European Journal of Applied Physiology (2019) 119:841–846
https://doi.org/10.1007/s00421-019-04073-1

ORIGINAL ARTICLE

# Moderate treadmill run worsened static but not dynamic postural stability of healthy individuals

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Received: 23 July 2018 / Accepted: 4 January 2019 / Published online: 17 January 2019


## Abstract

**Purpose** Running has been demonstrated to be one of the most relevant exercise in altering static postural stability, while limiting attention has been paid to its effects on dynamic postural stability. The aim of the present study was to investigate if 25 min of moderate running on a treadmill altered static and dynamic postural stability in healthy subjects.

**Methods** Eight female and six male participants (age 27.7 ± 8.3 years, height 170.9 ± 12.2 cm, weight 63.9 ± 15.6 kg) took part in the study. Before and after the run static postural stability was evaluated on a stabilometric platform (10 trials of 30 s each), while dynamic postural stability was assessed on an instrumented unstable platform (2 trials of 30 s each).

**Results** After the treadmill run the area of the confident ellipse (from 67.97 ± 34.56 to 93.08 ± 50.00 $mm^2$), sway path velocity (from 6.92 ± 1.85 to 7.83 ± 2.57 mm/s), sway area velocity (from 6.88 ± 3.27 to 9.54 ± 5.36 $mm^2/s$), and medio-lateral maximal oscillation (from 9.48 ± 2.80 to 11.44 ± 3.64 mm) significantly increased. Stabilogram diffusion analysis showed no statistically significant difference in the diffusion coefficients, both short and long term. No statistically significant differences were reported in all the parameters of the dynamic postural stability test.

**Conclusion** The contrasting results of the static and dynamic postural stability tests raise the question of which are the more selective tests to assess the acute effect of physical exercise on postural stability among healthy individuals. The proper interaction of both static and dynamic postural evaluations could represent the next challenge in the postural stability assessment.

**Keywords** Balance assessment · Postural stability · CoP · Running

### Abbreviations

| | |
|---|---|
| AP | Anterior–posterior |
| CoG | Centre of gravity |
| CoP | Centre of pressure |
| $Dfr^2l$ | Long-term diffusion coefficient combining *x*- and *y*-axes |
| $Dfr^2s$ | Short-term diffusion coefficient combining *x*- and *y*-axes |
| *Dfxl* | Long-term diffusion coefficient along the *x*-axis |
| *Dfxs* | Short-term diffusion coefficient along the *x*-axis |
| *Dfyl* | Long-term diffusion coefficient along the *y*-axis |
| *Dfys* | Short-term diffusion coefficient along the *y*-axis |
| FB | Full balance |
| FiB | Fine balance |
| GB | Gross balance |
| ML | Medio-lateral |
| SDA | Stabilogram diffusion analysis |

Communicated by Lori Ann Vallis.

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## Introduction

Visual, vestibular, and proprioceptive systems interact together to control human postural stability. To maintain postural stability, the three systems continuously send information to the central nervous system which, after processing them, produce response messages. These are sent to the skeletal muscle system with the aim of maintaining the centre of gravity (CoG) within the support base. The efficiency of these interactions is fundamental in maintaining postural stability, both in static and dynamic conditions.

The employment of force platforms for the measurement of the centre of pressure (CoP) displacement has been demonstrated as a reliable method to assess the static upright postural stability (Baldini et al. 2013). The most common parameters reported are the CoP sway length or velocity, the CoP sway area (based upon sequential locations of the CoP itself), and the CoP displacement along the anterior–posterior and medio-lateral axis (Baldini et al. 2013). In addition to these stabilometric parameters, CoP trajectory can be modeled as a fractional Brownian motion by means of the stabilogram diffusion analysis (SDA) which reveals two different neuromuscular control mechanisms: open-loop schemes and closed-loop schemes, over short-term, and long-term intervals, respectively (Collins and De Luca 1993).

