Journal of Athletic Training 2008;43(5):456–463
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original research

Return of Postural Control to Baseline After Anaerobic and Aerobic Exercise Protocols

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Context: With regard to sideline concussion testing, the effect of fatigue associated with different types of exercise on postural control is unknown.

Objective: To evaluate the effects of fatigue on postural control in healthy college-aged athletes performing anaerobic and aerobic exercise protocols and to establish an immediate recovery time course from each exercise protocol for postural control measures to return to baseline status.

Design: Counterbalanced, repeated measures.

Setting: Research laboratory.

Patients or Other Participants: Thirty-six collegiate athletes (18 males, 18 females; age = 19.00 ± 1.01 years, height = 172.44 ± 10.47 cm, mass = 69.72 ± 12.84 kg).

Intervention(s): Participants completed 2 counterbalanced sessions within 7 days. Each session consisted of 1 exercise protocol followed by postexercise measures of postural control taken at 3-, 8-, 13-, and 18-minute time intervals. Baseline measures were established during the first session, before the specified exertion protocol was performed.

Main Outcome Measure(s): Balance Error Scoring System (BESS) results, sway velocity, and elliptical sway area.

Results: We found a decrease in postural control after each exercise protocol for all dependent measures. An interaction was noted between exercise protocol and time for total BESS score ($P = .002$). For both exercise protocols, all measures of postural control returned to baseline within 13 minutes.

Conclusions: Postural control was negatively affected after anaerobic and aerobic exercise protocols as measured by total BESS score, elliptical sway area, and sway velocity. The effect of exertion lasted up to 13 minutes after each exercise was completed. Certified athletic trainers and clinicians should be aware of these effects and their recovery time course when determining an appropriate time to administer sideline assessments of postural control after a suspected mild traumatic brain injury.

Key Words: balance, fatigue, recovery, concussions, mild head injuries, mild traumatic brain injuries

Key Points

- Both anaerobic and aerobic exercise protocols adversely affected postural control, as measured with the Balance Error Scoring System, sway velocity, and elliptical sway area.
- The effects of fatigue persisted for up to 13 minutes before postural control returned to baseline.
- Clinicians assessing an athlete with a suspected concussion should wait at least 13 minutes after activity stops before testing with the Balance Error Scoring System.

Interest in the proper management of sport-related mild traumatic brain injuries (TBIs) within the sports medicine community has increased in recent years. In the past, assessment of mild TBI relied heavily on subjective symptoms reported by the athlete.[1] This practice can become dangerously problematic if an athlete withholds information in order to return to competition, leaving the clinician without a clear picture of the athlete's condition, including (but not limited to) mental status.[1,2] The lack of objective and quantifiable information on which to base a return-to-play decision after a mild TBI poses a quandary for sports medicine clinicians. Thus, clinicians managing mild TBI have started including alternative means of identifying deficits after a suspected head injury, which may help to prevent premature return to competition and serious injury.[3–6]

Postural control testing has been a very important component that allows clinicians to obtain an objective measure of mild TBI. Using force plate measures as a validity reference, researchers[7] developed the Balance Error Scoring System (BESS), which is used on the sideline to measure an athlete's balance after a suspected mild TBI. Baseline scores for the BESS are established during preseason screenings and are taken at rest. However, sideline evaluations for mild TBI are most often undertaken during practice or competition, not at rest. Therefore, numerous extraneous factors, aside from the mild TBI, may influence postural control.[8–10]

Fatigue has been shown to negatively affect postural control.[2,11–14] However, few authors have measured the effect of fatigue on the performance of the BESS. Crowell et al[2] demonstrated decreased postural stability after an exercise protocol consisting of squat jumps, sprints, and treadmill running. Similarly, Wilkins et al[9] found a decrease in postural stability as a result of a 7-station, 20-minute exercise protocol as measured by the BESS total error score. Although both of these groups investigated fatigue as a combined function of anaerobic and aerobic activity, they did not clearly delineate between the fatigue effects related to one versus the other.

Also, few authors have investigated the immediate recovery time after fatigue for postural control measures to return to baseline. The limited research available showed decreased postural stability immediately postexercise but no deficits as early as 20 minutes postexercise.[15–18] More importantly, these authors combined aerobic and anaerobic exercise into protocols lasting 20 minutes or longer. The recovery timeline may differ when an aerobic exercise protocol is compared with an anaerobic exercise protocol.

The aforementioned authors examined exercise protocols that were explicitly aerobic in nature. To our knowledge, the immediate effects of an anaerobic exercise protocol on postural control have yet to be established. In addition, the effects of fatigue induced by an anaerobic exercise protocol have not been compared with an aerobic exercise protocol.

