

# Patterns of Center of Pressure Migration During Prolonged Unconstrained Standing

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Prolonged (>30 min) unconstrained standing (PUS) was studied in 10 young healthy subjects. The usual methods of stabilographic analysis assume a random center of pressure (COP) migration. This study was based on the opposite idea and showed that during PUS, specific and consistent patterns of the COP migration can be recognized by a computer algorithm. Three COP migration patterns were found: (a) shifting, a fast displacement of the average position of COP from one region to another; (b) fidgeting, a fast and large displacement and returning of COP to approximately the same position; and (c) drifting, a slow continuous displacement of the average position of COP. A software code was written and default parameter values were chosen for recognizing COP migration patterns. For 30-min PUS the following patterns were identified: Shifting was generally observed every  $316 \pm 292$  sec in the anterior-posterior (a-p) direction with an average shift amplitude of  $17 \pm 15$  mm, and every  $199 \pm 148$  sec in the medial-lateral (m-l) direction with an average shift amplitude of  $22 \pm 38$  mm. Corresponding time intervals for fidgeting were  $59 \pm 15$  sec in the a-p direction and  $49 \pm 16$  sec in the m-l direction. The average drift-to-drift interval was  $319 \pm 173$  sec in the a-p direction and  $529 \pm 333$  sec in the m-l direction.

The measurement of the center of pressure (COP) during unperturbed standing, also called static posturography, has been intensely researched for 6 decades (Bensel & Dzendolet, 1968; Collins & De Luca, 1993; Hellebrandt, 1938; Nashner, 1981; Thomas & Whitney, 1959; Winter et al., 1990). This study differs from other posturographic studies in two aspects: (a) the type of motor task, and (b) the method of analyzing the posturographic data.

Typically, in static posturographic studies, subjects have been asked to stand quietly for 20 to 90 seconds (Kapteyn et al., 1983; Prieto et al., 1993). However, during normal daily activities people do not usually stand quietly. In this study we tried to imitate natural standing and we studied prolonged unconstrained standing (PUS). In such experiments, subjects are not instructed specifically on how to

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stand; they are allowed to change their posture as they choose. During PUS testing, the standing posture is maintained for several minutes and the subjects are permitted to do what they like—talk with someone, watch TV, listen to music, or do nothing.

Previous studies of prolonged standing in which subjects were instructed to “stay still as long as possible” mainly addressed the body’s physiological reactions to this task (Rys & Konz, 1994). We found only one study in the literature on body sway during prolonged standing under the “stay still” instruction (Katayoka et al., 1997). Unfortunately, the study was published as 1-page abstract and neither the methods nor the results were presented in full. To the best of our knowledge, the question of COP migration during PUS has not been addressed.

A large variety of mathematical methods have been used to analyze stabilographic data (Hufschmidt et al., 1980; Prieto et al., 1993; Winter et al., 1990). The methods include, but are not limited to, the following:

1. Parameters of statistical distribution (simple statistics: Murray et al., 1975; Paulus et al., 1984);
2. Ranges and areas of COP migration (Hasan et al., 1990; Riach & Starkes, 1993; Slobounov & Newell, 1994; Starkes et al., 1992);
3. Velocities of COP migration (Hasan et al., 1990; Riach & Starkes, 1994; Starkes et al., 1992);
4. Length of path traveled by the COP (Norre et al., 1987a, 1987b);
5. Transfer functions (Peeters et al., 1985);
6. Spectral characteristics (Aggashyan et al., 1973; Bensele & Dzendolet, 1968; Peeters et al., 1985; Soames et al., 1976; Williams et al., 1997; Yoneda & Tokumasu, 1986);
7. Autocorrelation and autoregression analysis (Bräuer & Seidel, 1981; Takata et al., 1983; Tokumasu et al., 1983);
8. Time-to-contact measures (Newell et al., 1997; Riccio, 1993);
9. Evolutionary spectral analysis (Schumann et al., 1995);
10. Fractal dimensions (Firsov & Rosenbum, 1990; Prieto et al., 1992);
11. Phase plane analysis (Riley et al., 1995);
12. Grassberger-Procaccia coefficients developed to study dimensionality of chaotic processes (Collins & De Luca, 1993, 1994; Newell et al., 1993);
13. Random walk analysis (Collins & De Luca, 1995a, 1995b; Lauk et al., 1998; Newell et al., 1997; Riley et al., 1997; Roy et al., 1987).

All the methods listed above are based on one common idea: they assume that the COP migration is purely stochastic (or chaotic, or represent a random walk) and, consequently, is nonpatterned. This study was based on the opposite idea in the analysis of PUS.

