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Stabilographic analysis of unconstrained standing

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Natural standing is characterized by postural changes and several hypotheses have been proposed to explain these changes. In this paper, four hypotheses were investigated by quantifying the number of postural changes in the centre of pressure data from unconstrained standing in different experimental conditions, studying the effects of mechanical loading, visual conditions, and type of support surface and sole of the shoes. The subjects stood for 30 min with no specific instructions other than not to step off a force plate. There were no significant effects on the number of centre of pressure patterns associated with the postural changes due to load, vision, surface and shoes during standing; on average, approximately two centre of pressure patterns per minute were observed in all conditions. The analysis of the centre of pressure data by the commonly used statistical parameters (standard deviation, velocity, and mean frequency of the centre of pressure displacement and area of the stabilogram) also did not reveal any effect of the different conditions.

1. Introduction

In working conditions as well as in the activities of everyday life, some people stand for a long time, often confined to a small area. In natural standing conditions, people usually adopt asymmetrical postures and tend to change their body position periodically while adopting a relatively fixed body posture (Bridger 1991, Whistance *et al*. 1995). Continuous low-amplitude and slow swaying of the body is commonly interrupted by postural changes characterized by fast and gross body movements. There are many studies in the literature on continuous low-amplitude sway, which have typically investigated the quiet stance, where subjects were instructed to stay as still as possible in the same place for short periods. The study of unconstrained standing has received less attention, particularly from a biomechanical perspective.

The importance of postural changes during unconstrained standing has been stated previously by Mosher in 1913 (as cited in Zacharkow (1988)) and by Carlsöö

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in 1961, who stressed the importance of *shifting* the body weight from side to side for better comfort. One hypothesis states that such postural changes decrease the venous pooling in the lower extremities, which has been regarded as the main source of discomfort during standing (Brantingham *et al.* 1970, Kim *et al.* 1994, Zhang *et al.* 1991). Cavanagh *et al.* (1987) identified *gross body movements* as the major strategy to avoid the occlusion of the blood flow through some regions of the sole of the foot caused by the continuous pressure in static standing. Alexander (1992) hypothesized that the purpose of the postural changes, which he termed *fidgeting*, is to alleviate the pressure on the joints by 'repumping' the cartilage fluid. The significance of postural changes has also been recognized for sitting tasks (Bhatnager *et al.* 1985) and during sleeping (Keane 1979).

From an ecological/psychological approach, the postural changes can also be interpreted as mechanisms to explore and gather information from the environment, mainly by using the visual sensory system (Riccio and McDonald 1998). According to this point of view, natural standing is more than a pure mechanical task; standing also involves interaction with the environment that could be mediated by the postural changes.

Unconstrained standing from several minutes to a few hours has been characterized in the literature by a large variety of measures. These criteria include electromyographic activity, venous pressure, heart rate, subjective comfort criteria, parameters from stabilography, kinematics of body segments, changes in the foot dimensions, and skin temperature (Rys and Konz 1994, Brantingham *et al.* 1970, Madeleine *et al.* 1998, Kim *et al.* 1994, Zhang *et al.* 1991, Duarte and Zatsiorsky 1999). Among the methods employed, the kinematic analysis of the standing task (e.g. video analysis) and stabilography are the only ones that have been developed to quantify postural changes.

The measurement of the centre of pressure (COP) location during standing, called stabilography or posturography, has been for decades the main biomechanical tool for understanding human balance. The COP is the point of application of the resultant of vertical forces acting on the surface of support; it represents the combined outcome of the postural control system and the force of gravity. Customarily, posturography is divided into static and dynamic analysis. Static posturography is concerned with unperturbed quiet stance, that is when a subject attempts to stay still (Hellebrandt 1938, Thomas and Whitney 1959, Gurfinkel *et al.* 1974, Winter 1995). In dynamic posturography, a perturbation is applied and the response of the subject to this specific perturbation is studied (for a review of dynamic posturography, see Johansson and Magnusson 1991). A comparison and the applications of static and dynamic posturography are discussed by Furman *et al.* (1993), Baloh *et al.* (1994) and Horak (1997). Neither static nor dynamic posturography seems to be appropriate to describe natural standing, since the former does not permit postural changes and the latter uses external and known perturbations. In addition, neither method directly quantifies the postural changes in unconstrained standing. Few studies have attempted to perform a posturographic analysis of unconstrained standing.

Duarte and Zatsiorsky (1999) measured the COP location during unconstrained standing of healthy adults and observed certain patterns that were associated with the postural changes of the subjects (which are described later). A computer algorithm for an automatic detection of such patterns was developed and a statistical analysis of this outcome was performed.

In the present work, the postural changes during unconstrained standing were investigated in different conditions by measuring the COP patterns. First, the effect of loading (i.e. holding loads) was studied to explore the different hypotheses suggested in the literature to explain the driving factors behind the postural changes: to answer the question ‘why do people repeatedly change their body posture?’. With the addition of an external load, the pressure on joint cartilage in the lower extremities and on the plantar sole increases. If the main reason for postural changes is to ‘repump’ the cartilage fluid, as proposed by Alexander (1992), the number of postural changes should increase when holding a load. If the reasons for postural changes are solely to decrease the venous blood pooling in the lower extremities and to allow momentary blood flow through some regions of the foot sole, the number of postural changes would not vary during the loaded standing. The pressure on the plantar sole during normal or unloaded standing is already large enough to occlude the circulation of blood in this region (Cavanagh *et al.* 1987). The first hypothesis proposed is that the number of postural changes will not change with the addition of a load.

