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# PERIPHERAL AND CENTRAL FATIGUE CAUSE SIMILAR DECREASES ON DYNAMIC POSTURAL STABILITY IN MALE RECREATIONAL RUNNERS

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## ABSTRACT

Decreased dynamic postural stability could be linked to a great number of injuries. Moreover, fatigue -both central and peripheral- may diminish dynamic postural stability and have an impact on injuries. Therefore, the main objectives of our study were to identify and compare the effects of central and peripheral fatigue on dynamic postural stability. The Modified Star Excursion Balance Test (mSEBT) in anterior, posterolateral and posteromedial directions was performed in eighteen male recreational runners before and after a central or peripheral fatigue protocol. Central fatigue was induced by a 30-minute run at 85% of maximal aerobic speed on a treadmill, while a localized fatigue protocol in quadriceps and hamstrings muscles using an isokinetic dynamometer was performed to cause peripheral fatigue. Our results indicate that the maximum and average reached distance in anterior, posterolateral, posteromedial and summation of three directions were decreased by both central and peripheral fatigue ($p < 0.001$). Moreover, mSEBT performance did not show significant differences between type of fatigue (peripheral vs central) ($p > 0.05$). Thus, dynamic postural stability was decreased by peripheral and central fatigue in recreational runners, and both have similar effects on mSEBT performance.

**Keywords**: running, central, peripheral, fatigue, stability

# LA FATIGA PERIFÉRICA Y CENTRAL CAUSAN DISMINUCIONES SIMILARES EN LA ESTABILIDAD POSTURAL DINÁMICA EN ATLETAS RECREATIVOS

## RESUMEN

La disminución de la estabilidad postural dinámica podría estar relacionada con un gran número de lesiones. Además, la fatiga, tanto central como periférica, puede disminuir la estabilidad postural dinámica y tener un impacto en las lesiones. Por lo tanto, los principales objetivos de nuestro estudio fueron identificar y comparar los efectos de la fatiga central y periférica sobre la estabilidad postural dinámica. Se realizó el test de la estrella modificado (mSEBT) en las direcciones anterior, posterolateral y posteromedial en dieciocho atletas de nivel recreativo varones, antes y después de un protocolo de fatiga central y/o periférica. La fatiga central fue inducida por una carrera de 30 minutos al 85% de la velocidad aeróbica máxima en una cinta rodante, mientras que se realizó un protocolo de fatiga local en los músculos del cuádriceps y los isquiotibiales, utilizando un dinamómetro isocinético para causar fatiga periférica. Nuestros resultados indican que la distancia máxima y promedio alcanzada en la dirección anterior, posterolateral, posteromedial y el sumatorio de las tres direcciones se redujo tanto para la condición de fatiga central como la periférica ($p <0,001$). Además, el rendimiento en el test mSEBT no mostró diferencias significativas entre el tipo de fatiga (periférica frente a central) ($p> 0.05$). Por lo tanto, la estabilidad postural dinámica disminuyó tanto en la fatiga periférica como en la central en los atletas analizados, demostrando que ambos tipos de fatiga tienen efectos similares en el rendimiento de la prueba mSEBT.

**Palabras clave:** carrera, fatiga, central, periférico, estabilidad

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## INTRODUCTION

The popularity of running has grown lasts years (Fields, Sykes, Walker, & Jackson, 2010; Ogueta-Alday, Morante, Gómez-Molina, & García-López, 2018), gathering recreational, moderately-trained, and highly-trained runners on the growing number of running events (Ogueta-Alday et al., 2018). Nevertheless, almost half of these runners suffer at least one injury during the year (Fields et al., 2010). Fatigue is one of the major factors that have been related to running injuries (Whyte, Burke, White, & Moran, 2015). Fatigue is most commonly divided into central, what happens mainly at the spinal level, and peripheral fatigue, which acts to a greater extent at muscular level (Millet, 2011).