The main goal of this study was to show that during PUS, there are specific and consistent patterns of the COP migration which can be recognized by a computer algorithm. The objectives were to (a) describe patterns of COP migration; (b) develop software to detect the COP migration patterns; (c) specify the parameters of computer algorithms and suggest a default classification procedure; and (d) present descriptive statistics on the patterns of COP migration during PUS.

## Preliminary Examples and Terminology

This section provides representative examples of COP recordings during PUS and introduces the terminology.

When the COP migration is mapped in the anterior-posterior versus medial-lateral plane, two typical patterns are observed: multi-region and single-region standing (Figure 1). In multi-region standing, subjects tend to change the average location of COP several times during the trial. The regions can also be called domains of COP attraction.

When COP data are presented as a time series, the following three PUS patterns are discernible (Figure 2):

1. Shifting: a fast, step-like displacement of the average position of COP from one region to another;
2. Fidgeting: a fast, large displacement and returning of COP to approximately the same position;
3. Drifting: a slow, continuous displacement of the average position of COP (linear or nonlinear trend).

If a trial is considerably long, all three patterns as a rule are present. In addition, oscillation of the instant COP position around a moving reference point can be distinguished. This oscillation, which we call trembling, is similar to those observed during brief standing tasks; it is analyzed in an accompanying paper (Zatsiorsky & Duarte, 1999).

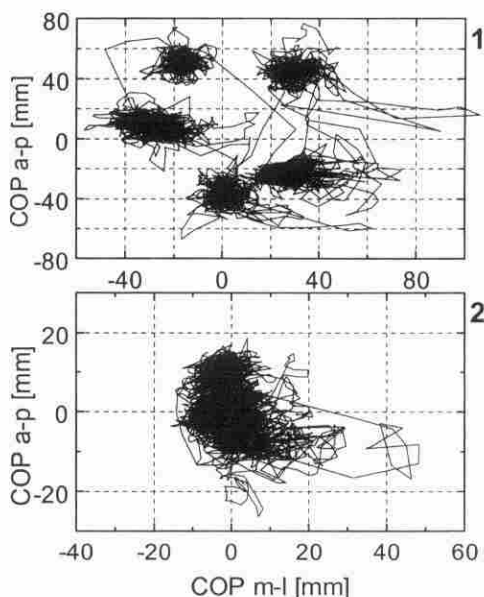
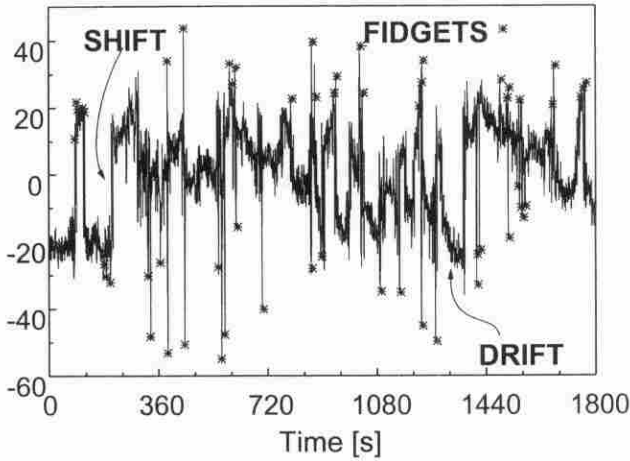


Figure 1 — COP migration in two attempts, a-p vs. m-l direction. (1) Multi-region standing, and (2) single-region standing. The same subject (25-yr-old female, Ht 1.74 m, Wt 59.2 kg) stood twice for 30 min with 1-week interval between trials.



**Figure 2 — COP migration and patterns during PUS, a-p direction (26-yr-old male, Ht 1.85 m, Wt 89.1 kg). Fidget peaks (\*) were selected at a threshold value of  $\pm 3.0$  SD. Of all the shifts and drifts recognized by the computer, one shift and one drift only are shown.**

### Model and Algorithm

A code was written using MatLab software (MatLab 5.1, MathWorks Inc., Natick, MA) with a graphical user interface wherein the parameters for pattern identification could be changed. The user interface allows selection and plotting of data, computation of simple statistics, and the identification of COP patterns based on objective criteria. The pattern recognition algorithm is described below.

#### 1. Shifting

Shifting was detected by comparing average values for consecutive moving windows. To detect shifts in the COP time series, we employed the following procedure:

- 1a. The average,  $\bar{x}_{W1}$ ,  $\bar{x}_{W2}$ , and standard deviation,  $SD_{W1}$  and  $SD_{W2}$ , values for two consecutive moving windows,  $W_1$  and  $W_2$ , separated by the period  $W_s$  were computed.
- 1b. Any two consecutive windows satisfying Equation 1 were classified as a shift.

$$\left| \frac{\bar{x}_{W1} - \bar{x}_{W2}}{\sqrt{SD_{W1}^2 + SD_{W2}^2}} \right| \geq f_{shift} \quad (1)$$

Therefore, identification of the shift pattern depends on the following parameters: (a) threshold value of shift amplitude ( $f_{shift}$ , in units of  $SD_{W1} + SD_{W2}$ ); (b) length of time windows  $W_1$  and  $W_2$ ; and (c) the period separating two consecutive windows,  $W_s$ , as represented in Figure 3.