Therefore, our primary purpose was to evaluate the effects of fatigue on postural control after anaerobic and aerobic exercise protocols in healthy, college-aged varsity athletes. A secondary purpose was to establish an immediate recovery time course from each exercise protocol over which the effects of fatigue lessened and postural control measures returned to baseline status. Although we hypothesized postural stability would decrease after each exercise protocol, we believed the deficits after the anaerobic protocol would be more pronounced than those after the aerobic protocol. Because force plate measures of postural control are more sensitive to fatigue-related and injury-related changes than the BESS is, we decided to include these measures as part of our research protocol to determine whether sensitive changes were identified by the BESS in these scenarios.

METHODS

Participants

The participants were 36 National Collegiate Athletic Association (NCAA) Division I athletes (18 males, 18 females; age = 19.00 ± 1.01 years, height = 172.44 ± 10.47 cm, mass = 69.72 ± 12.84 kg) who were recruited based on their sport involvement (Table 1). Athletes participating in sports with an increased risk of sustaining a mild TBI, such as soccer, lacrosse, field hockey, and wrestling, were included in this study. Participants were excluded if they had any preexisting lower extremity injury that put them at further risk of injury; a known visual, vestibular, or balance disorder; or a history of a mild TBI within the previous 3 months. Additionally, any participant who had undergone balance testing in the last 3 months was excluded. Volunteers were given an instructional orientation concerning the exercise protocols and the balance testing before participation and were required to read and sign an approved informed consent form. The university's institutional review board approved the study.

Procedures

Each participant reported to the laboratory for 2 testing sessions. The first session for all participants included an orientation, collection of baseline BESS scores and force plate measures, and the completion of 1 exercise protocol. Upon completing the orientation, participants were asked to perform 2 separate practice trials of the complete BESS test while standing on the force plate. Exercise protocols performed in the first testing session were counterbalanced, thus eliminating the potential for an order effect. A 5-minute rest was allowed between trials. Practice trials were administered in an effort to account for a potential learning effect for the BESS.[19] A third trial of the BESS was performed after the 2 practice trials. The participants' BESS scores and force plate measures collected on the third trial were used as their baselines in subsequent statistical analyses. During all balance testing, the participants were asked to remove their shoes to best replicate the implementation of the BESS on the sideline. All BESS testing was carried out by a certified athletic trainer experienced in the administration and evaluation of this test on NCAA Division I athletes at our institution.

Each testing session included 1 of the exercise protocols. To allow for an adequate physical recovery, testing sessions were 1 to 7 days apart (mean = 3.53 ± 1.57 days). Participants were required to wear shorts, a T-shirt, and athletic shoes while performing the protocol. Before the exercise protocol, all participants carried out a warm-up and stretching period consisting of the first 2 running intervals, followed by low back and lower extremity static and dynamic stretching consistent with their varsity team's typical routine. After completing the exercise protocol, participants were escorted back to the laboratory (approximate distance: less than 20 m), where they began the BESS test. We believe many clinicians would begin administering a sideline clinical evaluation within 3 minutes of a suspected head injury; therefore, 3 minutes separated the end of the protocol and the first BESS testing. Because the 6-stance BESS requires approximately 3 to 4 minutes to administer and we wanted our athletes to rest for at least 1 minute before the next test time, we staggered the remaining test times at 5-minute intervals. Each participant was then retested at 8, 13, and 18 minutes postexercise to establish a recovery timeline. Heart rate and rating of perceived exertion (RPE) were recorded at each testing interval.

Table 1. Descriptive Statistics for All Participants (n = 36) (Mean ± SD)

Team	n	Age, y	Height, cm	Mass, kg
Men's lacrosse	6	18.67 ± 0.82	183.83 ± 5.85	79.32 ± 6.25
Women's lacrosse	6	18.83 ± 0.75	166.33 ± 8.61	64.92 ± 11.25
Men's soccer	6	18.83 ± 0.75	183.17 ± 5.04	85.83 ± 6.77
Women's soccer	6	19.00 ± 0.89	162.50 ± 5.58	57.35 ± 5.30
Men's wrestling	6	19.33 ± 1.03	176.67 ± 8.98	76.44 ± 12.15
Women's field hockey	6	19.50 ± 1.64	166.33 ± 5.35	61.06 ± 5.04
Totals	36	19.00 ± 1.01	172.44 ± 10.47	69.72 ± 12.84

