Influence of prolonged wearing of unstable shoes on upright standing postural control

Andreia S. P. Sousa (PhD)
Escola Superior da Tecnologia de Saúde do Porto, Área Científica de Fisioterapia, Centro de Estudos de Movimento e Actividade Humana, Rua Valente Perfeito, 322 - 4400-330 Vila Nova de Gaia, PORTUGAL
Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, s/n, 4200-465 Porto, PORTUGAL
E-mail: asp@estsp.ipp.pt, andreia.asps@gmail.com

Rui Macedo (PhD)
Escola Superior da Tecnologia de Saúde do Porto, Área Científica de Fisioterapia, Centro de Estudos de Movimento e Actividade Humana, Rua Valente Perfeito, 322 - 4400-330 Vila Nova de Gaia, PORTUGAL
E-mail: rmacedo@estsp.ipp.pt

Rubim Santos (PhD)
Escola Superior da Tecnologia de Saúde do Porto, Área Científica de Física, Centro de Estudos de Movimento e Actividade Humana, Rua Valente Perfeito, 322 - 4400-330 Vila Nova de Gaia, PORTUGAL
E-mail: rss@estsp.ipp.pt

Filipa Sousa (PhD)
Laboratório de Biomecânica do Porto, Faculdade de Desporto, Universidade do Porto, Porto, PORTUGAL
E-mail: filipas@fade.up.pt

Andreia Silva (Msc)
Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, s/n, 4200-465 Porto, PORTUGAL
E-mail: andreiasilva88@gmail.com

João Manuel R. S. Tavares (PhD)
Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, Departamento de Engenharia Mecânica, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, s/n, 4200-465 Porto, PORTUGAL
E-mail: tavares@fe.up.pt
(**corresponding author**)

Number of words: 4599

ABSTRACT

Objective: To study the influence of prolonged wearing of unstable shoes on standing postural control in prolonged standing workers.

Methods: The participants were divided into two groups: one wore unstable shoes while the other wore conventional shoes for 8 weeks. Stabilometry parameters related to centre of pressure (CoP), rambling (RM) and trembling (TR) as well as the total agonist/antagonist muscle activity, antagonist co-activation and reciprocal activation were evaluated during upright standing, before and after the 8 week period. In both moments, the subjects were evaluated wearing the unstable shoes and in barefoot.

Results: The unstable shoe condition presented increased CoP displacement related variables and decreased co-activation command compared to barefoot before and after the intervention. The prolonged wearing of unstable shoes led to: (1) reduction of medial-lateral CoP root mean square and area; (2) decreased anteroposterior RM displacement; (3) increased anteroposterior RM mean velocity and mediolateral RM displacement; (4) decreased anteroposterior TR RMS; and (5) increased thigh antagonist co-activation in the unstable shoe condition.

Conclusion: The unstable shoe condition is associated to a higher destabilizing effect that leads to a selection of more efficient and accurate postural commands compared to barefoot. Prolonged wearing of unstable shoes provides increased effectiveness and performance of the postural control system, while wearing of unstable shoes in upright standing, that are reflected by changes in CoP related variables and by a reorganization of postural control commands.

Keywords: Stabilometry; Antagonist co-activation; Reciprocal activation; Postural control performance; Unstable support; Prolonged standing workers.

1. INTRODUCTION

The support surface type has a relevant impact over postural control in humans (Dietz et al., 1980; Gantchev & Dimitrova, 1996; Gavrilenko et al., 1995; Ivanenko et al., 1999). When standing on an unstable support, the new postural requirements lead to postural control reorganisation through increased central drive (Gavrilenko, et al., 1995; Ivanenko, et al., 1999) associated with augmented gamamotoneuron activity leading to higher sensitivity of the muscle spindles (Dietz, et al., 1980; Gorassini et al., 1993; Prochazka, 2010; Ribot-Ciscar et al., 2000), changes in synergies between antagonist and agonist muscles (Dietz, et al., 1980) and increased anticipatory postural control adjustments (Aruin et al., 1998; Gantchev & Dimitrova, 1996; Nardone & Schieppati, 1988; Nouillot et al., 1992). Based on this, it can be argued that, depending on the degree, the instability provided by the unstable support condition would have positive effects over the postural control. Despite this possibility, the effect of unstable support conditions has been explored mainly at the immediate level or in balance training exercises. Considering the adaptation of the central nervous system (CNS) in response to changing task and environment demands (Shumway-Cook & Woolacott, 2007), further investigation is required regarding the long-term influence of changes in afferent information during daily activities that could be beneficial to postural control. Recently, manufacturers have introduced new shoe designs to feature unstable conditions (Masai Barefoot Technology, MBT, USA (Figure 1)) during daily activities to induce a neuromuscular training stimuli to improve postural control (Hu & Woollacott, 1994), and generate structural and functional adaptations in the neuromuscular system (Hakkinen et al., 1996). However, divergence exists as to the benefits from wearing this kind of shoes on postural control. Previous research has demonstrated that wearing this kind of unstable shoes regularly leads to changes in muscle activity level, mainly at the ankle joint, during upright standing (Sousa et al., 2012) and to decreased centre of pressure (CoP) excursion in young subjects (Landry et al., 2010); although no changes have been observed in the mean velocity of the CoP in mid-aged women (Ramstrand et al., 2010), neither in the CoP excursion in one-leg stance in young subjects (Turbanski et al., 2011). This divergence could result from the few parameters analysed, as a larger set of measures is required to detect differences in postural control (Pavol, 2005).

Upright stance is associated with a process of continuous small body deviations countered by corrective torques, generating a pattern known as spontaneous body sway. Involving a complex sensorimotor control system, upright postural control can be evaluated based on measurements of the body segment displacement, muscle activity and displacement and motion patterns of the centre of mass (CoM) and CoP (Balasubramaniam & Wing, 2002).

From a biomechanical perspective, a number of parameters derived from the CoP migration have been often used to characterise postural control and to evaluate postural performance (Bennell & Goldie, 1994; Collins & De Luca, 1993; Kinzey et al., 1997; Maurer & Peterka, 2005). This is because the CoP migration represents the summed up effect of mechanical muscle properties and of a number of different neuromuscular components whose characteristics are strongly dependent on the main inputs that control postural stability (Baratto et al., 2002; Maurer & Peterka, 2005; Winter, 1995b). However, CoP measures only represent the control variable acting to compensate the CoM displacement (the controlled variable) (Morasso et al., 1999). The importance of CoM measurements in association with CoP measurements is because the difference between the two variables is proportional to the horizontal acceleration of the CoM representing the “error” signal in the balance control system (Winter, 1995b). According to Zatsiorsky and Duarte, 1999, the nature of postural sway is the result of a moving reference point (rambling, RM). This moving point is related to the supraspinal process and constitutes a reference about which the body oscillates (trembling, TR) through the action of spinal reflexes and changes in the intrinsic mechanical properties of muscles and joints (Zatsiorsky & Duarte, 1999). The decomposition technique of CoP time series proposed by authors to assess RM and TR has been demonstrated to provide a very good estimate for both components (Lafond et al., 2004). However, to the best of our knowledge, no previous study addressed the influence of wearing unstable shoes in CoP and CoM interrelation or in muscle synergies during quiet standing. Does wearing unstable shoes lead to a higher performance and effectiveness of upright standing postural control?