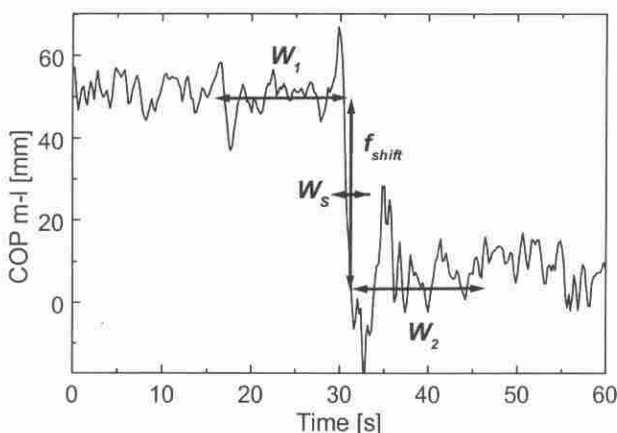


Figure 3 — Shift pattern and the parameters used in the algorithm for recognition.

## 2. Fidgeting

Fidgeting was detected by comparing a peak value with an average of a window centered at the peak. To detect the fidgets in a COP time series, we employed the following procedure:

- 2a. The data between two consecutive shifts were selected, and all peaks and valleys,  $x_F$ , with an estimated width  $\leq 4$  sec,  $W_F$ , were found. The fidget width was estimated as the full width at half maximum (FWHM).
- 2b. A moving window centered in  $x_F$  with the variable length  $W$  was used, and the moving average value,  $\bar{x}_W$ , and the moving standard deviation,  $SD_W$ , were computed.
- 2c. Any peak or valley satisfying Equation 2 was classified as a fidget.

$$\left| \frac{x_F - \bar{x}_W}{SD_W} \right| \geq f_{\text{fidget}} \quad (2)$$

According to Equation 2, the recognition of fidgets depends on the following parameters: (a) threshold value of fidget amplitude ( $f_{\text{fidget}}$ , in units of  $SD_W$ ); (b) length of the time window,  $W$ ; and (c) maximum fidget width,  $W_F$ , as represented in Figure 4.

## 3. Drifting

Drifting was detected to quantify a trend in the experimental data. Drift was identified in the following way:

- 3a. The data between two consecutive shifts were selected and filtered with a low-pass filter with a variable cutoff frequency  $F_C = 1/2W_D$ , where  $W_D$  was the minimal width of the drift.
- 3b. Local maxima and minima values were determined,  $X_{\text{MAX}}$  and  $X_{\text{MIN}}$ .
- 3c. The difference between any consecutive local maxima and minima located farther apart than  $W_D$  was determined.
- 3d. The difference was compared with a preselected threshold value  $f_{\text{drift}}$  (in units of  $SD_W$ ). If the computed difference exceeded  $f_{\text{drift}}$ , Step 3e was taken.

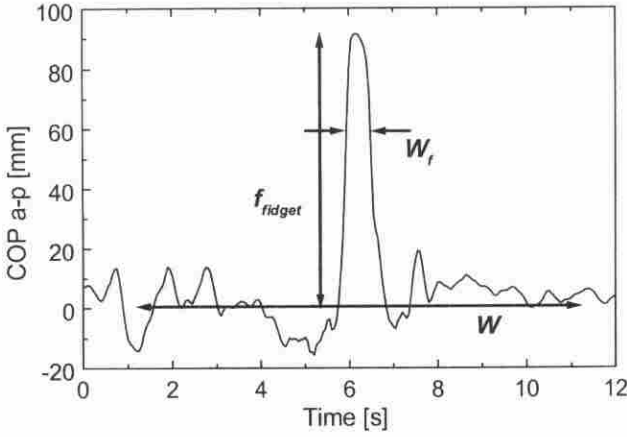


Figure 4 — Fidget pattern and the parameters used in the algorithm for recognition.

- 3e. A coefficient of variation of the data,  $CV = \sum_{i=1}^n \left( \frac{SD_i}{|\bar{x}_i|} \right)$ , was calculated, where  $SD_i$  and  $|\bar{x}_i|$  were, respectively, the standard deviation and absolute mean value of the difference between a raw datum  $i$  and a filtered datum  $i$ . The CV was calculated on the interval between consecutive local maximum and minimum.
- 3f. If the CV was less than a preselected value,  $CV_{drift}$ , and if the consecutive maximum and minimum satisfied Equation 3, the COP migration pattern was classified as a drift.

$$\left| \frac{x_{MAX} - x_{MIN}}{SD_W} \right| \geq f_{drift} \quad (3)$$

Hence, drift recognition depends on (a) threshold value of the drift amplitude ( $f_{drift}$ , in units of  $SD_W$ ); (b) minimum length of a drift,  $W_D$ , which also determines cutoff frequency,  $F_C$ ; and (c) maximum value of the coefficient of variability,  $CV_{drift}$ , as represented in Figure 5.

