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original research

Fatigue-Induced Alterations of Static and Dynamic Postural Control in Athletes With a History of Ankle Sprain

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Context: Sensorimotor control is impaired after ankle injury and in fatigued conditions. However, little is known about fatigue-induced alterations of postural control in athletes who have experienced an ankle sprain in the past.

Objective: To investigate the effect of fatiguing exercise on static and dynamic balance abilities in athletes who have successfully returned to preinjury levels of sport activity after an ankle sprain.

Design: Cohort study.

Setting: University sport science research laboratory.

Patients or Other Participants: 30 active athletes, 14 with a previous severe ankle sprain (return to sport activity 6–36 months before study entry; no residual symptoms or subjective instability) and 16 uninjured controls.

Intervention(s): Fatiguing treadmill running in 2 experimental sessions to assess dependent measures.

Main Outcome Measure(s): Center-of-pressure sway velocity in single-legged stance and time to stabilization (TTS) after a unilateral jump-landing task (session 1) and maximum reach distance in the Star Excursion Balance Test (SEBT) (session 2) were assessed before and immediately after a fatiguing treadmill exercise. A 2-factorial linear mixed model was specified for each of the main outcomes, and effect sizes (ESs) were calculated as Cohen d.

Results: In the unfatigued condition, between-groups differences existed only for the anterior-posterior TTS ($P = .05$, ES $= 0.39$). Group-by-fatigue interactions were found for mean SEBT ($P = .03$, ES $= 0.43$) and anterior-posterior TTS ($P = .02$, ES $= 0.48$). Prefatigue versus postfatigue SEBT and TTS differences were greater in previously injured athletes, whereas static sway velocity increased similarly in both groups.

Conclusions: Fatiguing running significantly affected static and dynamic postural control in participants with a history of ankle sprain. Fatigue-induced alterations of dynamic postural control were greater in athletes with a previous ankle sprain. Thus, even after successful return to competition, ongoing deficits in sensorimotor control may contribute to the enhanced ankle reinjury risk.

Key Words: sensorimotor control, neuromuscular activity, copers, balance, time to stabilization, Star Excursion Balance Test

Key Points

- When athletes were tested in the unfatigued state, only minimal differences in postural control were detected between athletes who had fully recovered from an ankle sprain and uninjured controls.
- Injured participants experienced larger fatigue-induced alterations of dynamic postural control than healthy controls.
- Persistent sensorimotor control deficits in recovered athletes might remain undetected in the unfatigued state.

Ankle sprains are the most common game-related injuries in team ball-sport athletes,[1] and are often associated with decreases in sensorimotor control, including proprioception (reduced joint position sense and kinesthesia), muscular strength, and balance performance (static and dynamic postural control). These alterations have been reported in individuals after acute ankle sprain[2,3] and in those with chronic ankle instability (CAI).[2,3] Along with additional complaints, such as swelling, pain, or episodes of "giving way," sensorimotor deficits persist even years after injury.[4,5] Consequently, sensorimotor impairments associated with lower extremity injuries may contribute to performance impairments[6] and increase the reinjury risk.[7] Athletes who successfully return to high-level sports activities and report normal function without persistent complaints have previously been defined as *copers*.[8] However, recent studies suggest that even though functional performance and self-reported disability in ankle-sprain copers are similar to those in individuals who have never sustained an ankle sprain,[8] sensorimotor control might still be affected.[9,10]

The incidence of match injuries in soccer players increases toward the end of both halves,[11] suggesting that physical fatigue might play an important role in injury-related sensorimotor control changes. This concept is supported by a number of studies examining sensorimotor alterations after fatiguing exercise in healthy, uninjured participants; among the observed changes were reduced muscle strength and activity,[12] and altered proprioception[13] and kinematics.[14] Additionally, static postural control was

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Table 1. Participants' Characteristics, Mean ± SD

Group	No.	Age, y[a]	Height, cm	Mass, kg	Time Since Injury, mo	Return to Competition, mo	Sports Time Loss, wk	Times Reinjured Since Initial Sprain
Coper group	14 (8 male, 6 female)	22.71 ± 2.81	176.27 ± 8.88	70.93 ± 8.10	16.71 ± 10.22	15.43 ± 10.07	6.36 ± 3.82	0.21 ± 0.43
Control group	16 (11 male, 5 female)	25.88 ± 2.66	176.13 ± 8.65	69.38 ± 10.17	NA	NA	NA	NA

Abbreviation: NA, not applicable.
[a] Significant ($P \leq .05$) difference between groups.

assessed in most of these studies, showing an increase in postural sway due to localized fatigue of the ankle,[15] knee, and hip[16] muscles that can persist up to 10 minutes after exercise ends.[17] Comparable results have been shown for fatiguing multijoint exercises[17] and whole-body fatigue.[18] Authors of only 2 studies have investigated the effects of fatiguing exercises on dynamic measures of postural control in healthy individuals[19] and participants with CAI[20]; however, because of different study populations and testing modalities, the effects remain uncertain.