The second goal of the study was to investigate the role of vision during unconstrained standing. If the movements during natural standing were performed to explore the environment through the visual sensory system (Riccio and McDonald 1998), fewer postural changes would be expected if the visual information were experimentally excluded. The absence of vision would also lead to a small increase in the postural instability in natural standing, resulting in an increase in the muscular activity in the lower leg to maintain postural stability. This increase in the muscular activity would decrease the venous pooling in the lower extremities and, consequently, provide less necessity for postural changes. Therefore the second hypothesis proposed is that the absence of vision will lead to fewer postural changes.

The third and fourth goals were to investigate the effects of the compliance of the support surface and of the sole of the shoes on standing behaviour during unconstrained standing. Madeleine *et al.* (1998) reported an increase in the displacement of COP when standing on a hard surface was compared to standing on an anti-fatigue mat (soft surface). However, Zhang *et al.* (1991) did not find any difference in the standard deviation of the COP displacement between standing on a hard and a soft surface; they also did not find any effect of the foot/floor interface on the number of postural changes for standing for up to 1 h. Physical reasoning would predict that there would be an increase of body oscillation on a soft surface due to mechanical instability and that therefore there would be a consequent increase in COP oscillation. This increase in the instability will increase the muscle activity and then the postural changes will not be so necessary, leading to fewer postural changes on a soft surface. The range and standard deviation of the COP displacement do not only measure the increase in oscillation due to the mechanical instability of a soft surface during unconstrained standing, but also the effect of the postural changes. Thus, the increase in the range of the COP displacement on a hard surface found by Madeleine and collaborators could be due to the postural change and not due to the mechanical instability. The third and fourth hypotheses are that the use of a soft surface and soft sole shoes would decrease the number of postural changes during unconstrained standing.

Published analyses of the COP displacement during unconstrained standing have been limited to two studies, each reporting only one parameter: standard deviation of the COP data (Zhang *et al.* 1991) and range of the COP data (Madeleine *et al.*

1998). Both studies investigated the effect of type of surface on the unconstrained standing. In the present study, in addition to the investigations of the postural changes using the COP-pattern analysis, a detailed characterization of the COP data has also been performed. To this end, measurements of standard deviation, velocity, and mean frequency of the COP displacement and the area of the stabilogram are reported. A more complete characterization of the COP location during unconstrained standing should contribute to the understanding of the effects of the different factors on the standing posture.

2. Methods

The study was conducted using a 40 ×90-cm force platform (Bertec, Worthington, OH) with a metallic surface (iron casting, considered to be a hard surface). The force plate measured the three force components, F_x, F_y and F_z, and the three moment components, M_x, M_y and M_z (x, y, and z are the anterior-posterior, medial-lateral and vertical directions, respectively). The COP position was given by $\mathrm{COP}_x = (-h \cdot F_x - M_y)/F_z$ and $COP_y = (-\mathrm{h} \cdot F_y + M_x)/F_z$, where h is the height of the material, e.g. the mat, over the force plate. The COP datum is given as a location (two coordinates) on the surface of the force plate. These two coordinates are identified in relation to the orientation of the subject: anterior-posterior (a-p) direction and medial-lateral (m-l) direction.

The subjects performed unconstrained standing for 31 min. The first minute of the data was excluded from the analysis to allow the subjects time to accommodate to the task. The subjects were allowed to change their posture freely at any time; there were no specific instructions on how to stand except the requirement not to step off the force platform. The experiments were performed in a quiet room (8 ×6 m) with the force platform positioned in the middle. During the unconstrained standing task, the subject was permitted to communicate occasionally with the experimenter (one of the authors) who was sitting or standing in front of the subject at a distance of about 2 m. The subject and the experimenter selected the topic of the discussion. All the subjects who participated in this study were healthy adults with no prior physical or mental illnesses. They took part in the experiments voluntarily. Before the experiments, the subjects signed a consent form approved by the Office of Regulatory Compliance of The Pennsylvania State University.

Five subjects participated in the experiments where the effects of load and of vision were investigated; the subjects were of mean age (±1 SD) of 21±2 years, mean height of 1.81±0.02 m, and mean weight of 79±9 kg. Each of the subjects performed an unconstrained standing task under four separate conditions, each condition on a different day and at the same time of the day. The four conditions were: (1) no load and eyes open (termed normal), (2) supporting a 32 kg load and eyes open, (3) no load and blindfolded, and (4) supporting a 32 kg load and blindfolded. All tasks were performed on the force plate surface with the subjects barefoot; the sequence of the tasks was randomized among the subjects. The load was worn as soft lead pouches strapped around the waist.

