Journal of Athletic Training 2014;49(4):454–461
doi: 10.4085/1062-6050-49.2.12
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original research

Fatigue-Induced Balance Impairment in Young Soccer Players

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Context: Although balance is generally recognized to be an important feature in ensuring good performance in soccer, its link with functional performance remains mostly unexplored, especially in young athletes.

Objective: To investigate changes in balance induced by fatigue for unipedal and bipedal static stances in young soccer players.

Design: Crossover study.

Setting: Biomechanics laboratory and outdoor soccer field.

Patients or Other Participants: Twenty-one male soccer players (age = 14.5 ± 0.2 years, height = 164.5 ± 5.6 cm, mass = 56.8 ± 6.8 kg).

Intervention(s): Static balance was assessed with postural-sway analysis in unipedal and bipedal upright stance before and after a fatigue protocol consisting of a repeated sprint ability (RSA) test (2 × 15-m shuttle sprint interspersed with 20 seconds of passive recovery, repeated 6 times).

Main Outcome Measure(s): On the basis of the center-of-pressure (COP) time series acquired during the experimental tests, we measured sway area, COP path length, and COP maximum displacement and velocity in the anteroposterior and mediolateral directions.

Results: Fatigue increased all sway values in bipedal stance and all values except COP velocity in the mediolateral direction in unipedal stance. Fatigue index (calculated on the basis of RSA performance) was positively correlated with fatigue/rest sway ratio for COP path length and COP velocity in the anteroposterior and mediolateral directions for nondominant single-legged stance.

Conclusions: Fatigued players exhibited reduced performance of the postural-control system. Participants with better performance in the RSA test appeared less affected by balance impairment, especially in single-legged stance.

Key Words: postural sway, repeated sprint ability test, athletes

Key Points

- In young soccer players, balance was adversely affected by fatigue.
- A moderate correlation existed between balance impairment and repeated sprint ability performance.

In soccer, as in many other disciplines, researchers continuously attempt to define which anthropometric, physiologic, psychological, and cognitive characteristics are most relevant to identifying talent at an early age. Such features, together with the development of new assessment methods in the laboratory or on the field, are essential to improving the chances of recognizing future top players.

In particular, somatotype, aerobic and anaerobic power, agility, joint flexibility, and muscular development are considered essential contributors to achieving high-level performance.[1] Nevertheless, it remains unclear how these factors are to be objectively selected, measured, weighed, and combined with coaches' subjective perceptions, which are mainly based on personal experience.[1,2]

Somewhat surprisingly, balance is not included among the most important features in athletic success; this quality is considered important mostly as a cofactor that helps reduce the risk of injuries.[3] Also, soccer is a discipline that relies a great deal on single-legged support under unstable conditions. In fact, players use 1 limb (the dominant limb) to control the force and direction of the ball while dribbling, maintaining ball possession, and kicking; the nondominant limb basically ensures the necessary stability to optimally perform the required technical maneuver.[4] Thus, it appears very important for players to have (and possibly improve during their maturation) excellent balance skills, especially for unipedal stance.

Although previous authors[5–7] have shown that soccer players are generally characterized by superior balance performance compared with athletes in other sports (except gymnasts) or nonathletes, few data are available on the relationship between balance variables and functional performance in soccer players.[8] Similarly, the possibility of improving postural-control performance in healthy athletes using specific balance-training protocols remains partly unexplored. However, recent investigators[9,10] have demonstrated that young athletes may benefit from proper stimulation of the proprioceptive system.

Balance and Fatigue

Both localized and whole-body fatigue cause degradation of postural-control performance, which is evident in the form of increased postural sway (ie, constant, slight corrective deviations from vertical when standing upright).[11] This phenomenon, which has been extensively reported in the literature, is mainly due to changes in cardiac and respiratory contractions, fluid movement in the body, and release of metabolic products by muscle fibers and is caused by altered sensory information from the proprioceptive system.[12] The magnitude of sway increase is partly influenced by exercise intensity and duration, but it also depends on the muscular groups involved.[13] From this point of view, localized fatigue and whole-body fatigue are thought to trigger different disturbances of the postural-control system,[14] although the net effect in terms of balance impairment may appear similar.

Typical experiments aimed at assessing the effect of fatigue on static balance involve exercise such as the treadmill,[15–17] cycle or rowing ergometer,[14,15,18] isokinetic concentric actions, squat jumps, and heel raises.[14,19] A few authors[20,21] have evaluated the fatiguing effects of actual sport performance in triathletes[22] and soccer players. In particular, Zemkova and Hamar[20] and Brito et al[21] analyzed center-of-pressure (COP) velocity of 19- to 21-year-old players (unipedal and bipedal stances with eyes open or closed) before a game, in the break period between the first and second halves, and after a game. When visual input was present, single-legged balance was reduced after the match. Less evident was the effect of fatigue on bipedal standing: changes were observed only when the support surface was unstable and visual input suppressed.

