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Symptom Provocation During Aerobic and Dynamic Supervised Exercise Challenges in Adolescents With Sport-Related Concussion

Michael Popovich, MD, MPH*; Andrew Sas, MD, PhD†; Andrea Ana Almeida, MD*; Jeremiah Freeman, BS, ATC‡; Bara Alsalaheen, PhD*; Matthew Lorincz, MD, PhD*; James T. Eckner, MD, MS§

Departments of *Neurology, ‡Sports Medicine and Physical Therapy, and §Physical Medicine and Rehabilitation, University of Michigan, Ann Arbor; †Department of Neurology, The Ohio State University, Columbus

Context: Supervised exercise challenges (SECs) have been shown to be safe and beneficial in the early symptomatic period after concussion. Thus far, most in-clinic SECs studied have included a form of basic aerobic exercise only. An SEC that also includes dynamic forms of exercise mimics all steps of a standard return-to-play progression and may enhance the detection of concussion symptoms to guide in-clinic management decisions.

Objective: To determine whether an SEC that includes a dynamic SEC (DSEC) uncovered symptoms that would not have been identified by an SEC involving an aerobic SEC (ASEC) alone in adolescent patients with sport-related concussion.

Design: Retrospective case series.

Setting: Multidisciplinary sport concussion clinic at a tertiary care center.

Patients or Other Participants: A total of 65 adolescent athletes (mean age = 14.9 ± 2.0 years, 72.3% males) who underwent an in-clinic SEC within 30 days of concussion.

Main Outcome Measure(s): Presence of pre-exercise symptoms and symptom provocation during the SEC were recorded, with exercise-provoked symptoms categorized as occurring during ASEC or DSEC.

Results: Of the total patient sample, 69.2% (n = 45/65) experienced symptom provocation at some point during the SEC. Symptoms were provoked in 20 patients during the ASEC, whereas 25 completed the ASEC without symptom provocation before becoming symptomatic during the subsequent DSEC and 20 completed the SEC without any symptom provocation. Of the 65 patients in the total sample, 46 were asymptomatic immediately before the SEC. Of these previously asymptomatic patients, 23.9% (n = 11/46) experienced symptom provocation during the ASEC, and an additional 37.0% (n = 17/46) remained asymptomatic during the ASEC but then developed symptoms during the DSEC.

Conclusions: The ASEC alone may not detect symptom provocation in a significant proportion of concussion patients who otherwise would develop symptoms during a DSEC.

Key Words: mild traumatic brain injury, assessment, return to play

Key Points

- Symptoms were commonly provoked in adolescents recovering from sport-related concussion during in-clinic supervised exercise challenges that included both aerobic and dynamic aspects.
- A dynamic supervised exercise challenge should be part of the in-clinic evaluation of adolescents with sport-related concussion to maximize the detection of symptoms in order to best inform concussion-management and return-to-sport decisions.

Exercise is increasingly used in the management of sport-related concussion (SRC), in line with the most recent consensus statement[1] that suggested a gradual return to activity after a short period of rest in the acute phase of recovery. Previously, longer periods of rest were recommended, partly on the basis of animal studies, which indicated that a premature return to activity might be harmful to recovery.[2] However, more recent research showed that an early return to activity was more beneficial than strict rest[3,4] but that a balance between too much and too little activity might be necessary.[5] Subsequently, exercise protocols were developed as a mode of therapy for prolonged recovery from concussion.[6,7] Furthermore, exercise in the acute symptomatic period after concussion appeared to benefit recovery,[8] perhaps via improved cortical plasticity,[9] upregulation of neurotrophic factors,[10] and positive effects on the autonomic nervous system,[11] mood,[12] and sleep.[13]

To date, postconcussion exercise has largely focused on the initiation of subsymptom threshold activity during the symptomatic period after injury.[7,8] In this approach, symptom provocation during an exercise challenge is used to identify exertion guidelines and physical activity recommendations. Exercising within these guidelines has been considered safe and beneficial to recovery, even in the early symptomatic period.[8,14] The absence of symptom provocation during exercise was used as a sign of recovery to inform clinical decisions on initiating and completing a

return-to-play protocol after concussion symptoms had resolved.[15,16] Whereas the standard protocols include a graduated course of aerobic and dynamic exercises,[1] it is notable that most exercise protocols studied for this purpose in a supervised clinic setting included only forms of basic aerobic exercise, such as the treadmill or stationary bike.[17–20]

Despite advances in the use of postconcussion exercise, patterns of symptom provocation during different types of exercise have not been addressed. Given that the return-to-sport process occurs on a continuum,[21] it is possible that evaluations of basic aerobic exercises alone may fail to identify concussion symptoms provoked only by dynamic exercises that occur later in the return-to-play progression (eg, sport-specific agility drills).[1] A supervised exercise challenge (SEC) that included both aerobic (ASEC) and dynamic (DSEC) aspects was safe and facilitated recovery when used in the early symptomatic period after concussion.[14] An SEC involving aerobic and dynamic exercises can mimic all stages of the return-to-play process and may offer advantages over a supervised exercise protocol of an ASEC alone. A better understanding of SECs, especially those including a DSEC, is needed to optimize concussion-management decisions that are based on performance during in-clinic SECs.

