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original research

A High-Intensity, Intermittent Exercise Protocol and Dynamic Postural Control in Men and Women

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Context: Deficits in dynamic postural control predict lower limb injury. Differing fatiguing protocols negatively affect dynamic postural control. The effect of high-intensity, intermittent exercise on dynamic postural control has not been investigated.

Objective: To investigate the effect of a high-intensity, intermittent exercise protocol (HIIP) on the dynamic postural control of men and women as measured by the Star Excursion Balance Test (SEBT).

Design: Descriptive laboratory study.

Setting: University gymnasium.

Patients or Other Participants: Twenty male (age = 20.83 ± 1.50 years, height = 179.24 ± 7.94 cm, mass = 77.67 ± 10.82 kg) and 20 female (age = 20.45 ± 1.34 years, height = 166.08 ± 5.83 cm, mass = 63.02 ± 6.67 kg) athletes.

Intervention(s): We recorded SEBT measurements at baseline, pre-HIIP, and post-HIIP. The HIIP consisted of 4 repetitions of 10-m forward sprinting with a 90° change of direction and then backward sprinting for 5 m, 2 repetitions of 2-legged jumping over 5 hurdles, 2 repetitions of high-knee side stepping over 5 hurdles, and 4 repetitions of lateral 5-m shuffles. Participants rested for 30 seconds before repeating the circuit until they reported a score of 18 on the Borg rating of perceived exertion scale.

Main Outcome Measure(s): A mixed between- and within–subjects analysis of variance was conducted to assess time (pre-HIIP, post-HIIP) × sex interaction effects. Subsequent investigations assessed the main effect of time and sex on normalized maximal SEBT scores. We used intraclass correlation coefficients to determine the test-retest reliability of the SEBT and paired-samples *t* tests to assess the HIIP effect on circuit times.

Results: We found a time × sex effect ($F_{8,69} = 3.5$; *P* range, <.001–.04; η^2 range, 0.057–0.219), with women less negatively affected. We also noted a main effect for time, with worse normalized maximal SEBT scores postfatigue ($F_{8,69} = 22.39$; $P < .001$; η^2 range, 0.324–0.695), and for sex, as women scored better in 7 SEBT directions ($F_{8,69} = 0.84$; *P* range, <.001–008; η^2 range, 0.088–0.381). The intraclass correlation coefficients demonstrated high (0.77–0.99) test-retest repeatability. Paired-samples *t* tests demonstrated increases in circuit time post-HIIP ($P < .001$).

Conclusions: The HIIP-induced fatigue negatively affected normalized maximal SEBT scores. Women had better scores than men and were affected less negatively by HIIP-induced fatigue.

Key Words: Star Excursion Balance Test, balance, sex

Key Points

- The high-intensity, intermittent exercise protocol negatively affected dynamic postural control.
- Women were less negatively affected by the high-intensity, intermittent exercise protocol than men.
- Women generally had better Star Excursion Balance Test scores than men before and after the exercise protocol.

Deficits in dynamic postural control are risk factors for sustaining lower limb injuries.[1] Dynamic postural control requires that postural control be maintained around a base of support during movement, thereby mimicking sporting demands more than static postural control does.[2] It is achieved by coordinating neuromuscular and somatosensory systems to process sensory information and react accordingly.[3] The Star Excursion Balance Test (SEBT) is a measure of dynamic postural control that can predict injury.[1] It is sensitive to dynamic postural-control deficits after ankle[4] and anterior cruciate ligament (ACL) injuries.[5] The SEBT also can detect improvements in dynamic postural control after interventions in patients with chronic ankle instability[6] and healthy participants.[7] However, research into the reliability of normalized SEBT scores is lacking.[8]