The findings described above suggest that long-term impairment of sensorimotor control exists after an ankle sprain and may even be present in those who do not develop persistent functional impairments and successfully return to preinjury levels of sport activity. To our knowledge, only 1 study[20] specifically investigated the effect of exercise-induced fatigue on participants with a previous ankle injury. Based on the findings of Gribble et al,[20] we hypothesize that these impairments are small under regular conditions but could expose athletes to an increased injury risk when they physically fatigue during intensive exercise.

Therefore, the aim of our study was to investigate fatigue-induced alterations of static and dynamic postural control in a sample of ankle sprain copers and to compare the effects with those of uninjured controls. We proposed that changes in postural control due to fatigue would be more substantial in previously injured participants than in controls.

METHODS

Participants

A total of 30 young athletes participated in this study. Participant characteristics are reported in Table 1. We obtained local ethics committee approval and written informed consent in accordance with the Declaration of Helsinki.

Participants were allocated into 1 of 2 groups: (1) ankle-sprain copers, consisting of 14 athletes with a history of a severe ankle sprain, and (2) a control group of 16 healthy athletes. Inclusion criteria for ankle-sprain copers were a history of 1 severe ankle sprain (loss of ≥21 days from sport) in the last 3 years before the study; full return to sport activity or competition no less than 6 months before study entry; no self-reported residual complaints such as pain, swelling, or instability in the involved ankle; and no injury to the lower extremity other than the ankle in the previous 3 years. If all other inclusion criteria were met, a maximum of 1 recurrent sprain was allowed.[9,10] The criterion of return to sports activity for at least 6 months was based on findings from Engebretsen et al,[21] who showed that the highest risk of reinjury is within the first 6 months after the initial sprain and becomes similar to the risk of a first-time injury after this period. Participants in the control group were free of any self-reported lower extremity injury in the previous 3 years.

Procedure

Three measurement protocols were applied. Because of the necessary complexity of the tests and the short time period after the fatiguing exercise, the measurements were conducted in 2 randomly ordered experimental sessions: session 1, single-legged postural sway and time to stabilization (TTS) after a unilateral jump-landing task; and session 2, the Star Excursion Balance Test (SEBT). The experimental sessions were separated by at least 3 days. Measurements were conducted in a counterbalanced order before and immediately after an exhausting treadmill exercise (TRF). Two trials were recorded for each outcome measure. In order to avoid recovery, duration of the postfatigue measures was ≤4 minutes. Participants performed all measurements barefoot. The injured foot of the coper group was tested, and the tested limb of the control group was matched for limb dominance. Leg length was measured as the distance from the floor to the bottom of the pelvis with the participant standing upright, barefoot, with feet hip width apart. A movable bar that was mounted on a ruler was placed between the participant's legs and lifted to the pelvis.

For static postural-sway measures, participants stood on a Kistler force plate (model 9260AA6; Kistler Instrumente GmbH, Ostfildern, Germany) with 1 leg as quietly as possible for 20 seconds with eyes open, hands on the hips, and the free foot touching the standing leg at the medial side of the shank. The test was performed twice with 10 seconds' rest between trials. Failed attempts due to loss of balance (nonbalancing foot touched the floor or hands off hips) were excluded from data extraction. Force and moment data, collected at 180 Hz, were measured to provide center-of-pressure (COP) data. The average of the 2 trials was calculated for data analysis.