It has been suggested that central fatigue could have negative effects on strength and muscular activity (Martin et al., 2010), running biomechanics (Fischer, Storniolo, & Eyre-Tartaruga, 2015) or dynamic postural stability (Gribble, Hertel, & Denegar, 2007; Gribble, Hertel, Denegar, & Buckley, 2004; Steib, Hentschke, Welsch, Pfeifer, & Zech, 2013; Whyte et al., 2015). In this study we focus on dynamic postural stability, which can be measured by the Star Excursion Balance Test (SEBT) created by Gray (1995). It is a valid and reliable test, widely used scientifically and clinically to assess dynamic postural control or predict the risk of injury (Gribble, Hertel, & Plisky, 2012). Further, some studies have suggested that poor SEBT performance is related to a higher risk of suffering lower limb injuries (Gonell, Romero, & Soler, 2015; Gribble et al., 2016; Plisky, Rauh, Kaminski, & Underwood, 2006; Smith, Chimera, & Warren, 2015).

The effects of central or peripheral fatigue on SEBT have been studied previously in the literature (Baghbani, Ramezani, & Hatami, 2013; Baghbani, Woodhouse, & Gaeini, 2016; Gribble et al., 2007; Gribble et al., 2004; Steib et al., 2013; Whyte et al., 2015; Zech, Steib, Hentschke, Eckhardt, & Pfeifer, 2012). There are studies that showed no change in SEBT performance after a central (Baghbani et al., 2013; Baghbani et al., 2016; Zech et al., 2012) or peripheral (Zech et al., 2012) fatigue protocols, while others studies described negative effects (Gribble et al., 2007; Gribble et al., 2004; Steib et al., 2013; Whyte et al., 2015). To the best of our knowledge, only Zech et al. (2012) analyzed and compared the effects of both fatigues on SEBT utilizing the same procedure. No changes were found on SEBT performance, but center of pressure sway velocity increased significantly after central and peripheral fatigue. These authors suggest both types of fatigue did not have negative consequences on SEBT performance despite objectifying changes at sensorimotor control(Zech et al., 2012).

Thus, due to the negative effects fatigue could have on dynamic postural stability (Gribble et al., 2007; Gribble et al., 2004; Steib et al., 2013; Whyte et al., 2015), the relationship between poor SEBT performance and injuries (Gonell et al., 2015; Gribble et al., 2016; Plisky et al., 2006; Smith et al., 2015) and the limited knowledge of the influence of central and peripheral fatigue on this test (Zech et al., 2012), the main objective was to identify and compare the effects of central and peripheral fatigue on the modified Star Excursion Balance Test (mSEBT) in male recreational runners. Based on the existing literature, we hypothesized that: (a) central fatigue will decreases mSEBT performance; (b) peripheral fatigue will decreases mSEBT performance; (c) central and peripheral fatigue similarly will decrease mSEBT performance.

## METHOD

*Experimental approach to the problem*

This study was made in order to know the effects that fatigue could have in dynamic postural stability. It has been suggested that poor dynamic postural stability or low values of SEBT are related to lower limb sport injuries (Butler, Lehr, Fink, Kiesel, & Plisky, 2013; de Noronha, Franca, Haupenthal, & Nunes, 2013; Gonell et al., 2015; Gribble et al., 2016; Plisky et al., 2006; Smith et al., 2015). Moreover, some studies have also described that central (Steib et al., 2013; Whyte et al., 2015) and peripheral (Gribble et al., 2007; Gribble et al., 2004) fatigue can decrease SEBT performance. However, to our knowledge only one study compared the influence of central and peripheral fatigue on SEBT under the same methodological conditions but they did not show changes in SEBT performance in either of the two fatigues conditions (Zech et al., 2012). Therefore, to respond to these problems, dynamic postural stability was measured in eighteen recreational runners before and after central and peripheral fatigue protocols. Central fatigue was induced through 30 min of treadmill running while peripheral fatigue was induced in quadriceps and hamstring muscles using an isokinetic dynamometer. We emphasize that central and peripheral fatigue were randomized and separated by a minimum of 72 h.