Considering the aforementioned, the main purpose of this study was to analyse the influence of long-term wearing of unstable shoes in upright standing postural control in prolonged standing workers. More explicitly, the purposes were to evaluate the effect of wearing unstable shoes on: 1) CoP displacement pattern, 2) CoP and CoM inter-relation through RM and TR components, 3) total agonist and antagonist muscle activity, and 4) agonist-antagonist muscle relation. Based on recent studies which have demonstrated that wearing unstable shoes improves the performance of postural control responses to external perturbations (Sousa et al., 2013a; Sousa et al., 2013b), it can be hypothesised that the long-term wearing of unstable shoes would lead to higher performance and effectiveness of upright standing postural control, reflected by decreased CoP displacement, area and velocity (Bennell & Goldie, 1994; Kinzey, et al., 1997; Norris et al., 2005) and dispersion (Prieto et al., 1996), respectively. Also, considering that the postural control system relies more strongly on co-activation commands at the beginning of learning (Feldman, 1980a; Flash, 1987; Serres & Milner, 1991), when the internal models are poor, and on reciprocal activation commands as the learning proceeds (Imamizu et al., 2000; Osu et al., 2002), increased reciprocal activation and decreased antagonist co-activation after prolonged wearing of unstable shoes can be hypothesised. Finally, because these postural control adaptation strategies lead to reduced noise and increased accuracy (Lacquaniti et al., 1993), a decreased postural control system error, demonstrated through the CoM and CoP relation (Winter, 1995a) (RM and TR (Zatsiorsky & Duarte, 2000)) can also be expected. The design of the unstable footwear used in this study (MBT) is based on observations of the Masai tribe, who are not accustomed to wearing shoes. This design recreates natural uneven walking surfaces to reduce problems caused by today's rigid soled shoes and hard ground. This assumption raises the question: are postural control variables while wearing unstable shoes similar to that obtained under barefoot conditions? Based on this, values obtained while wearing the unstable shoes were compared to reference values obtained in barefoot condition. Similar values of CoP related variables would be expected between barefoot and unstable shoe conditions, before and after prolonged use of the shoes, as no differences were previously demonstrated during compensatory postural adjustments in response to an external perturbation (Sousa et al., 2013a; Sousa et al., 2013b). Also, the results obtained in these studies support the hypothesis of a decreased co-activation command in the unstable shoe condition compared to barefoot.

2. METHODS

2.1 Subjects

The study included healthy female participants whose professional occupation requires prolonged standing positions (hairdressers) that were divided into two groups: 1) the experimental group included 14 individuals (age = 34.6 ± 7.7 years, height = 1.59 ± 0.06 m, weight = 65.3 ± 9.6 kg; mean ± SD), and 2) the control group included 16 individuals (age = 34.9 ± 8.0 years, height = 1.62 ± 0.06 m, weight = 61.1 ± 6.3 Kg; mean ± SD). Possible candidates with recent osteoarticular and musculotendinous injury or surgery of lower extremities, background and signs of neurological dysfunction or under medication that could affect motor performance and balance were excluded, as well as individuals who had used unstable footwear (specifically, Masai Barefoot Technology) prior to the study.

The study was conducted according to the involved Institutions' ethical norms and conformed to the Declaration of Helsinki, being informed consent obtained from all participants.

2.2 Instrumentation

The electromyographic (EMG) activity of the gastrocnemius medialis (GM), tibialis anterior (TA), rectus femoris (RF) and biceps femoris (BF) muscles was monitored using the *MP 150 Workstation* model from *Biopac Systems*, *Inc. (USA)*, bipolar steel surface electrodes, spaced 20 mm apart, and a ground electrode (*Biopac Systems, Inc.*). The EMG signal was collected at 1000 Hz, pre-amplified at the electrode site and then fed into a differential amplifier with adjustable gain setting (12-500 Hz; Common Mode Rejection Ratio (CMRR): 95 dB at 50 Hz and input impedance of 100 MΩ). The gain range used was equal to 1000. The electrodes were placed at the centre of the muscle belly of GM, TA, RF and BF (Table 1) after the skin was shaved, cleaned with alcohol and scrubbed to reduce impedance to at least 5000 Ω, measured through an Electrode Impedance Checker (Noraxon USA, Inc.). Stabilometry parameters in the horizontal plane and along the anteroposterior orthogonal axes (Winter et al., 1998) were obtained using a force plate, model FP4060-10 from Bertec Corporation (USA), connected to a Bertec AM 6300 amplifier, with default gains and a 1000 Hz sampling rate. The amplifier was connected to a Biopac 16 bit analogical-digital converter.

2.3 Procedures

2.3.1 Data collection

In the experimental group, the EMG and stabilometric data were acquired at: (1) prior to using the unstable shoes and (2) after wearing them for a period of 8 weeks. The subjects in the control group were also assessed at two moments separated by 8 weeks were they were tested barefoot and on the unstable footwear. However, in the 8-week period the control group used their own regular footwear (1.5 cm heel). In both groups and in all assessments, the variables evaluated were monitored under two randomised conditions: (1) upright barefoot standing and (2) upright standing wearing the unstable shoes (Figure 1). The EMG measurements were performed on the dominant limb, determined by asking participants to kick a ball (all participants were right leg dominant). Before the data acquisition, all subjects underwent an instruction session by a qualified instructor who explained how to use the unstable shoe, followed by approximately 10 minutes of walking, until the instructor felt they walked properly and were comfortable using the shoes (Nigg et al., 2006).

The data acquisition was initiated 3 seconds after starting the testing procedure and was done in a total of 3 trials (Pinsault & Vuillerme, 2009; Ruhe et al., 2010). All individuals were asked to stand as still as possible (Zok et al., 2008), with the support base aligned at shoulder width, keeping their arms by their sides and to focus on a target 2 meters away and at eye level during

30 seconds (Le Clair & Riach, 1996). Rest periods of 60 seconds were provided between trials, during which the subjects sat down while maintaining the foot position (Kitabayashi et al., 2003).

After the upright standing measurements and a warm-up consisting of 3 submaximal isometric contractions (Lehman & McGill, 1999), the EMG maximal isometric contraction (MIC) was acquired for signal normalisation. For the TA and GM, the ankle was placed in neutral position, and for the BF and RF, the knee was at 90º. All participants were asked to perform 3 trials of MIC for dorsiflexion, plantar flexion, knee flexion and knee extension, respectively, under resistance during 5 seconds, with a 60 seconds rest between trials (Brown & Weir, 2001). The signals collected within the first and last seconds were discarded.

Following an initial evaluation, a pair of the unstable shoes was given to each subject in the experimental group, being the subjects instructed to wear them as much as possible at least 8 hours a day, 5 days a week (working hours), for 8 weeks, to obtain training effects (Nigg, et al., 2006; Ramstrand et al., 2008; Ramstrand, et al., 2010; Romkes et al., 2006). All participants from the experimental group received a guide on how to use the shoes, and the participants in the control group were told to continue their normal activities and not begin any new exercise regime. The responsible for each company group guaranteed the adherence of the participants.

2.3.2 Data processing

i) Electromyography

The raw EMG signal was band-pass filtered (20-450 Hz) and the root mean square (RMS) was calculated. The EMG of each muscle was normalised to the corresponding value obtained during MIC (EGMnorm). Reciprocal activation and antagonist co-activation were calculated for joint level (i.e., for muscles that span one joint) and muscle group level (group of muscles that span multiple joints). For the joint level, the muscles acting on the ankle (TA/GM pair) and on the knee (RF/(GM + BF) pair) were considered. For the muscle group level, the sum of the EMGnorm of all the dorsal (GM and BF) and all the ventral (TA and RF) postural muscles was adopted.

The antagonist co-activation at joint level and at muscle group level were calculated using the following equations (Kellis et al., 2003):

a) Antagonist co-activation at the joint level:

$$\textit{Antagonist co-activation}_{TA/GM\ pair} = \frac{EMGnorm_{TA}}{EMGnorm_{GM} + EMGnorm_{TA}} \times 100, \qquad (1)$$

$$\textit{Antagonist co-activation}_{RF/(BF+GM)\ pair} = \frac{EMGnorm_{RF}}{EMGnorm_{(BF+GM)} + EMGnorm_{RF}} \times 100. \qquad (2)$$

b) Antagonist co-activation at the muscle group level:

$$\textit{Antagonist co-activation}_{ventral/dorsal\ pair} = \frac{EMGnorm_{(TA+RF)}}{EMGnorm_{(GM+BF)} + EMGnorm_{(TA+RF)}} \times 100. \qquad (3)$$

This approach provides an estimate of the relative activation of the pair of muscles, as well as the magnitude of the co-activation.

