Original article

Effects of different unstable supports on EMG activity and balance

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Running title: Equilibrium with unstable supports

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Abstract

This study analysed the equilibrium strategies and EMG activity during postural equilibrium in four different unstable surfaces. Thirteen team sport males were tested on a FLAT surface and on three different wobble boards (JAKOBS® with easy multidirectional displacements, FREEMAN with strong multidirectional displacements and LATERAL with unidirectional lateral displacements). They had to maintain single-limb stance during 5 s for each condition. The right foot centre of pressure (COP) position and its variability with concomitant EMG activity of soleus (SOL), tibialis anterior (TA), peroneus longus (PL) and extensor digitorum longus (EXD) muscles were recorded. Subjects maintained balance by making seesaw rotations. LATERAL and FREEMAN boards demonstrated significantly greater COP variability than JAKOBS® and FLAT in both anteroposterior and mediolateral directions. Similarly, PL, EXD, and TA muscles EMG activity were significantly greater using the LATERAL board, and in some cases using FREEMAN as compared with JAKOBS® and FLAT. These results highlighted new knowledge about central nervous system organization whilst keeping equilibrium with a predominant anteroposterior control.

Keywords: Proprioception; Equilibrium; Centre of pressure; Ankle.

1. Introduction

Humans, in contrast with other mammals, sustain bipedal stance which requires several systems to maintain equilibrium. Orientation information is derived from three independent sensory sources: somatosensory, vestibular and visual inputs. Proprioception is a component of the somatosensory system which has the ability to give afferent information on segments' position and movement from various receptors located, for example, in joints, muscles and tendons [19]. It plays an important role in the elaboration of postural reference [12, 26] and to maintain equilibrium.

In upright stable position, stabilisation mechanisms tend to counteract perturbations by reducing the horizontal distance between the centre of mass (CoM, point within the body where vertical forces may be applied) and the centre of pressure (CoP, point location of the resultant ground reaction force) [34]. In unstable conditions, humans rather maintain equilibrium by mechanisms located within the ankle joint. Indeed, the support instability alters the relation between sensory inputs and motor actions [16]. Balance is therefore maintained by means of displacements of the foot contact point on the unstable support in parallel with a body CoM shift [15]. More particularly, stabilization mechanisms are achieved through an active intervention of the central nervous system and a modulation of ankle joint angle and muscle stiffness [20, 21].

Exercising under unstable conditions is a strategy used to reduce equilibrium loss and falls in elderly peoples [25]. In addition, numerous studies have demonstrated balance exercises benefits in rehabilitation programs and for reducing injury risk rate [3, 11, 14], for example, for anterior cruciate ligament injuries [3, 27, 29] as well as ankle sprains [32]. Because injuries are related to ankle functional instability [6, 7], balance exercises may be efficient by improving motor control and strengthening stabilisation muscles [14, 24]. As a consequence, balance training is now a major component of sport training and is gaining recognition as an important part of the pre-season injury prevention programs for many athletes [10].

Balance training using unstable surfaces is most commonly performed on wobble boards. They are generally composed of a board with hemi-spherical or hemi-cylindrical bases that allow multi- or uni-planar movements, respectively. However, little data are available concerning their specific effects and detailed description of the different unstable supports are generally lacking. For instance, we know that balance platforms produce greater ankle muscular activity in comparison with flat surfaces or trampolines [1]. But, when considering different unstable supports, the neuromuscular solicitation of lower-limb muscles and the postural control is still unknown. Therefore, the goal of the present study was to investigate the effects of different unstable supports on electromyographic (EMG) activity of ankle muscles. We hypothesised that multi-directional unstable supports cause greater perturbations and consequently higher muscular activation than flat and uni-directional boards. Results should provide knowledge to better understand equilibrium on unstable supports and suggestions for adapting balance training to improve motor performance and reducing injury risk rate.

2. Material and methods

2.1 Subjects

Thirteen volunteer males (football, rugby and handball regional players) were recruited from a Sport Science Department. Their mean (± SD) age, height and body mass were 22.7 ± 2.6 yrs, 179.8 ± 5.9 cm and 78.9 ± 6.0 kg. Subjects had no history of musculoskeletal pathology, neuro-degenerative or infectious disease, chronic ankle instability, recent ankle sprain, vestibular pathology and visual impairment. To avoid any neuromuscular fatigue, subjects were requested not to perform any intensive training for at least 24 hours before the experiment. Before the onset of the study, all signed an informed consent form. The study was conducted according to the Declaration of Helsinki and approval was obtained from the local committee on human research.