*Participants*

Eighteen male recreational runners participated in the study (age: 28.2 ± 8.6 years; height: 177 ± 6.5 cm; body weight: 71.7 ± 8.4 kg; running experience: 7.3 ± 5.3 years, and running frequency: 2.8 ± 0.8 days/week). Participants were included if they had at least two years of experience in running (with a training frequency of at least twice a week in the last year), had not suffered a lower limb injury within the previous 6 months and had not use orthotics. As performance characteristics, the runners showed peak concentric quadriceps and hamstrings isokinetic strength of 245.0 ± 42.6 and 125.7 ± 32.9 Nm/kg respectively in the dominant limb. Psoas extensibility was assessed by the

Modified Thomas test and the mean of the group was -22.5 ± 7.2º (Wakefield, Halls, Difilippo, & Cottrell, 2015). Hamstring extensibility was assessed by the Straight Leg Raise test, and the being 68.4 ± 6.0º the mean of the runners (López-Miñarro & Rodríguez-García, 2010). The mean value of the gastrocnemius extensibility of the group was of 34.8 ± 8.3º, being analyzed by the Ankle Dorsiflexion with Knee Extended test (Cejudo, Sainz de Baranda, Ayala, & Santonja, 2015) and the soleus extensibility was 36.6 ± 8.0º, assessed by the Ankle Dorsiflexion with Knee Flexed test (Phillips, 2007). The maximal aerobic speed (MAS) was 17.7 ± 1.4 km/h and the estimated maximal oxygen consumption (VO2max) was 62.2 ± 4.7 ml/kg/min. The participants were informed of the benefits and risks of the investigation, and written signed consent was obtained. The study was approved by the University Ethics Committee (registry number: 6775).

*Procedure*

Before laboratory measurements, a maximal effort 5-minutes running test was used on a 400 m track to measure maximal aerobic speed (MAS) (Berthon et al., 1997; García-Pérez, Pérez-Soriano, Llana-Belloch, Lucas-Cuevas, & Sánchez-Zuriaga, 2014; Lucas-Cuevas et al., 2015). Furthermore, the analysis of the effects of central or peripheral fatigue on mSEBT performance of dominant limb was randomized and separated on two days, with a minimum of 72 h between sessions and between the maximal effort 5-minute running test. On measurement days participants performed a 10-min warm-up on a treadmill (Excite®+ Run MD Inclusive, Technogym Trading S.A., Barcelona, Spain) (García-Pérez et al., 2014; Lucas-Cuevas et al., 2015), followed by a 5-min rest before starting the test. Once finished, pre-fatigue dynamic postural control was evaluated by Modified Star Excursion Balance Test (mSEBT) (Gribble et al., 2012; van Lieshout et al., 2016), evaluating the reach in anterior (ANT), posterolateral (PL) and posteromedial (PM) directions, placing three tape measures on the laboratory floor with an angle of 135º in the posteromedial and posterolateral directions with respect to the anterior direction (Doherty et al., 2015; Gribble et al., 2012; van Lieshout et al., 2016). The test is performed barefoot with hands on hips, while the reach in anterior direction was performed by placing the most distal part of the first finger at the beginning of the tape measure, with the most posterior part of the heel at the beginning of posterior tape measures located to register the reach in posterolateral and posteromedial directions(Figure 1) (Gribble et al., 2012; van Lieshout et al., 2016).

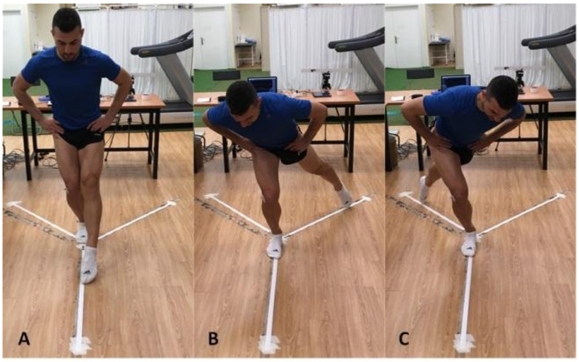


FIGURE 1: Execution of the modified Star Excursion Balance Test (mSEBT). A) Anterior reach direction, B) Posterolateral reach direction, and C) Posteromedial reach direction.

Participants were instructed to reach as far as possible with the contralateral limb to the limb supported, lightly touching the line with most distal portion of the foot and returning to initial position, reassuming a bilateral stance (Gribble et al., 2012). Prior to testing, four practice attempts in each direction were performed as familiarization (Doherty et al., 2015; van Lieshout et al., 2016) and then three randomized attempts in each direction were recorded (Doherty et al., 2015).

After pre-fatigue mSEBT, the peripheral or central fatigue protocols were performed. The transition between fatigue protocols and post-fatigue mSEBT was done as quickly as possible to avoid recovery processes.