The lack of experimental data regarding the effects of fatigue on balance in soccer players is somewhat surprising, considering that fatigue is implicated in injury occurrence[23] and that a deficit in postural control may increase the risk of ankle injuries.[24] Thus, it is reasonable to hypothesize that not only may fatigue associated with performance in a match impair balance (and thereby increase the risk of injuries) but also that superior physical fitness in better-trained athletes may limit this effect.

Our goal was to assess postural-sway changes induced by fatigue subsequent to a controlled field test (repeated sprint ability [RSA]) representative of actual soccer activity in a cohort of young elite soccer players. We had 2 questions: (1) Is unipedal and bipedal static balance impaired by fatigue? (2) Is there a functional relationship between performance level in RSA and balance alterations?

METHODS

Participants

A total of 21 male soccer players (age = 14.5 ± 0.2 years, height = 164.5 ± 5.6 cm, mass = 56.8 ± 6.8 kg, body mass index = 20.9 ± 1.9) from 2 teams in Italy were recruited for the study on a voluntary basis. All participants had been free from lower limb injuries for at least 6 months before the study, had regularly trained for at least 6 hours per week, and had competed in either national or regional tournaments organized by the Italian Football Association. Test procedures and purposes of the study were carefully explained to participants and their parents during a meeting followed by a question-and-answer session. Parents then received a written document that described the procedure in detail and signed an informed consent form. They were also allowed, on request, to watch the test sessions for RSA and postural-sway data collection from a convenient distance.

The study was carried out in compliance with the ethical principles for research involving human subjects expressed in the Declaration of Helsinki and was approved by the Departmental Review Board.

Data Acquisition and Postprocessing

Postural-sway data were calculated on the basis of COP time series acquired by means of a pressure platform Footscan (system 0.5; RSscan International, Olen, Belgium) composed of a pressure-sensitive plate (40967.62 × 5.08 mm with sensing elements based on piezoresistive technology arranged in a 64 × 64 matrix) and a universal serial bus (USB) interface box connected to a personal computer. The plate-management software allows a fixed number of 1000 events (frames) to be collected, regardless of trial length, so the acquisition frequencies were automatically set to 50 and 33 Hz for unipedal and bipedal trials, respectively. The raw COP time series were low-pass filtered (10-Hz cutoff, 4th-order Butterworth, bidirectional) and then postprocessed with a custom-developed MATLAB (The MathWorks, Inc, Natick, MA) routine to calculate the following sway values: sway area (SA, 95% confidence ellipse), COP path length (COP PL: the overall distance traveled by the COP during the trial), COP maximum displacement (MDISP: the difference between the maximum and minimum values of the selected coordinate recorded during the trial) in the anteroposterior (AP) and mediolateral (ML) directions, and COP velocity (V_{COP} calculated as the average of the 1000 values for each temporal event into which the trial was subdivided) in the AP and ML directions.

For bipedal tests, players were asked to stand barefoot, as still as possible for 30 seconds, on a pressure plate; the foot was placed on a sheet of paper with 2 footprints oriented at approximately 30° (Figure 1a) while maintaining a stable and relaxed position with the arms freely positioned by the sides and the gaze fixed on a target image. The unipedal tests were similar but shorter in duration (20 seconds); the participant raised 1 leg and put the back of the suspended foot in contact with the popliteal fossa of the standing limb while the arms were held in the lumbar region. For these

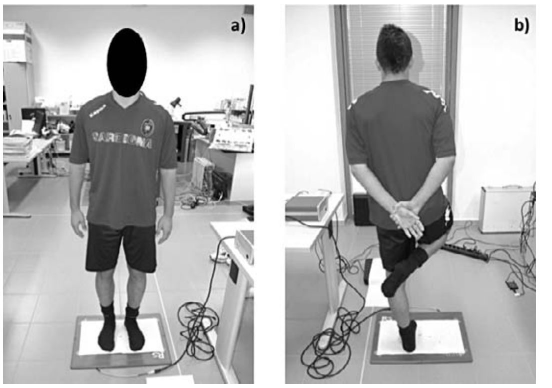

Figure 1. a, For the bipedal-stance test, the participant stood barefoot, as still as possible for 30 seconds, on a pressure plate; the foot was placed on a sheet of paper with 2 footprints oriented at approximately 30°. The participant maintained a stable and relaxed position with the arms freely positioned by the sides and the gaze fixed on a target image. b, The unipedal test was similar but shorter in duration (20 seconds). The participant raised 1 leg and put the back of the suspended foot in contact with the popliteal fossa of the standing limb while the arms were held in the lumbar region. The axis coincided with the minor axis of the instrument surface.

tests, the foot was placed on the platform so that the axis coincided with the minor axis of the instrument surface (Figure 1b).

