Exploring the dynamics of postural sway in humans using recurrence quantification analysis

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In humans, postural sway during quiet standing can be measured through the fluctuations of the center of pressure (COP) by means of a force platform (Winter, 1995). COP time series are irregular, non-stationary and exhibit high variability. The complexity of such data has motivated human movement scientists to go beyond the classical kinematical measures derived from COP signals (Collins & DeLuca, 1993; Yamada, 1995; Riley et al., 1999; Costa et al, 2007; Ramdani et al., 2009).

Recurrence Quantification Analysis (RQA) is a nonlinear tool for the characterization of the underlying dynamics of time series (Eckmann et al., 1987; Zbilut & Webber, 1992, 1994; Marwan et al., 2007). It can be applied to non-stationary data. RQA has been first applied to COP by Riley et al. (1999). Others have used RQA to explore the effect of disease or aging on postural dynamics (Schmit et al., 2006; Seigle et al., 2009). Generally, the high level of percentage of determinism (DET) output of RQA is implicitly associated to the presence of nonlinear determinism in COP time series. The nature of their dynamics is still discussed in the literature (Pascolo et al., 2005, 2006; Ramdani et al., 2009). Here, we propose to test the hypothesis of the presence of nonlinear determinism by combining the computation of DET with the Monte-Carlo based approach of phase randomized surrogates (Theiler et al., 1992).

We recruited 10 young and healthy adults who were tested in two visual configurations. The data were analyzed in both anteriorposterior (AP) and mediolateral (ML) directions. The recordings lasted for 51.2 sec. The sampling frequency was 40 Hz, leading to 2048-points time series.

After extracting 1800-points subsequences minimizing the end-to-end mismatch, we generated 39 iteratively refined amplitude adjusted Fourier transform (iAAFT) surrogates (Schreiber & Schmitz, 1996, 2000) for each recorded time series. iAAFT surrogates are designed to test the null hypothesis $\mathcal{H}_0$ of a linear stochastic underlying process. RQA was then performed on both original subsequences and their surrogate counterparts (with time delay 6, embedding dimension 8, radius 0.25 of mean distance and $l_{min} = 4$). The DET measure was used as a discriminating statistic.

The recurrence rates were 0.0749 ± 0.0435 (AP) and 0.0564 ± 0.0238 (ML). The DET values were 0.9650 ± 0.0289 and 0.9761 ± 0.0117. The null hypothesis $\mathcal{H}_0$ was rejected for only 4 of the 40 analyzed time series.

Our conclusion is that the high COP DET values are not the result of a nonlinear determinism but probably caused by the correlations characterizing these data. Indeed, it has been reported that DET is not a measure of determinism and that it can be related to the correlations observed in the analyzed time series (Marwan & Kurths, 2009). This result is in accordance with the stochastic modeling of COP time series (Collins & DeLuca, 1993, 1995; Bosek, 2008).