To determine changes in dynamic postural control, participants performed a jump-landing stabilization task. They were instructed to jump diagonally onto the force plate and to land on the test leg. Takeoff points were marked at an angle of 45° left and right from the center of the force plate at a distance of 1.5 times the individual's leg length. No precautions were taken to standardize jump height so that participants would choose their own strategies to accomplish the task. Participants were instructed to jump diagonally onto the center of the plate and to land on 1 leg. As soon as they made contact with the ground, participants were instructed to stabilize as quickly as possible and to maintain the quiet stance position for 20

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seconds. Failed attempts due to overbalancing were discarded and repeated. Force data were collected at 180 Hz and processed as described by Ross and Guskiewicz.[22] In brief, the TTS is the time it takes for the initial components of the ground reaction force (GRF) to become similar to the components of the GRF from a static single-legged stance. Therefore, medial-lateral (ML) and anterior-posterior (AP) GRF data are rectified, and a static horizontal line reflects the smallest absolute GRF range from 2 windows of the last 10 seconds (10–15 seconds, 15–20 seconds). Starting at the peak GRF, an unbounded third-order polynomial is fitted to each of the GRF components and TTS is determined as the point (ie, time) at which the polynomial transects the static horizontal lines. Because GRF ranges are expected to be higher in the fatigued condition, postfatigue TTS values might be influenced, leading to shorter stabilization times. Therefore, we used a single range value for each participant, calculated as the mean absolute GRF range from all prefatigue trials, to set an individual range target for all trials. The TTS was calculated in the AP (APTTS) and ML (MLTTS) directions. In addition, both scores were combined to the resultant vector TTS (RVTTS), calculated by the following formula: $\mathrm{RVTTS} = \sqrt{\mathrm{APTTS}^2 + \mathrm{MLTTS}^2}$.

The SEBT was assessed as a second measure of dynamic postural control. The participant stood barefoot with hands on hips and the test leg in the center of a grid (8 lines extending at 45° increments from the center) placed on the floor. Each participant was asked to reach the free leg as far as possible in each direction along the line, touch down lightly, and return to a double-legged stance position.[20] We used 4 of the original 8 reaching directions to keep postfatigue measures in an appropriate time period and to avoid recovery. Anterior, posterior, medial, and lateral directions were tested, as they correspond to the stabilization directions (AP and ML) used in the TTS measure. Reach directions were set in a random counterbalanced order. Each participant completed 5 familiarization trials in all 4 directions before the start of baseline measurements. Measurements for each direction were carried out twice before and twice after the exhausting exercise, and values from the 2 trials were averaged for data processing. Maximum reach distance (in centimeters) from the center of the grid was manually recorded by the examiner for each direction. Foot position was marked with tape on a removable, nonslip circular mat placed in the center of the grid. If a participant lost balance and touched the floor with the nondominant limb before reaching the start position or took hands off hips, the trial was discarded and repeated.

Fatigue Protocol

Whole-body fatigue was induced by having participants run on a motorized treadmill (quasar, h/p/cosmos, Nussdorf-Traunstein, Germany) with increasing speed until subjective exhaustion. The protocol started at 8 km/h, and speed was increased stepwise by 2 km/h every 3 minutes. Participants were instructed to run as long as possible until complete exhaustion, and verbal encouragement was provided toward the end of the run. Heart rate and subjective exertion were assessed 30 seconds into each stage and immediately after completion of the treadmill test using the Borg 6 to 20 rate of perceived exertion (RPE) scale.[23] This information was used to monitor cardiac response and exertion throughout the test and to document the participant's exhaustion at exercise termination. Based on unpublished pilot trials in our laboratory, in which the RPE was compared with blood lactate concentration at exhaustion, we defined an RPE of 17 (*very hard*) and higher as a fatigued state.

Data and Statistical Analysis

Bioware software (version 4.0.1.2; Kistler Instrumente GmbH) was used to acquire force-plate output at a sampling rate of 180 Hz. Force data were low-pass filtered at 14 Hz using a second-order Butterworth filter. The outcomes of interest were COP velocity for static postural sway, TTS in the AP and ML directions, RVTTS, and mean SEBT maximum reach distance (mean of all 4 directions) for dynamic postural control. Center-of-pressure velocity (cm/s) was defined as the sum of the resultant COP displacement divided by the total time.[24] Measures of SEBT reach distances were normalized for individual leg length by using the following formula: normalized reach distance = reach distance (cm) $*$ 100/leg length (cm).