## The Experiment

Ten healthy adults, 8 men and 2 women, participated in this study. Average age was  $28 \pm 5$  years, height was  $1.79 \pm 0.09$  m, and body mass was  $78 \pm 14$  kg. No subjects had any known history of postural or skeletal disorder. All subjects provided informed consent prior to testing, according to the Office of Regulatory Compliance of The Pennsylvania State University.

The subjects were asked to stand in an upright bipedal posture on a  $40 \times 90$ -cm force platform (model 4060S Bertec Inc., Worthington, OH), considered hard surface. Testing protocol consisted of 3 trials: (a) quiet stance during 40 sec (standard way); (b) prolonged unconstrained standing during 31 min (PUS); and (c) quiet stance during 40 sec (same as in first trial). There were 1-min intervals between trials. The same testing protocol was repeated 1 week later. During testing,

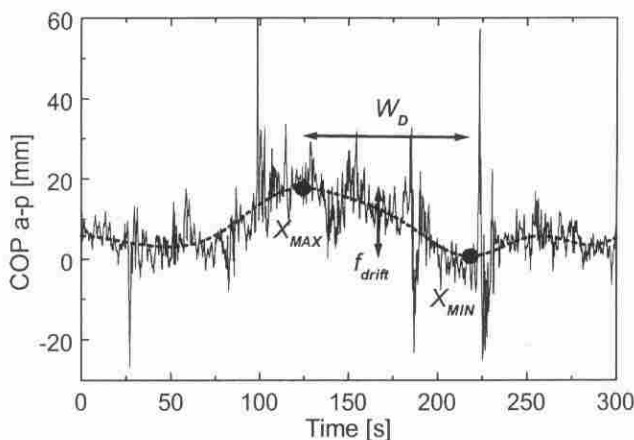


Figure 5 — Drift pattern and the parameters used in the algorithm for recognition.

the subjects stood barefoot with eyes open. Initially they were instructed to stand with their feet separated at a comfortable width (about shoulder-width apart) and arms at sides. In the first and third trials (standard way) they were asked to maintain the same position for the entire trial. In the second trial (PUS) they were allowed to change their posture at any time; there were no specific instructions on how to stand except the requirement to not step off the force platform.

The experiments were conducted in a quiet room measuring  $8 \times 6$  meters; the force platform was positioned in the middle. During the PUS trial each subject was permitted to speak occasionally with a partner sitting or standing in front of him or her about 2 meters away. The topic of the discussion was chosen by the subject and his/her partner, usually a friend. Only the PUS results are presented in this paper.

Data were collected via personal computer (model P5-100, Gateway 2000, Inc., N. Sioux City, IA) with a 12-bit A/D board (model AT-MIO-64E-3, National Instruments Corp., Dallas) controlled by a special code written using LabView software (LabView 4.1, National Instruments Corp.). The signals of three force components and three moment components from the force plate were acquired with a sampling frequency of 20 Hz and the data were recorded for future processing. Data were analyzed with the MatLab software code previously cited. During the trials, some subjects were recorded on video using a standard S-VHS camera for qualitative documentation.

The data collected during the last 30 min of the trial was analyzed for a-p direction (COPa-p) and m-l direction (COPm-l). The first minute of the trial was excluded from analysis to allow the subject to get into a comfortable position and because of the reported nonstationarity of the COP signal at the beginning of the standing trials (Carrol & Freedman, 1993).

Data were analyzed in two stages. During the first stage, the values of the computer algorithm parameters were varied. (The data on the dependence of pattern recognition on the parameter values are described in the next section.) Then, default values of the algorithm parameters were selected and the main analysis was performed. A one-way ANOVA with a 0.05 significance level was conducted on the number of patterns to determine the effects of different trials and time span (see Results section).

## Dependence of Pattern Recognition on Parameter Values

The parameters defining the sensitivity of recognition of the three patterns of COP migration can, in principle, be chosen by the researcher. The chosen values should determine the outcome statistics. But it is almost impossible to avoid subjectivity in assigning parameter values. The following analysis was performed to explore the influence of parameter values on pattern recognition.