Total body and local physical exercises have shown to deteriorate the effectiveness of sensory inputs and motor outputs due to the onset of general or local fatigue (Paillard 2012). Indeed, it has been demonstrated that muscular fatigue of the ankle plantar-flexors increased the COP mean velocity along both axis as well as the frequency of the body sway (Corbeil et al. 2003). Similarly, it has been reported that postural sway is affected by plantar-flexors fatigue mainly relative to the sagittal plane (Gimmon et al. 2011). It seems likely that fatigue negatively affects the proprioceptive feedback (Corbeil et al. 2003; Gimmon et al. 2011). Moreover, some exercises (e.g., running) affect the sensory receptors more than others (e.g., cycling) because of a great amount of mechanical constraints (Paillard 2012). Furthermore, running disturbs visual contribution to static postural stability more than walking (Derave et al. 2002). To this extent, it has been hypothesized that in treadmill running visual system misses the optical flow in the forward direction, thus failing in visuomotor calibration. The result is an alteration of the static postural stability after treadmill running (Derave et al. 2002). Again, it has been reported that 25 km run on a generally flat route decreased postural stability more than an ergocycle exercise of identical duration because of a higher stimulation of vestibular and visual inputs consequent to a marked head shaking (Lepers et al. 1997). Similarly, it has been shown that prolonged running at a sub-maximal intensity during a mountain ultra marathon decreased the static postural stability (Degache et al. 2014). Running intensity plays an important role as well, since postural impairment has been shown to be less affected when the exercise was performed below the estimated anaerobic threshold (Nardone et al. 1997). One possible explanation could be linked to the negative role of hyperventilation on static postural stability (Zemková and Hamar 2014).

Recent literature reported that standard posturography alone may fail to discriminate postural stability, thus underlying the importance of introducing dynamic tests to give more accurate information on the postural control (Petró et al. 2017). On this point, to the best of our knowledge, only one study evaluated the alteration of both static and dynamic postural stability (Marcolin et al. 2016). In this work, the authors assessed static and dynamic postural stability of 12 athletes before and after a mountain ultra marathon of 80 km. Results showed an overall worsening of the static postural stability, while dynamic postural stability remained substantially unchanged. However, it has to be taken into account that in this ecological study, results could have been influenced by variables that could not be standardized in a race. This is the case, for instance, of the intensity and the duration of the running as well as the level of hydratation.

Therefore, the aim of the present study was to deepen the acute alterations of both static and dynamic postural stability in a more controlled setting, thus before and after 25 min of moderate running on a treadmill. Based on the previous investigations, our hypothesis was that static and dynamic postural stability remained unchanged after running, due to the relative short time of running and the moderate level of intensity.

## Methods

### Participants

A total of 14 participants (8 female and 6 male; age 27.7 ± 8.3 years, height 170.9 ± 12.2 cm, weight 63.9 ± 15.6 kg) were enrolled in the study. All participants were familiar with treadmill running and regularly practiced running twice per week for at least 5 km for each run. Exclusion criteria were the presence of musculoskeletal lower limb injuries as well as ongoing vestibular pathologies and non corrected visual refractive errors (e.g., nearsightedness, farsightedness, astigmatism, and presbyopia). A detailed description of the experimental protocol was given to each participant who signed a written informed consent prior to testing. The research was approved by the ethical committee of the Department of Biomedical Sciences, University of Padova.