Lower limb injuries are common in sports with intermittent bouts of high-intensity exercise and multiple changes of direction (eg, soccer, basketball, and rugby) and toward the end of a period or game.[9–11] This has been noted particularly for knee-ligament[9] and thigh-muscle injuries,[11] suggesting that fatigue is a risk factor. In laboratory-based studies, researchers also have demonstrated that fatigue results in unwanted changes in movement technique, such as increased knee abduction,[12,13] which is an important component of the ACL injury mechanism.[14,15] Fatigue may contribute to detrimental changes in movement technique due to decreased efficiency of muscle-spindle afferent information,[2] delayed muscle contraction,[16] decreased muscle-torque generation,[2,16] and central nervous system changes.[17]

Given that injury rates increase when athletes are fatigued[9–11] and deficits in postural control are risk factors for sustaining lower limb injuries,[1,18,19] fatigue-induced postural deficits may be expected to contribute to the incidence of injury. However, this has not been examined

Table 1. Participant Characteristics by Sex

Characteristic	Participants	
	Men (n = 20)	Women (n = 20)
Age, y	20.83 ± 1.50	20.45 ± 1.34
Height, cm	179.24 ± 7.94	166.08 ± 5.83
Mass, kg	77.67 ± 10.82	63.02 ± 6.67
Lower limb length, cm	94.58 ± 6.05	87.95 ± 3.91
Primary sport		
Gaelic football	12	10
Hurling/camogie	5	6
Soccer	3	4

prospectively, and whereas several investigators have demonstrated that fatigue negatively affects dynamic postural control,[20–23] others have not.[21,23,24] These contrasting findings may be due to methodologic variations and sex-related differences. For example, researchers[4,25] have found that functional exercise protocols cause greater deficits than isokinetic protocols do. In addition, whereas fatigue affects dynamic postural control less in women,[26] results from males and females have been combined in several studies.[24,25,27] Despite investigations into the effects of fatigue on dynamic postural control using continuous whole-body fatiguing exercise[20,21,23,27,28] and localized muscle-fatiguing exercise,[22,26,28,29] no researchers have investigated the effects of high-intensity, intermittent exercise on dynamic postural control. This topic needs to be examined given the high incidence of injury during sports that contain regular bouts of high-intensity, intermittent exercise when participants are fatigued.[9–11]

Waldén et al[30] reported a sex disparity in the incidence of certain lower limb injuries, with higher incidences of ACL injuries occurring in women. Researchers[14,31] have proposed that it is due to neuromuscular and biomechanical differences. Despite the sex disparity in ACL injuries[30] and the relationship between lower SEBT scores and injury,[1] the only authors[26] who investigated the effect of fatigue and sex on dynamic postural control found that women had better scores for dynamic postural control and were less negatively affected than men. It is unclear if similar findings would be reproduced when male and female athletes are fatigued by high-intensity, intermittent exercise.

Therefore, the primary purpose of our study was to investigate the reliability of the SEBT. Our main purpose was to compare the effect of a high-intensity, intermittent exercise protocol (HIIP) on SEBT scores between men and women. Our secondary aims were to investigate the effect of the HIIP on SEBT scores across both sexes and the effect of sex on SEBT scores. We hypothesized that SEBT test-retest reliability would be high and that women would be less negatively affected by the HIIP than men. We also hypothesized that the HIIP would negatively affect SEBT scores in both men and women and that women would have higher SEBT scores.

METHODS

Participants

A cohort of 40 male and female university athletes volunteered to participate in the study (Table 1). Inclusion criteria required participants to be free from all lower extremity or head injuries within the 6 months before the study, to not be involved in a balance-training program, and to be generally healthy. Participants were excluded if they had ankle- or knee-joint instability, had any neurologic or central nervous system deficits, or were taking any medication that may have affected their balance. All participants provided written informed consent, and the study was approved by the Research Ethics Committee of Dublin City University.

Procedure

Participants were required to attend 3 separate sessions. They underwent a familiarization session, and after a 2-day interval, they underwent a baseline measurement session that was used to determine the repeatability of the SEBT protocol. Participants returned 5 to 7 days later for assessment of the SEBT pre-HIIP and post-HIIP.