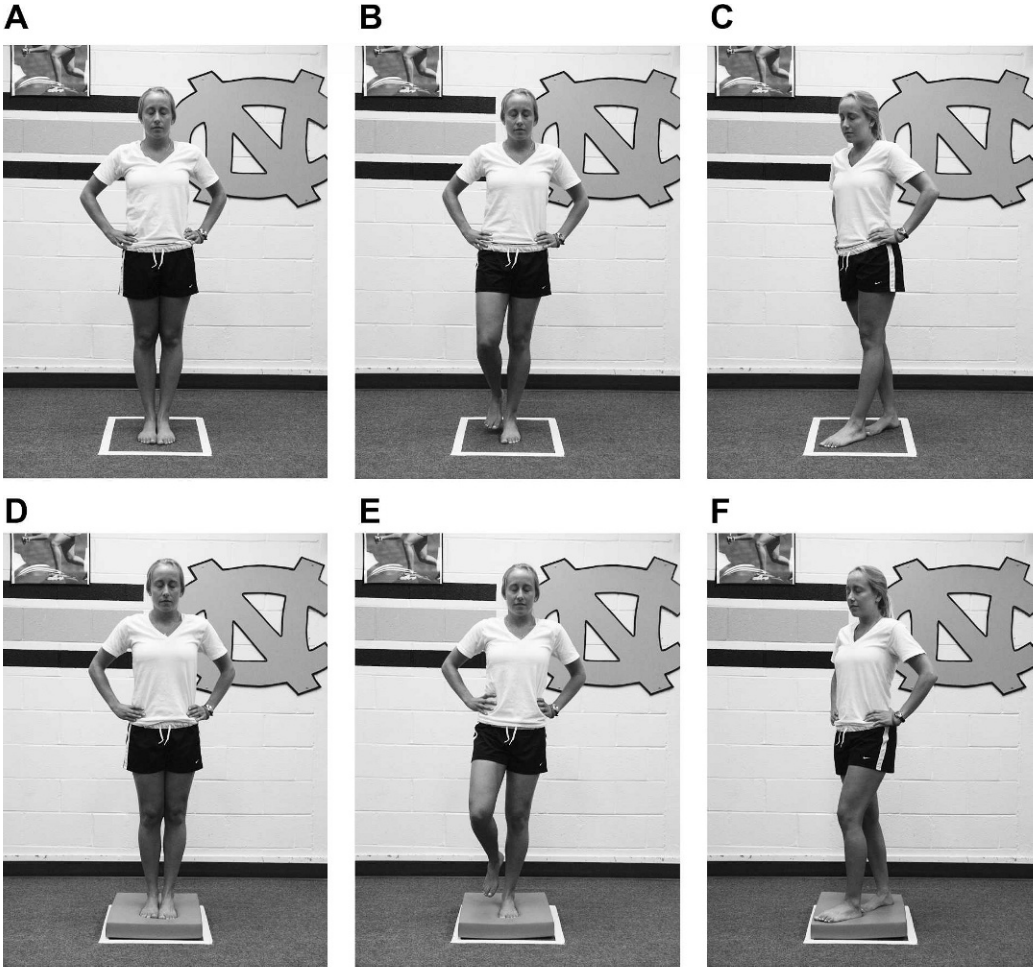

Figure 1. The 6 conditions of the Balance Error Scoring System. A, Double-leg stance, firm surface. B, Single-leg stance, firm surface. C, Tandem-leg stance, firm surface. D, Double-leg stance, foam surface. E, Single-leg stance, foam surface. F, Tandem-leg stance, foam surface.

Instrumentation

Balance Error Scoring System. The BESS[20] measures participants' postural control during 3 stances: double-leg, single-leg (nondominant), and tandem stance. These stances are performed on 2 surface conditions: firm and foam (Figure 1). The firm surface assessment occurred directly on a force plate surface, and the foam surface assessment occurred on a 41.6 × 50.1 × 6.1-cm Airex Balance Pad (uncompressed density = 70.389 kg/m^3; Alcan Airex AG, Sins, Switzerland), placed directly on a force plate. The balance tasks required the participant to balance for 20 seconds with eyes closed and hands on the iliac crests. Participants were provided with the test requirements and instructed to close their eyes to indicate when they were ready to begin a test trial. During the single-leg balance tasks, participants were required to balance on the nondominant leg, with the contralateral leg in 20° of hip flexion and 30° of knee flexion. The participant's dominant leg was determined by asking which leg was preferred to use to kick a soccer ball. Participants were instructed to stand quietly and motionless in the stance position, keeping the eyes closed and hands on the iliac crests. Upon losing their balance, they were to make any necessary adjustments and return to the initial testing position within 5 seconds. Verbal instructions and a demonstration of the BESS were given to each participant before testing began. Participants were scored based upon the errors recorded during each of the 6 balance tasks. Errors included lifting the hands off the iliac crest; opening the eyes; stepping, stumbling, or falling; moving the non-stance hip into more than 30° of abduction; lifting the forefoot or heel; and remaining out of the test position for more than 5 seconds. If a participant touched down off the force plate, the data were discarded for that particular trial, whereas the BESS errors were retained for analyses. When an individual steps off the force plate, the movement cannot be detected by the force plate system; thus, the actual shift in the center of pressure (COP) cannot be computed, rendering the center-of-pressure coordinates invalid. This occurred in only 33 of 1944 individual trials. A higher score (more errors) on the BESS compared with baseline measures indicated a deficit in postural control. The BESS has strong interrater reliability, with coefficients ranging from 0.78 to 0.96, and is a reliable and valid test to assess postural control in college-aged athletes.[21]