The *dominant limb* was defined by asking each athlete which leg he preferred for kicking. Four conditions were tested: right and left unipedal stance with eyes open and bipedal stance with eyes open and closed. The test sequences were fully randomized. Experiments were repeated twice: under absolute rest conditions to define reference baseline sway values and after a fatigue protocol, previously tested by Buchheit et al,[25] on same-age athletes, which consisted of an RSA test performed on an outdoor field (artificial grass carpet) in the form of 6 repetitions of maximal 2- × 15-m shuttle sprints interspersed with 20 seconds of passive recovery (including deceleration, slow walking, and preparing for the subsequent test).

Before the RSA test, all participants performed a brief standardized warm-up (approximately 20 minutes long), which consisted of 6 minutes of incremental running from 60% to 80% of maximal aerobic speed; 6 minutes of dynamic flexibility exercises; 2 minutes of forward, backward, and lateral jogging and high-knee and "butt-kick" runs; 2 minutes of 5 + 5 m shuttle sprints (5 m in 1 direction and 5 m in the opposite direction, repeated for 2 minutes) at submaximal speed (followed by 40 seconds of passive recovery); and 2 minutes of RSA test simulation at submaximal speed (2 repetitions), again followed by 40 seconds of passive recovery.

The participants then prepared for the start on a line 30 cm behind the actual starting line (delimited by 2 aligned photocells; model Microtac radio, TT Sport S.r.l., Galazzano, Republic of San Marino, also used to electronically record the sprint times) to avoid inaccurate triggering of the time-measurement system. They received a visual and an acoustic signal to start each sprint and were constantly encouraged by an assistant to perform at maximal speed. The fatigue index (FI) used to characterize the RSA performance was calculated in terms of percentage decrement score[26] as follows:

$$\mathrm{FI} = \left[100 \cdot \left(\frac{\text{Total sprint time}}{\text{Ideal sprint time}}\right)\right] - 100$$

where *total sprint time* represents the sum of the times recorded for each of the 6 sprints and *ideal sprint time* is the product of the lowest time recorded (ie, best performance) for the number of sprints.

At the end of the RSA, players immediately entered the room dedicated to balance tests, took off their shoes, and positioned themselves on the pressure platform for sway measurements. Usually the time elapsed between the end of the last sprint and the beginning of the balance measurements was no more than 20 seconds. To avoid masking effects related to progressive recovery from fatigue, unipedal and bipedal tests were carried out in different sessions.

The statistical significance of the possible differences in the postural-sway values introduced by fatigue was assessed using 2-way analysis of variance, where the independent variable was fatigue status (rest, fatigue) and either limb input (dominant, nondominant) for unipedal stance or visual input (eyes open, closed) for bipedal stance and dependent variables SA, COP PL, MDISP AP and ML, and V_{COP} AP and ML by setting the level of significance at $P < .05$. When necessary, a post hoc Holm-Sidak test for pairwise comparison was carried out to assess intragroup and intergroup differences. We checked the data for normality using the Shapiro-Wilk test and equal variance before performing analysis of variance.

The relationship between fatigue (expressed as the FI) and postural-sway modifications (expressed as the ratio of values after and before the RSA test) was assessed by means of the Pearson product moment correlation analysis. The level of significance was set at $P < .05$.

RESULTS

Unipedal Stance

In unipedal stance, the fatigue created by the RSA test induced increases in all sway factors except for V_{COP} in the ML direction, whereas no effects were detected for the interaction of fatigue and limb (Table 1).

The largest increase was for SA (+70%, $P < .001$) and only in this case did post hoc analysis reveal changes in both limbs. In all other cases, the fatigue effect appeared to be restricted to a single limb. In particular, increases in COP PL, MDISP, and V_{COP} in the AP direction were observed in the dominant limb only, whereas fatigue appeared to be responsible for increases in MDISP in the ML direction for the nondominant limb.

Table 1. Postural-Sway Values Before and After the Fatigue Protocol for Unipedal Stance

	Limb				*P* Value		
	Dominant		Nondominant				
Measurement	Rest[a]	Fatigue[b]	Rest	Fatigue	Repeated Sprint Ability Test	Limb	Repeated Sprint Ability Test × Limb
Sway area, mm^2	351.0 ± 153.1	521.4 ± 366.2	329.8 ± 192.1	564.6 ± 460.0	<.001[c]	.873	.592
Center-of-pressure path length, mm	655.2 ± 180.6	772.5 ± 230.4	636.9 ± 158.8	721.1 ± 181.9	.009[c]	.419	.764
Maximum displacement, mm							
Anteroposterior	33.5 ± 9.1	46.3 ± 19.3	35.2 ± 13.5	42.4 ± 19.2	.005[c]	.748	.429
Mediolateral	23.8 ± 6.1	27.5 ± 7.8	22.1 ± 7.2	29.0 ± 9.0	.002[c]	.751	.315
Center-of-pressure velocity, mm/s							
Anteroposterior	33.7 ± 8.3	43.2 ± 12.8	23.7 ± 6.6	27.7 ± 9.0	.003[c]	.417	.620
Mediolateral	18.3 ± 6.7	19.3 ± 5.9	17.8 ± 6.1	19.38 ± 6.0	.227	.920	.835

[a] Before repeated sprint ability test.
[b] After repeated sprint ability test.
[c] Significant effect.