Star Excursion Balance Test

The SEBT was performed according to Gribble et al.[25] Each participant stood with hands on hips and the dominant lower extremity in the center of a grid that was placed on the floor and consisted of 8 lines extending at 45° increments from the center. The *dominant lower extremity* was defined as the limb with which the participant would kick a ball.[26] The navicular tuberosity was marked while participants were weight bearing and positioned over the center of the SEBT. The hallux was positioned over the anterior progression line. Participants were instructed to maintain a single-legged stance while reaching with the free limb as far as possible along a given direction, to lightly touch the farthest point possible, and to return to bilateral stance while maintaining their equilibrium. Reach directions were completed in a random order 3 times in each direction and recorded manually by the tester (E. W., A. B., or E. W.). Trials were discarded and repeated if the participant used the reaching limb for a substantial amount of support on touching the tape, removed the foot from the designated center of the grid, lifted the heel of the stance limb, took hands off hips, or was unable to maintain balance. As Plisky et al[1] described, participants had a minimum of 6 practice trials in each direction using both limbs and then sat quietly for 5 minutes before data collection on each testing day. Measures of maximal SEBT reach distances were normalized for limb length using the following formula: normalized maximal reach distance = reach distance (cm)/leg length (cm) × 100.[32] The overall average SEBT score was calculated by averaging the normalized maximal SEBT in each direction. Lower limb length was measured as the distance from the anterior-superior iliac spine to the most distal point of the medial malleolus.[32]

High-Intensity, Intermittent Exercise Protocol

After a warm-up,[33] participants completed the HIIP with maximal effort (Figure). The HIIP was designed to mimic periods of high-intensity, intermittent activity leading to temporary fatigue.[34,35] Di Mascio and Bradley[36] reported that during such periods, soccer players ran for an average of 6.7 ± 1.8 m and recovered for an average of 30 seconds

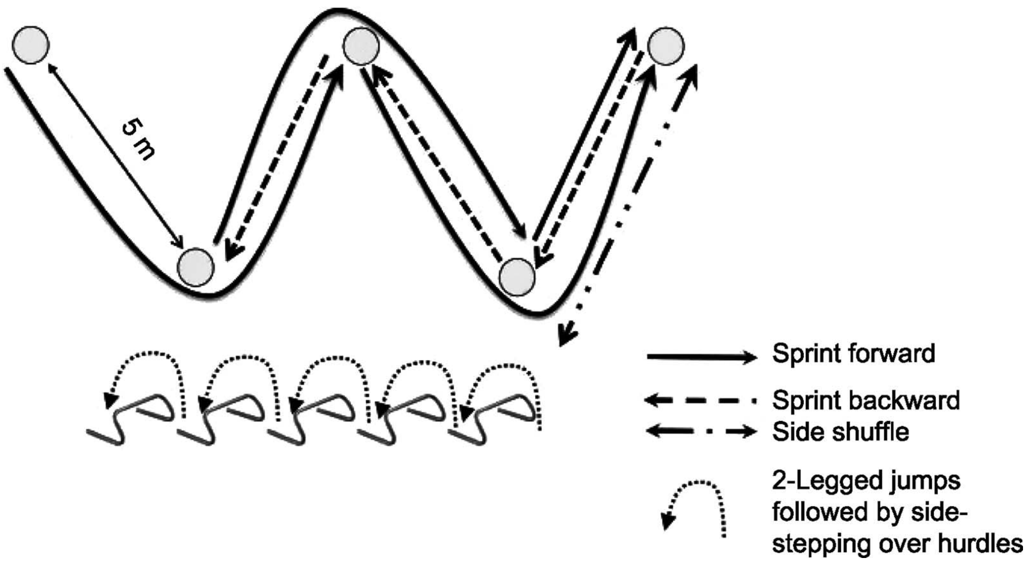

Figure. The high-intensity, intermittent exercise protocol.