*Peripheral fatigue protocol*

An isokinetic dynamometer (Biodex System Pro 3™, Biodex Medical Systems, Inc., New York, USA) was used to induce localized fatigue in quadriceps and hamstring muscles of the dominant limb. Runners adopted a sitting position with a hip flexion angle of 85º and the trunk, waist and thigh of the domain lower extremity stabilized with straps (Kellis, Zafeiridis, & Amiridis, 2011; Soleimanifar, Salavati, Akhbari, & Moghadam, 2012). In this position, the range of motion corresponded from 90º of knee flexion to full knee extension or 0º (Kellis et al., 2011; Soleimanifar et al., 2012).

Before the peripheral fatigue protocol, the concentric peak torque of quadriceps and hamstring muscles were evaluated through 2 sets of concentric/concentric knee flexion-extension movements at 120º/s (Kellis et al., 2011; Soleimanifar et al., 2012). Three submaximal and three maximal contractions were performed as familiarization in the first set (Soleimanifar et al., 2012). After 2 min, three repetitions of maximal effort were performed to record the highest concentric peak torque of quadriceps and hamstring values (Kellis et al., 2011; Soleimanifar et al., 2012).

Localized fatigue in this muscle was induced 3 min later by continuous concentric/concentric knee flexion-extension movements at 120º/s, exerting maximal effort. Fatigue was achieved when the peak torque fell below 50% for 3 consecutive movements in both directions (Soleimanifar et al., 2012).

*Central fatigue protocol*

Central fatigue was induced by 30 min of treadmill running at 85% MAS (García-Pérez et al., 2014) and 0% slope (Lucas-Cuevas, Pérez-Soriano, Llana-Belloch, Macián-Romero, & Sánchez-Zuriaga, 2014). To set this speed, the MAS, reached in the 5-minutes running test (Berthon et al., 1997; García-Pérez et al., 2014; Lucas-Cuevas et al., 2015), was used. In addition, the level of perceived fatigue was recorded just before and after the test. Runners had to manifest a perceived effort of 17 or "Very Hard" (Brown, Zifchock, & Hillstrom, 2014; Hafer, Brown, & Boyer, 2017; Steib et al., 2013) on Borg´s Scale 6-20 (Borg, 1982) to carry out the post-fatigue test.

*Data processing*

Biodex Advantage Software (Biodex Medical Systems, Inc., New York, USA) was used to process and analyze the quadriceps and hamstrings concentric peak torque and fatigue data. Furthermore, the reaches in the ANT, PL and PM directions were recorded calculating the average ($ANT_{AV}$, $PL_{AV}$ and $PM_{AV}$) and maximum ($ANT_{MAX}$, $PL_{MAX}$ and $PM_{MAX}$) reach in each direction and their composite score ($\sum_{AV}$ and $\sum_{MAX}$). Moreover, this reach distance was normalized to the limb length (%LL), dividing the reach distance between the limb length in centimeters and multiplying that value by 100 (van Lieshout et al., 2016; Whyte et al., 2015). We emphasize that limb length was calculated as the distance from the anterosuperior iliac spine to the ipsilateral center of the medial malleolus, in centimeters (van Lieshout et al., 2016; Whyte et al., 2015).

*Statistical analyses*

The results were expressed as mean ± SD. The Statistical Package for the Social Sciences V19.0 software was used (SPSS Inc., IBM Company, USA). The Shapiro-Wilk test was applied to ensure Gaussian distribution of all variables and the Levene test for the homoscedasticity of variances. A two-way or 2 by 2 repeated measures ANOVA was used to analyze the mSEBT performance modification between the type of fatigue (peripheral vs central fatigue) and fatigue condition (rested vs fatigued).

If the sample distribution was not normal, the Friedman test was used as non-parametric alternative to two-way repeated measures ANOVA. Moreover, Paired Samples t-test or Wilcoxon test were used to analyze the conditions under which these differences happened.