Force plate measures were simultaneously collected on a Bertec 4060-NC piezoelectric force plate (Bertec Corp, Columbus, OH). In BESS conditions using the foam surface, the foam pad was placed directly over the force plate and all offsets were taken to eliminate the effect of the foam-pad mass on our data. This system measures ground reaction forces produced by movement of the body's center of gravity about a fixed base of support. As participants were balancing in each of the 6 stances for the BESS, they were simultaneously standing on a force plate with data being collected through Motion Monitor software (version 6.74; Innovative Sports Training, Inc, Chicago, IL). Force plate measures to assess postural control are reliable and valid[22] and have been used in athletic populations.[4,23] Force plate raw voltage signals were amplified by a gain of 5 using a Bertec AM-6701 amplifier. Raw force plate data were sampled using Motion Monitor software at a frequency of 1 kHz.

Exercise Protocol. The protocol was performed indoors on running lanes (marked by cones) with a width of 2 m and a length of 20 m. Another cone placed 5 m behind the finishing line marked the running distance during the active recovery period. Before the exercise protocol, all participants carried out a warm-up and stretching period consisting of the first 2 running intervals followed by low back and lower extremity stretching. All participants were familiarized with the exercise protocols through oral explanations. The yo-yo intermittent recovery test is both reliable and valid in relation to the demands of soccer play, stressing both the aerobic and anaerobic metabolic pathways.[24]

For the aerobic exercise protocol, we used the yo-yo intermittent recovery test, level 1, to elicit fatigue in all participants. This test consists of repeated 20-m shuttle runs from the starting line to the turning point and then the finish line at progressively increased speeds controlled by audible tones delivered at known frequencies (Figure 2). The protocol began with 4 running bouts at 10 to 13 km/h over the first 160 m, followed by 7 running bouts at 13.5 to 14 km/h (160 to 440 m). It continued with stepwise 0.5-km/h speed increments after every 8 running bouts (ie, after 760, 1080, 1400, 1720 m, etc) until the participant became fatigued. Between running bouts, the participant had a 10-second active rest period consisting of a 5-m walk/jog at his or her own pace. When the participant failed to reach the finish line before the audible beep on 2 runs, he or she was considered fatigued and the exertion protocol was terminated. The missed runs did not have to occur in consecutive order for the participant to be deemed fatigued. The first miss was recorded, and whenever the second miss occurred, the exercise was terminated.

The anaerobic exercise protocol started at level 23.1 (19 km/h) and consisted of maximum-effort sprints between the cones. Participants were instructed that the test would run for 2 full minutes, in which they were to attempt to perform as many intervals as possible. For this protocol, the beeps were used as an external cue that informed the participants where they should be throughout the trial. If participants failed to reach the finish line twice during the 2-minute period, they did not end the test as in the aerobic protocol; instead, they continued for the full 2 minutes. Oral encouragement was used during both the aerobic and anaerobic exercise protocols in an effort to maintain the athlete's intensity level.

Heart rate was recorded before, during, and after each fatigue protocol with a digital heart rate monitor (Polar Electro Inc, Lake Success, NY). The Borg 15-point (6 to 20) category rating scale was used to measure each participant's RPE in order to ensure that exertion was adequate.

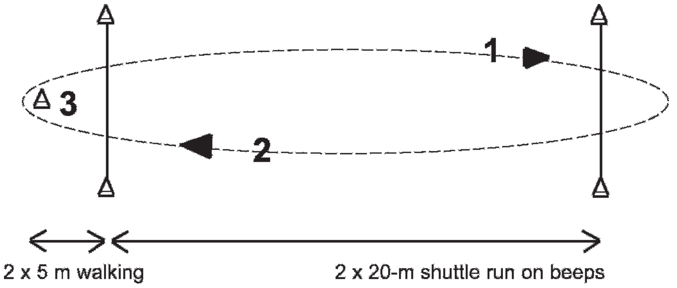

Figure 2. The yo-yo intermittent recovery test, level 1. Participants completed a (1) 20-m run to the end cone, (2) turned around the cone, and returned to the start line, for (3) a 10-s active recovery after each shuttle run. This 2 × 20-m shuttle run was repeated with progressively increased speeds controlled by audio beeps.