between repeated periods. During the HIIP, participants sprinted forward 5 m, cut at a 90° angle, sprinted forward another 5 m, and backpedaled 5 m. This activity was repeated 4 times before participants completed a series of hurdle activities. First, they performed 2-legged jumps over 5 hurdles that were 30 cm high, turned, and repeated the jumps. Second, they performed side-stepping exercises over the 5 hurdles. Third, they completed four 5-m lateral shuffles. Circuit time was recorded using infrared timing gates (model TC; Brower Timing Systems, Draper, UT). After completing a circuit, participants rested for 30 seconds before repeating the circuit. The HIIP was discontinued when participants reported a score of 18 on the Borg rating of perceived exertion (RPE) scale, which ranges from 6 to 20.[37] Heart rate was monitored throughout the HIIP using a heart-rate monitor (model FT1; Polar Electro Inc, Lake Success, NY). Dynamic postural-control assessments using the SEBT commenced within 15 seconds and were completed within 3 minutes. To minimize the effects of recovery, practice trials were conducted pre-fatigue protocol only.[20,21,26]

Statistical Analysis

Test-Retest Reliability. Intraclass correlation coefficients (ICCs) determined the repeatability of normalized maximal SEBT scores taken at baseline and pre-HIIP. Standard error of measurement (SEM) was used to assess intersession variability (ie, the degree of variation between repeated assessments in the same group). The SEM was calculated by multiplying the standard deviation of the test scores (S_T) by the square root of the difference of 1 minus the reliability coefficient (r_{xx}) ($SEM_x = S_T \sqrt{1 - r_{xx}}$).

Physiologic Effects of the HIIP. Paired-samples *t* tests compared the first and final HIIP circuit-completion times and resting heart rate with post-HIIP heart rate.

Effect of HIIP and Sex on Dynamic Postural Control. The main aim of the study was investigated using a mixed between- and within-subjects analysis of variance to assess time (pre-HIIP, post-HIPP) × sex interaction effect (ie, to determine if the difference in SEBT scores between men and women varied post-HIIP). We subsequently analyzed the effect of time and sex on normalized maximal SEBT scores. The dependent variables analyzed were the normalized maximal SEBT scores in 8 directions and the overall average normalized SEBT score. Post hoc Bonferroni analyses were conducted to correct for multiple comparisons. To determine the magnitude of any effect, effect sizes (η^2) were calculated and ranked using the Cohen d classification (0.01 = *small effect*, 0.06 = *medium effect*, 0.14 = *large effect*).[38] We used SPSS software (version 17.0; SPSS Inc, Chicago, IL) for all analyses and set the α level at $< .05$.

RESULTS

Test-Retest Reliability

The range of ICC values (0.77–0.99) for the 8 normalized maximal SEBT scores and the overall average SEBT score demonstrated strong test-retest reliability per the Cohen d classification. The SEM ranged from 0.62 to 2.60 for the different SEBT measurements (Table 2).

Time × Sex Interaction Effect

We found a time × sex interaction effect, with small to large effect sizes for each direction of the 8 normalized maximal SEBT scores and the overall average SEBT score (Wilks $\Lambda = 0.71$; $F_{8,69} = 3.5$; P range, $<.001$–.04; η^2 range, 0.057–0.219), indicating that the negative effects of the HIIP on dynamic postural control were less in women (Table 3).

Main Effects for Time and Sex

A main effect of time indicated that the HIIP had a detrimental effect on the normalized maximal SEBT scores in men and women for the 8 directions and the overall average SEBT score, with large effect sizes (Wilks $\Lambda = 0.28$; $F_{8,69} = 22.39$; $P < .001$; η^2 range, 0.324–0.695; Table 3). We found a main effect for sex with small to large effect sizes (Wilks $\Lambda = 0.91$; $F_{8,69} = 0.84$; P range, $<.001$–.008;

Table 2. Intraclass Correlations Between Baseline and Preexercise Normalized Star Excursion Balance Test Maximal Reach Distances (N = 40)