### Shifts

The shift recognition depends on (a) shift threshold ( $f_{\text{shift}}$ , in units of  $SD_{W1} + SD_{W2}$ ); (b) length of time windows,  $W_1$  and  $W_2$ ; and (c) the period separating two consecutive windows,  $W_3$ , with the shift threshold being the most important parameter. Two parameters were changed in a systematic manner: the shift threshold ( $\pm 1.0$ ,  $\pm 1.5$ ,  $\pm 2.0$ , and  $\pm 2.5 SD$ ) and length of the window (15, 30, and 60 sec). The shift duration,  $W_3$ , was fixed in 5.0 sec. Results are presented in Figure 6a. In the main study, the following default values were selected: a threshold value of  $\pm 2 SD$ ; a window duration of 15 sec; and a shift duration of 5 sec.

### Fidgets

The fidget selection depends on (a) fidget threshold ( $f_{\text{fidgets}}$ , in units of  $SD_W$ ); (b) length of time window,  $W$ ; and (c) maximum fidget width,  $W_F$ , with the fidget threshold being the most important parameter. Two parameters were changed in a systematic manner: the fidget threshold ( $\pm 1.0$ ,  $\pm 2.0$ ,  $\pm 3.0$ , and  $\pm 4.0 SD$ ) and length of the window (30, 60, and 120 sec). The maximum fidget duration,  $W_S$ , was fixed in 4 sec. Results are presented in Figure 6b. In the main study, the following default values were selected: a threshold value of  $\pm 3 SD$ ; a window length of 60 sec; and a maximum fidget duration of 4 sec.

### Drifts

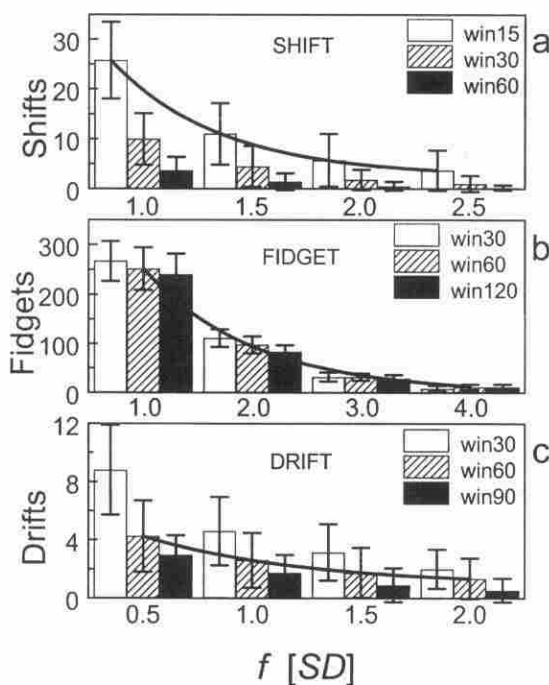
Drift recognition depends on (a) drift threshold ( $f_{\text{drift}}$ , in units of  $SD_W$ ); (b) minimum length of a drift,  $W_D$ , that also determines the cutoff frequency,  $F_C$ ; and (c) maximum value of the coefficient of variation,  $CV_{\text{drift}}$ , with the drift threshold being the most important parameter. Two parameters were changed in a systematic manner: drift threshold ( $\pm 0.5$ ,  $\pm 1.0$ ,  $\pm 1.5$ , and  $\pm 2.0 SD$ ) and length of the window (30, 60, and 90 sec). Maximum coefficient of variation was fixed at 5.0 units. Results are presented in Figure 6c. In the main study, the following default values were selected: a threshold value of  $\pm 1 SD$ ; a window length of 60 sec; and a maximum coefficient of variation of 5.

## Results

The developed algorithm recognized all three COP patterns in all subjects and in almost all trials (20 attempts), except for one attempt in which no shift was recognized and four attempts in which no drift was recognized. The average data (see Table 1) were as follows:

1. A fast displacement of the average COP position from one region to another (shift) took place generally every  $316 \pm 292$  sec in the a-p direction





**Figure 6** — Number of recognized patterns at various threshold values. (a) Shifts: 1.0, 1.5, 2.0, and 2.5 SD for windows of 15, 30, and 60 s; max shift width fixed in 5 s. (b) Fidgets: 1.0, 2.0, 3, and 4 SD for windows of 30, 60, and 120 s; max fidget width fixed in 4 s. (c) Drifts: 0.5, 1.0, 1.5, and 2.0 SD for minimum drift length of 30, 60, and 90 s, the coefficient of variability fixed in 5. (30-min PUS, 10 subjects, 2 trials, a-p direction.)