Our primary objective was to determine whether adolescent athletes with SRC who completed an ASEC without symptom provocation would experience symptoms during a subsequent DSEC. We hypothesized that a subset of those who did not experience symptom provocation during the ASEC would develop symptoms during the DSEC, suggesting incomplete recovery from concussion. The secondary objectives were to describe broader patterns of symptom provocation during SECs in patients with concussion and to explore relationships between symptom-provocation patterns and outcomes. We postulated that the type and frequency of symptom provocation would differ between the ASEC and DSEC and that symptom provocation during SECs would be associated with recovery time.

METHODS

Data Source

After institutional review board approval was granted, we obtained data from a retrospective chart review of patients treated in a multidisciplinary sport concussion clinic at a large academic university over a 6-month period in 2016–2017. Athletes younger than 18 years old who were diagnosed with a concussion and completed an SEC within 30 days of injury were eligible for inclusion. An *athlete* was defined as an individual involved in an organized sport or regular recreational sport activity. The concussion diagnosis was based on the clinical history and physical examination findings by a physician who specialized in SRC, in accordance with a consensus definition.[1] To investigate patients with acute SRC in the typical recovery period for adolescents, we excluded volunteers whose SEC occurred more than 30 days postinjury.[1] A total of 65 patients met the inclusion criteria. Patients were separated into 3 groups on the basis of presence and timing of symptom provocation during the SEC: those with symptom provocation during the ASEC (group A); those who completed the ASEC without symptom provocation but then had symptoms provoked during the DSEC (group B); and those who did not have symptom provocation with either the ASEC or DSEC (group C). Each patient completed an ASEC to start all SECs. After the ASEC, 6 patients in group A did not progress to a DSEC due to a high level of symptom provocation, as defined below.

Supervised Exercise

The SECs were conducted as part of standard care for patients with SRC.[14] All SECs were led by an athletic trainer or physician in a dedicated exercise area of the clinic. The SEC did not occur until the patient's second visit to the clinic (ie, first follow-up visit). Before the SEC, each patient was fitted with a chest-worn heart rate (HR) monitor (Polar, Bethpage, NY). Patients were asked to report the presence and severity of symptoms before exercise on a verbal 10-point Likert scale, with a score of 0 defined as *absent*, 5 defined as *moderate*, and 10 defined as *severe*. The HRs and symptom scores were then recorded at 2-minute intervals during exercise. A symptom was considered *provoked* by either of 2 metrics: (1) if a symptom that was not present before exercise developed during the workout or (2) if the severity of a preexisting symptom increased by 3 or more points on the Likert scale, which is similar to the cutoff used in previous investigations[14,18] of symptom provocation with postconcussion exercise interventions.

Symptom-provocation criteria were the same for ASEC and DSEC. Each exercise began at a *low intensity*, defined by a slow pace of movement or low exercise-machine resistance setting. For example, a stationary bike (Keiser M3i, Fresno, CA) workout began at approximately 50 to 60 revolutions per minute (RPM) and a resistance setting of 3. Low-intensity exercise corresponded with an HR of approximately 30% to 40% of the age-predicted maximum. Exercise intensity was gradually increased at 2-minute intervals as long as no persistent symptoms were provoked above the 3-point threshold. For instance, during the second 2-minute interval of a stationary bike workout, the RPM target increased to 60% to 75% of the age-predicted maximum and a resistance setting of 5. If symptom provocation $\geq$3 points occurred, the exercise intensity was decreased, and the patient was monitored at this reduced intensity for the following 2 minutes (ie, RPM and resistance settings were reduced to the previous 2-minute interval specifications). If the symptom decreased below the defined threshold, the SEC was continued at the reduced intensity. An analogous approach to exercise intensity was used for other exercises. During the ASEC, a peak HR of at least 80% of the age-predicted maximum was targeted when the exercise reached its highest intensity, as long as no stopping criteria were met. The *stopping criterion* was defined as a persistent $\geq$3-point increase despite the aforementioned reduction in exercise intensity. The clinician could also stop the SEC if the patient demonstrated any concerning physical signs (eg, skin pallor), and the patient could request to stop the SEC at any time. Multiple instances of symptom provocation could occur in 1 patient; for instance, a patient might experience headache during the ASEC and dizziness during the DSEC but could continue as long as the stopping criterion was not met.

