

# The maintenance of erected posture: The velocity control hypothesis

Didier Delignières, Kjerstin Torre and Pierre-Louis Bernard

EA2991 Motor Efficiency and Deficiency, University Montpellier 1, France

[didier.delignieres@univ-montp1.fr](mailto:didier.delignieres@univ-montp1.fr)

Abstract: The displacement of the center of pressure (COP) during the maintenance of quiet posture has often been interpreted as a control of COP position. Basing on an analysis of previous results, we argue that the hypothesis of a control of COP velocity could be more relevant. Applying Detrended Fluctuation Analysis, Stabilogram Diffusion Analysis, and Power Spectral Density analysis on COP position and velocity time series, we show that velocity appears typically bounded within two upper and lower limits. The implications and further developments of this hypothesis are discussed.

Key words: Posture, center of pressure velocity, Stabilogram Diffusion Analysis, Detrended Fluctuation Analysis

The aim of this paper is to put forward a new hypothesis suggesting the essential role of the control of the velocity of the center of pressure (COP) in the maintenance of upright posture. The starting point of our argumentation lies in the contrasted results provided by two fractal-related methods, the Stabilogram Diffusion Analysis (SDA, Collins & De Luca, 1993), and the Detrended Fluctuation Analysis (DFA, Delignières et al., 2003). These two methods are based on the formal definition of *fractional Brownian motion*, characterized by the following scaling law:  $\text{Var}(\Delta x) \propto \Delta t^{2H}$ . When  $H > 0.5$ , the process is persistent, and successive increments are positively correlated. Conversely, when  $H < 0.5$ , the series exhibits anti-persistent behavior.  $H = 0.5$  corresponds to Brownian motion, where successive displacements are uncorrelated.

SDA represents a direct application of this scaling law, and consists in computing the square of the displacement  $[(\Delta x)^2]$ ; i.e. an estimate of  $\text{Var}(\Delta x)$  between all pairs of points separated by a time interval  $\Delta t$ .  $H$  is determined as the slope (divided by 2) of the log-log plot of  $\langle \Delta x^2 \rangle$  as a function of  $\Delta t$ . DFA is based on the assessment of variability within intervals of varying lengths. The series is first integrated, and then linearly detrended within each considered interval. The mean standard deviation within each interval length is determined, and a scaling exponent is estimated as the slope of the double-logarithmic plot of standard deviation as a function of interval length. When applied on COP position series, DFA yields an almost perfect linear slope, whereas SDA provides a typical inflexion, with a positive slope for short intervals, and a flattening beyond a critical  $\Delta t$  value (Delignières et al., 2003).

This inflexion in diffusion plots is known as *crossover phenomenon*, and is typically related to a kind of bounding of the analyzed series (Liebovitch & Yang, 1997). COP position has often been described as bounded within the base of support. Nevertheless, SDA does not include the integration procedure exploited by DFA. Consequently, applying DFA on COP velocity rather than on position should also produce a crossover. This result could imply that bounding affects primarily velocity, rather than position. Bounding effects are essential, because they reflect the variables on which control is performed. This interpretation of SDA results suggests that COP trajectory could be considered the byproduct of a control of the dynamics of velocity within a bounded range. In the present experiment, we applied time series analyses on both COP position and velocity series, in order to verify the plausibility of this velocity control hypothesis.

## Methods and Results

26 participants (19.3 yrs  $\pm$  2.1) were involved in the experiment. They were asked to stay in upright position as still as possible. A force platform was used to record the vertical ground reaction force. Data were recorded for 25.6 sec, yielding series of 1024 points. We first applied SDA on position series, and DFA was applied to position and velocity series.

Figure 1 presents the mean graphical results obtained with the three methods, in the ML direction. Analyses gave qualitatively similar results in the AP direction. In each case, the mean graph was constructed by point-by-point averaging over the 26 participants. SDA yielded typical two-regime diffusion plots. The slopes revealed a highly persistent behavior in the short term. In the long-term, the slope was lower than 0.5, indicative of anti-persistent correlation. For position series, DFA yielded a global positive trend in the diffusion plot. However, the slope was higher in the short term than in the long term. In both cases the obtained slopes revealed persistent dependence. The inflexion of the diffusion plot was clearer when DFA was applied on velocity. In that case the slopes were close to 1.0 in the short term, revealing persistent correlation, but lower than 0.5 on the long term, showing the presence of negative correlations.

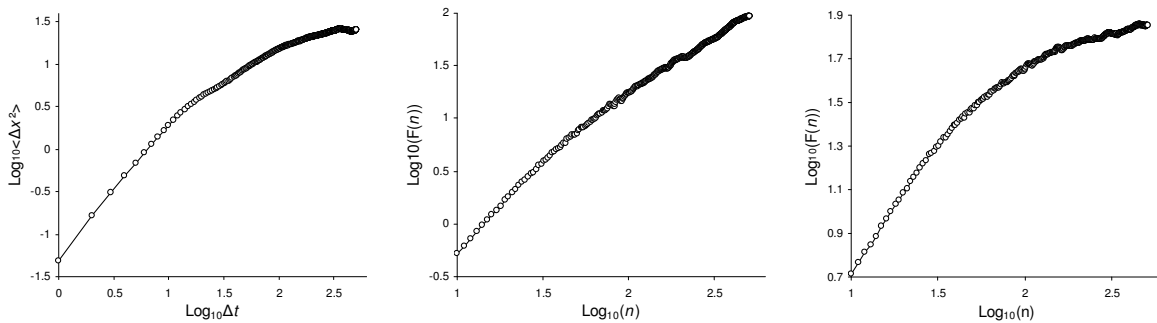


Figure 1: Averaged diffusion plots. left: Stabilogram Diffusion Analysis, applied on COP position. Middle: Detrended Fluctuation Analysis, applied on COP position, right: Detrended Fluctuation Analysis, applied on COP velocity.

## Discussion

These results show that the crossover phenomenon concerns velocity rather than position, and that bounding characterizes primarily velocity. In other words, COP velocity evolves between two (upper and lower) limits. Its evolution, from one boundary to the other, looks similar to that of a fractional Brownian motion (considering the slopes obtained in the short-term region for DFA). The dynamics observed in the long-term results from the systematic to-and-fro of velocity within the range defined by the upper and lower boundaries. These results suggest that an intermittent control of velocity, reversing its dynamics when a threshold is reached, could represent the main ingredient generating COP trajectory. This hypothesis suggests that control does not occur at the periphery of COP trajectory (i.e., when balance could be considered precarious), but, rather, somewhere in the central part of the stabilogram, when velocity reaches its maximal (positive or negative) values. The present study allows proposing new variables of interest in the study of postural control. Beyond the signatures of serial dependence presented in this study, the mean (absolute) value of the threshold that bounds velocity could be particularly interesting. Further research is needed to check whether task modalities (e.g., vision/non vision, hard/soft surface) and individual characteristics (e.g., age) could affect these variables.

## References

- Collins JJ, De Luca CD. Open-loop and closed-loop control of posture: A random-walk analysis of center-of-pressure trajectories. *Experimental Brain Research* 1993; 95: 308-318.
- Delignières D, Deschamps T, Legros A, Caillou N. A methodological note on non-linear time series analysis: Is Collins and De Luca (1993)'s open- and closed-loop model a statistical artifact? *Journal of Motor Behavior* 2003; 35: 86-96.
- Liebovitch LS, Yang W. Transition from persistent to antipersistent correlation in biological systems. *Physical Review E* 1997; 56, 4557-4566