Afterwards, confidence intervals of the differences (95% CI) and effect sizes using partial eta-squared ($\eta^2_p$) for two-way repeated measures ANOVA and Cohen's *d* (*d*) (Cohen, 1992) for Paired Samples t-Test were calculated to identify meaningful changes. Partial eta-squared was interpreted as small, moderate, and large based on values of 0.01, 0.06, and 0.14, respectively (Cohen, 1988). Furthermore, Cohen's *d* (Cohen, 1992) was calculated by the formula proposed by Hunter and Schmidt (2004) and it was interpreted as 0.0-0.2, very small; 0.2-0.5, small; 0.5-0.8, medium; 0.8-1.2, large; 1.2-2.0, very large; and > 2.0, huge (Sawilowsky, 2009).

Finally, a correlational analysis through Pearson's Correlation Coefficient was made to rule out the possible influence of the muscular strength and extensibility levels in mSEBT modifications caused by fatigue. The magnitude was interpreted as < 0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; 0.9-1.0, almost perfect; and 1.0, perfect (Hopkins, Marshall, Batterham, & Hanin, 2009). The level of statistical significance was set at $p < 0.05$.

## RESULTS

Peripheral fatigue protocol was performed by eighteen runners while seventeen runners completed the central fatigue protocol because one participant sustained an injury between tests and he was excluded before performing this protocol. In the central fatigue protocol, all runners completed the stipulated 30 min, with average running velocity 4.2 ± 0.3 $m \cdot s^{-1}$ and perceived effort 17.6 ± 0.5. Furthermore, quadriceps and hamstring levels were recorded after the localized fatigue protocol against the maximum torque value, with 55.8 ± 5.8% and 53.5 ± 6.4% respectively.

Muscle extensibility and isokinetic strength did not affect mSEBT peripheral and central post-fatigue performance as it showed a trivial or very minor relationship ($p > 0.05$, psoas extensibility; $r = -0.099$, hamstring muscle extensibility; $r = -0.174$, gastrocnemius extensibility; $r = 0.183$, soleus extensibility; $r = 0.052$, quadriceps isokinetic strength; $r = 0.059$, and hamstrings isokinetic strength; $r = 0.022$).

Two-way repeated measures ANOVA showed significant differences in variables $ANT_{AV}$ (95% Confidence Interval [95% CI] = 1.989 / 3.892, $p = 0.000$, $\eta^2_p = 0.728$), $PM_{AV}$ (95% CI = 3.250 / 5.682, $p = 0.000$, $\eta^2_p = 0.791$), $ANT_{MAX}$ (95% CI = 1.626 / 3.454, $p = 0.000$, $\eta^2_p = 0.685$) and $PL_{MAX}$ (95% CI = 3.353 / 6.354, $p = 0.000$, $\eta^2_p = 0.746$) between the fatigue condition (pre-fatigue vs post-fatigue). Friedman's test reflected the same behavior in variables $PL_{AV}$, $PM_{MAX}$, $\sum_{AV}$ and $\sum_{MAX}$ ($p = 0.000$) (Table 2).

TABLE 1
*Results of mSEBT performance before and after peripheral and central fatigue*

| | | Peripheral Fatigue | | | Central Fatigue | | |
|---|---|---|---|---|---|---|---|
| | Condition | Mean ± SD | CI95% | d | Mean ± SD | CI95% | d |
| ANTAV | Rested | 73.1 ± 7.3** | 1.381 / 4.155 | -0.369 | 74.0 ± 6.2** | 1.820 / 4.422 | -0.527 |
| | Fatigued | 70.3 ± 7.7** | | | 70.8 ± 5.6** | | |
| ANTMAX | Rested | 74.1 ± 7.5** | 1.164 / 4.102 | -0.351 | 74.7 ± 6.4** | 1.157 / 3.815 | -0.425 |
| | Fatigued | 71.4 ± 7.8** | | | 72.2 ± 5.3** | | |
| PLAV§ | Rested | 92.6 ± 7.7** | - | -0.721 | 94.2 ± 6.4** | - | -0.955 |
| | Fatigued | 87.5 ± 6.2** | | | 88.2 ± 6.1** | | |
| PLMAX | Rested | 93.6 ± 7.6** | 2.177 / 6.136 | -0.520 | 95.5 ± 6.3** | 3.836 / 7.167 | -0.857 |
| | Fatigued | 89.8 ± 7.1** | | | 90.0 ± 6.6** | | |
| PMAV | Rested | 97.0 ± 5.4** | 1.476 / 4.639 | -0.600 | 97.7 ± 6.2** | 2.922 / 5.879 | -0.666 |
| | Fatigued | 93.9 ± 4.7** | | | 93.3 ± 7.0** | | |
| PMMAX§ | Rested | 97.0 ± 5.3** | - | -0.613 | 97.7 ± 6.2** | - | -0.666 |
| | Fatigued | 93.9 ± 4.7** | | | 93.3 ± 7.0** | | |
| ΣAV§ | Rested | 261.4 ± 14.9** | - | -0.824 | 264.9 ± 14.8** | - | -0.922 |
| | Fatigued | 249.6 ± 13.8** | | | 251.0 ± 15.5** | | |
| ΣMAX§ | Rested | 265.0 ± 15.1** | - | -0.651 | 267.9 ± 14.8** | - | -0.816 |
| | Fatigued | 255.1 ± 15.2** | | | 255.5 ± 15.5** | | |