	Star Excursion Balance Test								
		Direction							
	Average Score[a]	Anterior	Anteromedial	Medial	Posteromedial	Posterior	Posterolateral	Lateral	Anterolateral
Intraclass correlation (95% confidence interval)	0.98 (0.96, 0.99)	0.90 (0.81, 0.95)	0.77 (0.60, 0.88)	0.77 (0.56, 0.88)	0.99 (0.99, 1.00)	0.99 (0.98, 0.99)	0.97 (0.95, 0.99)	0.99 (0.98, 0.99)	0.82 (0.62, 0.91)
Standard error of measurement	0.62	1.65	2.36	2.60	0.62	0.65	1.14	0.81	2.13

[a] Indicates average of 8 normalized maximal reach distances.

Table 3. Prefatigue and Postfatigue Values and Pretest-Posttest Differences for Dependent Measures and Effect Sizes of Main and Interaction Effects

	Participants						Exercise Main Effect[a]		Sex Main Effect		Group × Exercise Interaction[b]	
	Men			Women								
	Proximity to High-Intensity, Intermittent Exercise Protocol, Mean ± SD			Proximity to High-Intensity, Intermittent Exercise Protocol, Mean ± SD								
Variable	Before	After	% Change	Before	After	% Change	*P*	Effect Size[c]	*P*	Effect Size[c]	*P*	Effect Size[c]
Star Excursion Balance Test												
Overall mean score[d]	83.73 ± 3.75	78.29 ± 5.36	6.49	87.54 ± 4.04	84.67 ± 4.32	3.26	<.001	0.695	<.001[e]	0.281	.007	0.179
Direction												
Anterior	84.84 ± 4.83	80.33 ± 6.62	5.31	86.96 ± 5.09	84.73 ± 6.22	2.56	<.001	0.554	.008[e]	0.088	<.001	0.152
Anteromedial	84.71 ± 4.10	80.92 ± 5.69	4.48	87.35 ± 4.93	85.82 ± 4.75	1.75	<.001	0.337	<.001[e]	0.152	.008	0.090
Medial	84.12 ± 4.12	78.89 ± 5.85	6.23	88.87 ± 5.50	87.07 ± 5.59	2.03	<.001	0.461	<.001[e]	0.311	<.001	0.219
Posteromedial	86.69 ± 5.30	80.74 ± 5.49	6.87	92.70 ± 5.43	89.50 ± 4.90	3.45	<.001	0.540	<.001[e]	0.381	.003	0.110
Posterior	88.00 ± 6.33	81.25 ± 7.23	7.67	94.52 ± 5.00	89.55 ± 5.47	5.26	<.001	0.648	<.001[e]	0.305	.001	0.133
Posterolateral	84.63 ± 5.65	77.81 ± 6.13	8.05	90.19 ± 6.44	86.20 ± 5.89	4.43	<.001	0.625	<.001[e]	0.274	.003	0.111
Lateral	77.71 ± 7.37	70.94 ± 7.72	8.71	82.24 ± 8.86	78.03 ± 9.09	5.11	<.001	0.493	.001[e]	0.143	.04	0.057
Anterolateral	79.12 ± 4.41	75.49 ± 5.83	4.59	77.49 ± 5.67	76.47 ± 5.31	1.32	<.001	0.324	.50	0.006	.002	0.118

[a] Indicates before to after high-intensity, intermittent exercise protocol difference.
[b] Indicates group differences for prefatigue to postfatigue changes. Positive effect sizes indicate greater changes in the men.
[c] Effect sizes are η^2 values.
[d] Mean of all 8 directions normalized to lower limb length (reach distance [cm]/leg length [cm] × 100).
[e] Indicates sex differences.