2.2 Experimental procedure

All tests were performed in a standard position: (i) upright standing on the right foot, without shoes and with an extended leg, (ii) the left leg was flexed with a ~90° knee angle and maintained in contact with the right knee, (iii) hands were kept on the hips and (iv) open eyes fixed at a set point on a wall (170 cm height and 200 cm away). Subjects had to maintain this position on a flat surface and on three different wobble boards. Data collection, lasting 5 s, started when subjects achieved an equilibrium position. Trials shorter than 5 s or invalid (i.e., incorrect position or when boards touched the ground) were excluded from analyses. Each support was tested twice with at least 15 s rest between trials. Results from the two trials were then averaged.

Subjects were firstly tested on a posture platform only (Posture Win, Techno Concept, Cereste, France). It aimed to determine the foot centre of pressure (CoP) position [23] and to measure balance on a flat surface (FLAT). For this condition, the foot was lined up on the platform vis-à-vis to the heel and second toe imaginary axis using a graduate grid.

Then, subjects randomly performed the 5 s tests on three different wobble boards (Fig. 1) placed on the posture platform. The foot CoP, found on FLAT, was vertically lined up with each wobble board's geometric centre and posture platform centre, as shown in Fig. 2. Boards were chosen from commercially available supports. One large plastic (JAKOBS®, 109 cm circumference and 5 cm height) and one small wood (FREEMAN, 31 cm circumference and 8 cm height) hemi-spherical board permitted multidirectional displacements. The third board, called LATERAL, with a hemi-cylindrical wood base, only allowed lateral movements (12.5 cm circumference and 7 cm height).

Finally, subjects performed isometric maximal voluntary contractions (~5 s) in order to obtain maximal EMG activity and then normalise EMG activity during balance tests. Maximal voluntary contractions consisted in maximal plantarflexion, dorsiflexion and eversion with the foot in a neutral position (tibia perpendicular to the sole of the foot, i.e., same position as during balance) [18].

(Figure 1 and Figure 2 here)

2.3 Measurements

During all tests, the CoP position was measured using the posture platform in mediolateral and anteroposterior directions. From the stabilograms were retained the mean CoP position (i.e., average position; Fig. 2) and CoP position variation (i.e., CoP variability calculated from standard deviation values) [8, 17]. CoP position signals were recorded during 5 s for each trial at a 40 Hz sampling frequency and synchronised with EMG.

Surface EMG was measured using four pairs of silver-chloride electrodes. EMG electrodes were positioned parallel to muscle fibre orientation over the belly of soleus (SOL), tibialis anterior (TA), peroneus longus (PL) and extensor digitorum longus (EXD). The interelectrode distance was 2 cm centre to centre. Low impedance of the skin-electrode interface (< 5 kΩ) was obtained by shaving, abrading and cleansing the skin. The reference electrode was then fixed to the patella of the opposite knee. EMG signals were amplified with a bandwidth frequency ranging from 10 to 2 kHz (gain = 1,000) and recorded by means of Biopac system (Biopac, Santa Barbara, CA). Root Mean Square values (RMS) were calculated using 125 ms long windows with 50% overlap and averaged to obtain a mean RMS for every 5 s tests. RMS obtained during balance was then normalised with respect to maximal values obtained during maximal voluntary contractions.

2.3 Statistical analysis

After verification of application conditions using Levene and Kolmogorov-Smirnov tests, analyses of variances (ANOVA) were used. For CoP, differences between conditions (FLAT and the three wobble boards) were tested using a one-way ANOVA with repeated measures. For RMS, a two-way ANOVA was used to test differences between conditions and muscles. F ratios were considered significant at a P level < 0.05. When significant main effects or interactions were present a Newman-Keuls post hoc test was subsequently conducted. Furthermore, to assess the magnitudes of changes between conditions, Cohen's d were calculated to report effect sizes, with $d = 1.3$ is a very large effect, $d = 0.8$ is a large effect, $d = 0.5$ is moderate and $d = 0.3$ as a small effect size [4]. At the end of the experiment, five subjects were excluded from analyses, as they were unable to maintain balance for 5 s on the FREEMAN or LATERAL boards.