The reciprocal activation at joint and muscle group levels was calculated using the following equations (Slijper & Latash, 2004):

a) Reciprocal activation at the joint level:

$$Reciprocal\ activation_{TA/GM\ pair} = EMGnorm_{GM} - EMGnorm_{TA}\ , \qquad (4)$$

$$Reciprocal\ activation_{RF/(BF+GM)\ pair} = EMGnorm_{(BF+GM)} - EMGnorm_{RF}\ . \qquad (5)$$

b) Reciprocal activation at the muscle group level:

$$Reciprocal\ activation_{ventral/dorsal\ pair} = EMGnorm_{(GM+BF)} - EMGnorm_{(TA+RF)}\ . \qquad (6)$$

ii) Stabilometry

A fourth-order, zero phase-lag, low-pass Butterworth filter with a cut-off frequency of 10 Hz (Ruhe, et al., 2010) was applied to all the CoP displacement time series. The peak-to-peak amplitude (*P-P*), mean velocity (*MV*), which was defined as the total CoP displacement divided by the total period, and dispersion time series estimated by *RMS* were calculated. A 95% confidence ellipse for each trial was estimated to enclose approximately 95% of the CoP motion points in the 2D domain. These parameters were selected as they were demonstrated to be sensitive to postural performance and efficiency (Rocchi et al., 2004).

The RM and TR displacement components were obtained according to the method proposed in (Zatsiorsky & Duarte, 1999). In brief, the RM component expresses the movement of a moving reference point (an attractor point), with respect to which the balance of the body is maintained instantly. To obtain this component, the particular moments when the horizontal forces (shear forces measured by the force plate) changed its signs were selected, and the instants when the horizontal forces were equal to zero were estimated by linear interpolation. The CoP positions at these instants (instant equilibrium points, IEP) were determined. To obtain an estimate of the RM trajectory, the IEP discrete positions were interpolated by cubic spline functions with gravity line. The difference between the RM and CoP trajectories was defined as the TR component. The TR component reflects the oscillation of the body around the reference point. From the RM and TR time series, the *RMS*, *area*, *MV* and *P-P* variation were calculated. The data analysis was performed using the Matlab software *(MathWorks, USA)*.

2.4 Statistics

The statistical analysis was processed using *Statistic Package Social Science* (*SPSS*) from *IBM Company (USA)*. The sample was characterised by descriptive statistics. To evaluate if wearing unstable shoes lead to higher performance and effectiveness of standing postural control, the main effect and interactions between the effects of the condition (unstable shoe vs barefoot), the intervention period and the group (experimental vs control), in total agonist and antagonist muscle activity, antagonist co-activation and reciprocal activation values and stabilometric data, were analysed according to the repeated-measures ANOVA. Also, the magnitude of the intervention effects was assessed through the Cohen's d for the electromyographic and stabilometric data (Cook, 2008). To verify if postural control variables while wearing unstable shoes are similar to that obtained under barefoot conditions, the main effect of the condition (unstable shoe vs barefoot) was analysed according the repeated-measures ANOVA

3. RESULTS

To investigate the effect of wearing the unstable shoes on the postural control, the values of stabilometry and of agonist and antagonist relation in the experimental group were compared against the reference values obtained in: 1) the control group; 2) the barefoot condition of the experimental group; and 3) the first evaluation of the experimental group in the unstable shoe condition.

No differences between the experimental and control groups were found at the first time point, before the intervention of the experimental group, in the CoP related variables in barefoot ($p>0.194$) and unstable shoe conditions ($p>0.117$). Also, no differences were observed in the postural commands in barefoot ($p>0.172$) and unstable shoe conditions ($p>0.118$).

3.1 Does wearing unstable shoes lead to a higher performance and effectiveness of upright standing postural control?

<u>CoP displacement variables</u>

A significant interaction between the effects of the condition (unstable shoe vs barefoot), the training period and the group (experimental vs control) was observed in the CoP *area* ($F(1,27)=8.296$, $p=0.01$) and in the medial-lateral CoP *RMS* ($F(1,27)=4.376$, $p=0.046$), Figure 2. The experimental group presented higher decrease of the CoP *area* and decrease medial-lateral CoP *RMS* after wearing the unstable shoes for 8 weeks in the unstable shoe condition (Tables 2-3 and Figure 3). The control group presented an increase of the medial-lateral CoP *RMS* in the second evaluation. No significant main effects and 2-way interactions were observed for the CoP variables. A large strength in the intervention effect was obtained for the reduction of the medial-lateral CoP *RMS* (Cohen's d=0.98) in the unstable shoe condition after 8 weeks of wearing the unstable shoes.

<u>RM related variables</u>

A significant interaction between the effects of condition (unstable shoe vs barefoot), the training period and the group (experimental vs control) was observed for the anteroposterior RM

P-P ($F(1,27)=8.414$, $p=0.007$) and *MV* ($F(1,27)=4.641$, $p=0.040$), Figure 2. The experimental group presented decreased anteroposterior RM *P-P* and increased anteroposterior RM *MV* while wearing the unstable shoes after the training period, when compared to the first evaluation, the barefoot condition and the control group (Table 2 and Figure 3). A large strength in the intervention effect was obtained in reducing the anteroposterior RM *P-P* (Cohen's d=0.9) in the experimental group in the unstable shoe condition. A significant main effect of the group ($F(1,27)=17.547$, $p<0.001$) and the training period ($F(1,27)=21.799$, $p<0.001$) was also observed in the medial-lateral RM *P-P*. After training, the experimental group presented increased medial-lateral RM *P-P* when compared to the first evaluation, while the control group presented decreased of medial-lateral RM *P-P* in the second evaluation compared to the first (Table 3 and Figure 3). No statistically significant 2-way interactions were observed for the RM variables.

TR related variables

A significant interaction between the effects of condition (unstable shoe vs barefoot), the training period and the group (experimental vs control) was observed for the anterior-posterior TR *RMS* component ($F(1,27)=8.069$, $p=0.001$). A significant main effect was observed for the training period ($F(1,27)=4.309$, $p=0.048$) (Figure 2). The experimental group presented decreased anteroposterior TR *RMS* after training when compared to the first evaluation, while the control group presented increase values for this variable (Table 2). Also, the experimental group presented an increase of anterior-posterior TR RMS from the first to the second evaluation in the barefoot condition (Figure 2).

Postural commands

A significant interaction between the effects of condition (unstable shoe vs barefoot), the training period and the group (experimental vs control) was observed for the thigh antagonist co-activation ($F(1,27)=6.414$, $p=0.012$) (Figure 2). No significant main effects and 2-way interactions were observed. A large strength in the intervention effect was obtained through increased thigh antagonist co-activation (Cohen's d=0.8) in the experimental group. The experimental group presented increased thigh antagonist co-activation while wearing the unstable shoes after the training period, when compared to the first evaluation, the barefoot condition and the control group (Table 4 and Figure 3).

3.2 Are postural control variables while wearing unstable shoes similar to that obtained under barefoot conditions?

<u>CoP displacement related variables</u>

There was a significant main effect of the unstable shoe condition vs barefoot condition on the anteroposterior CoP *MV* ($F(1,27)=6.684$, $p=0.015$), anteroposterior ($F(1,27)=37.694$, $p<0.001$) and medial-lateral ($F(1,27)=83.820$, $p<0.001$) CoP *RMS* and *area* ($F(1,27)=40.175$, $p<0.001$). Generally, higher values were obtained while wearing the unstable shoes when compared to the ones obtained in the barefoot condition in first and second evaluations (Tables 2-3 and Figure 3).

<u>RM related variables</u>

A significant main effect of the unstable shoe condition vs barefoot condition was observed in the RM *P-P* and *RMS* in anteroposterior ($F(1,27)=5.073$, $p=0.033$), ($F(1,27)=21.667$, $p<0.001$, respectively) and medial-lateral ($F(1,27)=137.664$, $p<0.001$), ($F(1,27)=11.084$, $p=0.003$, respectively) directions, and in the RM *area* ($F(1,27)=102.5334$, $p<0.001$). Generally, lower values of anteroposterior RM *P-P* and RMS were obtained in the unstable shoe condition when compared to the barefoot condition, while higher values of medial-lateral RM *P-P*, RM *RMS* and RM *area* were obtained in the unstable shoe condition when compared to the barefoot condition, in both evaluations (Tables 2-3 and Figure 3).