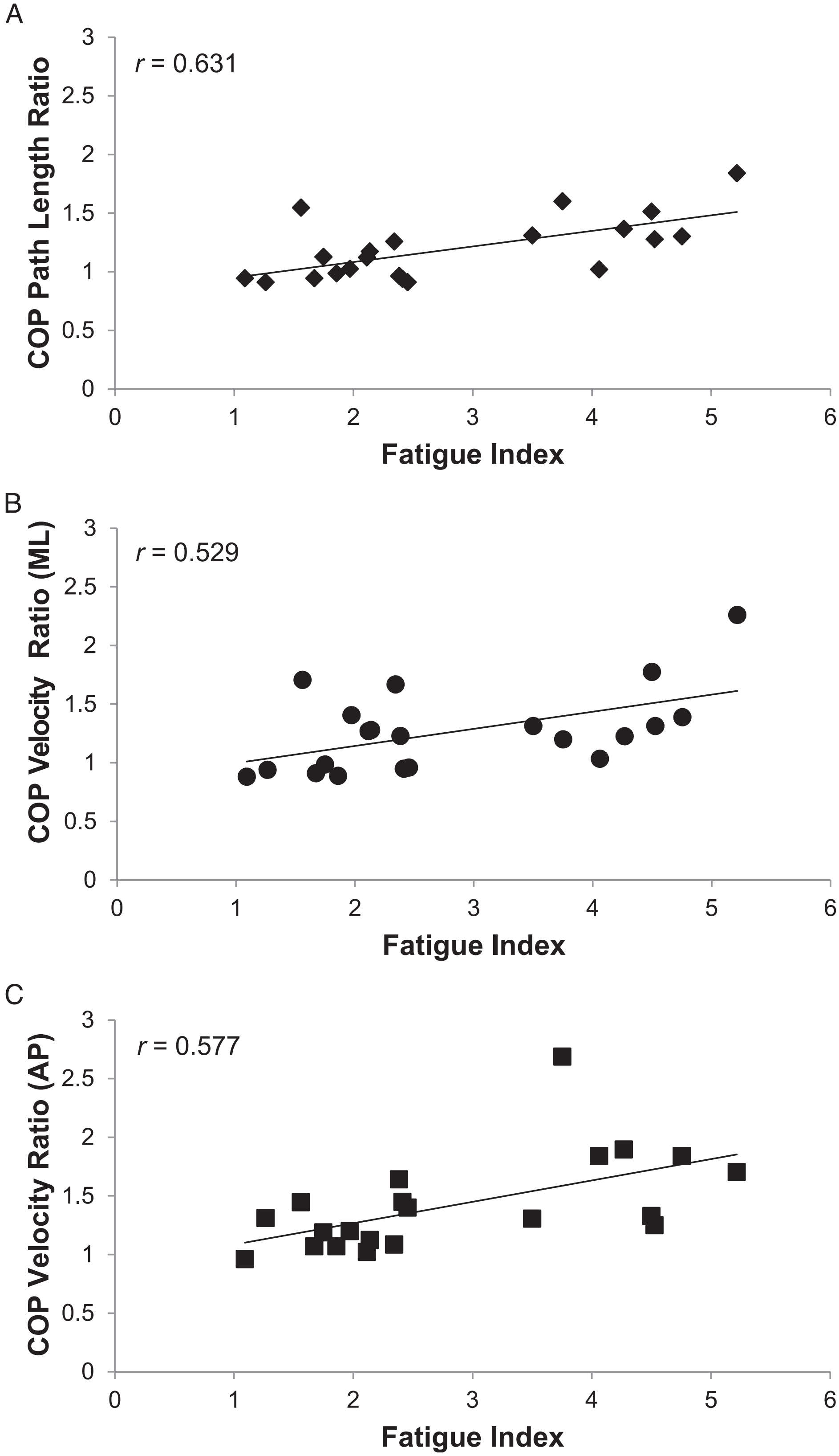

Figure 2. Correlation for the nondominant limb between the fatigue index and the fatigue/rest sway ratio for center-of-pressure (COP) path length ($r = 0.631$, $P < .01$) and center-of-pressure velocity in the anteroposterior (AP; $r = 0.577$, $P < .01$) and mediolateral (AP; $r = 0.529$, $P = .014$) directions.