Results

Mean values for CoP position and variability in the mediolateral and anteroposterior axes are shown in Table 1. While no significant effect was obtained for mediolateral CoP mean position, a significant effect was obtained in the anteroposterior axis ($F_{2,14} = 4.42$, $P < 0.05$). CoP anteroposterior position was lower for LATERAL board than JAKOBS® ($P < 0.05$, $d = 0.51$). No differences were obtained between the other conditions for CoP anteroposterior position ($P > 0.05$, $d < 0.45$). CoP variability denoted significant differences between conditions in both the anteroposterior ($F_{3,18} = 8.62$, $P < 0.01$) and mediolateral ($F_{3,18} = 4.35$, $P < 0.05$) directions. FREEMAN and LATERAL anteroposterior and mediolateral variability were significantly higher than FLAT and JAKOBS® ($P < 0.05$, $d > 1.24$). No significant differences were obtained for CoP variability between FLAT and JAKOBS® ($P > 0.05$, $d < 0.38$) and between FREEMAN and LATERAL ($P > 0.05$, $d < 0.07$).

(Table 1)

EMG activity denoted significant differences between muscles ($F3,28 = 14.49$, $P < 0.001$). TA activity was significantly lower than PL and EXD ($P < 0.01$, $d = 0.93$ and $P < 0.05$, $d = 0.65$, respectively). Similarly, SOL activity was significantly lower than PL and EXD ($P < 0.01$, $d = 1.24$ and $P < 0.01$, $d = 1.00$, respectively). Significant differences between boards were obtained. EMG activity was significantly different for EXD ($F3,21 = 11.95$, $P < 0.001$) and TA muscles ($F3,21 = 9.20$, $P < 0.001$) in FREEMAN and LATERAL conditions as compared with FLAT and JAKOBS® (Fig. 3). For SOL muscle, EMG was significantly higher in FREEMAN and LATERAL boards as compared with FLAT ($F3,21 = 3.91$, $P < 0.05$). For PL muscle ($F3,21 = 9.14$, $P < 0.001$), EMG was significantly higher in LATERAL condition as compared with FLAT and JAKOBS®. Moreover, FREEMAN demonstrated significant differences with respect to FLAT. Whatever the comparison within boards, effect sizes were always high with $d > 1.47$. One exception is for SOL muscle for which effect size was smaller when comparing LATERAL and FREEMAN ($d = 0.96$).

(Figure 3)

Discussion

The main finding of the current study was that CoP displacements and EMG activity of some leg muscles were significantly affected by the unstable condition applied. Briefly, LATERAL and FREEMAN boards demonstrated significantly higher CoP variability than other surfaces in both anteroposterior and mediolateral directions. This effect is generally associated with a higher EMG activity in PL, EXD and TA muscles. In addition, an unexpected similar variability for anteroposterior CoP displacements was found between FREEMAN and LATERAL boards.

According to previous studies [2, 28] we considered CoP position and variability in both the anteroposterior and mediolateral directions. CoP sway-position revealed wider displacements on FREEMAN and LATERAL than FLAT and JAKOBS® boards. This result suggests that CoP variability depends on the geometry of the wobble boards: the smaller the board bases, the bigger the instability. This is important for advising balance exercises on wobble boards once the subject's balance ability is estimated. Consequently, during balance training sessions, stance difficulty can easily be increased using small-bases boards. Quite similarly, previous studies revealed that the subjective difficulty in maintaining balance was also affected by the unstable supports' degree of freedom number. For instance, subjects reported that it was easier to keep balance while standing on an anteroposterior rather than mediolateral or multidirectional spherical boards [16]. Nevertheless, we are surprised to find that balance was similar using LATERAL and FREEMAN boards. Indeed, we primarily hypothesised that uni-directional conditions would provoke less perturbation than multi-directional supports. However, whilst LATERAL boards only allowed mediolateral movements, similar anteroposterior CoP displacements were registered for both boards. Thus, despite different balance conditions, our results are in line with previous experiments which confirmed that CoP control behaviour depends on the magnitude of the perturbation (i.e., wobble board used for balance workouts) and on the nature of the perturbation (e.g., visual manipulation by subjects' blindfolding) [13].