(range = 82 to 1,800 sec), with an average shift amplitude of  $2.6 \pm 0.9$  SD ( $17 \pm 15$  mm). In the m-l direction, a shift generally occurred every  $199 \pm 148$  sec (range = 75 to >1,800 sec), with an average shift amplitude of  $4.3 \pm 3.9$  SD ( $22 \pm 38$  mm) (Figure 7). The difference between the number of shifts in the a-p and m-l directions was not statistically significant,  $F(3, 36) = 1.55$ ,  $p > 0.05$ . The data were reproducible among trials. The number of shifts in the first and second trials was similar,  $F(1, 18) = 0.17$ ,  $p > 0.05$  for a-p direction, and  $F(1, 18) = 1.22$ ,  $p > 0.05$  for m-l direction.

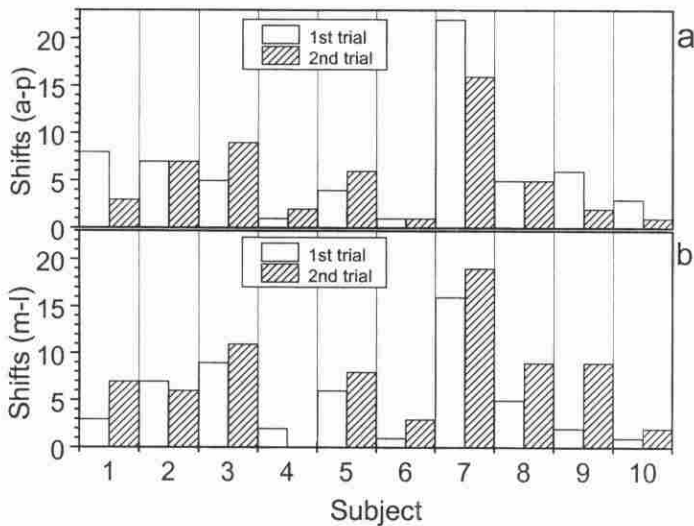
The shifts were observed during both single-region standing and multi-region standing (Figure 1), the only difference being in shift amplitude. There were 3 multi-region attempts, with an average shift amplitude of  $2.7 \pm 0.8$  SD in the a-p direction and  $5.3 \pm 3.6$  SD in the m-l direction; during the 17 single-region attempts the average shift amplitude was  $2.6 \pm 1.0$  SD in the a-p direction and  $3.9 \pm 1.0$  SD in the m-l direction. The shift amplitude was larger in the m-l than in the a-p direction.

2. A fast and large displacement and returning of the COP to approximately the same position (fidget) occurred generally every  $59 \pm 15$  sec in the a-p direction (range = 41 to 112 sec), with an average fidget amplitude of  $4 \pm 1$  SD ( $35 \pm 20$  mm). In the m-l direction, fidgets occurred generally every  $49 \pm 16$  sec (range = 31 to 106 sec), with an average fidget amplitude of  $4.4 \pm 1.5$  SD ( $32 \pm 36$  mm). The

**Table 1    Average Number of COP Migration Patterns Recognized by Algorithm**

Variable	A-P Direction	M-L Direction
Shift (shifts/30 min)	6 ± 5	9 ± 7
Mean amplitude (SD)	2.6 ± 0.9	4.3 ± 3.9
Mean amplitude (mm)	17 ± 15	22 ± 38
Fidget (fidgets/30 min)	30 ± 8	36 ± 12
Mean amplitude (SD)	4 ± 1	4.4 ± 1.5
Mean amplitude (mm)	35 ± 20	32 ± 36
Drift (drifts/30 min)	6 ± 3	3 ± 2
Mean amplitude (SD)	2.5 ± 1.6	1.8 ± 1.1
Mean amplitude (mm)	16 ± 8	12 ± 7
Mean duration (sec)	178 ± 199	165 ± 187

PUS 30 min, 10 subjects, 2 trials, a-p and m-l directions.



**Figure 7 — Number of shifts during 30-min PUS for 10 subjects and 2 trials: (a) for a-p direction; (b) for m-l direction.**

data were reproducible from trial to trial (Figure 8). Most fidgets were in an oblique direction. Therefore the number of their occurrences on the a-p and m-l axes were very similar, on average 30 and 36 fidgets per 30-min trial, respectively. The difference was not statistically significant,  $F(3, 36) = 1.73, p > 0.05$ .

The fidgets were more or less evenly distributed over individual trials without any visible fidget clustering in a given period of the trial (Figure 9). There