Data Reduction

The analog force plate data were converted into a digital signal via an analog-to-digital converter board to allow the computer to recognize and interpret the measures. The data were low-pass filtered within the Motion Monitor software using a 10-Hz Butterworth dual-pass filter. Force plate data (3-dimensional forces and moments) were used to compute the x- and y-coordinates of the COP. These data were then imported into a custom MATLAB 7 program (The Mathworks, Inc, Natick, MA). For this study, force plate measures included COP average sway velocity (SV) and elliptical sway area (ESA). The COP SV was defined as the average speed at which an individual's COP moved within the base of support. The ESA was the area defined by the minor and major axes of an ellipse that encompassed an area containing 95% of the COP data points. The COP SV and ESA were ensemble averaged across the 6 BESS conditions, resulting in 1 outcome measure for each variable per time interval.

Statistical Analysis

We calculated means and SDs for both the BESS total scores and the force plate measures. Separate, 1-way repeated-measures analyses of variance were calculated to determine the recovery time course for the BESS total score for each exercise protocol (6 total) and for each force plate measure (SV and ESA). Additionally, 3 separate 2 (protocols) × 4 (recovery time intervals) repeated-measures analyses of variance were performed to determine if an interaction existed between exercise protocol and recovery time. Sphericity of the data was assessed using the Mauchly test of sphericity. In the event sphericity was not assumed, a Huynh-Feldt correction was employed. Pairwise comparisons across protocols at each postexercise recovery time interval were conducted using a Bonferroni correction for multiple *t* tests. An α level of .05 was set a priori for all analyses. An a priori power calculation for BESS and sway area outcome measures suggested that 36 participants would yield statistical power exceeding 0.85 for both variables. All data were analyzed using SPSS statistical software (version 13.0; SPSS Inc, Chicago, IL).

RESULTS

Postural control was adversely affected after the anaerobic exercise protocol for all 3 dependent variables:

Table 2. Descriptive Data (Mean ± SD) and Summary of Statistical Analyses

Variable Exercise Protocol	Baseline[a]	Time Postexercise				Time Main Effect	Protocol × Time Interaction
		3 min	8 min	13 min	18 min		
Balance Error Scoring System (total errors)							
Anaerobic	4.89 ± 2.29	8.08 ± 3.10[b]	6.33 ± 2.75[b]	5.89 ± 2.20	4.69 ± 2.18	$F_{4,140}$ = 24.16, $P < .001$[b]	$F_{3,105}$ = 5.44, P = .002[c]
Aerobic	4.89 ± 2.29	10.03 ± 3.19[b]	7.33 ± 3.14[b]	5.53 ± 2.40	5.14 ± 2.70	$F_{4,140}$ = 56.68, $P < .001$[b]	
Sway velocity, cm/s							
Anaerobic	8.15 ± 2.06	9.47 ± 2.61[b]	9.00 ± 2.85	8.47 ± 2.43	7.89 ± 2.17	$F_{3.11,140}$ = 11.95, $P < .001$[b]	$F_{2.53,88.37}$ = 1.91, P = .143
Aerobic	8.15 ± 2.06	10.18 ± 2.41[b]	9.06 ± 2.59[b]	8.39 ± 2.30	8.11 ± 2.28	$F_{4,140}$ = 35.69, $P < .001$[b]	
Elliptical sway area, cm^2							
Anaerobic	49.14 ± 17.56	72.82 ± 31.98[b]	62.46 ± 30.89	56.54 ± 21.69	47.80 ± 22.18	$F_{4,140}$ = 11.93, $P < .001$[b]	$F_{2.54,88.74}$ = 0.79, P = .485
Aerobic	49.14 ± 17.56	80.10 ± 28.23[b]	61.82 ± 27.44	55.25 ± 21.84	51.70 ± 22.29	$F_{3.49,\ 140}$ = 15.55, $P < .001$ [b]	

[a] Baseline measures were the same for both anaerobic and aerobic exercise protocols because baseline was assessed during the first session only.

[b] Denotes a difference from baseline ($P < .05$).