This CoP variability was accompanied by different EMG activity of lower limb muscles. First and quite similarly than CoP, the smaller the board bases, the higher the muscular participation. Such conclusion has previously been obtained [9]. But, as for CoP variability, we are surprised to detect high EMG activity for both TA and SOL muscles in FREEMAN as well as in LATERAL boards. Let's remember that this latter exclusively allowed mediolateral displacements while TA and SOL act in anteroposterior direction. Quite similarly, Dohm-Acker et al. [9] previously registered the highest EMG activity in TA, PL and gastrocnemius muscles. Also, Braun Ferreira et al. [1] found high EMG activity in TA (in association with PL) on trampolines and force platforms. One possible explanation could be related to the mechanical contribution of plantarflexor and dorsiflexor muscles. These muscles, stronger than evertor and invertor muscles, may therefore more easily participate in lateral ankle stability. This result may also be explained by the reduced mobility of the ankle joint along the mediolateral axis.

Our findings are consistent with the idea that equilibrium in unstable surfaces is modulated by ecological strategies along the anteroposterior axis and by biomechanics and stabilisation strategies. In the literature, it is well established [33] that standing postural control in humans is direction-dependent, and that goal oriented actions (for instance, reaching or locomotion) are mainly along the anteroposterior axis, and primarily involves muscles from the anteroposterior plane [30, 31]. This direction dependence results from several biomechanical factors that characterise human posture [30]. During upright standing, the main degree of freedom of the ankle joint is in the sagittal plane. This produces a polarised statokinesigram, reflecting greater excursions of the CoP in the forward and backward directions as compared to the mediolateral axis [5, 22]. Precisely, in the sagittal plane, the disposition of body segments cause the CoM to be located ahead of the ankle joint, which leads the body to fall forward due to the external torque caused by gravity forces. This disposition enables a simplified and more efficient stabilisation strategy that mainly involves muscles from the posterior compartment (e.g., SOL) which can act as springs to maintain the CoM within the base of support [33, 34]. A similar explanation could explain our results during balance since we observed that SOL was similarly solicited for multidirectional or lateral displacements. Muscles from the anterior compartment (e.g., TA) also contribute to regulate anteroposterior body sway, but to a lesser extent. Indeed, our results demonstrated that, to maintain equilibrium using the LATERAL board, TA is much more activated than on the other surfaces. Comparatively, lateral muscles present a relatively low contribution.

Finally, authors reported the importance of the intermuscular coordination patterns on motor control strategy constrained by a specific task (in our case the perturbation) [16,20]. Therefore, our results might also suggest that the intermuscular coordination patterns might change at different neuromuscular activation levels and at different speed oscillations. For this reason, an interesting perspective of this research could be a training protocol aiming to increase ankle stability muscles strength under important disequilibrium constraints to verify its impact on the motor control strategy whilst performing balance exercises.

Conclusions

This study is one of the first investigating the effect of different wobble boards in postural control and EMG activity of lower limb muscles. Our results extend new knowledge about processes of the central nervous system using unstable supports and demonstrate that postural equilibrium is modulated by ecological strategies mostly oriented around the anteroposterior axis. Thus, specific ankle stability exercises are strongly recommended for athletes training and rehabilitation with exercises in both the anteroposterior and also mediolateral planes to exacerbate lateral muscles activation. For example, both FREEMAN and LATERAL boards could be used for athletic training in standing position but also during walking so as to improve sensorimotor function, dynamic equilibrium, ankle strength and joint stability but also for injury prevention. During rehabilitation but also for falls prevention in elderly adults, progressive sequences could be proposed, starting with JAKOBS®, followed by FREEMAN then LATERAL boards.

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Figure legends

Figure 1. Wobble boards used during balance tests.

Figure 2. *Upper part:* Alignment of the foot centre of pressure (A point), geometric center of the wobble board (B point) and posture platform center (C point). *Lower part:* Experimental graph representing the foot center of pressure displacement during 5s. Mediolateral and anteroposterior planes are represented by X and Y axes, respectively.