<u>TR related variables</u>

A significant main effect on the TR component was observed for the condition (barefoot vs unstable shoe), for the anteroposterior TR *RMS* ($F(1,27)=18.704$, $p<0.001$), medial-lateral TR *RMS* ($F(1,27)=6.804$, $p=0.015$) and TR *area* ($F(1,27)=37.721$, $p<0.001$). Both groups presented increased TR *RMS* and *area* in the unstable shoe condition compared to the barefoot condition in both evaluations (Tables 2-3 and Figure 3).

Postural commands

A significant main effect of condition (barefoot vs unstable shoe) was observed in the thigh co-activation ($F(1,28)=21.038$, $p<0.001$) and reciprocal activation ($F(1,28)=18.23$, $p<0.001$), in leg co-activation ($F(1,28)=8.131$, $p=0.008$) and reciprocal activation ($F(1,28)=22.292$, $p<0.001$), and in global antagonist co-activation ($F(1,28)=12.940$, $p=0.001$) and total agonist activity ($F(1,28)=25.711$, $p<0.001$). Decreased antagonist co-activation and increased reciprocal activation and total agonist activity were observed in the unstable shoe condition when compared to the barefoot condition in both evaluations (Table 4 and Figure 3).

4. DISCUSSION

The aim of the present study was to evaluate the effect of prolonged wearing of unstable shoes on postural control components. The results obtained confirm our hypothesis that prolonged wearing of unstable shoes increases postural control performance, demonstrated by a decrease of the most representative CoP displacement parameters (Collins & De Luca, 1993; Maurer & Peterka, 2005; Pavol, 2005; Rocchi, et al., 2004), and decreased postural control system error, demonstrated by the adaptation of the RM and TR components (Zatsiorsky & Duarte, 2000), more marked in the unstable shoe condition. However, our results failed in demonstrating a decreased co-activation command and increased reciprocal activation command as a training effect. Also, upright standing while wearing the unstable shoes is more demanding from a postural control perspective than standing barefoot, even after prolonged wearing of the shoes. This higher demand was reflected by increased CoP related variables while wearing unstable shoe compared to barefoot, but also by a selection of more challenging postural commands by the postural control system.

Wearing of the unstable shoes led to a higher performance and effectiveness of upright standing postural control in the unstable shoe condition

Unstable shoes have been reported as promoters of increased instability (Nigg, et al., 2006). However, training effects over postural control system resulting from prolonged wearing of unstable shoes have not been found (Ramstrand, et al., 2010; Turbanski, et al., 2011). Our results demonstrate a reduction of the CoP *area* and of the medial-lateral CoP *RMS* in unstable shoe condition after prolonged wearing of the shoes, revealing increased efficiency and effectiveness of the postural control system (Bennell & Goldie, 1994; Murray et al., 1975; Prieto, et al., 1996; van Wegen et al., 2002).

Training effects from wearing the unstable shoes were also evident in the RM parameter. The reduction of the *P-P* of RM trajectory in the anteroposterior direction reflects a higher efficiency of the postural control system (Bennell & Goldie, 1994; Kinzey, et al., 1997; Norris, et al., 2005; Prieto, et al., 1996) related to supraspinal processes that define an instantaneous point about which the body is stabilised (Zatsiorsky & Duarte, 1999, 2000). The increased *MV* of the RM component could be related to a reweighted combination of reciprocal activation and co-activation commands (Drew & Rossignol, 1987; Feldman, 1980a, 1980b; Feldman & Levin, 1995; Lacquaniti, 1992; Lacquaniti et al., 1991; Levin et al., 1992). Indeed, the results of this study reveal that prolonged wearing of the unstable shoes led to a large effect in the increase of thigh antagonist co-activation. A transfer of postural control synergy for the thigh has been demonstrated in compensatory responses after a 8 weeks period of wearing unstable shoes (Sousa et al., 2014) and has been reported as more beneficial to optimise postural stability (Day et al., 1993; Horak et al., 1990; Kuo, 1993; Runge et al., 1999; Yang et al., 1990). This association is corroborated not only by the decrease of the most representative CoP displacement parameters and RM *P-P*, but also by decreased anterior-posterior TR *RMS*. Changes in the TR *RMS* indicate an increased effectiveness provided by an adaptation of spinal reflexes and changes in the intrinsic mechanical properties of muscles and joints (Zatsiorsky & Duarte, 1999).

Standing with unstable shoes is more demanding in terms of postural control than standing barefoot

The design of the unstable footwear used in this study (MBT) is based on observations of the Masai tribe, who are not accustomed to wearing shoes. This design recreates natural uneven surfaces to reduce problems caused by today's rigid soled shoes and hard ground. In spite of the adaptations aforementioned after prolonged wearing of the unstable shoes, the total agonist activity and CoP displacement related variables are still higher than in barefoot condition (Figure 2), suggesting that the destabilising effect of the unstable shoes remains even after the extended use of the shoes. Based on the evidence that unstable support surfaces lead to increased proprioceptive acuity provided by agonist muscles (Gandevia et al., 1992) as a result of a higher fusimotor drive (Gorassini, et al., 1993; Gurfinkel et al., 1992; Ribot-Ciscar et al., 2009), it can be argued that the permanence of a higher destabilizing effect promoted by the unstable shoes adopted are responsible for higher performance of the postural control system. Also, the results of the present study indicate that, in both pre- and post-training, wearing unstable shoes leads the postural control system to rely more on reciprocal activation than on co-activation to compensate for the decreased stability compared to barefoot. This has been demonstrated to be more efficient and accurate, but also more challenging for the postural control system (Aruin & Almeida, 1997; Friedli et al., 1984; Garland et al., 1997; Hogan, 1984; Hong et al., 1994; Latash et al., 1995; Massion et al., 1999), and it has been observed also in compensatory postural adjustments in response to an external perturbation (Sousa, et al., 2013a; Sousa, et al., 2014). These findings demonstrate that wearing unstable shoes is more demanding in terms of postural control than barefoot, but lead to a higher efficiency and accuracy in postural commands. This postural control advantage is also observed even after prolonged use of unstable shoes.

Wearing unstable shoes can be a beneficial ergonomic intervention for prolonged standing workers

It should be noted that the results presented were obtained from participants that work in prolonged standing positions. It has been demonstrated that subjects spending at least 50% of the working time in a standing position are in risk for developing neuromusculoskeletal impairments and venous insufficiency (Krijnen et al., 1998; Macfarlane et al., 1997; Tomei et al., 1999). The static contraction of lower back and legs results in diminished function of the calf muscle, muscle fatigue, discomfort and even low back pain (Krijnen, et al., 1998). Discomfort or subjective fatigue can be linked to psychological fatigue and has been recognised as a factor in the decline of alertness, mental concentration, and motivation (Simonson & Weiser, 1976). Commonly chosen ergonomic intervention methods to reduce pain and discomfort associated with prolonged standing are the alteration of the flooring on which workers stand, and the use of in-soles in the footwear (King, 2002), as one of the strategies is to make the body sway naturally and imperceptibly. The results of the present study encourage the use of unstable shoes as a beneficial ergonomic intervention, since they demonstrate that the instability provided by wearing the shoes leads to a reorganisation of postural control that result in increased performance and effectiveness during upright standing. This reorganisation of upright standing postural control is accompanied by increased calf muscle activity, improving venous return (Sousa, et al., 2012). However, studies on the influence of wearing unstable shoes on subjective rating of fatigue and discomfort while standing are demanded to support our hypothesis.