### Procedures

Participants accessed the laboratory twice. In the first visit each participant underwent a 10 min familiarization session on an unstable platform (see below). After 1 week the participants attended the testing session. First, they were asked to perform the static postural stability test standing on a dynamometric platform recording at a sampling rate of 100 Hz (RGMD S.p.a., Genova, Italy). The platform allowed to collect the trajectory of the CoP in the anterior–posterior (AP) and medio-lateral (ML) directions. Briefly, each participant had to stand on the platform without wearing shoes and with the heels aligned and forming an angle of 30° between the feet as recommended by the International society of posturography guidelines (Kapteyn et al. 1983). This posture was reached by means of specific lines drawn on the surface of the platform. Legs had to stay straight and arms had to remain positioned along their sides. A target was placed on a wall at 1 m of distance, centrally with respect to the platform width. Participants had to gaze the target for the whole duration of each trial (30 s). Each participant had to perform ten trials with a rest of 20 s between the trials. Participants were not allowed to step down from the plate during rest time. After 2 min rest from the end of the tenth trial, the dynamic postural stability test took place on an instrumented unstable platform which rotated along a single axis providing medio-lateral perturbations. An MTw™ 3D inertial sensor (dimensions 34.5 mm x 57.8 mm x 14.5 mm; weight 27 g) with MEMS technology (Xsens Technologies B.V., Enschede, The Netherlands) was placed over the plate as described previously (Marcolin et al. 2016), allowing to collect the right and left oscillations of the plate. The inertial sensor measured 0° when the table was parallel to the ground. Positive angular values corresponded to a clockwise rotation, while negative angular values to a counter clockwise rotation. Participants were asked to stand on that plate with their sagittal axis parallel to the rotational axis of the unstable plate. Subsequently, they were instructed to maintain the plate parallel to the floor as much as possible without moving their feet for the whole duration of the trial. Each participant performed two trials of 30 s wearing running shoes with a 20 s rest between the trials.

After static and dynamic postural stability tests participants ran on a motorized treadmill (Artis® Run, Technogym, Cesena, Italy) at a constant speed for 25 min. A moderated treadmill velocity was defined by each participant who indicated a level of exertion between 5 and 6 according to the Borg category-ratio scale (Borg 1982). At the end of the run, after 2 min rest, static and dynamic postural balance tests were repeated following the same procedures adopted before the session on the treadmill.

### Data analysis

The following parameters relative to the static postural stability test on the force platform were calculated from the CoP trajectory: (1) area of the confidence ellipse ($mm^2$); (2) sway path velocity (mm/s) (mean velocity of the CoP during each 30 s trial); (3) sway area velocity ($mm^2$/s) (area swept per time unit); and (4) maximal oscillation (mm) in the anterior-posterior (AP) and medio-lateral (ML) direction. For each participant, these parameters were averaged among the ten trials. The stabilogram diffusion analysis (SDA) allowed to calculate mean square CoP displacement as a function of time interval $\Delta t$ (ranged from 0.01 to 10 s with steps of 0.01) that represented the stabilogram diffusion plot (Collins and De Luca 1993). The short- and long-term diffusion coefficients along the medio-lateral ($x$) (*Dfxs* and *Dfxl*) and anterior–posterior ($y$) (*Dfys* and *Dfyl*) axis or considering the combination of the two ($Dfr^2s$ and $Dfr^2l$) were calculated as half the slopes of two linear regressions referred to the stabilogram diffusion plot (Marcolin et al. 2016). The CoP trajectories were processed with MATLAB (The MathWorks, Inc., MA, USA).

In the dynamic stability test, the MTw™ 3D inertial sensor data was employed to determine 3 parameters (Marcolin et al. 2016): (1) overall integral of the curve (Full Balance, FB); (2) time participants kept the table between + 5° and − 5° (Fine Balance, FiB); and (3) time participants kept the table between + 10° and − 10° (Gross Balance, GB). Parameters were calculated for each of the two 30 s trials and then averaged.

### Statistical analysis

A two-tailed paired $t$ test was employed to compare dependent variables before and after the 25 min of running on the treadmill. The significance level was set at $p \leq .05$. The analysis was performed by means of GraphPad Prism version 4.00 for Windows (GraphPad Software, San Diego California USA), while effect size was calculated with G*Power 3.1.5 (Faul et al. 2007). In particular, the effect size calculation followed Cohen's guidelines (Cohen 1988) and was interpreted as follow 0.00–0.19: trivial; 0.20–0.59: small; 0.60–1.19: moderate; 1.20–1.99: large and > 2.00: very large (Hopkins et al. 2009).