Figure 3. Normalised RMS values for extensor digitorium longus (EXD), soleus (SOL) peroneus longus (PL) and tibialis anterior (TA) muscles (mean values ± SE). Significant differences with FLAT (** $P < 0.01$). Significant differences with JAKOBS® († $P < 0.05$, †† $P < 0.01$).

Figure1
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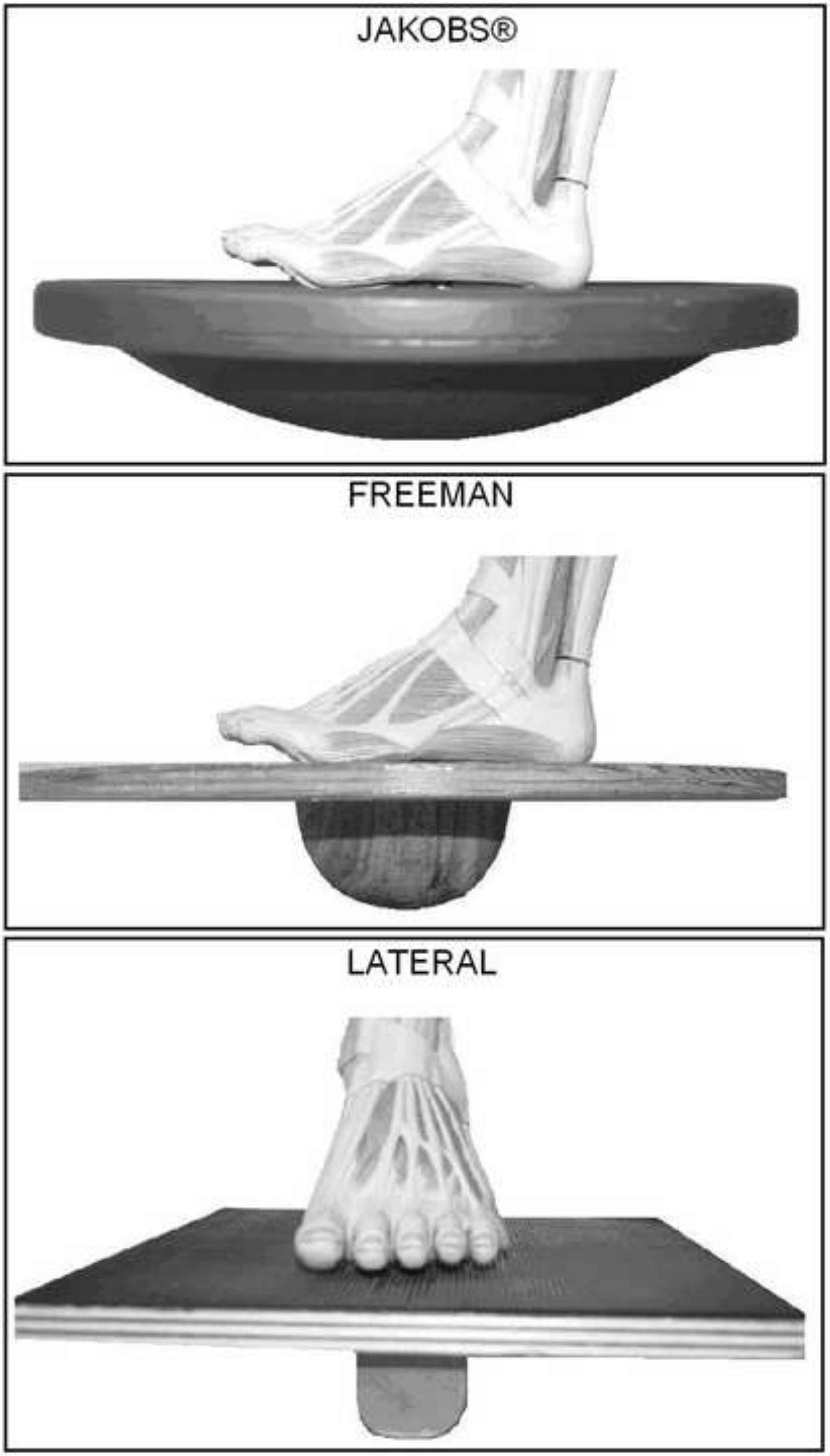