5. CONCLUSION

Our results demonstrate that wearing unstable shoes is more demanding in terms of postural control than barefoot and consequently, could be used to reduce problems caused by today's rigid soled shoes and hard ground. The prolonged exposure to this postural challenge led to higher effectiveness and performance of the postural control system, while wearing unstable shoes in upright standing, that are reflected by changes in CoP related variables and by a reorganization of postural control commands.

This study is the first demonstrating comprehensively that wearing unstable shoes during prolonged standing work leads to positive effects over standing postural control. Therefore, the results are innovative and provide valuable information for the design of shoes that can diminish the negative effects of prolonged standing in the musculoskeletal system and contribute for better occupational health.

REFERENCES

Aruin, A., & Almeida, G. (1997). A coactivation strategy in anticipatory postural adjustment in persons with Down syndrome. Motor Control 2: 178-197.

Aruin, A., Forrest, W., & Latash, M. (1998). Anticipatory postural adjustments in conditions of postural instability. Electroencephalography and clinical neurophysiology 109(4): 350-359.

Balasubramaniam, R., & Wing, A. M. (2002). The dynamics of standing balance. Trends in Cognitive Sciences 6(12): 531-536.

Baratto, L., Morasso, P., & Spada, G. (2002). A new look at posturographic analysis in the clinical context: sway-density versus other parameterization techniques. Motor Control 6(3): 246-270.

Bennell, K., & Goldie, P. (1994). The differential effects of external ankle support on postural control. Journal of Orthopaedics and Physical Therapy 20(6): 287-295.

Brown, L., & Weir, J. (2001). Asep procedures recommendation I: Accurate assessment of muscular strength and power. Official Journal of the American Society of Exercise Physiologists 4(3): 1-21.

Collins, J. J., & De Luca, C. J. (1993). Open-loop and closed-loop control of posture: a random-walk analysis of center-of-pressure trajectories. Experimental Brain Research 95(2): 308-318.

Cook, C. (2008). Clinimetrics Corner: Use of Effect Sizes in Describing Data. Journal of Manual & Manipulative Therapy 16(3): 54E-57E.

Day, B. L., Steiger, M. J., Thompson, P. D., & Marsden, C. D. (1993). Effect of vision and stance width on human body motion when standing: implications for afferent control of lateral sway. Journal of Physiology 469: 479-499.

Dietz, V., Mauritz, K., & Dichgans, J. (1980). Body oscillations in balancing due to segmental stretch reflex activity. Experimental Brain Research 40(1): 89-95.

Drew, T., & Rossignol, S. (1987). A kinematic and electromyography study of cutaneous reflexes evoked from forelimb of unrestrained walking cats. Journal of Neurophysiology 57: 1160-1184.

Feldman, A. (1980a). Superposition of motor programs: 1. Rhythmic forearm flexion in man. Neuroscience 5: 81-90.

Feldman, A. (1980b). Superposition of motor programs: 2. Rapid forearm flexion in man. Neuroscience 5: 91-95.

Feldman, A. G., & Levin, M. F. (1995). The origin and use of positional frames of reference in motor control. Behavioral Brain Sciences 18: 723-806.

Flash, T. (1987). The control of hand equilibrium trajectories in multi-joint arm movements. Biological Cybernetics 57(4): 257-274.

Friedli, W. G., Hallett, M., & Simon, S. (1984). Postural adjustments associated with rapid voluntary arm movements 1. Electromyographic data. Journal of Neurology, Neurosurgery & Psychiatry.

Gandevia, S. C., McCloskey, D. I., & Burke, D. (1992). Kinaesthetic signals and muscle contraction. Trends in Neurosciences 15(2): 62-65.

Gantchev, G. N., & Dimitrova, D. M. (1996). Anticipatory postural adjustments associated with arm movements during balancing on unstable support surface. International Journal of Psychophysiology 22: 117-122.

Garland, S. J., Stevenson, T. J., & Ivanova, T. (1997). Postural responses to unilateral arm perturbation in young, eldery, and hemiplegic subjects. Archives of Physical Medicine and Rehabilitation 78(10): 1072-1077.

Gavrilenko, T., Gatev, N., & Dimitrova, D. (1995). Somatosensory evoked potentials during standing posture on different support conditions. Homeostasis 33: 39-46.

Gorassini, M., Prochazka, A., & Taylor, J. L. (1993). Cerebellar ataxia and muscle spindle sensitivity. Journal of Neurophysiology 70(5): 1853-1862.

Gurfinkel, V. S., Popov, K. K., & B.N., S. (1992). The support input as a reference for postural control. In M. Woolacott & F. Horak (Eds.), *Posture and Gait: Control Mechanisms* (Vol. 1, pp. 182-186). Oregon: University of Oregon Books.

Hakkinen, K., Kallinen, M., Linnamo, V., Pastinen, U., Newton, R., & Kraemer, W. (1996). Neuromuscular adaptations during bilateral versus unilateral strength training in middle-aged and elderly men and women. Acta Physiologica Scandinavica 158(1): 77-88.

Hogan, N. (1984). Adaptive control of mechanical impedance by coactivation of antagonist muscles. IEEE Trans Autom Control 29: 681-690.

Hong, D., Corcos, D., & Gottlieb, G. (1994). Task dependent patterns of muscle activation at the shoulder and elbow for uncontrained arm movements. Journal of Neurophysiology 71(3): 1261-1265.

Horak, F., Nashner, L., & Diener, H. (1990). Postural strategies associated with somatosensory and vestibular loss. Experimental Brain Research 82(1): 167-177.
Hu, M., & Woollacott, M. (1994). Multisensory training of standing balance in older adults: I. Postural stability and one-leg stance balance. Journal of Gerontology 49(2): M52-61.
Imamizu, H., Miyauchi, S., Tamada, T., Sasaki, Y., Takino, R., Putz, B., . . . Kawato, M. (2000). Human cerebellar activity reflecting an acquired internal model of a new tool. [10.1038/35003194]. Nature 403(6766): 192-195.
Ivanenko, Y. P., Talis, V. L., & Kazennikov, O. V. (1999). Support stability influences postural responses to muscle vibration in humans. European Journal of Neuroscience 11(2): 647-654.
Kellis, E., Arabatzi, F., & Papadopoulos, C. (2003). Muscle co-activation around the knee in drop jumping using the co-contraction index. Journal of Electromyography and Kinesiology 13(3): 229-238.
King, P. (2002). A comparison of the effects of floor mats and shoe in-soles on standing fatigue. Applied Ergonomics 33: 477-484.
Kinzey, S., Ingersoll, C., & Knight, K. (1997). The effects of selected ankle appliances on postural control. Journal of Athletic Training 32(4): 300-303.
Kitabayashi, T., Demura, S., & Noda, M. (2003). Examination of the factor structure of center of foot pressure movement and cross-validity. Journal of Physiology Anthropology and Applied Human Science 22: 265-272.
Krijnen, R. M. A., de Boer, E. M., Ader, H. J., & Bruynzeel, D. P. (1998). Diurnal volume changes of the lower legs in healthy males with a profession that requires standing. Skin Research and Technology 4(1): 18-23.
Kuo, A. Z., FE. (1993). Human standing posture: multi-joint movement strategies based on biomechanical constraints. Progress in Brain Research 97: 349-358.
Lacquaniti, F. (1992). Automatic control of limb movement and posture. Current Opinion in Neurobiology 2: 807-814.
Lacquaniti, F., Borghese, N., & Carrozzo, M. (1991). Transient reversal of the stretch reflex in human arm muscles. Journal of Neurophysiology 66: 939-954.
Lacquaniti, F., Carrozzo, M., & Borghese, N. A. (1993). Time-varying mechanical behavior of multijointed arm in man. Journal of Neurophysiology 69(5): 1443-1464.
Lafond, D., Duarte, M., & Prince, F. (2004). Comparison of three methods to estimate the center of mass during balance assessment. Journal of Biomechanics 37(9): 1421-1426.
Landry, S., Nigg, B., & Tecante, K. (2010). Standing in an unstable shoe increases postural sway and muscle activity of selected smaller extrinsic foot muscles. Gait and Posture 32(2): 215-219.
Latash, M., Aruin, A., Neyman, I., & Nicholas, J. (1995). Anticipatory postural adjustments during self-inflicted and predictable perturbations in Parkinson's disease. Journal of Neurology, Neurosurgery & Psychiatry 58(3): 326-334.
Le Clair, K., & Riach, C. (1996). Postural stability measures: what to measure and for how long. Clinical Biomechanics 11(3): 176-178.
Lehman, G., & McGill, S. (1999). The importance of normalization in the interpretation of surface electromyography: a proof principle. Journal of Manipulative and Physiological Therapeutics 22(7): 369-370.
Levin, M. F., Feldman, A. G., Milner, T. E., & Lamarre, Y. (1992). Reciprocal and coactivation commands for fast wrist movements. Experimental Brain Research 89: 669-677.
Macfarlane, G. J., Thomas, E., Papageorgiou, A. C., Croft, P. R., Jayson, M. I. V., & Silman, A. J. (1997). Employment and physical work activities as predictors of future low back pain. Spine 22(10): 1143-1149.
Massion, J., Ioffe, M., Schmitz, C., Viallet, F., & Gantcheva, R. (1999). Acquisition of anticipatory postural adjustments in bimanual load-lifting task: normal and pathological aspects. Experimental Brain Research 128(1-2): 229-235.
Maurer, C., & Peterka, R. J. (2005). A new interpretation of spontaneous sway measures based on a simple model of human postural control. Journal of Neurophysiology 93(1): 189-200.
Morasso, P. G., Baratto, L., Capra, R., & Spada, G. (1999). Internal models in the control of posture. Neural Networks 12(7–8): 1173-1180.
Murray, M., Seireg, A., & Sepic, S. (1975). Normal postural stability and steadiness: quantitative assessment. Journal of Bone Joint Surgery 57-A(4): 510-516.
Nardone, A., & Schieppati, M. (1988). Postural adjustments associated with voluntary contraction of the leg muscles in standing man. Experimental Brain Research 69(3): 469-480.
Nigg, B., Hintzen, S., & Ferber, R. (2006). Effect of an unstable shoe construction on lower extremity gait characteristics. Clinical Biomechanics 21(1): 82-88.