*§: Non-parametric variables (Friedman´s Test), SD: Standard Deviation, CI95%: 95% Confidence Intervals, d: Effect Size, AV: Average, MAX: Maximum, ANT: Anterior direction, PL: Posterolateral direction, PM: Posteromedial direction, Σ: Summation of three directions **: p < 0.01 pre-fatigue vs post-fatigue.*

In these significant variables, Paired Samples t-Test or Wilcoxon test showed a significant decrease in reach distance in all directions of mSEBT in fatigue state compared to rested in both central and peripheral fatigue ($p < 0.001$) (Figure 2).

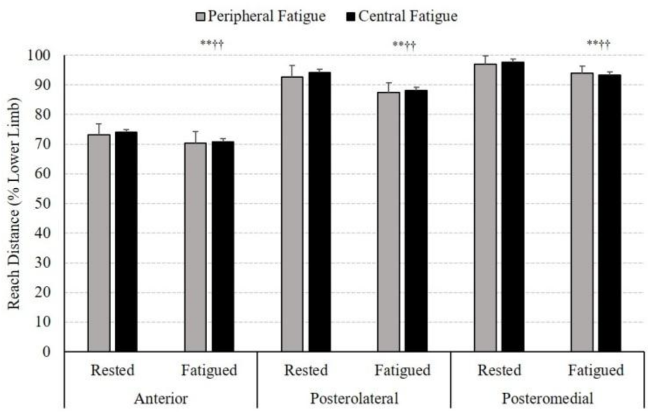


FIGURE 2: Results of effects of peripheral and central fatigue on Modified Star Excursion Balance Test performance. **: $p < 0.01$ peripheral pre-fatigue vs peripheral post-fatigue, ††: $p < 0.01$ central pre-fatigue vs central post-fatigue

Conversely, two-way repeated measures ANOVA and Friedman´s test did not show significant differences in mSEBT performance between type of fatigue (peripheral vs central) ($p > 0.05$).

## DISCUSSION

The aim of this study was to identify and compare the effects of central and peripheral fatigue on dynamic postural stability, evaluated by the mSEBT All the hypothesis was supported by the data.

Central fatigue decreased mSEBT performance, as Steib et al. (2013) showed a decrease in SEBT performance in anterior, posterior, medial and lateral directions after an incremental treadmill running protocol until subjective exhaustion. Equally, Whyte et al. (2015) showed that SEBT performance decreased by 6.5% on average in the 8 directions evaluated (83.7 ± 3.8 %LL vs 78.3 ± 5.4 %LL) after a high-intensity intermittent protocol. In the directions evaluated in our study, mSEBT performance decreased by 5.3% in ANT direction (84.8 ± 4.8 %LL vs 80.3 ± 6.6 %LL), 8.0% in PL direction (84.6 ± 5.6 %LL vs 77.8 ± 6.1 %LL) and 6.9% in PM direction (86.7 ± 5.3 %LL vs 80.7 ± 5.5 %LL).