Figure2
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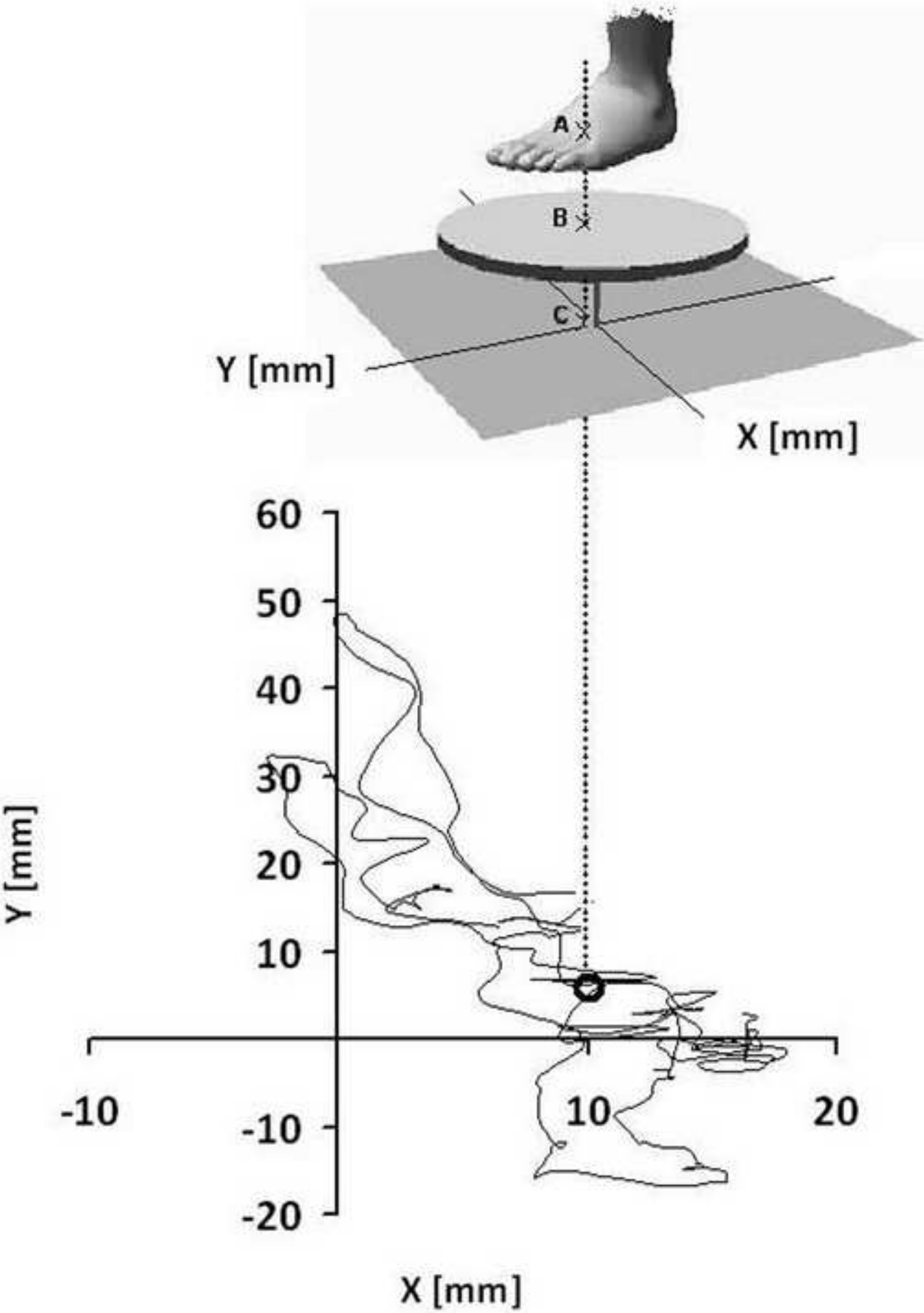