Norris, J. A., Marsh, A. P., Smith, I. J., Kohut, R. I., & Miller, M. E. (2005). Ability of static and statistical mechanics posturographic measures to distinguish between age and fall risk. Journal of Biomechanics 38(6): 1263-1272.

Nouillot, P., Bouisset, S., & Do, M. C. (1992). Do fast voluntary movements necessitate anticipatory postural adjustments even if equilibrium is unstable? Neuroscience Letters 147(1): 1-4.

Osu, R., Franklin, D. W., Kato, H., Gomi, H., Domen, K., Yoshioka, T., & Kawato, M. (2002). Short- and long-term changes in joint co-contraction associated with motor learning as revealed from surface EMG. Journal of Neurophysiology 88(2): 991-1004.

Pavol, M. J. (2005). Detecting and understanding differences in postural sway. Focus on "A new interpretation of spontaneous sway measures based on a simple model of human postural control". Journal of Neurophysiology 93(1): 20-21.

Pinsault, N., & Vuillerme, N. (2009). Test-retest reliability of centre of foot pressure measures to assess postural control during unperturbed stance. Medical Engineering & Physics 31: 276-286.

Prieto, T., Myklebust, J., Hoffmann, R., Lovett, E., & Myklebust, B. (1996). Measures of postural steadiness: differences between healthy young and elderly adults. Biomedical Engineering, IEEE Transactions on 43(9): 956-966.

Prochazka, A. (2010). Proprioceptive Feedback and Movement Regulation *Comprehensive Physiology*: John Wiley & Sons, Inc.

Ramstrand, N., Andersson, B., & Rusaw, D. (2008). Effects of an unstable shoe construction on standing balance in children with developmental disabilities: a pilot study. Prosthetics and Orthotics International 32(4): 422-433.

Ramstrand, N., Thuesen, A., Nielsen, D., & Rusaw, D. (2010). Effects of an unstable shoe construction on balance in women aged over 50 years. Clinical Biomechanics 25(5): 455-460.

Ribot-Ciscar, E., Hospod, V., Roll, J.-P., & Aimonetti, J.-M. (2009). Fusimotor drive may adjust muscle spindle feedback to task requirements in humans. Journal of Neurophysiology 101(2): 633-640.

Ribot-Ciscar, E., Rossi-Durand, C., & Roll, J.-P. (2000). Increased muscle spindle sensitivity to movement during reinforcement manoeuvres in relaxed human subjects. The Journal of Physiology 523(1): 271-282.

Rocchi, L., Chiari, L., & Cappello, A. (2004). Feature selection of stabilometric parameters based on principal component analysis. Medical & Biological Engineering & Computing 42: 71-79.

Romkes, J., Rudmann, C., & Brunner, R. (2006). Changes in gait when walking with Masai Barefoot Technique. Clinical Biomechanics 21(1): 75-81.

Ruhe, A., Fejer, R., & Walker, B. (2010). The test–retest reliability of centre of pressure measures in bipedal static task conditions – A systematic review of the literature. Gait & Posture 32(4): 436-445.

Runge, C., Shupert, C., Horak, F., & Zajac, F. (1999). Ankle and hip postural strategies defined by joint torques. Gait & Posture 10(2): 161-170.

Serres, S. J., & Milner, T. E. (1991). Wrist muscle activation patterns and stiffness associated with stable and unstable mechanical loads. Experimental Brain Research 86(2): 451-458.

Shumway-Cook, A., & Woolacott, M. (2007). *Motor control: translating research into clinical practice* (3 ed.): Lippincott Williams & Wilkins.

Simonson, E., & Weiser, P. C. (1976). *Psychological aspects and physiological correlates of work and fatigue*: Thomas.

Slijper, H., & Latash, M. L. (2004). The effects of muscle vibration on anticipatory postural adjustments. Brain Research 1015(1–2): 57-72.

Sousa, A. S. P., Macedo, R., Santos, R., & Tavares, J. M. R. S. (2013a). Influence of wearing an unstable shoe construction on compensatory control of posture. Human Movement Science 32(6): 1353-1364.

Sousa, A. S. P., Silva, A., Macedo, R., Santos, R., & Tavares, J. M. R. S. (2013b). Influence of long-term wearing of unstable shoes on compensatory control of posture: An electromyography-based analysis. Gait & Posture 39(1): 98-104.

Sousa, A. S. P., Silva, A., Macedo, R., Santos, R., & Tavares, J. M. R. S. (2014). Influence of long-term wearing of unstable shoes on compensatory control of posture: An electromyography-based analysis. Gait & Posture 39(1): 98-104.

Sousa, A. S. P., Tavares, J. M. R. S., Macedo, R., Rodrigues, A. M., & Santos, R. (2012). Influence of wearing an unstable shoe on thigh and leg muscle activity and venous response in upright standing. Applied Ergonomics 43(5): 933-939.

Tomei, F., Baccolo, T. P., Tomao, E., Palmi, S., & Rosati, M. V. (1999). Chronic venous disorders and occupation. American Journal of Industrial Medicine 36(6): 653-665.

Turbanski, S., Lohrer, H., Nauck, T., & Schmidtbleicher, D. (2011). Training effects of two different unstable shoe constructions on postural control in static and dynamic testing situations. Physical Therapy in Sport 12(2): 80-86.

van Wegen, E. E. H., van Emmerik, R. E. A., & Riccio, G. E. (2002). Postural orientation: aged related changes in variability and time-to-boundary. Human Movement Science 21: 61-84.

Winter, D. A. (1995a). Human balance and posture control during standing and walking. Gait & Posture 3: 193-214.

Winter, D. A. (1995b). Human balance and posture control during standing and walking. Gait & Posture 3(4): 193-214.