For statistical analyses, a 2-factorial linear mixed model appropriate for repeated-measures data was specified for each of the main outcomes. The experimental factors time and group were included as fixed factors, nested in the random individual's factor. Sway velocity, mean SEBT reach distance, and TTS were defined as dependent variables and analyzed in separate models. A random-intercept and random-slope model was used to allow for random individual variability, and an unstructured variance-covariance matrix was assumed. Effect sizes (ESs) were calculated as Cohen d for the following comparisons: group main effect (between-groups comparison prefatigue), fatigue main effect (prefatigue versus postfatigue comparison in coper group), and group × time interaction (postfatigue group comparison adjusted for baseline differences). The Cohen d was interpreted as small (0.2), moderate (0.5), or strong effect (0.8). All statistical analyses were performed by a statistician using the statistical software R (R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria). The level of significance was set at $P < .05$.

RESULTS

Participants' characteristics are provided in Table 1. The treadmill running lasted between 6 and 20 minutes (mean = 13.79 minutes), and maximum running speed varied between 12 and 20 km/h. No adverse events were reported during the fatiguing running. Mean RPE at exhaustion (TRF) was 19.7 ± 0.7 (coper group, 19.5 ± 0.7; control group, 19.8 ± 0.6) and mean maximum heart rate was 194.0 ± 8.2 beats/min (coper group, 193.9 ± 9.2; control group, 194.0 ± 7.2). No differences were noted between sessions 1 and 2 for any of these measures.

In the unfatigued condition, between-groups differences existed for the APTTS ($P = .05$, ES = 0.39) with slightly shorter stabilization times in the coper group (3.94 seconds) compared with the control group (4.04 seconds). No group differences were seen for any other outcome measure at baseline (Table 2).

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Table 2. Prefatigue and Postfatigue Values and Pre-Post Differences for Dependent Measures, Mean ± SD, and Effect Sizes (Cohen d) of Main and Interaction Effects

	Control Group			Coper Group			Group Main Effect[a]		Fatigue Main Effect[b]		Group by Fatigue Interaction[c]	
	Prefatigue	Postfatigue	Difference (95% CI)	Prefatigue	Postfatigue	Difference (95% CI)	*P*	ES	*P*	ES	*P*	ES
COP velocity, cm/s	2.2 ± 0.5	2.8 ± 0.7	0.59 (−0.33, 1.52)	2.4 ± 0.7	3.3 ± 1.2	0.82 (0.43, 1.20)	0.25	0.22	0.00	0.80	0.42	0.16
SEBT[d]	104.6 ± 4.3	104.2 ± 3.4	−0.37 (−3.49, 2.75)	100.9 ± 8.8	98.5 ± 7.5	−2.43 (−3.75, −1.11)	0.17	0.27	0.00	−0.69	0.03	0.43
APTTS, s	4.0 ± 0.2	4.1 ± 0.2	0.03 (−0.28, 0.34)	3.9 ± 0.1	4.2 ± 0.3	0.26 (0.14, 0.39)	0.05	0.39	0.02	0.77	0.02	0.48
MLTTS, s	3.9 ± 0.3	4.1 ± 0.2	0.25 (−0.30, 0.81)	3.8 ± 0.1	4.2 ± 0.5	0.44 (0.21, 0.67)	0.24	0.23	0.00	0.72	0.26	0.22
RVTTS, s	5.6 ± 0.3	5.8 ± 0.2	0.20 (−0.34, 0.74)	5.5 ± 0.1	6.0 ± 0.6	0.50 (0.28, 0.73)	0.09	0.33	0.00	0.83	0.08	0.35

Abbreviations: APTTS, anterior-posterior time to stabilization; CI, confidence interval; COP, center-of-pressure; ES, effect size; MLTTS, medial-lateral time to stabilization; RVTTS, resultant vector time to stabilization; SEBT, Star Excursion Balance Test.
[a] Indicates group differences prefatigue.
[b] Indicates prefatigue–postfatigue changes in the coper group.
[c] Indicates group differences for prefatigue–postfatigue changes. Positive effect sizes indicate greater changes in the coper group.
[d] Mean of all 4 directions normalized to leg length (reach distance in cm * 100/leg length in cm).

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A main effect for fatigue was shown for all dependent measures (Table 2). The TRF resulted in increased COP sway velocity; a prolonged APTTS, MLTTS, and RVTTS; and a reduced normalized SEBT maximum reach distance. No group-by-time interaction was found for static postural control ($P = .42$, ES $= 0.16$). A group × time interaction ($P = .03$, ES $= 0.43$) was evident for the SEBT, with larger reductions in mean reach distances in the coper group (–2.43) than in the control group (–0.37). Another group × time interaction ($P = .02$, ES $= 0.48$) was found for TTS in the AP direction. Stabilization times were more affected in the injured participants (+0.26 seconds) than the controls (+0.03 seconds). No group-by-time interactions were observed for MLTTS ($P = .26$, ES $= 0.22$) or RVTTS ($P = .08$, ES $= 0.35$). Fatigue-induced changes in MLTTS were +0.44 and +0.25 seconds and in RVTTS +0.50 and +0.20 seconds for the coper and control groups, respectively.