Figure3

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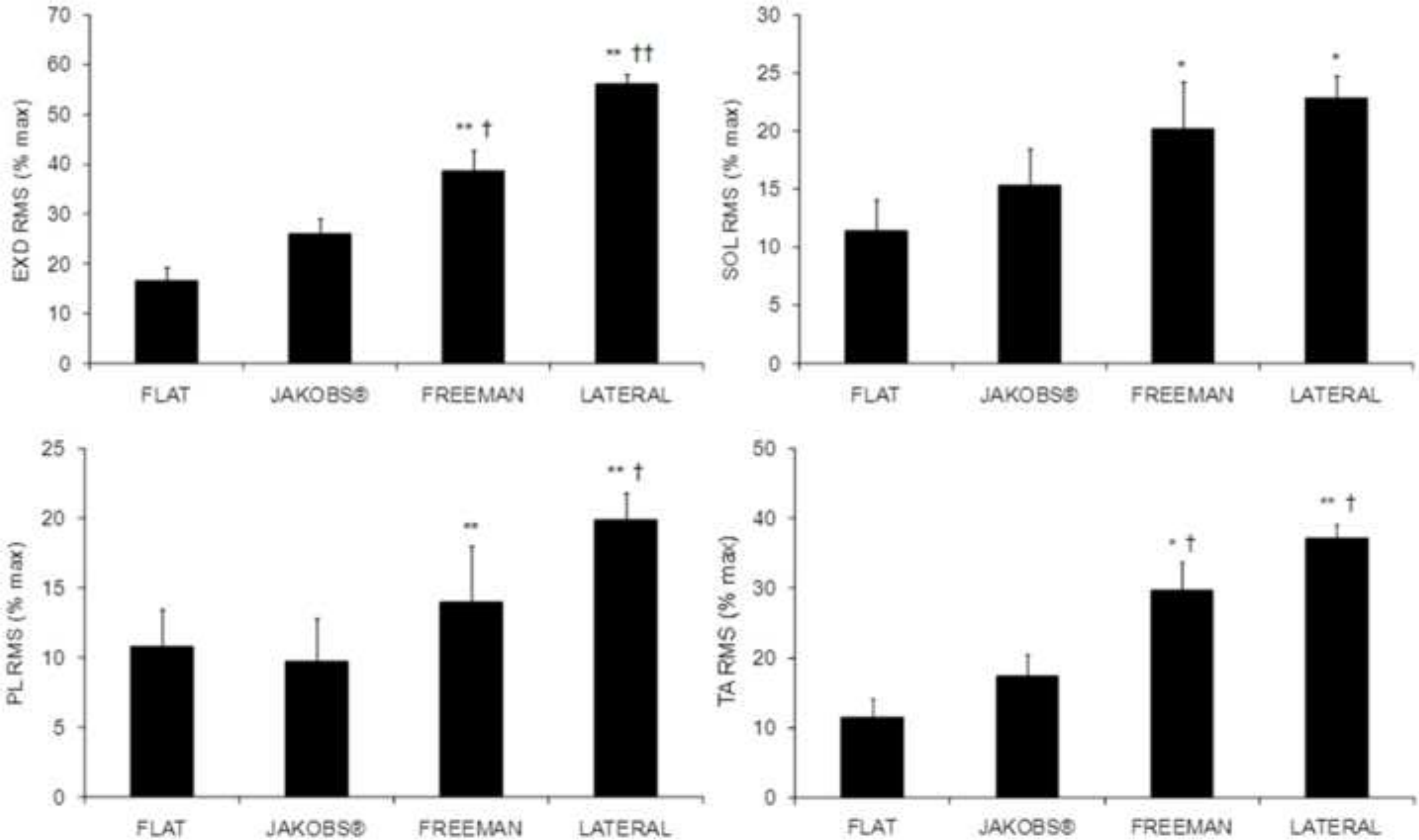

Table 1. Foot centre of pressure mean position and variability.

Condition	X mean position	Y mean position	X variability	Y variability
FLAT	-	-	3.8 ± 1.0	4.5 ± 1.1
JAKOBS®	3.6 ± 11.2	13.8 ± 27.2	4.0 ± 0.7	4.3 ± 0.6
FREEMAN	7.6 ± 22.0	10.2 ± 18.7	7.2 ± 2.8*†	11.6 ± 4.3**††
LATERAL	1.2 ± 19.8	2.0 ± 17.7 †	7.1 ± 3.5*†	11.3 ± 4.7**††

Mean values ± SD (mm). X (mediolateral axis); Y (anteroposterior axis). Significant differences with FLAT (* $P < 0.05$; ** $P < 0.01$). Significant differences with JAKOBS® († $P < 0.05$; †† $P < 0.01$).