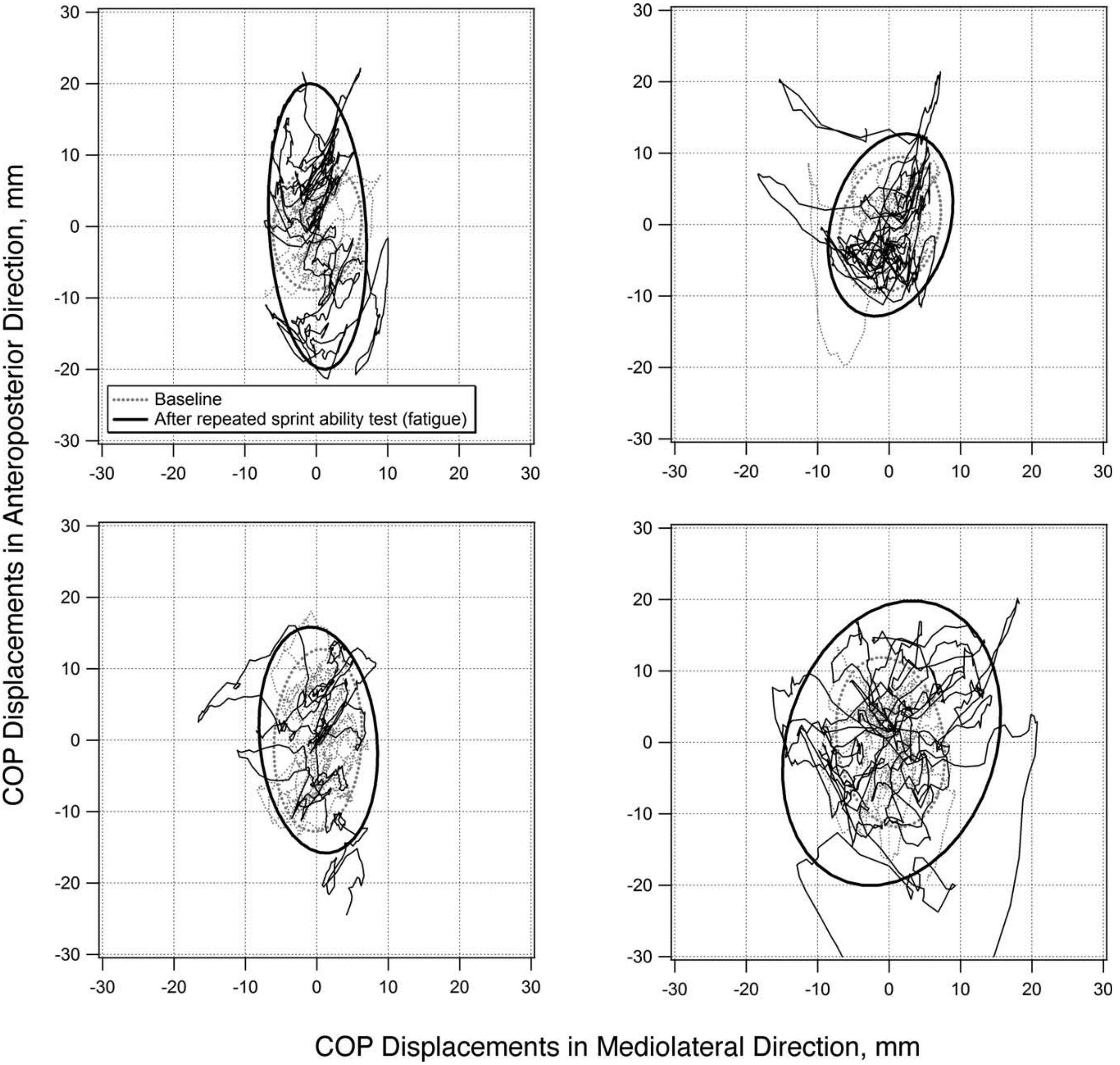

Figure 3. Examples of sway paths and areas (95% confidence ellipses) before and after the repeated sprint ability test. Abbreviation: COP, center of pressure.

We noted a significant positive correlation for the nondominant limb between the FI and the fatigue/rest sway ratio for COP PL ($r = 0.631$, $P < .01$) and V_{COP} in the AP ($r = 0.577$, $P < .01$) and ML directions ($r = 0.529$, $P = .014$; Figure 2). Therefore, the more fatigued the athlete was, the more his unipedal static balance was impaired, at least in terms of these 3 factors. Examples of sway paths and areas (95% confidence ellipses) before and after the RSA test are shown in Figure 3.

Bipedal Stance

In bipedal stance, the RSA test led to higher values in all sway factors than at baseline (Table 2). The largest increase was observed for SA (ratios = 3.9 [eyes open] and 4.0 [eyes closed]).

We found no major effect of visual input, although participants generally exhibited poorer balance performances in the eyes-closed condition. Similarly, statistical analysis revealed no interaction for fatigue by visual input.