In the experiment where the effects of floor surface and of sole of the shoes were investigated, six subjects participated in the study: the subjects were of mean age (± 1 SD) 28±12 years, mean height 1.65±0.09 m, and mean weight 58±11 kg. Each of the subjects performed an unconstrained standing task under four separate conditions, each condition on a different day and at the same time of the day. The four conditions were: (1) hard sole shoes on a hard support surface, (2) soft sole shoes on a hard support surface, (3) hard sole shoes on a soft support surface, and (4) soft sole shoes on a soft support surface. This sequence was randomized among the subjects. The soft sole shoes were comfortable sport shoes belonging to the subjects and the criterion of selection was that they should present a sole of soft material and a heel lower than 2 cm. The hard sole shoes were shoes belonging to the subjects and these shoes were required to have a hard sole material and a heel lower than 2 cm. The hard floor surface was the metallic surface of the force plate and the soft surface was a commercial anti-fatigue mat (Model Ergomat Standard, Tinby LLC, Westlake, OH, USA) made of polyurethane with a compressibility of 35 kg for 3-mm compression with a 105 mm diameter probe. The mat was cut to the size of the force plate and put over it. The COP data were calculated taking into account the elevation of the mat surface using the preceding formula.

2.1. *Treatment of the data*

Prior to analysis, all COP signals were low-pass filtered with a Butterworth filter of fourth order and zero-phase lag with a cutoff frequency of 8 Hz since most of the power of the signal is below 1 Hz (see Winter (1995) for a review on this topic).

3. Data analysis

3.1. *Patterned analysis of the COP data*

The following three patterns were identified in the COP time-series by Duarte and Zatsiorsky (1999).

(1) *Shifting*: a fast displacement of the average position of the COP from one region to another (step-like).
(2) *Fidgeting*: a fast and large displacement followed by a return of the COP to approximately the same position (pulse-like).
(3) *Drifting*: a slow continuous displacement of the average position of the COP (ramp-like).

Figure 1 shows a representative example of the three patterns in a COP time-series of the present study.

A computer algorithm based on moving windows analysis was developed to recognize these patterns (Duarte and Zatsiorsky 1999). This algorithm and other parameter evaluations were implemented in the Matlab software with a friendly graphical user interface. The codes are available from the authors upon request.

For recognition of shifting, any two consecutive non-overlapping moving windows, W_1 and W_2, satisfying equation (1) were classified as a shift:

$$\left| \frac{\overline{x}_{W_1} - \overline{x}_{W_2}}{\sqrt{SD^2_{W_1} + SD^2_{W_2}}} \right| \geq f_{\text{shift}} \tag{1}$$

where $\overline{x}_{W_i}$ ($i = 1,2$) is the mean of the COP data for the windows W_1 and W_2, SD_{Wi} is the standard deviation of the COP data in the window W_i, and f_{shift} is the threshold value of the amplitude of the shift pattern (in units of $SD_{W1} + SD_{W2}$). The amplitude of the shift is defined as $|\overline{x}_{W_1} - \overline{x}_{W_2}|$. The estimated width of the shift (the time taken to shift the COP position) is given by the interval, W_S, separating the two consecutive windows.

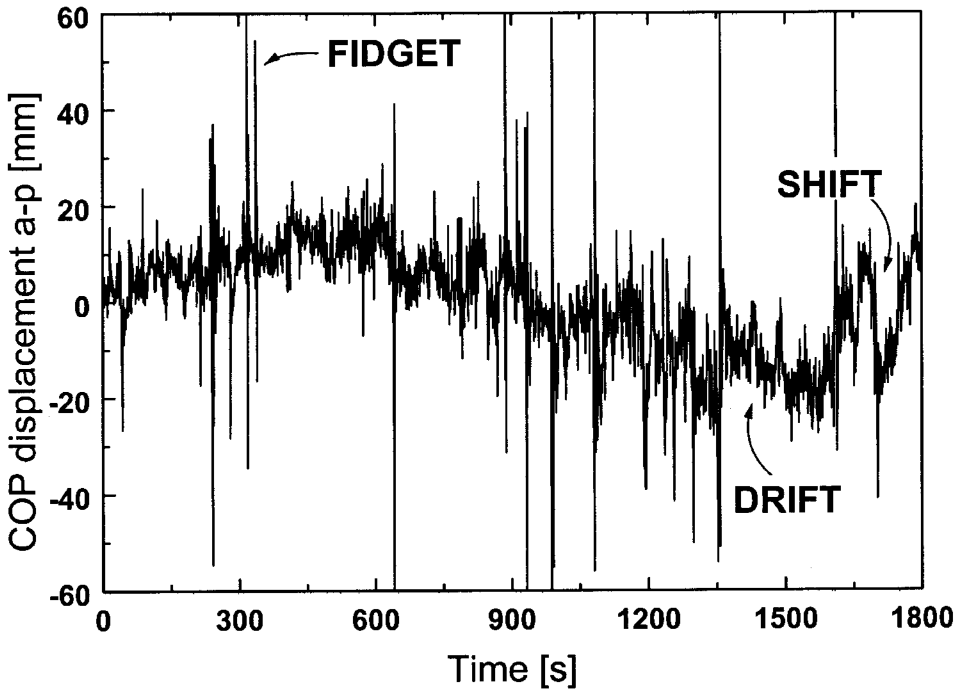

Figure 1. A representative example of the COP time-series during unconstrained standing for 30 min. Subject was barefoot on the force plate surface. Positive values represent anterior displacement.