Table 4. Comparison of Standard Error of Measurement and Fatigue-Induced Decline in Star Excursion Balance Test Scores in Men and Women

Star Excursion Balance Test	Standard Error of Measurement	Star Excursion Balance Test Score Decline Induced by High-Intensity, Intermittent Exercise Protocol	
		Men	Women
Average score	0.62	5.44	2.87
Direction			
Anterior	1.65	4.51	2.23
Anteromedial	2.36	3.79	1.53
Medial	2.60	5.23	1.80
Posteromedial	0.62	5.95	3.20
Posterior	0.65	6.75	4.97
Posterolateral	1.14	6.82	3.99
Lateral	0.81	6.77	4.21
Anterolateral	2.13	3.63	1.02

η^2 range, 0.088–0.381), with women demonstrating better normalized maximal SEBT scores than men in all directions except anterolateral (Table 3). The relationship between the SEM calculated for the SEBT and the fatigue-induced decline in SEBT scores is displayed in Table 4.

Effect of HIIP on Lap Completion Times and Heart Rate

On average, participants completed 6.58 ± 0.81 circuits of the HIIP before reporting a score of 18 on the Borg RPE scale, with an average heart rate at completion of 189.95 ± 5.58 beats/min versus 56.20 ± 9.40 beats/min at rest (Table 5). Circuit-completion times increased from the initial (54.86 ± 4.48 seconds) to the final (57.42 ± 4.56 seconds) circuit ($P < .001$; Table 5).

DISCUSSION

The results of our study demonstrate HIIP-induced decrements in SEBT scores in both men and women, with women less negatively affected than men. Women also had higher SEBT scores pre-HIIP and post-HIIP. Confidence can be placed in these findings for 2 reasons. First, strong test-retest reliability, similar to that previously reported,[32] was shown between baseline and pre-HIIP SEBT scores. Second, all SEBT scores in men and 6 of 9 SEBT scores in women showed an HIIP-induced decline greater than the respective SEM (Table 4), indicating that the HIIP resulted in reductions in SEBT scores that were greater than intersession variability in most measurements.

The HIIP physiologically stressed participants, with high RPEs and heart rates similar to the 187 ± 9 beats/min reported in soccer players during match play (Table 5).[34] It required participants to run for an average distance of 460.6 m over 8 minutes, 47.8 seconds, on average. This approximates to 261.7 m in 5 minutes, similar to the typical peak distance reported for soccer players over 5 minutes (219 ± 8 m).[35] The increased circuit-completion times indicated that the HIIP induced fatigue, which may be due to a number of potential central and peripheral mechanisms. Centrally, the HIIP can lead to altered cardiovascular, respiratory, thermoregulatory, and muscular afferent input that, when combined with high levels of perceived exertion, can negatively affect cortical motor drive and result in the inhibition of the lower motor neuron at the spinal level,[17,39] ultimately decreasing muscle-force output and contributing to the observed increased circuit time. Peripherally, the HIIP may result in several changes, such as decreased neuromuscular transmission[40,41] and elevated inorganic phosphate levels,[42] that can interfere with cross-bridge formation. It can also lead to hyperkalemia,[42] acidosis,[43,44] and the presence of reactive oxygen species[42,45]; these changes can impair contractile protein activity and stimulate muscle afferents, reducing central motor drive. The combined central and peripheral effects can result in reduced muscle-force output that, when combined with fatigue-induced decreases in sensorimotor afferent information[2] and delayed muscle contraction,[16] may lead to technique changes[12,13] and dynamic postural-control deficits[20,23,26–28] in exercising athletes. This could increase the susceptibility to lower limb injuries and explain, at least in part, the observed relationship between fatigue and injury in sports with intermittent bouts of high-intensity exercise.[9–11]

Our results support previous research in which investigators demonstrated that a fatiguing protocol led to worse dynamic postural control.[20,23,26–28] Given that the exercise performed dictates the resultant fatigue,[22,23] it is not surprising that our results conflict with other studies[21,23,24] in which researchers used different protocols including closed kinetic chain dynamometry,[24] cycling,[23] continuous treadmill running,[21,23,27] and step up with resistance.[21] These protocols may have fatiguing effects that are very different from the HIIP. Indeed, the percentage changes in normalized maximal SEBT scores were generally greater in our study than in previous studies,[25,26] suggesting that the HIIP-induced fatigue resulted in lower normalized maximal SEBT scores than did fatigue induced by continuous treadmill running[20,21] and isokinetic and lunging[25,26] and step-up-with-resistance[21] protocols. Even studies in which researchers have investigated the effect of functional