The SECs were individualized by stage of recovery and sport. A typical SEC began with an ASEC on a stationary bike, treadmill, or elliptical machine. The stationary bike was most commonly chosen, because the goal of the ASEC was to elevate HR while limiting movement of the head and body. However, an elliptical or treadmill was selected if the patient was already tolerating stationary bike exercise. A stationary bike was chosen for 80% (n = 16/20) in group A, 80% (n = 20/25) in group B, and 50% (n = 10/20) in group C. An elliptical was chosen for 20% (n = 4/20) in group A, 20% (n = 5/25) in group B, and 30% (n = 6/20) in group C. The treadmill was chosen for 5% (n = 1/20) in group A, none in group B, and 20% (n = 4/20) in group C. Among patients who tolerated the ASEC without symptom provocation above the defined stopping point, a DSEC immediately followed. The DSEC typically began with stationary medicine ball exercises that incorporated dynamic head movements with rotational maneuvers, starting with medicine ball wall tosses without visual tracking, followed by increasingly dynamic exercises, including wall tosses with visual tracking, medicine ball chops, and side-to-side rotations. For patients who tolerated this portion of the DSEC without significant symptom provocation, the DSEC continued with agility drills that incorporated more challenging tasks that combined dynamic head movements with movements of the body through space, including changes of speed and direction and quick turns. Sport-specific drills were also incorporated into the DSEC to simulate the types of drills performed during practice and game situations. For example, a soccer athlete might dribble a soccer ball while weaving at a fast pace between cones.

Data Elements

Data elements extracted from the medical record included patient demographic characteristics, relevant medical history, and physical examination findings. Patients were cleared for return to sport when they were deemed to be *recovered*, which was based on the resolution of concussion symptoms and a lack of symptom provocation during an SEC. Patients were also required to complete all stages of a standard step-by-step return-to-play progression without experiencing concussion symptoms, including a full-contact practice when appropriate for the sport.[1] Criteria for concussion recovery and clearance were consistent across all providers in our clinic. Vestibular/ocular motor screening (VOMS) maneuvers were performed as a component of the physical examination before the SEC at each clinic visit to screen for vestibular system dysfunction. A VOMS maneuver was considered *abnormal* if either dizziness occurred or preexisting dizziness increased during any of the following components of the standard VOMS: smooth pursuits, horizontal or vertical saccades, convergence testing, vestibular-ocular reflex, or visual-motion sensitivity test; or if *convergence insufficiency* (defined as near-point convergence >5 cm) was observed.[22] Before each visit, patients completed the Sport Concussion Assessment Tool 3 (SCAT3) symptom checklist, and their reporting of headache, nausea, dizziness, and blurred vision symptoms on this checklist was recorded in order to match symptoms that were recorded during exercise.

Statistical Analyses

To meet the primary objective that a DSEC would cause symptom provocation not detected by an ASEC alone, as well as the secondary objective of describing symptom-provocation patterns during SECs, we calculated descriptive statistics to determine the frequency of exercise types and symptoms during the SECs. Statistical tests were used to evaluate differences among groups A, B, and C. Kruskal-Wallis tests were used for age, the number of days from concussion to first SEC, SCAT3 total symptom score, SCAT3 symptom severity score, peak HR reached during SEC, and number of days from concussion until clearance for return to sport. A χ^2 test was used for sex. Fisher exact tests were used for race, total number of concussions (by category), history of migraine and anxiety, presence of individual symptoms reported, and presence of abnormal VOMS maneuvers. Post hoc Mann-Whitney *U* tests and Fisher exact tests were conducted for pairwise comparisons where appropriate. A Bonferroni correction was applied to account for multiple comparisons with an adjusted *P* value of .017 for comparisons among groups A, B, and C and an adjusted *P* value of .008 when these groups were further stratified by the presence or absence of pre-exercise symptoms (for a total of 6 groups, as shown in Figure 1). To explore the secondary objective that symptom provocation might be associated with recovery, we created a linear regression model using the number of days from concussion until clearance for return to sport as the dependent variable. The primary independent variables were symptom provocation during the ASEC and DSEC. Other factors possibly associated with recovery time were included as covariates: age, sex, history of migraine, history of anxiety, history of concussion, SCAT3 symptom severity score at the initial clinic visit,[23] and the number of days from concussion to SEC.[14] All analyses were performed using SAS Studio (university edition 1; SAS Institute Inc, Cary, NC).

RESULTS

Patient and SEC Characteristics

A total of 65 patients were included in the sample: 20 patients (30.7%) had symptoms provoked by the ASEC (group A); 25 (38.5%) did not have symptoms provoked by the ASEC but did have symptoms provoked by the DSEC (group B); and 20 (30.7%) did not have symptom provocation during either the ASEC or DSEC (group C). We found no differences in the sample characteristics among groups (Table 1). Despite the lack of differences in concussion acuity among the groups (as determined by the number of days from concussion to the SEC), several clinical differences were evident, including SCAT3 total symptom score, SCAT3 symptom severity score, and the reporting of headache and dizziness symptoms on the SCAT3 at the clinic visit in which the SEC occurred (Table 2).

The stationary bike (70.8%) was most commonly chosen during the ASEC, and medicine ball exercises (70.8%) were most often selected during the DSEC. In group C, agility drills (80.0%) were performed more often as part of the DSEC than were medicine ball exercises (50.0%). The frequencies of exercise types for each group are listed in Table 3. All groups achieved a similar peak HR during the SEC.