For recognition of fidgeting, any peak or valley satisfying equation (2) was classified as a fidget:

$$\left| \frac{x_F - \overline{x}_w}{SD_w} \right| \geq f_{\text{fidget}} \tag{2}$$

where x_F is the amplitude of the peak or valley, $\overline{x}_w$. is the mean COP data for the window W, SD_W is the standard deviation of the COP data in the window W, and f_{fidget} is the threshold value for the amplitude of the fidget pattern (in units of SD_W). The amplitude of the fidget is defined as $|x_F - \overline{x}_w|$. The width of the fidget, W_f, was estimated by the full width at half maximum amplitude of the fidget (figure 2(b)).

For recognition of drifting, the data between two consecutive shifts were smoothed using a low-pass filter with a variable cut-off frequency $F_c = 1/2W_D$, where W_D was the pre-selected minimal drifting width. This procedure preserves only the low frequency trend (drift) in the data. If the difference between the amplitudes of two consecutive local maximum and minimum satisfied the equation (3), the COP displacements between the consecutive maximum and minimum were classified as a drift.

$$\left| \frac{x_{max} - x_{min}}{SD_w} \right| \geq f_{\text{drift}} \tag{3}$$

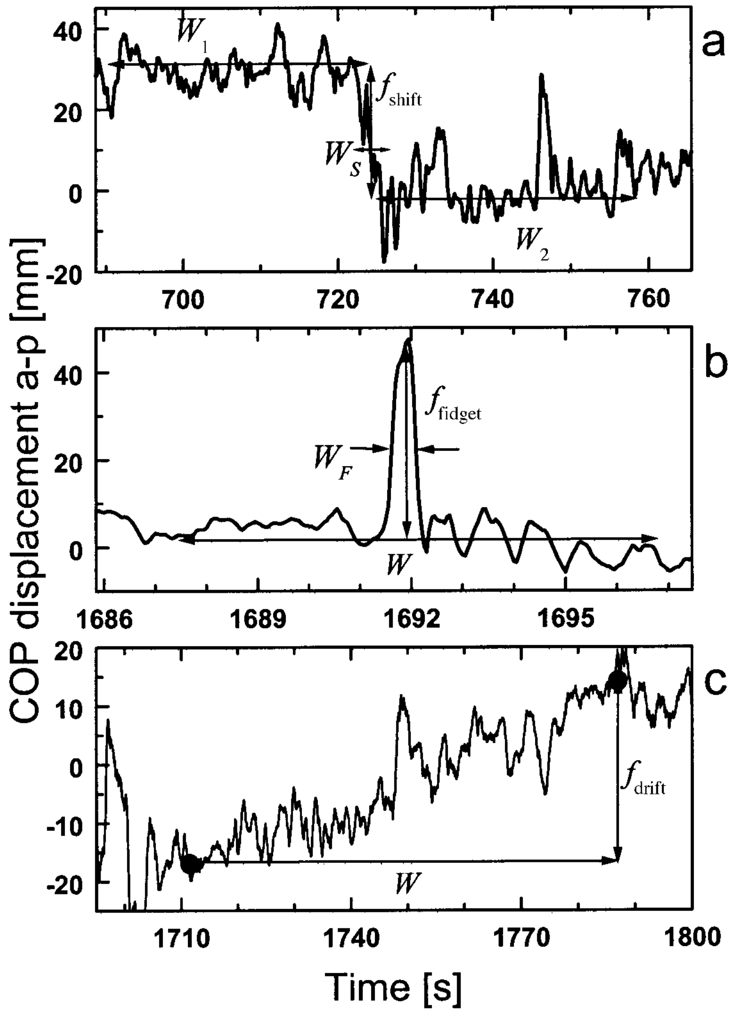

Figure 2. An example of single patterns (a) shift, (b) fidget, and (c) drift during unconstrained standing, with the corresponding parameters used for identification. Subjects were barefoot on the force plate surface. The time axes are on different scales for clarity.

where x_{max} and x_{min} are the consecutive local maximum and minimum amplitudes, SD_W is the standard deviation of the COP data in the window containing the data between the maximum and minimum values, and f_{drift} is the threshold value of the drift amplitude (in units of SD_W). The amplitude of the drift is defined as $|x_{max} - x_{min}|$.

The following criterion values were chosen for classifying the data as shift, fidget or drift patterns, respectively: a minimum shift amplitude of 2 SD, a maximum shift width of 5 s, and a base window of 15 s; a minimum fidget amplitude of 3 SD, a maximum fidget width of 4 s, and a base window of 60 s; a minimum drift amplitude of 1 SD, a minimum drift width of 60 s. These values are similar to the values used previously in the literature (Duarte and Zatsiorsky 1999). Examples of single shift, fidget and drift patterns, and the parameters used for the identification are shown in figure 2.

The patterns were first determined separately for the anterior-posterior and medial-lateral directions using the same criteria. The patterns appearing at the same instant in both directions were identified and were counted as one pattern. Further analysis focused on the total numbers of patterns. The numbers of shifts and fidgets were also examined as a function of time by dividing the 30-min unconstrained standing trial into 10 non-overlapping segments with a width of 3 min.