## Results

### Static postural stability test

The area of the confident ellipse significantly increased after the treadmill run ($p < .05$; $t = 2.457$; $df = 13$; effect size 0.57). In addition, sway path velocity ($p < .05$; $t = 2.546$; $df = 13$; effect size 0.40), sway area velocity ($p < .05$; $t = 2.305$; $df = 13$; effect size 0.50), and ML maximal oscillation ($p < .05$; $t = 2.594$; $df = 13$; effect size 0.59) increased after the run. AP maximal oscillation showed no statistically significant differences. These data are summarized in Table 1.

The SDA results are reported in Fig. 1. The short- and long-term diffusion coefficients along $x$- (*Dfxs* and *Dfxl*) and $y$- (*Dfys* and *Dfyl*) axes or considering the combination of the

**Table 1** Results of the static postural stability test on the stabilometric platform

| | Pre | Post |
|---|---|---|
| Sway path velocity (mm/s) | 6.92 ± 1.85 | 7.83 ± 2.57* |
| Sway area velocity ($mm^2$/s) | 6.88 ± 3.27 | 9.54 ± 5.36* |
| Confident ellipse area ($mm^2$) | 67.97 ± 34.56 | 93.08 ± 50.00* |
| AP oscillations (mm) | 14.37 ± 2.79 | 15.88 ± 3.52 |
| ML oscillations (mm) | 9.48 ± 2.80 | 11.44 ± 3.64* |

*$p < .05$

two ($Dfr^2s$ and $Dfr^2l$) showed higher values after the 25 min run, but these differences were not statistically significant.

### Dynamic postural stability test

Dynamic postural stability results are reported in Table 2. Data underlined no statistically significant differences for all the three parameters calculated in the comparison before and after the treadmill running. However, it was observed a tendency towards improvement for both FB, FiB, and GB (5.8%, 13.0%, and 7.7%, respectively).

**Table 2** Dynamic postural stability results on the instrumented unstable platform

| | Pre | Post |
|---|---|---|
| Full balance (FB) | 256.70 ± 43.60 | 241.90 ± 50.20 |
| Fine balance (FiB) (s) | 8.47 ± 3.47 | 9.58 ± 4.45 |
| Gross balance (GB) (s) | 16.28 ± 4.08 | 17.54 ± 4.40 |

## Discussion

The aim of the present study was to investigate the effect of a moderate treadmill running on static and dynamic postural stability parameters. Results of the static postural stability test highlighted an overall worsening of the performance