[c] Denotes a difference between exercise protocols at 3 minutes postexercise ($P < .05$).

total BESS score ($F_{4,140}$ = 24.16, $P < .001$), SV ($F_{3.11,108.85}$ = 11.95, $P < .001$), and ESA ($F_{4,140}$ = 11.93, $P < .001$) (Table 2). Bonferroni post hoc analyses revealed differences between baseline and 3 minutes after anaerobic exercise for each dependent variable (total BESS score [$P < .001$], SV [$P < .001$], and ESA [$P < .001$]) and between baseline and 8 minutes after anaerobic exercise for total BESS score (P = .018). No differences were seen at the 13-minute or 18-minute recovery intervals.

After the aerobic exercise protocol, all 3 dependent variables were different: total BESS score ($F_{4,140}$ = 56.68, P = < .001), SV ($F_{4,140}$ = 35.69, $P < .001$), and ESA ($F_{3.49,122.25}$ = 15.55, $P < .001$). Bonferroni post hoc analyses revealed a difference between baseline and 3 minutes after aerobic exercise for each dependent variable (total BESS score [$P < .001$], SV [P = < .001], ESA [$P < .001$] and between baseline and 8 minutes for total BESS score ($P < .001$) and SV (P = .004). No differences were seen at the 13-minute or 18-minute recovery intervals.

An interaction between exercise protocol and postexercise recovery time was observed for total BESS score ($F_{3,105}$ = 5.44, P = .002). Bonferroni post hoc analyses revealed a difference at 3 minutes postexercise (Figure 3). No differences were found at 8, 13, or 18 minutes postexercise.

DISCUSSION

Our most important finding was that both anaerobic and aerobic exercise protocols adversely affected postural control as measured through the BESS, SV, and ESA. More importantly for athletic trainers and clinicians, the effects of fatigue appear to persist up to 8 minutes postexercise, regardless of exercise protocol, with postural control returning to baseline on average between 8 and 13 minutes after exercise.

Postural Control and Recovery Time From Fatigue

By 13 minutes after both the anaerobic and aerobic exercise protocols, postural control (according to total BESS error score, SV, and ESA) had returned to baseline levels. The recovery trend continued through the 18-minute recovery time interval, as we observed no differences in any of the dependent variables. Interestingly, although not statistically significant, postural control measures after the anaerobic exercise protocol for all 3 dependent variables improved at the 18-minute recovery mark when compared with baseline. A reasonable explanation for this trend can be attributed to sampling error, as all of the differences were less than 5% and nonsignificant.

Effect of Each Exercise Protocol, Heart Rate, and Rating of Perceived Exertion

We chose the anaerobic and aerobic exercise protocols in an effort to replicate the different types of exertion athletes may experience during the course of exercise. The Borg 15-point scale was used to measure each participant's RPE as the criterion to confirm fatigue after each exercise protocol.[25] Heart rate was also monitored throughout each testing session due to its strong positive correlation with RPE scores. Prior investigators[26,27] have used the RPE scale with a similar population and found that a score

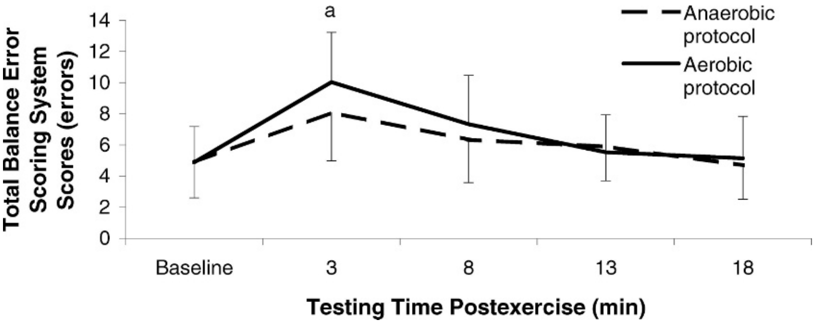

Figure 3. Protocol × time interaction for total Balance Error Scoring System scores. [a] Indicates difference between protocols at 3 minutes postexercise.

of 15 correlated with 75% to 90% of maximal oxygen consumption.

Immediately after the aerobic exercise protocol, mean RPE was 18.3, whereas the anaerobic exercise protocol produced a mean RPE of 17.6. Both values suggest that participants' levels of exertion reached *very, very hard.* The corresponding heart rate measures immediately after aerobic and anaerobic exercise were 191 and 180 beats per minute, respectively. Using the age-predicted heart rate formula, participants exercised at an intensity equal to 95% and 90% of maximal heart rate for the aerobic and anaerobic exercise protocols, respectively. From these measures, we are confident that participants exerted adequately and that the decrease in postural control was a result of the very high exertion level, which could lead to fatigue.