We noted no correlations between the FI and the fatigue/rest sway ratio for any of the factors investigated. The average FI values calculated after the 2 RSA test sessions were 2.84 ± 1.28 for the unipedal session and 3.04 ± 1.3 for the bipedal session. We observed no differences between the RSA performances on the test days.

DISCUSSION

Although a number of authors previously reported effects of fatigue on static balance, only a few investigated early adolescents. In this period of life, the postural-control

Table 2. Postural-Sway Values Before and After the Fatigue Protocol for Bipedal Stance

Measurement	Eyes Open Rest[a]	Eyes Open Fatigue[b]	Eyes Closed Rest	Eyes Closed Fatigue	*P* Value Repeated Sprint Ability Test	*P* Value Visual Input	*P* Value Repeated Sprint Ability Test × Visual Input
Sway area, mm^2	55.9 ± 38.6	195.8 ± 166.0	57.9 ± 38.7	220.8 ± 160.4	<.001[c]	.665	.766
Center-of-pressure path length, mm	254.7 ± 41.3	368.8 ± 80.5	281.5 ± 43.7	363.4 ± 99.9	<.001[c]	.795	.182
Maximum displacement, mm							
Anteroposterior	10.2 ± 3.0	23.0 ± 11.5	12.5 ± 3.6	23.7 ± 10.1	<.001[c]	.168	.381
Mediolateral	11.2 ± 3.9	16.4 ± 6.6	10.6 ± 5.3	19.7 ± 7.3	<.001[c]	.522	.089
Center-of-pressure velocity, mm/s							
Anteroposterior	5.2 ± 1.0	10.6 ± 13.0	5.8 ± 1.0	8.1 ± 1.8	<.001[c]	.845	.207
Mediolateral	5.9 ± 1.2	8.0 ± 1.8	6.3 ± 1.0	8.4 ± 1.6	<.001[c]	.125	.719

[a] Before repeated sprint ability test.

[b] After repeated sprint ability test.

[c] Significant effect.

system is still developing and is thus likely to be influenced when proper stimulation (eg, focused on the proprioceptive system) is administered.

Our results confirm that even in young athletes, fatigue appeared to worsen balance performance, as shown by the increased values for most sway factors after the RSA test in both unipedal and bipedal stance. The increments we observed are quantitatively similar to those reported in adults. For example, for the eyes-open bipedal stance, sway-path ratios (fatigue/rest) have been in the range of 1.2 to 2[15,17,22]; our result was 1.46. Increases in COP velocity were between 1.22 and 3.73[16,18,21]; our ratio was between 1.4 and 2.0, depending on the direction. Few authors have tested unipedal stance (which is of great interest in soccer players[14,21]) but even in this case, postfatigue increases in amplitude of COP maximum displacement in the ML and AP directions and COP velocity were consistent with those we demonstrated.

Nevertheless, Greig and Walker-Johnson[27] and Gioftsidou et al[28] found no change in balance alterations due to fatigue in soccer players. Greig and Walker-Johnson[27] induced fatigue by means of an intermittent soccer-specific treadmill protocol, whereas Gioftsidou et al[28] tested 16-year-old athletes performing a realistic soccer training session. In both studies, single-legged balance was assessed with the Biodex system, which provides several stability indexes. Greig and Walker-Johnson[27] used a protocol that was intended to replicate the walking and running profile of a typical soccer match, although, of course, directional changes, jumps, and ball handling could not be replicated. Gioftsidou et al[28] gave no specific information as to the content of their training. We believe the different results we observed are partly due to the nature of the stability indexes that form the output of the Biodex system (which are difficult to compare directly with sway values calculated on the basis of COP time series) and also related to the exercise protocol. As pointed out by Paillard,[12] depending on exercise intensity and duration, the postural system returns to baseline performance more quickly than does muscular strength. Thus, in some cases, the fatigue protocol used may simply be insufficient to trigger detectable sway increases.

For the dominant and nondominant limbs in the rest and fatigue conditions, the absence of significant differences between single-legged balance in the dominant and nondominant limbs agrees with previous observations on adult soccer players[5] but contrasts with the findings of Brito et al.[21] It has been hypothesized[4] that the nondominant limb, which is often called upon to assume a support role for the body while the dominant leg provides the force and accuracy necessary to kick the ball in the desired direction, may develop superior balance capabilities due to repeated exercise. If such a difference really exists as a consequence of the specific training that soccer players undergo, it probably takes many years to become evident; thus, the young age and relatively limited experience of our participants were perhaps insufficient for this type of lateralization to emerge.