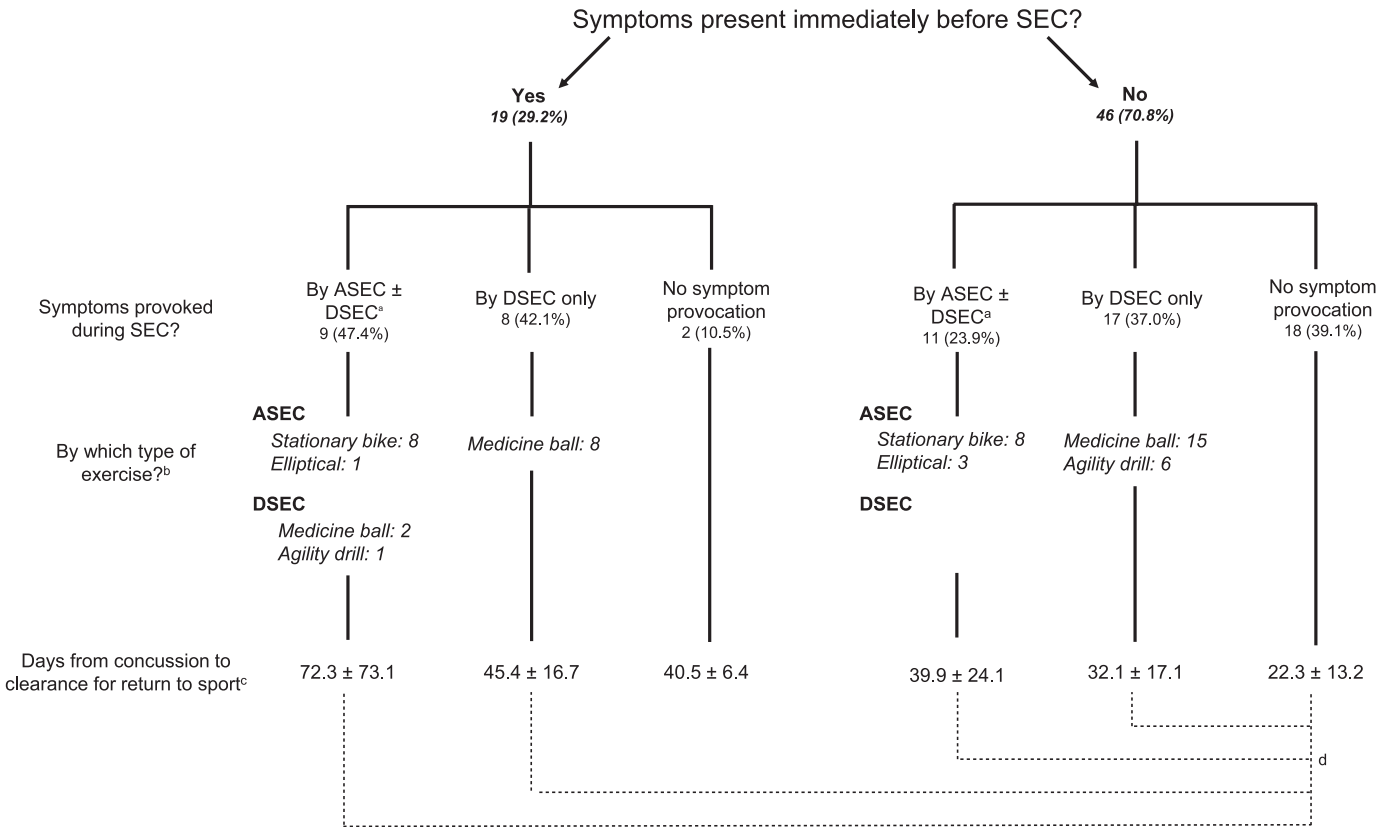

Figure 1. Symptom provocation by SEC type by the presence or absence of pre-exercise symptoms. Symptom-provocation occurrences are presented as counts and proportions. The number of days from concussion to clearance for return to sport (mean ± SD) is listed by subgroup. Abbreviations: ASEC, aerobic supervised exercise challenge, DSEC, dynamic supervised exercise challenge; SEC, supervised exercise challenge. [a] Six of 20 patients did not undergo the DSEC after their ASEC due to a high level of symptom provocation. All other patients underwent both the ASEC and DSEC. [b] Multiple instances of symptom provocation could occur during the patients' SECs, so the total occurrences of symptom provocation did not equal the number of patients. [c] The number of days from concussion to clearance for return to sport differed among the 6 groups ($P = .004$). [d] Pairwise comparisons (dashed lines) in the number of days from concussion to clearance for return to sport were different ($P < .05$). No other pairwise comparisons were statistically significant.

Table 1. Patient Sample Characteristics[a]

Characteristic	Group A: Symptoms Provoked by Aerobic Supervised Exercise Challenge (n = 20)	Group B: Symptoms Provoked Only by Dynamic Supervised Exercise Challenge (n = 25)	Group C: Symptoms Not Provoked During Either Challenge (n = 20)
Age, y (mean ± SD)	15.4 ±1.7	15.1 ± 1.9	14.2 ± 2.3
		n (%)	
Male	13 (65.0)	19 (76.0)	15 (75.0)
Race			
White	19 (95.0)	22 (88.0)	17 (85.0)
African American	0	0	1 (5.0)
Nonwhite Hispanic	0	0	2 (10.0)
Asian	1 (5.0)	1 (4.0)	0
Other	0	2 (8.0)	0
Total concussions			
1	9 (45.0)	18 (72.0)	12 (60.0)
2	4 (20.0)	3 (12.0)	7 (35.0)
3+	7 (35.0)	4 (16.0)	1 (5.0)
History of migraine	5 (25.0)	4 (16.0)	6 (30.0)
History of anxiety	1 (5.0)	2 (8.0)	2 (10.0)

[a] The sample characteristics did not differ among groups (P values $> .017$).