3.2. *Non-patterned analysis of the COP data*

The objective of the study was to give a detailed characterization of the COP displacement. To this end, four of the most commonly used parameters in stabilography were selected: the standard deviation of the data (Murray *et al.* 1975), the velocity of the COP displacement, the area of the stabilogram and the mean frequency. The velocity (V) of the COP displacement was determined by dividing the total excursion of the COP displacement by the total period of the data, 30 min (Riach and Starkes 1994). The area of the stabilogram (the plot of the COP displacement in the anterior-posterior direction versus the COP displacement in the medial-lateral direction) was computed using the ellipse area method; the principal axes of the ellipse were determined by the principal-component analysis (PCA) (Oliveira *et al.* 1994). Frequency parameters have been used in the literature to gain further insight into the temporal characteristics of postural stability (Bensel and Dzendolet 1968, Williams *et al.* 1997). In this study, the mean frequency (F_{mean}) of the COP displacement was computed from the power spectral density of the COP displacement, which was estimated by using the Welch's averaged periodogram method with a resolution of 0.039 Hz (using Matlab software; MathWorks, Inc. 1996).

For the non-patterned analysis, the data for the anterior-posterior and medial-lateral directions were analysed separately—a regular procedure in COP analysis since the COP displacements for different directions are poorly correlated.

3.3. *Statistical analysis*

A 2×2 analysis of variance (ANOVA) for repeated measures with a significance level of 0.05 was conducted to examine the effects of the variables load and vision between the trials in the first experiment and the effects of the surface and shoe variables in the second experiment.

4. Results

4.1. *Patterns of the COP displacement*

All the three patterns of the COP displacement were observed in the subjects' behaviour during the experiments. However, individual patterns prevailed in different subjects, as shown in figure 3(a–c). Different subjects appeared to *prefer* to use shifting, fidgeting or drifting during standing, thus indicating different strategies of posture change during unconstrained standing. A very low frequency of sway with an approximate period of almost 30 min can be seen in figure 3(c). This is an indication of a long-range correlation or a long-memory process (the long-term fluctuations in addition to short-term fluctuations) in the COP data during unconstrained standing. Owing to the long-range correlation, the data separated by the large time intervals are dependent on each other.

4.2. *Effects of supporting a load and obscured vision on unconstrained standing*

The analysis of the COP patterns during the 30-min unconstrained standing yielded the results shown in figure 4. Analysis of variance showed that the only statistically significant effect was an interaction between vision and load for the number of fidgets ($F(1,4) = 14.69$, $p < 0.05$). In the blindfolded condition, there was an increase of the number of fidgets when the subjects supported a load, while in the eyes open condition there was a slight decrease of the number of fidgets when the subjects supported a load, as seen in figure 4.

Fidgeting was the most frequent pattern, followed by shifting (about two to three times less frequent than fidgeting) and then by drifting (about six times less frequent than fidgeting). The total number of COP patterns per minute was just below 2 patterns/min, varying by less than 15% among the different conditions.

The analysis of the temporal dependence of the shifting and fidgeting patterns across the 10 non-overlapping 3-min periods showed that the number of COP patterns varied among the windows but without any evident trend.

The results for the four parameters—standard deviation of displacement, velocity of displacement, mean power frequency, and area of the stabilogram are shown in table 1. Analysis of variance showed that there was only one statistically significant effect, which was the effect of vision on the mean frequency F_{mean} of the COP displacement in the a-p direction ($F(1,4) = 10.97$, $p < 0.05$).

4.3. *Effects of floor surface and shoe type on unconstrained standing*

The analysis of the COP patterns during the 30-min unconstrained standing trial yielded the results shown in fig. 5. The results of the ANOVA for the number of patterns showed no statistical differences among the four conditions. Again, fidgeting was the most frequent pattern, followed by shifting (about two to three times less frequent than fidgeting) and then by drifting (about seven times less frequent than fidgeting). Similar to the load and vision results, the total number of COP patterns per minute was just below 2 patterns/min, varying by less than 15% among the different conditions.

Again, there was no systematic trend in temporal dependence in the number of COP patterns across the duration of the task. The results for the four parameters—standard deviation of displacement, velocity of displacement, mean power frequency and area of the stabilogram are shown in table 2.

Besides the quantification of the total number of patterns per trial, the amplitude of each pattern, as previously defined, was also analysed. The mean amplitude for each pattern did not depend on the load, vision, surface and shoes.

5. Discussion

5.1. *Effects of supporting a load and obscured vision on unconstrained standing*

The addition of load did not significantly affect the occurrence of the different COP patterns. The fidgets, the most frequent pattern, are evidently not performed to change either the position of COP or the projection of the centre of gravity displacement of the body onto the base of support (known as the gravity line). (Although the gravity line was not measured for low frequencies of displacements below 0.2 Hz, the COP location approximately corresponds to the gravity line).