Of importance was the finding that 2 exercise protocols, 1 aerobic in nature and the other anaerobic, yielded similar postural control recovery rates from fatigue. For both the anaerobic and aerobic exercise protocols, postural control deficits from fatigue were no longer different at 13 minutes postexercise. Although the aerobic protocol was designed to simulate the demands of long-duration exercise (eg, soccer), the similar heart rate and RPE values immediately after each protocol terminated suggest that the final phases of each protocol imposed similar metabolic demands. Although the variables of the 2 protocols (ie, intensity and duration) were designed to distinguish between anaerobic and aerobic metabolic pathways, the final metabolic costs were similar in nature. This similarity may account for the lack of differences in postural control deficits and recovery after exercise between the protocols. For fatigue to be truly characterized within an aerobic protocol, the results of this study suggests that a submaximal protocol (ie, exercising at a high enough intensity for fatigue to be reached between 8 and 12 minutes) would be more appropriate. More research is needed to truly compare the effect of fatigue on postural control between 2 protocols that impose different metabolic demands.

Using varied fatigue protocols, other researchers[8,11,15,16,28] have found similar results, observing postural control deficits after bouts of exercise. Yaggie and Armstrong[29] observed transiently degraded postural control after fatigue from bouts of exercise performed on a cycle ergometer as measured by postural sway. Changes in balance indices were observed immediately after fatigue and returned to baseline values within 10 minutes of recovery.[29] Our results are consistent with these results. Harkins et al[14] found SV was greater when the ankle local musculature was fatigued but that the effects lasted only 75 seconds to 90 seconds. The short recovery time can potentially be attributed to local muscle fatigue rather than systemic, or whole-body, fatigue.

Our findings with regard to the BESS are supported by previous researchers[2,9] in the area of fatigue and balance using this clinical balance tool. Both of these groups observed an increase in postfatigue errors as measured by the BESS after bouts of exercise. Crowell et al[2] investigated postural stability after a fatigue protocol consisting of squat jumps, sprints, and treadmill running in male and female club-sport athletes. Differences between baseline and postfatigue BESS total scores were observed, leading to the conclusion that any decrease in performance on the BESS might be attributed to the fatigue that had occurred in the lower extremity. Similarly, Wilkins et al[9] looked at performance on the BESS after a fatigue protocol in NCAA Division I collegiate athletes. They used a fatigue protocol lasting 20 minutes and consisting of 7 stages, including a 5-minute moderate jog, 3 minutes of sprints, 2 minutes of push-ups, 2 minutes of sit-ups, 3 minutes of step-ups, 3 minutes of sprints, and a 2-minute run. Total errors increased from pretest to posttest in the fatigue group. Both groups concluded that clinicians should not administer the BESS immediately after an injury due to the potentially confounding effects of fatigue.

Although our results suggest that postural control returned to baseline for both exercise protocols between the 8-minute and 13-minute recovery intervals, an interaction between exercise protocol and time was shown for total BESS score. Further post hoc analyses revealed a difference only at the 3-minute postexercise interval (mean difference = 1.94). These findings differ slightly from those in the previous literature. Observing postural sway deviations after a 25-minute treadmill run, Nardone et al[15] found that sway measures were still elevated after 13 minutes of recovery but had returned to baseline after 23 minutes. More recently, researchers[18] tried to determine a balance recovery timeline using the BESS and a 7-station exertion protocol. Balance was affected by fatigue, but balance recovery (ie, return to pretest score) occurred within 20 minutes after exercise ceased. The difference in recovery time from the Susco et al[18] study to our study can be attributed to many factors. The participant pool in their study was "recreationally active college students," whereas we observed NCAA Division I collegiate athletes. Different physical abilities (eg, endurance, flexibility, strength) between active students and collegiate athletes might best explain these differences. Another explanation might be that the study designs were different. For example, Susco et al[18] divided the participants into posttest groups tested at different time intervals after exercise, thus using a between-subjects, repeated-measures testing design. We tested all participants at the same posttest time intervals, using a within-subjects, repeated-measures design. Both groups demonstrated differences between baseline and postexercise postural control using the BESS. Of equal importance, both showed that postural control needs time to recover from the effects of fatigue.