Other than the age of the athletes tested, our approach was novel in searching for a relationship between balance and functional performance as quantified by the RSA FI. This topic is mostly unexplored in soccer athletes, and to our knowledge, only 1 group[8] attempted to investigate it, using running and jumping tests. They found a correlation between single-legged balance and vertical jump height but not with sprinting ability. On the contrary, we showed that unipedal-stance RSA performance (in terms of the FI) was positively correlated with increases in COP path length and V_{COP} in the ML direction. Wisløff et al[29] noted that sprint test and vertical jump performance of soccer players was related to maximal strength. This suggests that better-trained athletes, who are likely to be stronger in both running and jumping skills, might be less affected by some of the physiologic effects (eg, increases in cardiac and breathing rhythm, metabolic by-products) that, together with disturbances of the vestibular and proprioceptive systems, influence postural control.[12] Butler et al[30] showed that muscular weakness was associated with worse performance in proprioceptive postural control and suggested a functional link between contractile and sensory muscular processes. Thus, it is reasonable to hypothesize that people (especially the young) who feel more fatigue due to physiology or insufficient training may experience more and longer balance impairment during sport performance.

The differences between our results and those obtained by Erkmen et al[8] may be explained by 2 factors: the intensity and pace of the sprints performed to induce fatigue. Whereas Erkmen et al[8] tested adult athletes using a single session of the "4-line sprint"[31] or "3-corner run,"[31] which are basically continuous running with changes in direction, we used intermittent, standardized sprints with a greater number of repetitions. Perhaps the tests of Erkmen et al[8] failed to cause sufficient fatigue to impair balance.

The limitations of our study suggest the need for further investigation. Although RSA is recognized as valid in reproducing performance decrement (and thus fatigue) in soccer players and other team-sport athletes, during an actual match, sprints are performed while also leading the ball (rather than without it), and recovery time may be longer than 20 seconds.

Therefore, balance assessment should be performed during or at the end of a match to provide a better idea of what kind of postural impairments occur during a game and how much time is needed to regain full neuromuscular control. This situation is not easy to replicate in a single experimental test session because it would involve standardizing both the amount of time spent in the game and the interval between the end of the effort and the balance measurement for all athletes tested. Moreover, in planning experiments, researchers should consider that soccer players, especially those who are experienced, are characterized by different postural abilities according to their role (eg, defenders are more stable than forwards[32]) and level (high-level players are more stable than low-level players[33]). Thus, the mechanisms by which fatigue tends to alter their balance might also differ. All these considerations, together with a higher degree of standardization of balance assessment (currently performed under a wide variety of conditions, which include different foot positions and trial durations, presence or absence of visual input, etc) should be carefully analyzed when researchers plan similar experiments.

CONCLUSIONS

The adverse effects of fatigue on balance, which are known and documented in the literature, appear to affect young athletes in ways similar to those observed in adults. Fatigued, elite young soccer players exhibited increases in almost all sway measurements for both unipedal and bipedal stances. Because the fatiguing protocol was based on intermittent sprint sequences, which reproduce quite faithfully the muscular efforts that characterize a soccer match, it is reasonable to imagine that during actual play, repeated sprints will induce temporary balance impairments of mostly unknown duration (and duration of recovery). Another issue to analyze is the possibility that effects may accumulate over the course of the match.

The increased risk of lower limb injuries (particularly to the ankle), which has been attributed to fatigue due to altered neuromuscular control of the ankle, and the higher incidence of injuries observed in young players compared with older ones suggest that great attention must be paid to planning technical and physical-training programs. Practical preventive interventions to reduce the occurrence of injuries should include continuous monitoring of basic balance skills, development of specific static and dynamic balance-training protocols, and lower limb strength training integrated into regular training sessions.

ACKNOWLEDGMENTS

We thank the clubs that participated in the research (Cagliari Calcio and ASD Selargius) as well as their coaches, athletes, and parents.