Table 2. Clinical Characteristics at SEC Visit

Variable	Group A: Symptoms Provoked by Aerobic SEC (n = 20)	Group B: Symptoms Provoked Only by Dynamic SEC (n = 25)	Group C: Symptoms Not Provoked During Either Challenge (n = 20)
	Mean ± SD		
Days from concussion to first SEC	17.2 ± 7.3	16.9 ± 7.1	14.1 ± 6.9
SCAT3 total symptom score at SEC visit (maximum = 22)[a]	9.9 ± 5.6	6.4 ± 6.6	2.1 ± 3.6
SCAT3 symptom severity score at SEC visit (maximum = 132)[b]	21.5 ± 19.7	12.8 ± 17.5	4.8 ± 12.7
Symptoms reported on SCAT3 at SEC visit			
Headache[c]	16 (80.0)	13 (52.0)	4 (20.0)
Nausea	2 (10.0)	3 (12.0)	2 (10.0)
Dizziness[d]	10 (50.0)	10 (40.0)	1 (5.0)
Blurred vision	4 (20.0)	3 (12.0)	2 (10.0)
VOMS maneuver abnormality present at SEC visit	11 (55.0)	11 (44.0)	4 (20.0)

Abbreviations: SEC, supervised exercise challenge; SCAT3, Sport Concussion Assessment Tool 3; VOMS, vestibular/ocular motor screening.

[a] P value < .0001; group C was lower than groups A ($P < .0001$) and B ($P = .01$).
[b] P value = .0001; group C was lower than groups A ($P \leq .0001$) and B ($P = .01$).
[c] P value < .0001; group C was lower than group A ($P = .0002$).
[d] P value < .001.

Supervised Exercise Symptom Data

Of all patients, 70.8% (n = 46) reported no symptoms immediately before the SEC. Of these 46 patients, 23.9% (n = 11) became symptomatic during the ASEC, whereas 37.0% (n = 17) completed the ASEC without symptoms but became symptomatic during the DSEC and 39.1% (n = 18) remained asymptomatic throughout the SEC. The frequency of symptom provocation in those with and those without symptoms at rest immediately before the SEC is illustrated in Figure 1.

Of all patients, 60.0% (n = 39) had a normal VOMS examination before the SEC. Of these patients, 38.5% (n = 15) reported dizziness during the SEC (Figure 2). Overall, dizziness and headache were the most common symptoms provoked during an SEC. During ASECs, headaches were experienced by 14 patients and dizziness by 9. During DSECs, headaches were described by 9 patients and dizziness by 29. In addition, nausea was provoked in 1 patient during the ASEC and in 2 patients during the DSEC. Three patients reported that blurred vision was provoked during the DSEC. Dizziness was provoked during the SEC in 49.2% (n = 30) of the patients who did not report dizziness immediately before their SEC, whereas headache was provoked during the SEC in 30.4% (n = 14) of the patients who did not report headache immediately before their SEC (Figure 3).

Recovery Outcomes

Among groups A through C, the number of days until clearance for return to sport differed ($P = .015$), with group C clearing in fewer days (24.1 ± 13.7 days) than group A (54.5 ± 53.2 days; $P = .003$) and group B (36.3 ± 17.8 days; $P = .009$). When days until clearance for return to sport was stratified by the presence or absence of symptoms before the SEC, a difference was observed when all subgroups were compared ($P = .004$; Figure 1). Those who were asymptomatic before the SEC and did not experience symptom provocation were cleared to return to sport in fewer days than those with symptom provocation during the SEC. In the linear regression model exploring predictors of recovery, symptom provocation during an ASEC predicted a greater number of days from the concussion until

Table 3. Supervised Exercise Challenge Characteristics

Characteristic	Group A: Symptoms Provoked by Aerobic SEC (n = 20)	Group B: Symptoms Provoked Only by Dynamic SEC (n = 25)	Group C: Symptoms Not Provoked During Either Challenge (n = 20)
Peak heart rate during SEC, beat/min (mean ± SD)	170.0 ± 27.2	184.1 ± 14.4	186.1 ± 25.0
Exercise(s) used during SEC, No. (%)			
Aerobic exercise challenges	20 (100.0)	25 (100.0)	20 (100.0)
Stationary bike	16 (80.0)	20 (80.0)	10 (50.0)
Treadmill	1 (5.0)	0	4 (20.0)
Elliptical	4 (20.0)	5 (20.0)	6 (30.0)
Dynamic exercise challenges	14 (70.0)	25 (100.0)	20 (100.0)
Medicine ball	12 (60.0)	24 (96.0)	10 (50.0)
Agility drill	5 (25.0)	7 (28.0)	16 (80.0)

Abbreviation: supervised exercise challenge.