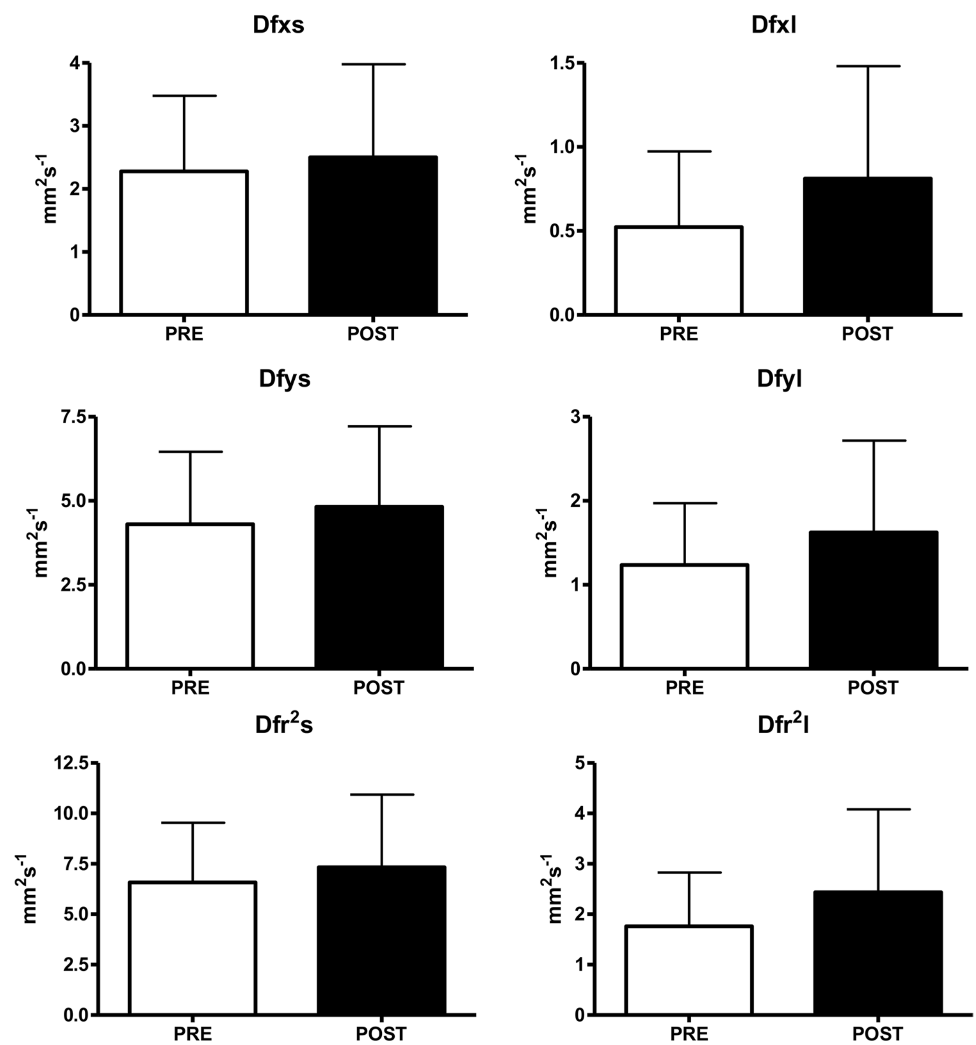


**Fig. 1** Stabilogram diffusion analysis (SDA) results relative to the static postural stability test on the stabilometric platform

with respect to the area of the confidence ellipse, the sway path velocity, the sway area velocity, and the maximal oscillation in the ML direction. This impairment is in agreement with previous investigations, where static balance was investigated after prolonged running (Nardone et al. 1997) or walking (Nardone et al. 1998) at moderate intensities. The explanation of the worsening reported can be due to a profound stimulation of muscle spindles, joint receptors, and cutaneous mechanoreceptors on the feet sole which leaded to a deterioration of their sensitivity (Zemková and Hamar 2014). An additional explanation supporting the worsening could be linked to the fact that running tends to disturb postural stability because of the vertical displacement and acceleration pattern of the head, which alter vestibular and visual information centres (Derave et al. 2002). Nevertheless, this second explanation seems to be less plausible than the first one. In fact, although the otolithic organs have a low sensitive threshold to linear acceleration equivalent to 5 $m/s^2$ (Lepers et al. 1997) and previous investigations showed head vertical accelerations of 10.52 $m/s^2$ (Derave et al. 2002), Charles and colleagues did not found any significant change in the visually perceived eye level after 20.5 km over-ground running (Charles et al. 2002). Indeed, visually perceived eye level is the task to indirectly assess the otholitic sensitivity when motionless (Zemková and Hamar 2014). Conversely, the moderate rate of perceived exertion score required, together with the short duration of the treadmill exercise, let us exclude that the static postural stability impairment detected was due to hyperventilation (Jeong 1991; Sakellari et al. 1997; Zemková and Hamar 2014). Therefore, according to the previous studies (Zemková and Hamar 2014), we can assume that the main responsible for the greater increase of static postural alterations after running is the profound proprioceptive stimulation. SDA demonstrated that the postural control system does not employ only closed-loop feedback mechanisms consequent to the afferent signals from visual, vestibular, and somatosensory systems. In fact, SDA indicates the presence of open-loop control schemes, the output of which may be considered as descending signals to different postural muscles (Collins and De Luca 1993). These signals are left unchecked by the postural control system (open-loop control mechanisms) until a threshold is reached, thus indicating the intervention of the closed-loop control mechanisms (Collins and De Luca 1993). Moreover, in SDA, the diffusion coefficients represent an objective quantification of the postural instability. In our study, all the diffusion coefficients increased, indicating a less tightly regulated or a more random control system for both open and closed loop control mechanisms (Collins and De Luca 1993). Although no statistical difference was reached, it is interesting to note that the major increase was recorded for the long-term diffusion coefficients (55% for *Dfxl*, 31% for *Dfyl*, 38% for $Dfr^2l$) with respect to the short term ones (10% for *Dfxs*, 12% for *Dfys*, 11% for $Dfr^2s$). This means that 25 min of moderate running worsened the efficacy of the control system which calls into play corrective feedback mechanisms. Again, the profound proprioceptive stimulation (muscle spindles and Golgi tendon organs) during running would indicate a decrease in sensitivity of the postural control loop thus being the cause of the less effective control when closed loop control dominates behaviour. This is similar to what has been observed on postural control after plantar flexor muscle fatigue (Gimmon et al. 2011). Moreover, this more pronounced increase of the long-term diffusion coefficients could reflect a higher sway amplitude in the long-term region which has been suggested to decrease the closed-loop effectiveness in the postural sway control (Gimmon et al. 2011).