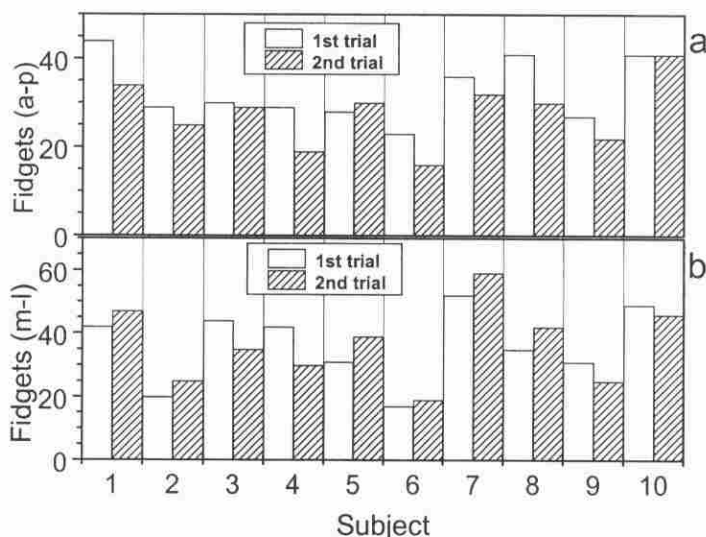


Figure 8 — Number of fidgets during 30-min PUS for 10 subjects and 2 trials: (a) for a-p direction; (b) for m-l direction.

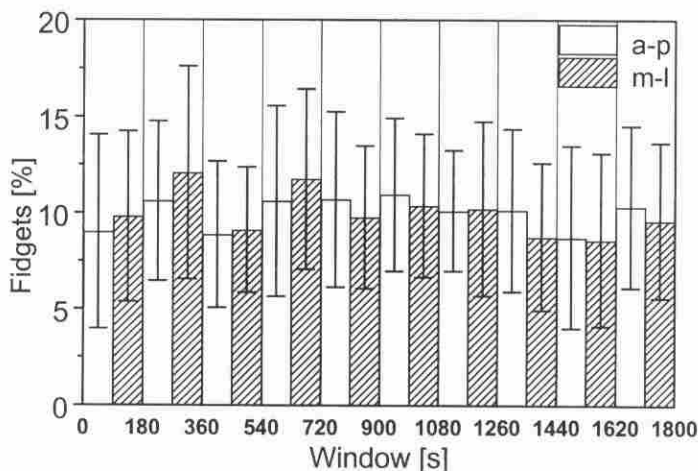
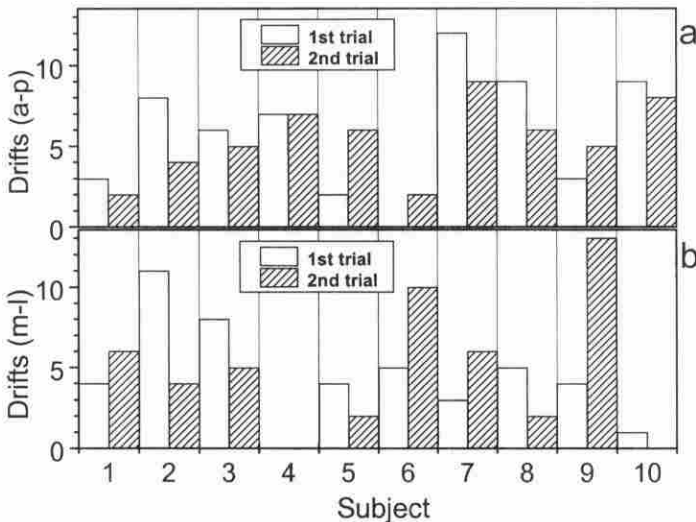


Figure 9 — Fidget distribution for 180-sec window during 30-min PUS, percentage of total number of drifts for each of 10 subjects (2 trials, a-p and m-l directions).

was no difference in the number of fidgets among the time windows for the a-p direction  $F(9, 190) = 0.73$ ,  $p > 0.05$ , and for the m-l direction,  $F(9, 190) = 1.50$ ,  $p > 0.05$ .

3. There was a slow, continuous displacement of the average COP position (drift) in the a-p direction generally every  $319 \pm 173$  sec (range = 150 to >1,800 sec), with an average drift amplitude of  $2.5 \pm 1.6$  SD ( $16 \pm 8$  mm) and average drift duration of  $178 \pm 199$  sec. In the m-l direction, a drift-to-drift interval was generally equal to  $529 \pm 333$  sec (range = 225 to >1,800 sec), with an average drift



**Figure 10 — Number of drifts during 30-min PUS for 10 subjects and 2 trials: (a) for a-p direction; (b) for m-l direction.**

amplitude of  $1.8 \pm 1.1$  SD ( $12 \pm 7$  mm) and average drift duration of  $165 \pm 187$  sec (Figure 10). The data were reproducible among trials. There was no difference between trials both for the a-p direction,  $F(1, 18) = 0.13$ ,  $p > 0.05$ , and the m-l direction  $F(1, 18) = 4.13$ ,  $p > 0.05$ .

Compared to the number of fidgets, the number of shifts and drifts varied substantially between subjects (Figures 7 and 10). The extreme values ranged from 0 to 22 shifts and 0 to 12 drifts.