Winter, D. A., Patla, A., Prince, F., Ishac, M., & Gielo-Perczak, K. (1998). Stiffness control of balance in quiet standing. Journal of Neurophysiology 80(3): 1211-1221.

Yang, J. F., Winter, D. A., & Wells, R. P. (1990). Postural dynamics in standing human. Biological Cybernetics 62(4): 309-320.

Zatsiorsky, V. M., & Duarte, M. (1999). Instant equilibrium point and its migration in standing tasks: rambling and trembling components of the stabilogram. Motor Control 3(1): 28.

Zatsiorsky, V. M., & Duarte, M. (2000). Rambling and Trembling in quiet standing. Motor Control 4: 185-200.

Zok, M., Mazzà, C., & Cappozzo, A. (2008). Should the instructions issued to the subject in traditional static posturography be standardised? Medical Engineering & Physics 30(7): 913-916.

TABLE CAPTIONS

Table 1: Anatomical references to electrode placement. (Electrode locations were confirmed by palpation of the muscular belly with the subject in the test position, being the electrodes placed on the most prominent area.)

Table 2: Mean ± standard deviation values of stabilometry parameters obtained in the barefoot and in the unstable shoe conditions for the AP direction before (1) and after (2) 8 weeks of wearing unstable shoes (WUS) in the experimental group, and before (1) and after (2) the same period by the control group.

Table 3: Mean ± standard deviation values of stabilometry parameters obtained in the barefoot and in the unstable shoe conditions for the ML direction and area before (1) and after (2) 8 weeks of wearing unstable shoes (WUS) in the experimental group, and before (1) and after (2) the same period by the control group.

Table 4: Mean ± standard deviation values of total agonist and antagonist activity, antagonist co-activation (*C*) and reciprocal activation (*R*) at thigh, leg and muscle group levels obtained in the barefoot and in the unstable shoe conditions before (1) and after (2) 8 weeks of wearing unstable shoes (WUS) in the experimental group, and before (1) and after (2) the same period by the control group.

FIGURE CAPTIONS

Figure 1: Unstable shoe model used in this study: The MBT shoe has a rounded sole in the antero-posterior direction, thus providing an unstable base.

Figure 2: Main effects of prolonged wearing unstable shoes on postural control variables. (Black symbols represent values obtained in unstable shoe condition while grey symbols represent values obtained in barefoot condition. Only the results related to interactions and main effects statistically significant are represented.)

Figure 3: Effects of prolonged wearing of unstable shoes on upright standing CoP displacement related variables while wearing unstable shoes (A); differences obtained between measures performed in unstable shoe and barefoot conditions in both groups before and after the 8 weeks period (B).

TABLES

TABLE 1

Muscle	Electrode placement
TA	1/3 on the line between the tip of the tibia and the tip of the medial malleolus
GM	Most prominent bulge of the muscle
RF	1/2 on the line from the anterior spina iliaca to the superior border of the patella
BF	1/2 on the line from the ischial tuberosity and the lateral epicondyle of the tibia
RA	3 cm to the right of the umbilicus
ES	2 fingers width lateral from the spinous process of L1
Ground electrode	Patella centre

TABLE 2

Parameters				Experimental group		Control group	
				Barefoot condition	**Unstable shoe condition**	**Barefoot condition**	**Unstable shoe condition**
Anteroposterior direction	*P-P (mm)*	CoP	**1**	5.75±1.23	6.19±1.91	6.24±1.16	6.21±1.25
			2	5.57±1.23	5.49±1.16	5.67±0.87	5.49±0.80
		RM	**1**	5.53±1.16	5.59±1.10	5.96±1.05	5.98±0.76
			2	5.52±1.17	5.40±1.51	5.52±0.85	5.59±0.76
		TR	**1**	1.71±0.39	1.75±0.34	1.89±0.38	1.73±0.38
			2	1.69±0.54	2.26±1.50	1.71±0.21	1.78±0.28
	RMS (mm)	CoP	**1**	2.98±0.18	5.02±0.48	3.02±0.31	5.88±0.51
			2	3.09±0.77	4.23±0.76	2.75±0.50	4.63±1.00
		RM	**1**	2.84±1.55	4.81±1.72	2.63±0.95	5.56±2.02
			2	3.32±1.47	2.85±1.79	2.68±2.32	6.78±0.65
		TR	**1**	0.50±0.17	1.75±1.40	0.58±0.28	1.64±1.63
			2	1.57±0.80	1.65±1.84	0.63±0.32	1.89±1.04
	MV ($mm.s^{-1}$)	CoP	**1**	0.24±0.056	0.25±0.050	0.27±0.050	0.28±0.055
			2	0.16±0.035	0.16±0.034	0.24±0.038	0.25±0.038
		RM	**1**	0.06±0.012	0.05±0.011	0.06±0.012	0.06±0.013
			2	0.05±0.017	0.06±0.014	0.06±0.007	0.05±0.009
		TR	**1**	0.18±0.039	0.18±0.037	0.20±0.035	0.19±0.025
			2	0.18±0.039	0.21±0.070	0.18±0.028	0.19±0.025

TABLE 3

Parameters				Experimental group		Control group	
				Barefoot condition	**Unstable shoe condition**	**Barefoot condition**	**Unstable shoe condition**
Medial lateral direction	*P-P (mm)*	CoP	**1**	2.87±0.626	2.83±0.622	3.09±0.584	3.07±0.569
			2	2.78±0.663	2.91±0.639	3.01±0.359	2.97±0.320
		RM	**1**	2.87±0.625	2.91±0.608	3.06±0.539	3.16±0.570
			2	3.06±0.917	3.10±1.51	3.06±0.351	3.10±0.313
		TR	**1**	2.86±0.596	1.00±0.217	1.18±0.230	1.09±0.220
			2	1.19±0.696	1.24±0.399	1.18±0.156	1.08±0.124
	RMS (mm)	CoP	**1**	1.99±1.017	3.46±1.890	1.71±1.125	2.95±0.907
			2	1.92±1.135	2.68±1.211	1.63±0.854	3.88±0.854
		RM	**1**	1.57±0.800	1.65±1.840	1.29±0.736	2.18±0.602
			2	2.32±1.012	2.77±2.607	1.66±1.088	3.32±2.248
		TR	**1**	0.50±0.17	1.75±1.40	0.36±0.164	0.89±0.470
			2	0.77±0.530	0.97±1.357	0.51±0.456	1.68±1.993
	MV ($mm.s^{-1}$)	CoP	**1**	0.16±0.056	0.16±0.035	0.17±0.034	0.17±0.033
			2	0.16±0.035	0.16±0.034	0.17±0.018	0.17±0.017
		RM	**1**	0.04±0.008	0.03±0.007	0.04±0.008	0.04±0.007
			2	0.04±0.023	0.04±0.008	0.04±0.005	0.04±0.004
		TR	**1**	0.10±0.039	0.10±0.020	0.10±0.018	0.11±0.019
			2	0.10±0.030	0.13±0.081	0.10±0.012	0.10±0.010
Area (mm^2)		CoP	**1**	170±145	361±80.9	142±37.6	334±50.3
			2	124±50.6	214±54.2	160±116	254±63.7
		RM	**1**	125±30.8	466±368	106±26.5	562±282
			2	110±190	452±279	88.7±23.8	363±206
		TR	**1**	9.31±6.31	81.9±57.8	13.1±12.0	79.9±76.9
			2	22.7±18.9	141±187	15.7±10.2	113±94.9