Although dynamic postural stability results highlighted a slight improvement of the performance after the treadmill run, no statistically significant difference was detected. However, this trend is comparable to those reported in a previous work on mountain ultra marathon runners (Marcolin et al. 2016). The small changes can be explained by a greater contribution of cognitive resources called into play to make up for the increased alteration of the other control systems (Paillard 2012). A second explanation, complementary to the first, is that an increase in the vigilance level could have improved the effectiveness of the descending drive for the postural muscle motor neurons activation and the integration of afferent information (Nardone et al. 1998). Finally, it is interesting to note that the acute effect on dynamic postural stability seems not to be related neither to the duration of the running (several hours in a mountain ultra marathon against 25 min in the present work) nor to the level of fatigue (extreme in a mountain ultra marathon while moderate in the present work).

## Conclusion

The dissimilar trends of static (worsening) and dynamic (not statistically significant improvement) postural stability parameters recorded in our study represent challenging information that should be considered when evaluating the effect of specific physical exercises on the postural control in different populations (e.g., healthy adults, athletes, frail elderly, etc). As such, drawing any conclusion from our study on the overall postural stability if only one of the two conditions (static and dynamic) took place, would have been incomplete. Therefore, since the relative contribute of static and dynamic tests in the assessment of postural stability is still debated, the question on which are the more suitable tests to underline the acute effect of running and, more in general, of specific physical exercises on postural stability deserves further investigations. Our findings suggest that a combination of static and dynamic test should be considered in the postural stability assessment. However, we studied a group of young healthy participants, and thus a limitation of our study is that results might not necessarily apply to other populations. Moreover, although all participants were familiar with treadmill running, they preferably run outdoor and could not exactly quantify the time they usually spent on the treadmill. Indeed, a different amount of this time among participants could have somehow influenced the postural stability results and it has to be acknowledged as a limitation of the study. Nevertheless, our findings could motivate further studies among elderly people on the assessment of acute postural stability alteration after aerobic exercises to support the prescription of the less risky exercises for this population. Again, it seems conceivable consider as fall-risk indicators not only the CoP related parameters derived from static postural tests (Bigelow and Berme 2011; Zanotto et al. 2017), but also their interactions with parameters referred to dynamic postural tests.

**Author contributions** GM, FAP, and AP conceived and designed the experiments. GM, EB performed the experiments. GM, EB, MC, and NP analyzed the data. NP and AP contributed materials. GM, FAP, and MC wrote the paper. All authors approved the final version of the manuscript.

## Compliance with ethical standards

**Conflict of interest** The authors declare no conflict of interest.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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