## Discussion

The main finding of this study was the existence of the three COP migration patterns during prolonged, unconstrained standing. Such patterns as shifts, fidgets, and drifts can be recognized by an appropriate computer algorithm. Note that the patterns were recognized during prolonged standing ( $>30$  min; usually stabilographic testing is limited to 30–90 sec), and the trembling (fast oscillation of COP around a reference point trajectory) was excluded from analysis.

Almost nothing is known about these phenomena. Qualitative observation of the subjects revealed that the three patterns result from various movements of body segments or the body as a whole. The most commonly observed were arms, head, and trunk movement, as well as a shifting of body weight from one leg to the other.

The word fidgeting has been used by some to describe any postural changes without specifying the type of movement. For instance, Bhatnager et al. (1984, 1985) reported that during long sitting tasks the frequency of postural changes ("fidgeting") increased by more than 50% over 3 hours of observation. Alexander (1992) used the word fidgeting to designate posture changes during standing. He suggested that a goal of fidgeting is to change the pressure on the joint cartilage.

We use the term fidgeting in a more specific sense; it is not just any COP displacement but rather a fast deviation and return of the COP to its initial position. Among the identified patterns, fidgeting is by far the most frequent pattern of

COP migration. Because the COP returns to approximately the same position, the fidgets are not performed to change the average position of COP. It may be that fidgeting serves to redistribute the joint pressure, to "repump" joint synovial liquid into the joint cartilage, and/or to alleviate local pressure in the sole of the foot.

When the subjects in the present study were asked to report what they felt during PUS, their most frequent complaint after staying in the same position for few minutes was foot discomfort. One possible reason may be fatigue in the pressure receptors in the soles of the feet. Fidgeting may be a response to this discomfort. Whether fidgets are due to temporal changes in the joint cartilages or to constant pressure on the sole of the foot is not yet known. There may be other reasons, such as preventing leg swelling. These questions cannot be answered without further research.

In contrast to fidgeting, shifting and drifting represent strategies of the CNS to change the average location of COP over long periods. Shifting is a more dramatic and permanent change of COP position than fidgeting; typically it is the result of a redistribution of body weight from one foot to the other, or even a step, or both. The fast transitions from one spot to another during multi-region standing (Figure 1) are related to the shifting pattern. The existence of shifting and drifting fits well into the hypothesis of Lestienne and Gurfinkel (1988), who suggested that the motor control system responsible for maintaining balance is a hierarchical, two-level system. The upper level ("conservative") determines a reference frame for an equilibrium, with respect to which the equilibrium is maintained. The lower level ("operative") maintains the equilibrium around the predetermined reference position.

The hypothesis was supported by the experiments of Gurfinkel et al. (1995). In their experiments, the supporting surface rotated slowly. It was observed that for some time the subjects maintained the fixed body orientation with respect to the surface (the perceived vertical) rather than with respect to the real vertical. Lestienne and Gurfinkel (1988) as well as Gurfinkel et al. (1995) did not address in their studies a possible reference point migration during natural standing.

The present study suggests that such migration does occur. In the framework of the hypothesis, shifting and drifting can be considered two different patterns of the reference point migration. This idea is analyzed further in an accompanying paper (Zatsiorsky & Duarte, 1999).

The reason for a slow change of COP position, drifting, is not clear. Because COP changes its average position very slowly during drifting, this pattern is certainly not an effective and spontaneous solution to avoiding discomfort or preventing falling. Perhaps the drifting simply indicates that the CNS is not sensitive to small changes of average COP position in a certain domain (cf. Collins & De Luca, 1994). During drifting, the body not only migrates as whole but also oscillates around a moving reference point. Only when small displacements accumulate and the total displacement exceeds a certain level does the CNS correct the average COP position.

The average drifting amplitude is 16 mm for the a-p direction and 12 mm for the m-l direction for about 3 min, resulting in an average drifting speed of approximately 0.23 mm/sec. By using a simple inverted pendulum model, the body's average angular displacement during drifting was estimated as  $0.8^\circ$ . Gurfinkel et al. (1995) reported that when the force plate rotated  $1.5^\circ$  very slowly ( $f = 0.006$  Hz), the COG maintained its average position around a slowly moving reference point (thus the gravitational vertical is not used as an absolute reference). Our data are in good agreement with these findings and suggest that during natural standing, the

reference point migrates. Note that the fidgeting was observed during the drifting, indicating that these two processes serve different purposes.

Presently we are at the very beginning of the study of these just discovered phenomena. Many problems should be addressed. What causes the migration patterns? What determines their amplitude and frequency? Exactly how are these movements performed? Other immediate questions center on the role of vision (what is happening with the migration patterns during PUS with the eyes closed?), the role of attention (how does mental concentration change COP migration patterns?), the influence of fatigue (changes during 8-hr shifts in standing workers), the influence of the shoes, tight clothes, surfaces, etc. We plan to address some of these issues in future research.

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