The venous pooling in the lower legs rather than muscle fatigue has been named as the main cause of discomfort during prolonged standing (Brantingham *et al.* 1970, Basmajian 1979, Kim *et al.* 1994, Madeleine *et al.* 1998). Body movements are

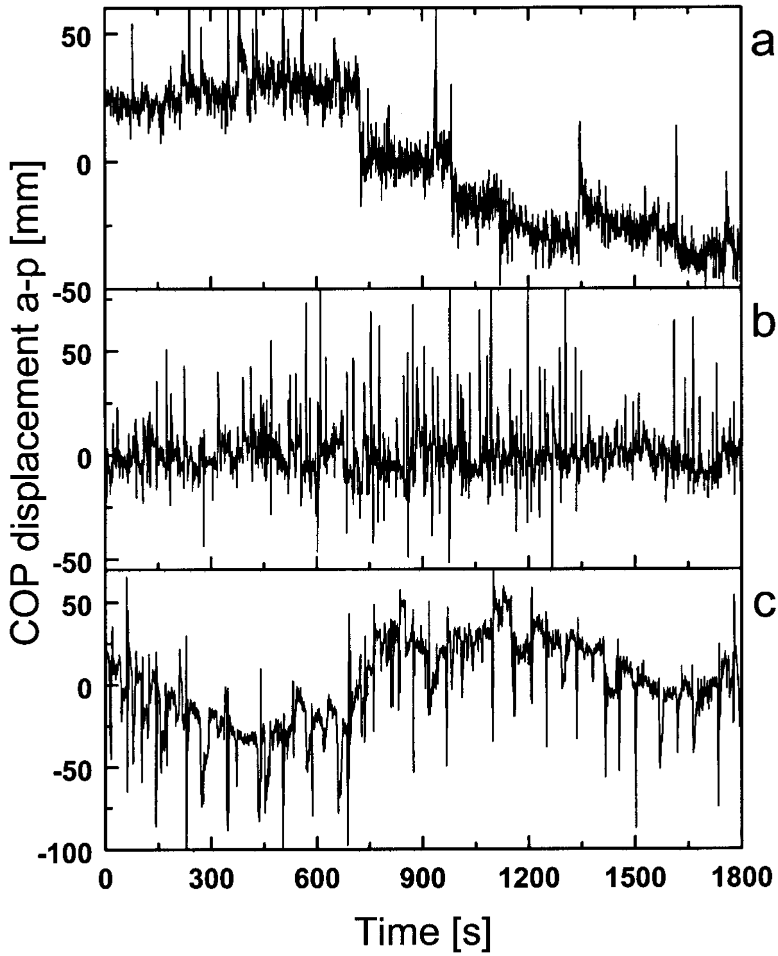

Figure 3. Examples of dominance of (a) shift, (b) fidget, and (c) very long drift patterns in different subjects during unconstrained standing. Subjects were barefoot on the force plate surface.

thought to enhance the venous pump activity (Brantingham *et al.* 1970, Madeleine *et al.* 1998). The present results support this point of view. They suggest that the main role of fidgeting is to enhance the venous pump activity and to allow the momentary blood circulation in the sole of the feet as proposed by Cavanagh *et al.* (1987) who reported that the peak pressure in the foot during standing was approximately 137 kPa. The normal peak systolic pressure is 17 kPa. Hence, during normal standing, the vessels in the sole of the foot are already closed. Fidgeting may be a mechanism of momentarily relieving this pressure to restore blood flow and therefore decrease fatigue. An increase in the pressure (addition of load) does not increase the closure and therefore does not induce additional fidgets. The data from the present study seem to support the 'blood occlusion' hypothesis. However, the biomechanical analysis is too limited to allow any further conclusions on such mechanisms.

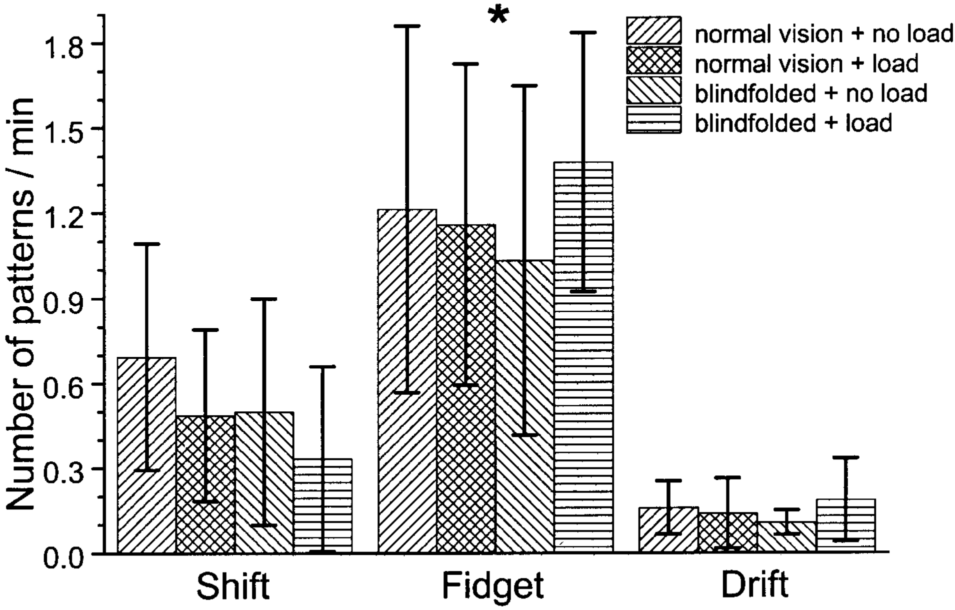

Figure 4. Mean (and standard deviation) of numbers of shifting, fidgeting and drifting patterns per minute during unconstrained standing for different load and vision conditions (n= 5).