For these authors, possible technical modifications and deficits in dynamic postural control could be responsible for the decline in SEBT performance, which could be related to an increased risk of injury (Whyte et al., 2015; Wright, Lyons, & Navalta, 2013). These results agree with our findings, because central fatigue diminished the average reached distance by 4.2%, 6.3%, 4.5% and 5.3% in ANT, PL, PM and summation of three directions respectively, and the maximum reached distance by 3.3%, 5.8%, 4.5% and 4.6% in the same sequence. Possibly, the high levels of perceived exertion and the cardiovascular, respiratory, thermoregulatory and muscular afferent input alterations that may occur in central fatigue state could inhibit the lower motor neuron at the spinal level due to the negative effects suffered on cortical motor drive that could decrease muscle-force output (Whyte et al., 2015).

Conversely, Zech et al. (2012), after an incremental treadmill running protocol until subjective exhaustion, did not find modifications in anterior, posterior, medial and lateral directions of SEBT. Likewise, Baghbani et al. (2016) did not observe modifications to SEBT performance in young female athletes after a 20-minute multistage fatigue protocol, although the reached distance in medial, posteromedial and posterior directions decreased in young female non-athletes. Baghbani et al. (2013) did not show changes in SEBT reach distance in young female basketball players in fatigue state induced by multistage functional protocol.

Baghbani et al. (2016) and Baghbani et al. (2013) used a 20-minute multistage fatigue protocol divided into 7 stations combining jogging, sprints, push-ups, sit-ups, step-ups and fast speed running. The nature of this protocol is different to that used in the study by Zech et al. (2012) and in ours. Moreover, the level of perceived fatigue was lower (16.0 ± 1.3 on Borg's Scale) (Baghbani et al., 2013; Baghbani et al., 2016) than the minimum required in this investigation (≥ 17 on Borg's Scale) based on previous studies (Brown et al., 2014; Hafer et al., 2017; Steib et al., 2013), perhaps not reaching the minimum fatigue threshold for dynamic postural control to be affected. Baghbani et al. (2016) also evaluated young female nonathletes, and after fatigue SEBT performance decreased in the medial, posteromedial, and posterior directions. Nonathletes described a level of perceived fatigue of 16.9 ± 1.6 on Borg's Scale after fatigue, values more approximate to the demands in our study. Therefore, the absence of the influence of central fatigue on SEBT performance shown in these studies (Baghbani et al., 2013; Baghbani et al., 2016) could be due to the different protocol used and the lower level of perceived fatigue as well as differences in gender, age and sport.

Zech et al. (2012) used a treadmill running fatigue protocol and athletes managed to reach a perceived effort superior to that required in our study (17.2 ± 1.3 on Borg's Scale). Even so, speed was not constant, but increased with time, and the grade was a constant 1.5%. These athletes were young male team handball players (16.8 ± 0.6 years) while our athletes were older runners (28.2 ± 8.6 years), being different the athlete characteristics. Handball is an intermittent sport where game actions are short and intense. The greater similarity between the test used to generate fatigue employed in our study with the running, long runs and constant speed, and the differences in age between samples, could explain the decrease in SEBT performance associated with a more-realistic fatigue protocol used in our study.

The second hypothesis, that peripheral fatigue decreases mSEBT performance, was supported. Coinciding with our findings, Gribble et al. (2004) showed that quadriceps and hamstrings isokinetic fatigue negatively affected SEBT performance in the three directions evaluated. In addition, Gribble et al. (2007) showed that the anterior, medial and posterior reach of SEBT decreased after a lunge continuous fatigue protocol and after following an ankle isokinetic fatigue protocol.

Muscular fatigue could cause alterations in postural control due to possible damage to joint receptors, that it produces delays in afferent conduction. These delays could affect the efferent signals, responsible of muscle contractions during corrective actions (Freeman, Dean, & Hanham, 1965; Gribble et al., 2004).

Moreover, it has been demonstrated that actions that involves changes on stability or reach-tasks, as in SEBT, is dependent on proximal joint (hip and knee joint) movement (Gribble & Hertel, 2004; Riemann, Myers, & Lephart, 2003). Muscular fatigue induces a reduction in the activation of both the quadriceps and hamstring muscles during full body destabilizing perturbations, reducing the stability around the knee (Hassanlouei, Arendt-Nielsen, Kersting, & Falla, 2012). This could be linked to agonist-antagonist coactivation modifications and a delay in activation which could increase the vulnerability of the knee to damage and injury during rapid destabilizing disturbances (Hassanlouei et al., 2012). This coincides with Gribble and Hertel (2004), who showed how participants possibly used proximal joint control during SEBT that was disrupted with fatigue and caused the lower SEBT performance.