Clinical Significance

Sideline assessment of mild TBI has evolved into a comprehensive approach, which should include an evaluation of postural control.[4,5,30–33] Although baseline postural control measures for each athlete are taken at rest, most postinjury measures are taken after bouts of exercise. It is well established that fatigue affects postural control, but the question remains, "How long do these deficits last?" The findings of earlier research imply that administering the BESS to an athlete just taken off the field is contraindicated. In this situation, the athlete may commit an abnormally high number of errors due to the combined effects of fatigue and injury.[9] Thus, a postexercise recovery time of 20 minutes has been recommended, so the effect of fatigue does not compromise the sideline postural control assessment.[8,15–18] Our findings suggest that athletic trainers and other clinicians who choose to use the BESS as part of their sideline assessment after a suspected mild TBI should wait at least 13 minutes for the effects of fatigue to lessen and the athlete to return to a resting state. The sideline assessment will then be more comparable with baseline, which increases the validity of attributing postural control deficits noted during the sideline assessment to a potential mild TBI. Regardless of exercise type, the recovery period suggested could be applied to all sports in which athletes participate at high levels of intensity, similar to our exercise protocols.

Limitations

First, when interpreting the results from our research, the reader should be reminded that we analyzed the effects of fatigue on healthy participants in a controlled environment. The results may differ with injured participants or in uncontrolled environments (ie, sideline of practice or game). Different sports require various metabolic demands; thus, athletes experience different levels of exertion.[18] We attempted to isolate the effects of a primarily anaerobic exercise protocol from a primarily aerobic exercise protocol. The aerobic exercise protocol began at a low intensity and gradually increased as participants successfully completed each stage. Eventually, participants were required to perform at a near-maximal effort in order to complete the exercise protocol. Therefore, the ending periods of the aerobic and anaerobic exercise protocols were strongly similar; as participants advanced in stages during the aerobic exercise protocol, their intensity was approaching that of a sprint in order to heed the beeps. This procedure may have too closely paralleled the effort expended during the anaerobic exercise protocol, thus yielding similar results at the end of each protocol, which may explain the similar recovery times we observed after anaerobic and aerobic exercise. Further, standardizing 2 fatigue protocols is a difficult task due to extraneous variables that can alter how a specific individual views the exercise (eg, psychological state, level of fitness, and environmental conditions). Because we studied in-season NCAA Division I athletes, we were unable to entirely control the level of activity in our sample. For example, on days when they were not playing or practicing, our athletes were sometimes required to lift weights and undergo conditioning. In order to control for this, participants were scheduled when they had at least 2 hours of rest from team training. Per our protocol, heart rates were measured before both testing sessions in order for us to ensure that athletes were at rest before starting each exercise protocol.

Another possible limitation of this study was the presence of a learning effect from baseline to postfatigue after the anaerobic exercise protocol. Participants' mean BESS scores, SVs, and ESAs were all lower at recovery interval 18 when compared with baseline. We tried to control for a learning effect by giving participants 2 practice trials before measuring the baseline. However, each participant performed 7 total BESS trials during the first session and another 4 during the second session (within 7 days). Multiple trials in such a short period of time may have contributed to improved scores after the shorter-duration anaerobic exercise protocol. A learning effect has been demonstrated in control groups,[9,19] but further research is needed to specifically examine the learning effects after exercise. This potential confounding variable likely had a minimal influence on our data, as the decreased postural control indices at the last postexercise interval (ie, 18 minutes) were not different from baseline.

Future Research

Future investigators should examine the recovery rate from exercise with specific sports and possibly specific positions. For example, it is unlikely that a wide receiver is fatigued in a manner similar to a soccer player or a track and field sprinter to a lacrosse player. We attempted to differentiate between anaerobic and aerobic exercise, but more research is needed to accomplish this goal. Further, because many athletes suffer a mild TBI at a time during play when they may not have reached physical fatigue, a more thorough study of balance performance within this research protocol after different levels of exertion seems warranted. By comparing different exercise intensities (levels of exertion) with various recovery time intervals, a regression model may be developed to predict the recovery time needed before balance is assessed after a mild TBI. This will allow clinicians a more accurate diagnosis on the appropriate time to return to play if, indeed, the player can be cleared to return to the game. Researchers should also evaluate the effects of exertion and its recovery rate on other tools used to assess mild TBI, such as the Standardized Assessment of Concussion and the Graded Symptom Checklist. Sideline BESS testing of athletes during practice at different intervals may also provide important, relevant research into the effects of fatigue on postural control.

CONCLUSIONS

In a participant pool of collegiate athletes, postural control was affected by anaerobic and aerobic exercise protocols as measured by total BESS error score and force plate measures of SV and ESA. The effect of fatigue remained present until 13 minutes after both aerobic and anaerobic exercise. At this time, postural control returned to baseline. Certified athletic trainers and other clinicians should be aware of these effects and their recovery time course when determining an appropriate time to assess postural control after a suspected mild TBI.

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