Table 1. Standard deviation of COP displacement (SD), velocity of COP displacement (V), mean frequency (F_{mean}) of the COP displacement and the area of the stabilogram during unconstrained standing for different load and vision conditions (n= 5). Data presented as mean ± standard deviation.

		Direction	
Variable	Task	Anterior-posterior	Medial-lateral
SD (mm)	Normal vision+ no load	20 ± 8	23 ± 13
	Normal vision+ load	14 ± 6	18 ± 14
	Blindfolded+ no load	17 ± 9	23 ± 22
	Blindfolded+ load	20 ± 12	26 ± 21
V (mm/s)	Normal vision+ no load	14 ± 3	13 ± 4
	Normal vision+ load	12 ± 2	9 ± 4
	Blindfolded+ no load	14 ± 3	12 ± 4
	Blindfolded+ load	17 ± 5	15 ± 9
F_{mean} (Hz)	Normal vision+ no load	0.26 ± 0.03	0.28 ± 0.06
	Normal vision+ load	0.27 ± 0.03	0.29 ± 0.04
	Blindfolded+ no load	0.34 ± 0.05	0.33 ± 0.12
	Blindfolded+ load	0.33+ 0.10	0.31 ± 0.11
Area (mm^2)	Normal vision+ no load	5500 ± 3400	
	Normal vision+ load	4000 ± 3800	
	Blindfolded+ no load	6100 ± 8100	
	Blindfolded+ load	6800 ± 6300	

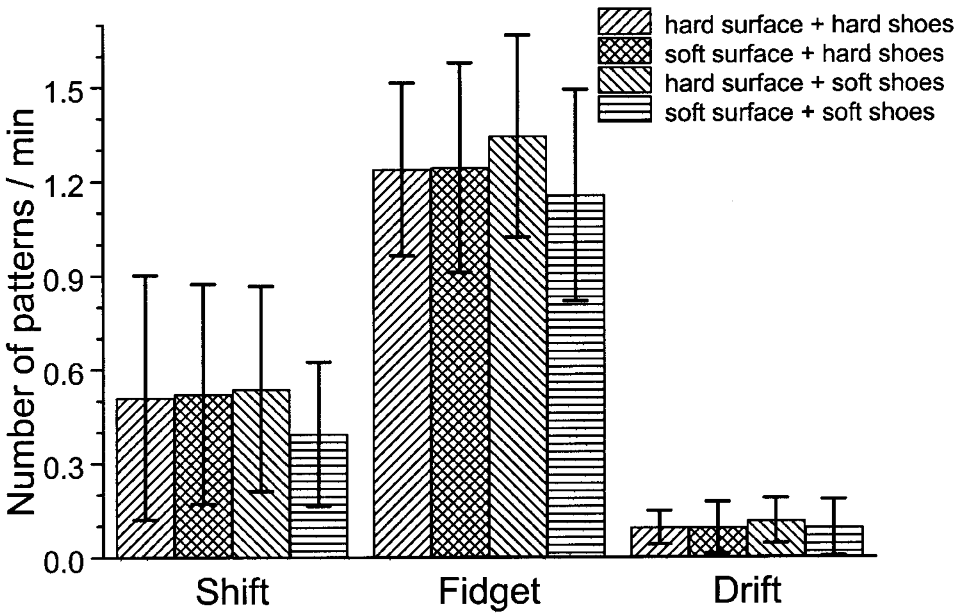

Figure 5. Mean (and standard deviation) of numbers of shifting, fidgeting and drifting patterns per minute during unconstrained standing for different floor surface and shoe conditions (n= 6).

Table 2. Standard deviation of COP displacement (SD), velocity of COP displacement (V), mean frequency (F_{mean}) of the COP displacement and the area of the stabilogram during unconstrained standing for different load and vision conditions (n= 6). Data presented as mean ± standard deviation.

		Direction	
Variable	Task	Anterior-posterior	Medial-lateral
SD (mm)	Hard surface+ hard shoes	18 ± 8	20 ± 11
	Soft surface+ hard shoes	19 ± 8	17 ± 9.5
	Hard surface+ soft shoes	17 ± 7	19 ± 10
	Soft surface+ soft shoes	17 ± 8	23 ± 14
V (mm/s)	Hard surface+ hard shoes	18 ± 13	12 ± 4
	Soft surface+ hard shoes	19 ± 16	12 ± 4
	Hard surface+ soft shoes	19 ± 13	12 ± 3
	Soft surface+ soft shoes	18 ± 13	13 ± 6
F_{mean} (Hz)	Hard surface+ hard shoes	0.33 ± 0.10	0.35 ± 0.09
	Soft surface+ hard shoes	0.31 ± 0.09	0.38 ± 0.13
	Hard surface+ soft shoes	0.34 ± 0.12	0.36 ± 0.09
	Soft surface+ soft shoes	0.35 ± 0.10	0.37+ 0.12
Area (mm^2)	Hard surface+ hard shoes	4300 ± 3100	
	Soft surface+ hard shoes	4100 ± 3000	
	Hard surface+ soft shoes	3900 ± 2700	
	Soft surface+ soft shoes	5000 ± 3600	

Another explanation for the postural changes as proposed by Alexander (1992) was not supported by the findings of this study. Alexander suggested that unconscious postural changes might happen to 'repump' the joint synovial fluid in the joint cartilage of the lower extremities. If that were the case, an increase in the pressure (increase in load) should increase the occurrence of these changes. The present study showed no such increase in postural changes.