As with central fatigue, Zech et al. (2012) did not show modifications in SEBT performance after single-leg barbell step-ups on a bench until the athlete was unable to perform the step-up. The difference of results with our study could be due to the different exercises used to cause localized fatigue. Single-leg barbell step-ups could induce fatigue in quadriceps and gluteal muscles, but hamstring fatigue would be less than in our investigation. Moreover, the level of fatigue was controlled by perceived exertion, not directly as a percentage of diminished strength. Perhaps the difference in results could be explained by the lower hamstring fatigue that would limit SEBT performance to a lesser extent, and possibly by a lower level of fatigue in the muscles evaluated. As a result of not controlling the loss of strength, it is possible that athletes reached the perceived exhaustion earlier than the 50% diminished strength as in our study.

The third hypothesis, that central and peripheral fatigue similarly decrease mSEBT performance was supported. To our knowledge, there is only one study that compares the effect of peripheral and central fatigue on SEBT performance

(Zech et al., 2012). In this study, fatigue did not decrease SEBT performance, obtaining contrary results comparing with our study in which peripheral and central fatigue diminished reached distance in SEBT in a similar way. The disparity of results between the studies of Zech et al. (2012) and ours, as explained above, could be due to the differences in the central and fatigue protocols and the age or the sport practiced by the athletes.

Although the tasks used to induce fatigue in our study were different in nature and duration, having a greater impact on spinal or muscle level in treadmill running and isokinetic task respectively, the effects on dynamic postural stability were similar. Moreover, there could also be a contribution of both fatigues within each task. Therefore, the combined effects of central and peripheral fatigue could decrease the sensorimotor afferent information and delayed muscle contraction, and therefore reduce muscle-force output (Whyte et al., 2015).

So, central and peripheral fatigue decreased the performance of mSEBT in all directions in recreational runners, and the magnitude of effect or influence of both fatigues in lower dynamic postural stability measured by this test was not different. In addition, higher or lower values of quadriceps and hamstrings isokinetic strength or psoas, hamstrings, gastrocnemius and soleus extensibility did not protect or exacerbate the decrease that fatigue caused to dynamic postural stability. Thus, peripheral and central fatigue affected and directly caused deficits in the body's ability to maintain dynamic postural control.

It has been demonstrated that lower SEBT values are related to lower limb injuries (Butler et al., 2013; de Noronha et al., 2013; Gonell et al., 2015; Gribble et al., 2016; Plisky et al., 2006; Smith et al., 2015). A range of less than 67% of lower limb in the anterior direction or 80% in the posterolateral direction of SEBT are related to a probability of lateral ankle sprain injury three times higher, or 48% more risk of injury in football players (Gribble et al., 2016) or college athletes (de Noronha et al., 2013) respectively. In addition, in football players a reach of less than 99% or 89% in summation of the three directions in the Lower Quarter Y Balance Test, an alternative to SEBT, meant that it was 2.25 (Gonell et al., 2015) or 3.5 (Butler et al., 2013) times more likely that these players would suffer injuries in the lower limb respectively.

These results and the relationship between low SEBT performance and sports injuries described in the literature and the findings of this study, suggest the inclusion of complementary training programs aimed to improving dynamic postural stability and to attemptto reduce and/or delay the effects of fatigue on postural control. In addition, stability training should allow to maintain the levels of postural stability as stable as possible without fatigue and with fatigue. To do this, complementary stability sessions in central fatigue state after the usual running training sessions or peripheral fatigue state after strengthening training could be of interest to improve the ability to maintain postural control in fatigue state.

Our findings suggested that central and peripheral fatigue, despite being different damaged mechanisms, cause a similar decrease in postural control. Therefore, coaches and trainers could use peripheral fatigue protocols to quantify the stability losses associated to fatigue state, and to keep control over the effects of a stability training program. Finally, the advantages of these tests lie in their short duration compared to the protocols for generating central fatigue.

Finally, it would be helpful if future investigations could analyze the effect of stability training programs performed under fatigue conditions on the impairment or decrease of SEBT performance with fatigue.

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