DISCUSSION

The aim of our study was to compare fatigue-related changes in sensorimotor control between healthy athletes and those who had successfully returned to their preinjury levels of sport activity after an ankle sprain. The latter group is individuals who have been referred to as *copers* and is thought to have regained normal functional levels. No differences existed between the groups in the unfatigued (baseline) condition except for 1 measure (APTTS). Dynamic postural control was more substantially affected by physical fatigue in copers compared with uninjured controls, indicating persisting sensorimotor control deficits that were not evident in the unfatigued state. Nevertheless, these athletes successfully participated in demanding sport activities without being reinjured or having episodes of giving way. Copers appear to develop strategies that allow them to successfully compensate for the fatigue-induced postural-control alterations.

Effects of Injury on Postural Control

Postural-control deficits in individuals with acute ankle sprains and with CAI are well documented in the literature.[2] Further, differences exist between those who develop long-term complaints and instability after a sprain and those who do not (copers).[25] Our results from the present study suggest that the postural control of ankle-sprain copers is minimally affected in the unfatigued state. Further, of the measures investigated, APTTS seems to have the greatest sensitivity to detect residual postural-control deficits.

Postural sway during quiet standing has been used extensively to study sensorimotor control, and deficits have been reported after acute ankle sprains and in participants with CAI.[2] However, static postural control seems to be less affected in individuals who do not develop CAI (copers). Wikstrom et al[9] reported that sway velocity (in the ML direction) was greater in participants with CAI than in copers and healthy controls. We found no differences in resultant COP velocity between the groups at baseline, suggesting that static postural control was not affected in athletes who did not develop CAI after an ankle sprain. However, postural-control measures derived from quiet stance have been criticized for their static nature, as they do not adequately reflect the sensorimotor control mechanisms in dynamic, sport-specific actions and injury situations.[26] Equilibrium control often contains reactive, compensatory movements that occur immediately after perturbations or moments of instability.[27] Thus, dynamic postural-control measurements may provide a better understanding of injury-related sensorimotor control strategies.

Two well-established measures of dynamic postural control were used in this study: the TTS and the SEBT. We examined the participants' ability to stabilize in a single-legged jump-landing task. Previous authors have used different methods of analysis by calculating either the TTS (eg, Wikstrom et al[19] and Ross et al[22]) or a dynamic postural stability index (eg, Wikstrom et al[10] and Brown et al[28]), and most of them have used a forward jump-landing protocol. In this study, we calculated the TTS from a diagonal jump-landing maneuver, as this type of movement typically occurs in sport-specific and injury-related situations. Because of discrepancies in reported findings for stabilization performance using different jump directions (frontal, medial, and diagonal) in adults with[28] or without CAI,[29] results from the present study need to be interpreted with care. We found group differences in the unfatigued condition only for TTS in the AP direction. Other researchers[10] reported greater ML but not greater AP postural variability in a sample of ankle-sprain copers compared with uninjured controls. However, jump direction was different in this trial (forward jump) and might explain the discrepancy. Potential mechanisms leading to the differences in AP stabilization times in our sample remain speculative, but deficits in dynamic postural control might persist after injury even in athletes who have not developed CAI after a single ankle sprain.

The SEBT is a simple and inexpensive method to assess dynamic balance and has been shown to be associated with increased lower limb injury risk.[27] Sensorimotor control, knee kinematics,[30] and strength[27] may influence SEBT performance. In the present study, SEBT reach distances did not differ between the groups in the unfatigued condition. Other authors[20,31] reported smaller SEBT maximum reach distances in participants after ankle injury when compared with healthy controls. However, this discrepancy is likely caused by the difference in the study samples. All of these investigators studied participants with CAI, whereas we studied participants who did not report any residual complaints or instability. To our knowledge, this is the first trial using the SEBT in this specific sample.