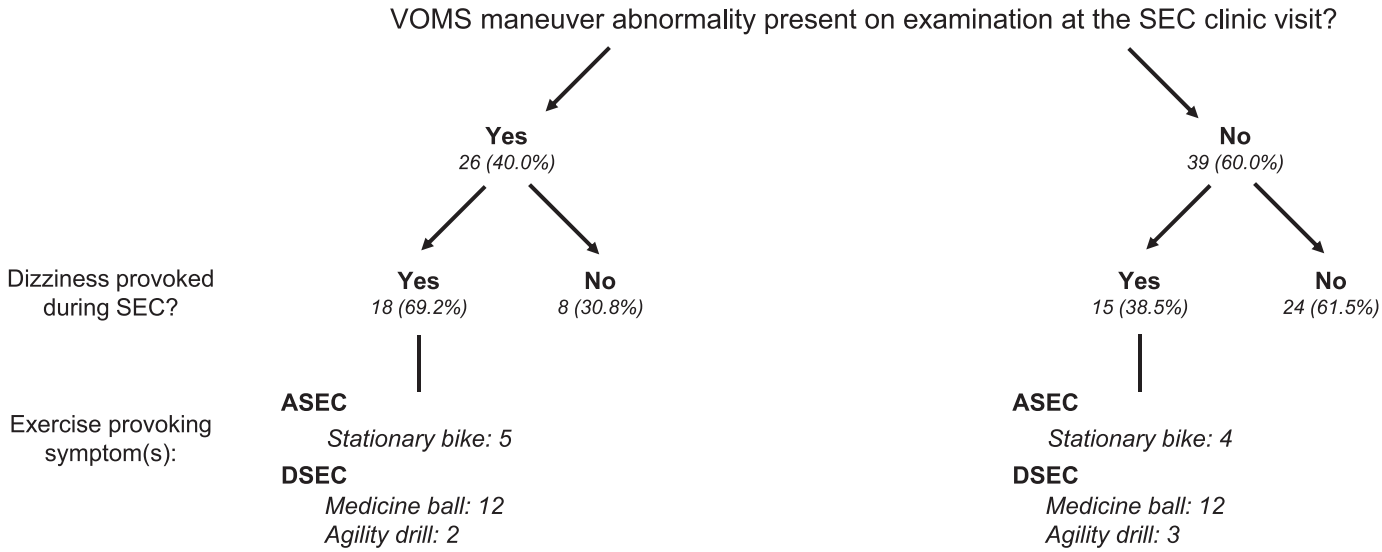

Figure 2. Dizziness provocation by SEC type and the presence or absence of pre-exercise VOMS abnormalities. Symptom-provocation occurrences are presented as counts and proportions. Abbreviations: ASEC, aerobic supervised exercise challenge; DSEC, dynamic supervised exercise challenge; SEC, supervised exercise challenge; VOMS, vestibular/ocular motor screening.

clearance for return to sport ($P = .03$). The number of total concussions ($P = .03$) and the number of days from concussion until the SEC ($P < .0001$) also predicted a greater number of days until return-to-sport clearance.

DISCUSSION

Based on our findings, we suggest that symptom provocation during an SEC, particularly during dynamic exercises, is common in adolescent athletes during recovery from concussion. A number of patients who did not report symptoms immediately before an SEC (60.9%, n = 28/46) and who did not experience symptom provocation during an ASEC (38.5% n = 25/65) did report symptom provocation during a subsequent DSEC. Whereas basic forms of aerobic exercise have been used to identify symptom provocation and to plan subsymptom threshold exercise, these results indicate that an ASEC alone is insufficient to determine the presence or absence of concussion symptoms. These findings are consistent with the standard suggested practice of guiding athletes recovering from concussion through a graduated return-to-play progression that includes both aerobic and dynamic exercises.[1] This study highlights the importance of incorporating a DSEC during in-clinic supervised exercise to best guide recommendations on return-to-play status when medical clearance may be sought. Notably, the total number of concussions was a significant predictor of a longer recovery among our participants. This finding may reflect an association between the concussion burden and recovery time versus an alternative explanation such as provider conservatism due to concern regarding concussion history.

Aerobic exercises were placed first in the SEC to enable us to determine whether symptom provocation occurred during exercises associated with minimal head and body movement, such as riding a stationary bike. During the DSEC, the initial medicine ball exercises were chosen to challenge the vestibular system by introducing rotational head and torso movements while otherwise maintaining a largely stationary body position without translational movement through space to potentially uncover symptoms that were not provoked by stationary physical exertion alone. For those able to tolerate aerobic exercises and dynamic medicine ball exercises, agility drills were added to provide a greater challenge to the vestibular system via movement of the head and body through space. The current SEC was completed in 20 to 40 minutes; 10 to 20 minutes were dedicated to the ASEC and an additional 10 to 20 minutes to the DSEC after the ASEC.