Table 5. Markers of Exertion

Marker	Participants: Men (n = 20)	Women (n = 20)	Overall (N = 40)
Resting heart rate, beats/min	55.63 ± 9.96	56.77 ± 9.15	56.20 ± 9.40
Maximal heart rate, beats/min	190.33 ± 5.54	189.59 ± 6.31	189.95 ± 5.58
% Maximal heart rate at final lap	95.56 ± 2.78	95.01 ± 3.16	95.28 ± 2.95
Number of circuits	6.35 ± 0.67	6.80 ± 0.89	6.58 ± 0.81
Time of circuit 1, s	56.59 ± 3.15	53.13 ± 5.02	54.86 ± 4.48
Time of final circuit, s	59.04 ± 3.94[a]	55.8 ± 4.65[a]	57.42 ± 4.56[a]

[a] Indicates difference between time of circuit 1 and time of final circuit ($P < .001$).

whole-body fatiguing protocols on dynamic postural control have demonstrated conflicting results, with several showing detrimental effects[23,27,28,46] or no effects.[21,23] Steib et al[20] found that a treadmill fatiguing protocol involving an RPE similar to the one we used to terminate the protocol (17 and 18, respectively) led to a decrease in normalized maximal SEBT scores for healthy male athletes in the anterior (–0.8), medial (–1.44), lateral (–1.65), and posterior (–0.55) directions. These scores are considerably lower than the HIIP-induced decreases we observed (–4.51, –5.23, –6.77, and –6.75, respectively), supporting the concept that fatigue and its effects depend on the exercise.[22,23] In general, protocols involving continuous running with multiple changes of direction[28,46] have resulted in decrements in dynamic postural control; however, protocols involving continuous treadmill running only[21,23,27] have produced mixed results, and protocols involving cycling have produced no effects.[21,23] A potential limitation in studies using running protocols with multiple changes of direction[28,46] is that the fatigued state was determined when the lap-completion time increased by 50%. Given that Krustrup et al[47] reported sprint times increased by only 4% after a soccer match, the severity of this induced fatigue was greater than that observed in some sports. The HIIP that we used, however, increased circuit-completion time by 4.7% on average.

Dynamic postural control requires the coordination of the neuromuscular and somatosensory systems to process sensory information and react accordingly.[3] Fatigue has been reported to negatively affect joint proprioception[48] because of decreased muscle-spindle activity[17] and increased joint laxity,[49] which may disturb the somatosensory input of ligament mechanoreceptors. In addition, Hassanlouei et al[16] observed that fatigue delays muscle-contraction onset and decreases activation. These results may have the combined effect of reducing the efficiency of neuromuscular and somatosensory coordination and impairing postural control. In a prospective study, Plisky et al[1] demonstrated that deficits in postural control predict lower limb injury. Their results, in conjunction with ours, suggest that HIIP-induced fatigue may increase susceptibility to lower limb injury. Prospective investigations should be conducted to determine if a link exists between injury and fatigue-induced decrements in postural control.

Our results support the findings of Gribble et al[26] that fatigue negatively affects women less than men. This finding may partially result from the observed sex differences in muscle fatigability, purportedly due to several interrelated processes.[50] Researchers have demonstrated that men have a lower rate of oxidative muscle metabolism than women[51] and a strength-dependent reduction in muscle perfusion.[52] These characteristics can lead to an accumulation of muscle metabolites and subsequent greater stimulation of inhibitory afferents in men,[50] resulting in a decreased motor response and evidence of neuromuscular fatigue.[17] Given that neuromuscular control is an essential element of dynamic postural control,[3] a reduction therein may explain, in part, the observation that fatiguing exercise has a less negative effect on SEBT scores in women. In conjunction with the relationship between lower SEBT scores and a higher incidence of lower limb injury,[1] this suggests that women are at lower risk of sustaining lower limb injuries post-HIIP. However, to our knowledge, no one has investigated the relationship between fatigue-induced decrements in SEBT scores and injury incidence.