REFERENCES

1. Williams AM, Reilly T. Talent identification and development in soccer. *J Sports Sci*. 2000;18(9):657–667.
2. Reilly T, Bangsbo J, Franks A. Anthropometric and physiological predispositions for elite soccer. *J Sports Sci*. 2000;18(9):669–683.
3. Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for acute ankle injuries among male soccer players: a prospective cohort study. *Scand J Med Sci Sports*. 2010; 20(3):403–410.
4. Teixeira LA, de Oliveira DL, Romano RG, Correa SC. Leg preference and interlateral asymmetry of balance stability in soccer players. *Res Q Exerc Sport*. 2011;82(1):21–27.
5. Matsuda S, Demura S, Uchiyama M. Centre of pressure sway characteristics during static one-legged stance of athletes from different sports. *J Sports Sci*. 2008;26(7):775–779.
6. Bieć E, Kuczyński M. Postural control in 13-year-old soccer players. *Eur J Appl Physiol*. 2010;110(4):703–708.
7. Hrysomallis C. Balance ability and athletic performance. *Sports Med*. 2011;41(3):221–232.
8. Erkmen N, Taşkın H, Sanioğlu A, Kaplan T, Baştürk D. Relationships between balance and functional performance in football players. *J Hum Kinet*. 2010;26(1):21–29.
9. Gioftsidou A, Malliou P, Pafis G, Beneka A, Godolias G, Maganaris CN. The effects of soccer training and timing of balance training on balance ability. *Eur J Appl Physiol*. 2006;96(6):659–664.
10. Pau M, Loi A, Pezzotta MC. Does sensorimotor training improve the static balance of young volleyball players? *Sports Biomech*. 2012; 11(1):97–107.
11. Sheldon JH. The effect of age on the control of sway. *Gerontol Clin (Basel)*. 1963;5:129–138.
12. Paillard T. Effects of general and local fatigue on postural control: a review. *Neurosci Biobehav Rev*. 2012;36(1):162–176.
13. Lin D, Nussbaum MA, Seol H, Singh NB, Madigan ML, Wojcik LA. Acute effects of localized muscle fatigue on postural control and patterns of recovery during upright stance: influence of fatigue location and age. *Eur J Appl Physiol*. 2009;106(3):425–434.
14. Springer BK, Pincivero DM. The effects of localized muscle and whole-body fatigue on single-leg balance between healthy men and women. *Gait Posture*. 2009;30(1):50–54.
15. Nardone A, Tarantola J, Giordano A, Schieppati M. Fatigue effects on body balance. *Electroencephalogr Clin Neurophysiol*. 1997; 105(4):309–320.
16. Derave W, Tombeux N, Cottyn J, Pannier JL, De Clercq D. Treadmill exercise negatively affects visual contribution to static postural stability. *Int J Sports Med*. 2002;23(1):44–49.
17. Bove M, Faelli E, Tacchino A, Lofrano F, Cogo CE, Ruggeri CP. Postural control after a strenuous treadmill exercise. *Neurosci Lett*. 2007;418(3):276–281.
18. Zemkova E, Hamar D. Postural sway response to exercise: the effect of intensity and duration. *Int J App Sports Sci*. 2005;17(1):1–6.
19. Dickin DC, Doan JB. Postural stability in altered and unaltered sensory environments following fatigue exercise of lower extremity joints. *Scand J Med Sci Sports*. 2008;18(6):765–772.
20. Zemkova E, Hamar D. The effect of soccer match induced fatigue on neuromuscular performance. *Kinesiology*. 2009;41(2):195–202.
21. Brito J, Fontes I, Ribeiro F, Raposo A, Krustrup P, Rebelo A. Postural stability decreases in elite young soccer players after a competitive soccer match. *Phys Ther Sport*. 2012;13(3):175–179.

22. Nagy E, Toth K, Janositz G, et al. Postural control in athletes participating in an ironman triathlon. *Eur J Appl Physiol*. 2004;92(4–5):407–413.
23. Frisch A, Urhausen A, Seil R, Croisier JL, Windal T, Theisen D. Association between preseason functional tests and injuries in youth football: a prospective follow-up. *Scand J Med Sci Sports*. 2011; 21(6):e468–e476.
24. Willems TM, Witvrouw E, Delbaere K, Mahieu N, De Bourdeaudhuij I, De Clercq D. Intrinsic risk factors for inversion ankle sprains in male subjects. *Am J Sports Med*. 2005;33(3):415–423.
25. Buchheit M, Mendez-Villanueva A, Delhomel G, Brughelli M, Ahmaidi S. Improving repeated sprint ability in young elite soccer players: repeated shuttle sprints vs. explosive strength training. *J Strength Cond Res*. 2010;24(10):2715–2722.
26. Fitzsimons M, Dawson B, Ware D, Wilkinson A. Cycling and running tests of repeated sprint ability. *Aust J Sci Med Sport*. 1993; 25(4):82–87.
27. Greig M, Walker-Johnson C. The influence of soccer-specific fatigue on functional stability. *Phys Ther Sport*. 2007;8(4):185–190.
28. Gioftsidou A, Malliou P, Pafis G, Beneka A, Godolias G. Effects of a soccer training session fatigue on balance ability. *J Hum Sport Exer*. 2011;6(3):521–527.
29. Wisløff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med*. 2004; 38(3):285–288.
30. Butler A, Lord SR, Rogers MW, Fitzpatrick RC. Muscle weakness impairs the proprioceptive control of human standing. *Brain Res*. 2008;1242:244–251.
31. Rösch D, Hodgson R, Peterson L, et al. Assessment and evaluation of football performance. *Am J Sports Med*. 2000;28(5 suppl):S29–S39.
32. Bizid R, Paillard T. Do the soccer players' postural activities at national level of competition differ between offensive and defensive players? *Sci Sports*. 2006;21(1):23–25.
33. Paillard T, Noé F, Rivière T, Marion V, Montoya R, Dupui P. Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. *J Athl Train*. 2006;41(2): 172–176.

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