Headache and dizziness were the most often reported symptoms during SECs in this sample. These symptoms are common during the acute period after concussion,[24] as well as in postconcussion syndrome.[25,26] Within the sample, many patients who did not report headache or dizziness immediately before exercise went on to report these symptoms during an SEC. Nearly all dizziness during an SEC occurred in patients without dizziness immediately before exercising. Most of the dizziness was provoked by the DSEC rather than the ASEC, whereas headache was more often provoked during the ASEC. Because an ASEC was performed first, it is possible that headaches were less often provoked during a DSEC because they had already been provoked. In contrast, because the stationary bike was the most common form of ASEC, it is not surprising that dizziness was seen less often during the ASEC than during dynamic exercises that are more challenging to the vestibular system.

Dizziness was commonly provoked during the DSEC (38.5%, n = 15/39) in patients without dizziness during pre-exercise VOMS maneuvers, suggesting that DSECs have value in identifying dizziness that could otherwise be missed using VOMS maneuvers alone. Detection of vestibular dysfunction resulting from concussion is important because it has been associated with prolonged recovery in children.[26] Maximizing the recognition of vestibular symptoms may identify patients who could benefit from vestibular physical therapy, which has been shown to be beneficial in concussion recovery.[27] The frequent provocation of dizziness suggested that even

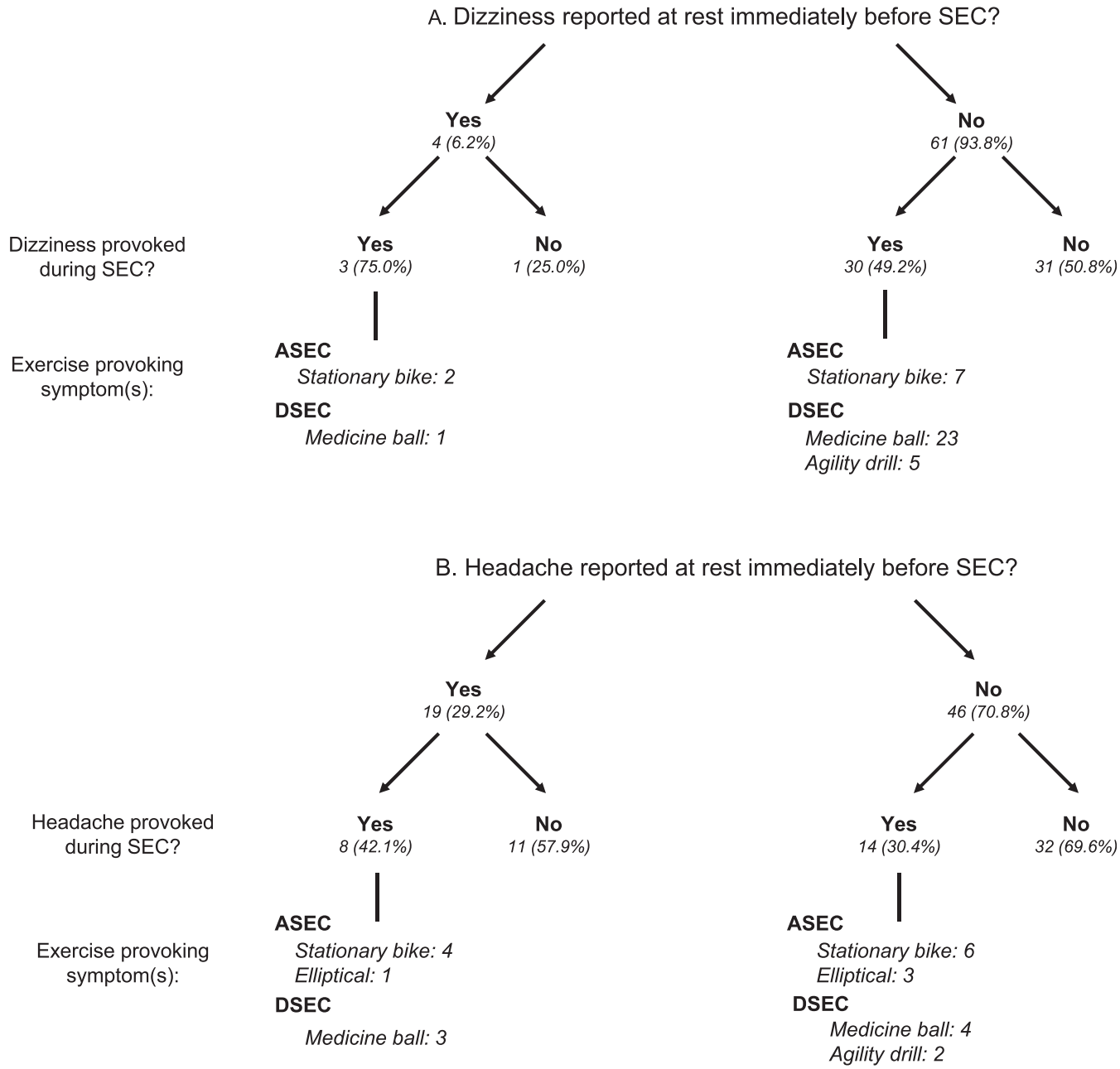

Figure 3. Dizziness and headache provocation by SEC type on the basis of presence or absence of (A) pre-exercise dizziness or (B) headache symptoms. Symptom-provocation occurrences are presented as counts and proportions. Abbreviations: ASEC, aerobic supervised exercise challenge; DSEC, dynamic supervised exercise challenge; SEC, supervised exercise challenge.

