
Headache	0–8	0.25 (1.29)	0.00 [0.00]	0–4	0.77 (0.55)	0.00 [0.00]	.545
Dizziness	0–0	0.00 (0.00)	0.00 [0.00]	0–8	0.38 (1.28)	0.00 [0.25]	.003[d]
Nausea	0–0	0.00 (0.00)	0.00 [0.00]	0–1	0.57 (0.23)	0.00 [0.00]	.080
EXiT total symptoms	0–8	0.25 (1.29)	0.00 [0.00]	0–8	0.51 (1.14)	0.00 [1.25]	.021[e]

Abbreviations: CONCUSS group, outpatient concussion clinic; CONTROLS group, healthy athletes; EXiT, Dynamic Exertion Test; IQR, interquartile range.
[a]50.50 versus 54.50; $U = 1456$, $z = 2.029$, $P = .042$. [b]50.00 versus 55.00; $U = 1482$, $z = 2.280$, $P = .023$. [c]48.50 versus 56.50; $U = 1560$, $z = 2.927$, $P = .003$. [d]48.50 versus 56.50; $U = 1560$, $z = 2.927$, $P = .003$. [e]48.18 versus 55.75; $U = 1521$, $z = 2.309$, $P = .021$.

Practical Applications

Structured exercise has recently emerged as a critical component of the clinical evaluation of SRC,[15,32,33] and to date, there is currently no standardized objective exercise assessment to determine an athlete's readiness to RTP. Other EXiTs have been studied but are reliant on symptom reporting and/or do not assess both cardiovascular responses and change of direction task performance.[15,32,33] In addition, these other assessments require clinicians to determine if symptom reporting is reliable, given the potential of underreporting behaviors among athletes.[3,7] The EXiT is a standardized 30-minute clinical assessment based on ACSM exercise prescription and is readily interpretable. EXiT has physiological (HR and BP), performance (change of direction task completion time and errors), and clinical (symptoms and RPE) outcomes that can help determine physical readiness to return to sport participation. Although further investigation is required to determine assessment reliability and validity, the EXiT progresses the currently available evidence to suggest objective exercise testing may be able to inform clinical decision making for SRC.

Limitations

The current investigation has several limitations to be addressed in future work. First, the CONCUSS group was younger and comprised a greater proportion of individuals with previous concussions and self-reported headache/migraine history. These variables have been associated with worse clinical outcomes and are important considerations in determining safe medical clearance after injury.[1] Future work should consider the implications of preinjury and postinjury factors, including age, sex, and physical fitness capabilities, that influence performance, symptoms, and errors outcomes from EXiT. Like Marshal et al,[15] we did not account for multiple raters and although the 2 administrators underwent similar training and were assigned to their respective groups, the agreement between multiple raters is unknown. Finally, CONCUSS and CONTROL participants completed EXiT on different nonslip surfaces. Although the authors agree that each surface would present minimal influence on the study's outcomes, implementing EXiT for all participants on one surface would improve overall consistency and strengthen the comparison between CONCUSS and CONTROL groups.

Table 5 Median [IQR] and Mann–Whitney *U*-Test Results of RPE and Errors Across EXiT Components Between CONCUSS (n = 52) and CONTROLS (n = 52) Groups

	RPE					Errors				
	CONCUSS		CONTROLS			CONCUSS		CONTROLS		
Outcome	Range	Median [IQR]	Range	Median [IQR]	Sig	Range	Median [IQR]	Range	Median [IQR]	Sig
Aerobic component										
Pretest	6–6	6.0 [0.00]	6–8	6.22 [0.00]	.042[a]	—	—	—	—	—
Warm-up	6–18	10.0 [4.00]	6–12	7.83 [2.00]	<.001[b]	—	—	—	—	—
Mid-interval	6–19	13.25 [4.00]	6–15	11.00 [1.00]	.001[c]	—	—	—	—	—
End	8–20	14.00 [2.80]	6–18	13.017 [4.00]	.009[d]	—	—	—	—	—
Dynamic movement component										
Dynamic circuit	8–19	13.50 [6.00]	6–17	13.00 [5.00]	.064	0–6	0.00 [0.00]	0–10	0.00 [0.00]	.744
Ball toss	6–19	12.50 [5.00]	6–16	10.50 [5.00]	.265	0–2	0.00 [0.00]	0–2	0.00 [0.00]	.969
Box drill shuffle	7–18	13.00 [4.00]	6–17	12.00 [4.00]	.282	0–3	0.00 [1.00]	0–4	0.00 [0.00]	<.001[e]
Box drill carioca	6–17	12.00 [6.00]	6–17	11.22 [3.00]	.278	0–9	0.00 [0.00]	0–4	0.00 [0.00]	.960
Zigzag	7–20	13.00 [7.00]	6–18	13.00 [4.00]	.804	0–6	0.00 [0.00]	0–3	0.00 [0.00]	.813
Pro agility	7–20	12.50 [6.00]	6–18	12.00 [3.00]	.599	0–2	0.00 [0.00]	0–0	0.00 [0.00]	.080
Arrow agility	9–20	15.00 [3.00]	7–20	14.00 [3.00]	.359	0–1	0.00 [0.00]	0–0	0.00 [0.00]	.317
Total	—	—	—	—	—	0–12	1.00 [4.00]	0–12	1.00 [2.00]	.126

Abbreviations: CONCUSS group, outpatient concussion clinic; CONTROLS group, healthy athletes; EXiT, Dynamic Exertion Test; IQR, interquartile range; RPE, rating of perceived exertion.
[a]50.50 versus 54.50; $U = 1456.00$, $z = 2.029$, $P = .042$. [b]65.00 versus 40.00; $U = 702.00$, $z = -4.303$, $P < .001$. [c]62.66 versus 42.34; $U = 823.50$, $z = -3.475$, $P = .001$. [d]60.14 versus 44.86; $U = 954.50$, $z = -2.610$, $P = .009$. [e]60.47 versus 44.53: $U = 937.50$, $z = -3.782$, $P < .001$.

Conclusion

The EXiT was designed to better inform healthcare professionals' decision-making process to determine safe RTP after SRC. The EXiT is based on ACSM exercise prescription recommendations and comprises dynamic movements that athletes commonly engage in across a variety of sports. As expected, performance on all EXiT change of direction tasks; as well as HR, BP, RPE, and errors were equivalent between groups. These equivocal findings suggest that the EXiT may be useful as a standardized, multiplanar exertion evaluation in informing RTP readiness in athletes following SRC. As such, EXiT may be able to address a critical gap in evidence-based, systematic, and dynamic exertion assessments to better inform safe RTP decisions across sports and age groups.

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