Fatigue Effects on Postural Control

Treadmill running fatigue negatively affected all postural-control measures. This result is consistent with findings from numerous studies of participants who displayed impaired static and dynamic balance in a fatigued state. Several postural-control measures were studied in these trials, such as sway velocity, horizontal and sagittal sway magnitude,[18,32] the SEBT,[20] and the TTS.[19] Consistent negative effects on static and dynamic balance abilities were reported after local muscle and whole-body fatiguing exercise.

We found group × fatigue interactions for the TTS and SEBT. For the TTS, stabilization performance was more substantially affected in the coper group; however, only in the AP direction group were differences statistically significant. Similarly, fatigue-induced reductions in SEBT reach distance were larger in ankle-sprain copers compared with uninjured controls. No group differences were noted for mean SEBT results at baseline, and only minor differences were seen for the APTTS. These findings suggest that existing sensorimotor control deficits in ankle-sprain copers are small and might remain undetected under regular conditions but become evident in the presence of physical fatigue. To our knowledge, only 1 group[20] has compared fatigue-induced postural control changes between participants with and without a history of ankle sprain. Similar to the present study, larger prefatigue to postfatigue reductions in SEBT reach distances were reported for the participants with a history of ankle sprain; however, the sample consisted of participants with CAI. The persisting sensorimotor control deficits emerging with physical fatigue during competition might expose the athlete with a previous ankle sprain to an increased risk of reinjury. Yet because of the lack of studies specifically looking at fatigue effects on sensorimotor control in previously injured populations, the potential underlying mechanisms remain speculative. Physical fatigue alters joint stability in healthy adults by increasing joint laxity[33] and by causing sensorimotor and biomechanical deficits, such as reduced muscle strength and activity[12] and altered proprioception[13] and kinematics.[14] It is reasonable to assume that those factors contribute to a reduction in dynamic postural control, but the underlying mechanisms and the contribution of each single component to the overall effect remain unclear.

Fatigue-induced changes in static postural control did not differ between groups. This result is contrary to the observations for the dynamic balance measures and supports the current view that static and dynamic balance measures assess different aspects of sensorimotor control mechanisms.[34] If a single balance measure is being assessed, dynamic tests might be advantageous, as they are more sport specific and seem to be more sensitive in detecting persisting sensorimotor deficits in an athletic population. We observed dynamic balance impairments in previously injured athletes that emerged when participants became physically fatigued. This finding has direct consequences for the assessment and treatment of sport injuries. Neuromuscular training should be a key component of rehabilitation programs,[35] accompanied by exercises aimed at increasing fatigue resistance. Additionally, when joint stability and functional status after injury are being assessed, conducting tests under fatigued conditions might be helpful in making decisions regarding return to competition.

Limitations

We tested a convenience sample with athletes from different sports and did not perform an a priori power analysis. Further, injury severity was graded by time lost from sport, and we did not quantify self-reported disability or mechanical joint stability. Therefore, it is difficult to judge whether ankle instability truly did not exist in the coper group, which may have led to some heterogeneity in the measured outcomes. Other investigations of ankle-sprain copers enrolled participants who had returned to sport activity at least 12 months before study entry. In our study, the interval was shorter (6 months), but baseline data from both groups indicate that our sample was comparable with those described in other trials.

We used a subjective measure (RPE) to rate physical fatigue after treadmill running. Without an objective measure used to quantify muscular fatigue, we cannot ascertain that all participants were completely exhausted. However, maximal heart rates were high in all tested athletes, and previous work in our laboratory showed a good correlation between subjective (RPE $\geq$17) and objective (blood lactate $\geq$8 mmol/L) measures of exhaustion with our treadmill protocol. The type of fatiguing protocol used may also have influenced our results. Treadmill running does not mimic specific actions such as cutting or jumping that typically occur in ball sports. A more specific protocol including those activities might have led to different findings.

Conclusions

The results of this study support our hypothesis that athletes with a history of lower extremity injury display greater fatigue-induced impairments in postural control compared with healthy athletes. In the injured group,

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prefatigue to postfatigue differences in dynamic postural control were greater than in the controls. Persistent sensorimotor control deficits in recovered athletes seem to be masked until participants are physically fatigued. These impairments might expose the athlete to an increased risk of reinjury with progressing exercise time. Exercise programs in rehabilitation need to account for this fact and should focus on neuromuscular endurance and sensorimotor training strategies. The interaction between physical fatigue and sensorimotor impairments after injury needs to be further investigated to gain a better understanding of the underlying mechanisms. The differences in static and dynamic postural-control outcomes suggest that both dimensions should be considered in a sophisticated assessment.

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