exercises that provide a relatively small challenge to the vestibular system may be sufficient to uncover vestibular system dysfunction. Although dizziness occurred less often during agility drills, this may be because such drills tended to be administered to those further along in their recovery and thus able to tolerate more demanding dynamic exercises. Our results indicated that athletic trainers and clinicians evaluating patients after concussion should consider incorporating exercises that substantially challenge the vestibular system.

In this sample, nearly all patients underwent an SEC that included both an ASEC and a DSEC. Thus, these SECs expanded on the currently studied in-clinic aerobic exercise–only protocols that typically used treadmill or stationary bike exercises.[17–19] A few researchers[6,16] have evaluated protocols that expanded on ASECs in a limited fashion, such as including light sport-specific coordination or plyometric exercises. However, none of these authors added more challenging DSECs, such as sport-specific agility drills, to evaluate symptom resolution before initiating or completing a return-to-play progression. To our knowledge, we are the first to describe patterns of symptom provocation during in-clinic SECs that combine both ASECs and DSECs.

Based on our findings, it appears that the stages of concussion recovery can be defined by symptom provocation during an SEC as well as the type of exercise challenge that provokes symptoms. Previously, symptom provocation

during treadmill exercise was shown to predict a longer recovery.[19] This study expands on these findings by demonstrating a potential recovery progression according to the type of exercise challenge that provokes symptoms. Longer recovery times were observed in patients with symptom provocation during an SEC than in those without. The patients whose symptoms were provoked during the ASEC appeared to be earlier in the recovery process (ie, experienced longer recovery times) than those who tolerated the ASEC without symptoms but became symptomatic during the DSEC. The patients who experienced symptom provocation during the SEC demonstrated a greater symptom burden, as measured by the SCAT3 total symptom and severity scores, as well as greater reporting of headache and dizziness. Taken together, these findings are concordant with standard return-to-play progressions, whereby aerobic exercises are introduced before dynamic exercises, with clearance to advance to subsequent stages granted as patients demonstrate tolerance to the earlier stages.[1]

Because this was a retrospective review, a formal research exercise protocol was not applied, resulting in variable SEC administrations across patients. It is important to note that although different types of exercise were chosen for individual patients, a high level of maximal exertion was reached across all sample subgroups (ie, peak HR of at least 170 beats per minute) to ensure that patients had exerted sufficiently to elicit potential symptoms. This sample reflected a recovering population undergoing an SEC approximately 2 to 3 weeks after concussion, so these results may not apply to other time frames after concussion, including a population with postconcussion syndrome. Furthermore, the inclusion criterion of being within 30 days of concussion resulted in a heterogeneous mix of patients seen at different phases of recovery in which physiological factors resulting from concussion may differ. Because some patients were symptomatic at rest at the time of the SEC and thus unable to be cleared to return to sport whether or not symptom provocation occurred during exercise, symptom-provocation patterns during exercise cannot solely be used to determine recovery. Whereas symptoms were commonly provoked during an SEC in this sample, the clinical importance of this factor in relation to concussion is not always certain. For instance, symptom reporting can be influenced by a baseline history of migraine,[28] anxiety,[29] or motion sensitivity.[30] Symptom reporting is also inherently subjective, with the potential for both overreporting and underreporting. Therefore, it is important to consider the entire clinical context, including symptoms, examination findings, and medical history, when interpreting the significance of symptom provocation.

This study had several additional notable limitations. Given that this was an adolescent and predominantly White male sample of athletes, our results may not be applicable to a population featuring a wider age range, balanced sex ratio, greater racial and ethnic diversity, or nonathletes. Whereas most of the patients in the study sample completed both the ASEC and DSEC, a small number (9.2%, n = 6/65) were unable to advance from the ASEC to the DSEC due to early symptom provocation, so the total occurrence of symptom provocation during DSECs may have been underreported.

CONCLUSIONS

Symptoms are commonly provoked during in-clinic SECs in adolescent athletes recovering from concussion. Symptoms occurred more often during DSECs than during ASECs and were frequently provoked by dynamic exercise in patients who reported being asymptomatic at rest as well as in those who were able to tolerate aerobic exercise without symptom provocation. In addition, DSECs elicited dizziness in some patients with a normal VOMS examination at baseline. Thus, SECs featuring an ASEC alone may miss symptom provocation in a significant proportion of concussed patients. The inclusion of a DSEC as part of the in-clinic evaluation of patients with SRC may optimize medical decision making in managing concussion symptoms as well as guiding safe return-to-sport recommendations.

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Address correspondence to Michael Popovich, MD, MPH, Department of Neurology, University of Michigan, 2301 Commonwealth Boulevard, Ann Arbor, MI 48105. Address email to mipopovi@med.umich.edu.