TABLE 4

Parameters			Experimental group		Control group	
			Barefoot condition	**Unstable shoe condition**	**Barefoot condition**	**Unstable shoe condition**
Thigh level (%)	*C*	**1**	30.20±14.75	18.79±8.16	28.20±14.79	23.30±13.80
		2	28.50±11.46	24.02±16.68	24.90±16.01	17.20±11.41
	R	**1**	5.70±3.891	11.71±8.072	6.33±4.468	9.76±7.052
		2	5.38±3.053	8.67±5.240	6.51±3.660	12.61±7.931
Leg level (%)	*C*	**1**	31.00±14.23	20.60±9.18	27.40±13.02	25.10±10.37
		2	29.00±11.40	24.60±13.05	28.50±14.77	25.30±12.03
	R	**1**	2.54±2.927	8.81±7.444	4.29±3.780	6.61±4.687
		2	3.21±2.145	5.20±3.868	3.88±1.862	6.47±5.819
Muscle group level (%)	*C*	**1**	42.30±14.53	35.40±13.00	38.40±14.65	35.40±12.90
		2	39.50±9.28	34.20±15.50	34.70±16.55	27.90±14.04
	R	**1**	3.83±2.967	9.85±7.513	4.41±3.726	13.68±5.426
		2	3.27±2.523	6.71±5.096	5.78±4.270	10.60±7.817
Agonist muscle activity (%)		**1**	8.58±4.397	14.72±8.543	9.61±6.752	13.36±6.282
		2	8.67±3.755	11.52±5.480	9.19±3.351	14.13±6.930
Antagonist muscle activity (%)		**1**	6.36±4.168	6.23±3.928	6.73±7.26	7.00±3.505
		2	5.72±3.154	5.73±3.335	5.39±3.859	5.96±2.775

FIGURES

Figure 1

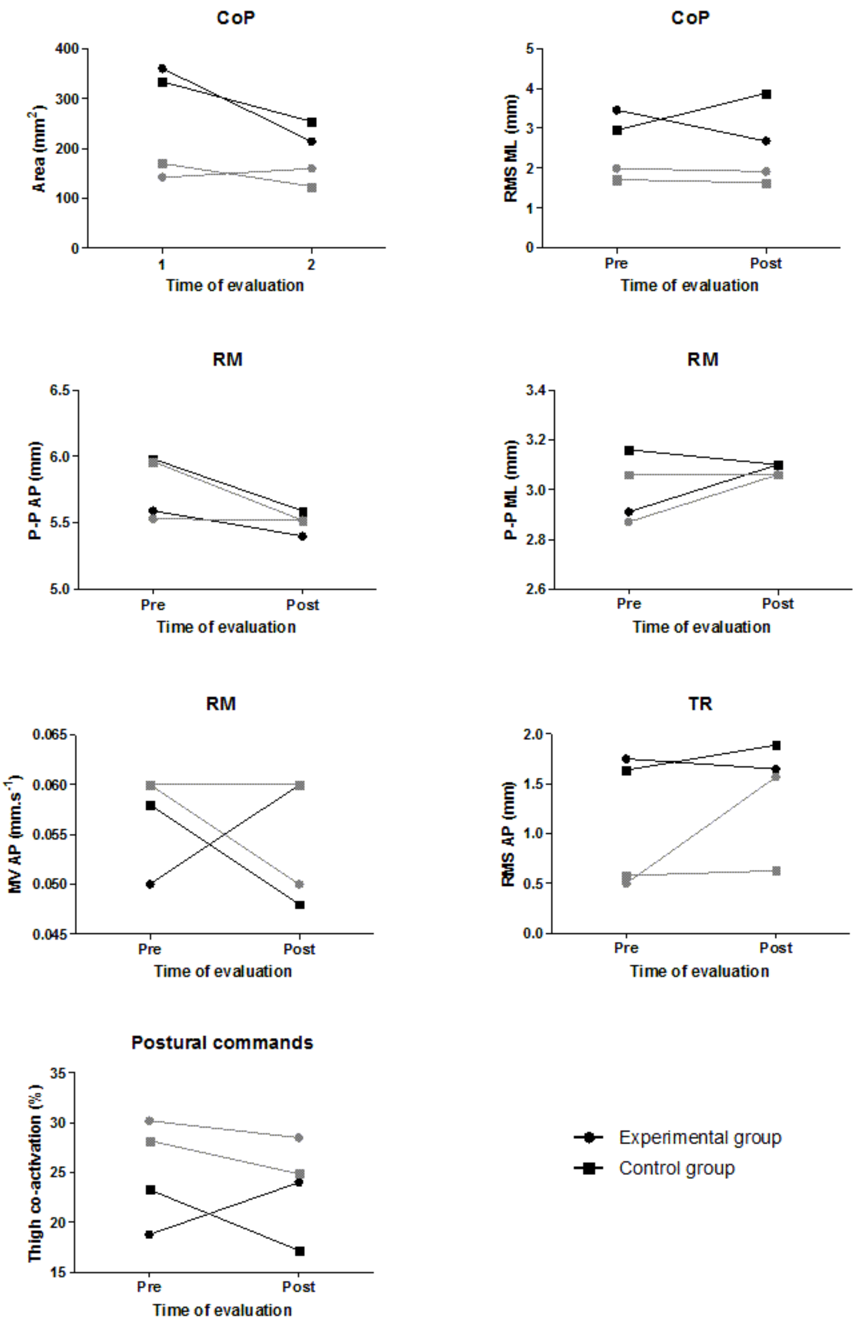
CoP
Area (mm2)
400
300
200
100
0
1
2
Time of evaluation
CoP
RMS ML (mm)
5
4
3
2
1
0
Pre
Post
Time of evaluation
RM
P-P AP (mm)
6.5
6.0
5.5
5.0
Pre
Post
Time of evaluation
RM
P-P ML (mm)
3.4
3.2
3.0
2.8
2.6
Pre
Post
Time of evaluation
RM
MV AP (mm.s-1)
0.065
0.060
0.055
0.050
0.045
Pre
Post
Time of evaluation
TR
RMS AP (mm)
2.0
1.5
1.0
0.5
0.0
Pre
Post
Time of evaluation
Postural commands
Thigh co-activation (%)
35
30
25
20
15
Pre
Post
Time of evaluation
Experimental group
Control group

Figure 2

A

8 weeks of unstable shoe wearing in prolonged standing activities

↓ CoP *area* ↓ CoP *RMS* ML ↓ RM *P-P* AP ↑ RM *MV* AP ↑ RM *P-P* ML ↓ TR *RMS* AP ↑ Thigh antagonist co-activation

Wearing unstable shoe in upright standing

B

Pre experimental group			Post experimental group		
Unstable shoe condition		**Barefoot condition**	**Unstable shoe condition**		**Barefoot condition**
CoP *MV* AP	<	CoP *MV* AP	CoP *MV* AP	=	CoP *MV* AP
CoP *RMS* AP	>	CoP *RMS* AP	CoP *RMS* AP	>	CoP *RMS* AP
CoP *RMS* ML	>	CoP *RMS* ML	CoP *RMS* ML	>	CoP *RMS* ML
CoP *area*	>	CoP *area*	CoP *area*	>	CoP *area*
RM *P-P* AP	>	RM *P-P* AP	RM *P-P* AP	<	RM *P-P* AP
RM *P-P* ML	>	RM *P-P* ML	RM *P-P* ML	>	RM *P-P* ML
RM *RMS* AP	>	RM *RMS* AP	RM *RMS* AP	<	RM *RMS* AP
RM *RMS* ML	>	RM *RMS* ML	RM *RMS* ML	>	RM *RMS* ML
RM *MV* AP	<	RM *MV* AP	RM *MV* AP	>	RM *MV* AP
RM *area*	>	RM *area*	RM *area*	>	RM *area*
TR *RMS* AP	>	TR *RMS* AP	TR *RMS* AP	>	TR *RMS* AP
TR *RMS* ML	>	TR *RMS* ML	TR *RMS* ML	>	TR *RMS* ML
TR *area*	>	TR *area*	TR *area*	>	TR *area*
Thigh C	<	Thigh C	Thigh C	<	Thigh C
Thigh R	>	Thigh R	Thigh R	>	Thigh R
Leg C	<	Leg C	Leg C	<	Leg C
Leg R	>	Leg R	Leg R	>	Leg R
Global C	<	Global C	Global C	<	Global C
Total agonist activity	>	Total agonist activity	Total agonist activity	>	Total agonist activity

Control group presented the same results in both evaluations than the obtained in experimental group in the first evaluation (pre experimental group)

Figure 3