Our findings are also consistent with those of Gribble et al[26] in that women had better SEBT scores than men in fatigued and unfatigued conditions. We observed that in all directions except the anterolateral direction, women had prefatigue SEBT scores ranging from 2.12 to 6.52 higher than men. In the fatigued condition, women had SEBT scores ranging from 0.98 to 8.76 points higher than men in all directions. Women demonstrated greater knee and hip flexion during the SEBT than their male counterparts,[26] allowing women to lower their centers of gravity and achieve better SEBT scores.[26,53] Given that lower postural-control scores[1] and lower SEBT scores in particular[1] predict a higher incidence of lower limb injury, this implies that the women in our study were at a lower risk of sustaining lower limb injuries than the men and seems to contradict epidemiologic data that demonstrate women have a higher incidence of certain lower limb injuries, such as ACL injuries.[30] However, investigators[26,53] studying differences in SEBT technique have examined kinematics only in the sagittal plane. The increased knee flexion and hip abduction during the SEBT possibly were combined with hip and knee transverse- and frontal-plane motions that may predispose women to injury. This may be especially relevant in fatigued conditions, because authors[12,13] of laboratory-based studies have observed that fatigue results in altered movement patterns in the frontal, transverse, and sagittal planes, which may increase the loading of the ACL in female compared with male athletes. Therefore, the observed higher injury incidence of certain lower limb injuries in women may be due to biomechanical differences in technique (eg, landing[12]) in fatigued and unfatigued conditions rather than changes in dynamic postural control as measured by the SEBT. Kinematic studies of sex differences in SEBT techniques in 3 planes of motion in both the fatigued and unfatigued states would be valuable additions to our understanding of sex differences in the SEBT and their potential relationship with injury.

Our study had limitations. No criterion standard measurement of dynamic postural control exists,[21] so it has been assessed in a number of tasks, including the SEBT,[26,29] time to stabilization,[28,46] center-of-pressure sway,[21,27] and Biodex Balance System.[22,23] Given the differences in these tasks, our findings should be related to sporting movements aligned with the SEBT, such as kicking and cutting.

The HIIP developed for our study to mimic the high-intensity, intermittent activities common in field sports has not been investigated, making comparisons with previous research difficult. However, in a recent review of the manifestations of fatigue in sport, Knicker et al[45] specifically recommended examining temporary fatigue resulting from high-intensity, intermittent activity.

The determinant of the fatigued condition (18 on the Borg RPE scale) is a subjective measurement of exertion and may not be consistent across participants. However, it has been used in previous studies of the effect of fatigue on postural control[21,27] and resulted in similarly elevated heart rates and distances covered during bouts of high-intensity, intermittent activity in soccer.[35]

Finally, the HIIP-induced decline in SEBT scores for women in the anteromedial, medial, and anterolateral directions was lower than the SEM for these directions (Table 4). This indicates that the intersession variability, rather than the effect of HIIP-induced fatigue, may account for the decline in scores. The relatively lower ICC values in these directions may partially explain the higher SEM values. The reason these values were relatively lower is unclear and may be that, in the anterior- and medial-reach directions, maintaining a level pelvis is especially challenging.[54]

CONCLUSIONS

The HIIP negatively affected dynamic postural control as assessed by the SEBT in athletes. Women were affected less negatively by the HIIP and displayed better levels of dynamic postural control than men. Given that many field sports consist of high-intensity, intermittent exercise, our results suggest that athletes involved in these sports should perform postural-control programs after such exercise and aim to increase their abilities to reduce the extent and effect of fatigue.

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