Being blindfolded for 30 min did not change the occurrence of COP patterns in the unloaded condition. These results indicate that postural changes are not influenced by vision in the environmental conditions of the experiments. Hence, the role of postural changes in interaction/exploration of the environment mediated by vision during standing, as understood in an ecological/psychological approach, was not supported here. It is quite possible that the small amplitude of the body displacement and the constant visual environment of the laboratory do not instigate this exploration of the environment. However, in the loaded condition, an increase of the fidget patterns was observed when the eyes were closed. Perhaps the instability created by the load plus the removal of the visual input increased the postural changes, increasing the input from the proprioceptors and therefore helping to maintain balance, as stated in the 'ecological' hypothesis earlier. Proprioception becomes more important when one does not have visual input. Thus, the exploration hypothesis cannot be disregarded completely.

An increase in the variability (standard deviation) and mean power frequency of the COP displacement during quiet standing for both directions with closed eyes has been reported many times in the literature (Amblard *et al.* 1985, Diener and Dichgans 1988, Collins and De Luca 1995). In the present study, similar findings were only obtained for the mean power frequency in the anterior-posterior direction. It seems that the unconstrained nature of the task masked any changes in the body sway in the absence of vision.

5.2. *Effect of floor surface and shoe type on unconstrained standing*

It was expected that standing on a soft mat (a commercial anti-fatigue mat) should reduce fatigue and decrease the number of postural changes. Contrary to these expectations, the occurrence of the COP patterns did not change when different surfaces and shoes were used. This finding is in contrast with the commercially advertised benefits of soft surfaces and shoes with soft soles. Zhang *et al.* (1991), using video analysis, analysed 120 min of unconstrained standing on a hard and soft surface with soft sole shoes and also reported no effects on the number of postural changes.

In the present study, no changes were observed in the variability of the COP displacement when subjects stood on different surfaces. Madeleine *et al.* (1998) studied unconstrained standing for 105 min and reported an increase in the variability of the COP displacement when the subjects were standing on a hard surface as compared to standing on an anti-fatigue mat. However, in their experiment the subjects applied forces to a table as well as to the force plate and only the COP location on the force plate was recorded. Hence, the COP analysis may have been confounded. In agreement with the present results, Zhang *et al.* (1991), who analysed the COP standard deviation, did not find any difference during 120 min of unconstrained standing on a hard or soft surface with soft sole shoes. Again, it seems that the unconstrained nature of the task masked any changes in the body sway due to the compliance of the support surface.

5.3. *Comparison between the COP-pattern analysis and the video analysis of Zhang* et al. (*1991*)

A detailed quantitative analysis of the postural changes seen on videotape records during 120 min of unconstrained standing was performed by Zhang *et al*. (1991). (It should be noted that those authors used the term constrained standing for the identical task termed unconstrained standing in the present study.) The authors reported an increasing number of postural changes across time with a mean number of just above one postural change per minute. Their results in graph form (Zhang *et al*. 1991, figure 3) start with about 0.8 postural changes/min in the first 15 min, increase to 1.2 postural changes/min at the end of the first hour, and increase slowly to about 1.3 postural changes/min in the last 15 min of the 120-min standing period. However, no trend in the number of postural changes was found over the 30 min in the present study, where the total number of COP patterns (the sum of shifting, fidgeting and drifting) per minute was just below 2 patterns/min for all the conditions studied. The difference between the two studies can be explained, at least in part, by the different classification of a postural change; a visual classification by the experimenter versus a threshold set in the present statistical classification. Duarte and Zatsiorsky (1999) discussed the effects of setting different thresholds for the pattern identification. Basically, with higher thresholds, the technique would be less sensitive to postural changes. It should also be noted that the recognition of drifting is technically difficult if using the video method since this pattern presents a very long period (typically a few minutes).

6. Conclusions

The occurrence of the postural changes measured by the COP patterns, standard deviation of COP displacement, mean power frequency of COP displacement, velocity of the COP displacement, and the area of the stabilogram were remarkably invariant with respect to the supporting of a load, obscuration of vision, compliance of the support surface and softness of shoe soles.

The invariance of the postural changes with the additional of load supports the hypothesis that postural changes allow momentary blood circulation in the soles of the feet. In a visually constant environment, the number of postural changes was not affected by the absence of vision during unconstrained standing. This supports hypotheses suggesting the physiological nature of postural changes in standing rather than mechanisms related to interactions with the environment. The commercially advertised benefits of anti-fatigue mats and soft sole shoes for unconstrained standing are questionable from a biomechanical point of view, at least for periods of up to 30 min.

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