Fractal models for uni-manual timing control

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Robertson et al. (1999) showed that timing variability in discrete tasks (tapping) was not correlated with timing variability in continuous tasks (circle drawing). Zelaznik, Spencer & Ivry (2002) proposed to distinguish between event-based timing (discrete tasks), and emergent timing (continuous tasks). Event-based timing is conceived as prescribed by events produced by a central clock, and emergent, or dynamical timing refers to the exploitation of the dynamical properties of the effectors.

We recently showed that these two timing processes present distinct spectral signatures, contrasted by opposite behaviors in high frequencies (Delignières, Lemoine & Torre, 2004). Event-based timers are characterized by a positive slope in the high frequency region of the log-log power spectrum, whereas dynamical timers are revealed by a simple flattening of the spectrum in this region. We also evidenced that both timers produced interval series possessing fractal properties.

The aim of this paper is to present two models that produce time interval series presenting the statistical properties previously evidenced in discrete and continuous rhythmic tasks. The first one is an adaptation of the classical activation/threshold models. This 'shifting strategy model' was introduced by Wagenmakers, Farrel and Ratcliff (2004), and suggest that (1) the threshold present plateau-like non-stationarity over time, and (2) the speed of activation increase varies between successive trials according to an auto-regressive process. This first process is completed by the addition of a differenced white noise, according to the principles of the Wing and Kristofferson (1973)'s model. This first model was expected to take account for the time series observed in tapping experiments.

The second model is derived from the 'hopping model' proposed by West and Scafetta (2003). A Markov chain obeying an auto-regressive process is supposed to represent a set of (correlated) potential states of the effector. A random walk is the performed on this chain, providing the series of stiffness parameters of a dynamical hybrid model (Kay et al., 1987). This second model was expected to take account for the time series observed in unimanual oscillations.

As showed in Figure 1, both models reproduced satisfactorily the spectral signatures of, respectively, event-based and dynamical timing processes. The models also produced auto-correlation functions similar to those observed experimentally, with a negative lag-one autocorrelation for the shifting strategy model, and then slightly positive, and persistent correlation for lag superior to one, and a persistent, power-law auto-correlation function for the hopping model. We show, using ARFIMA modeling, that these simulated series possess fractal properties.

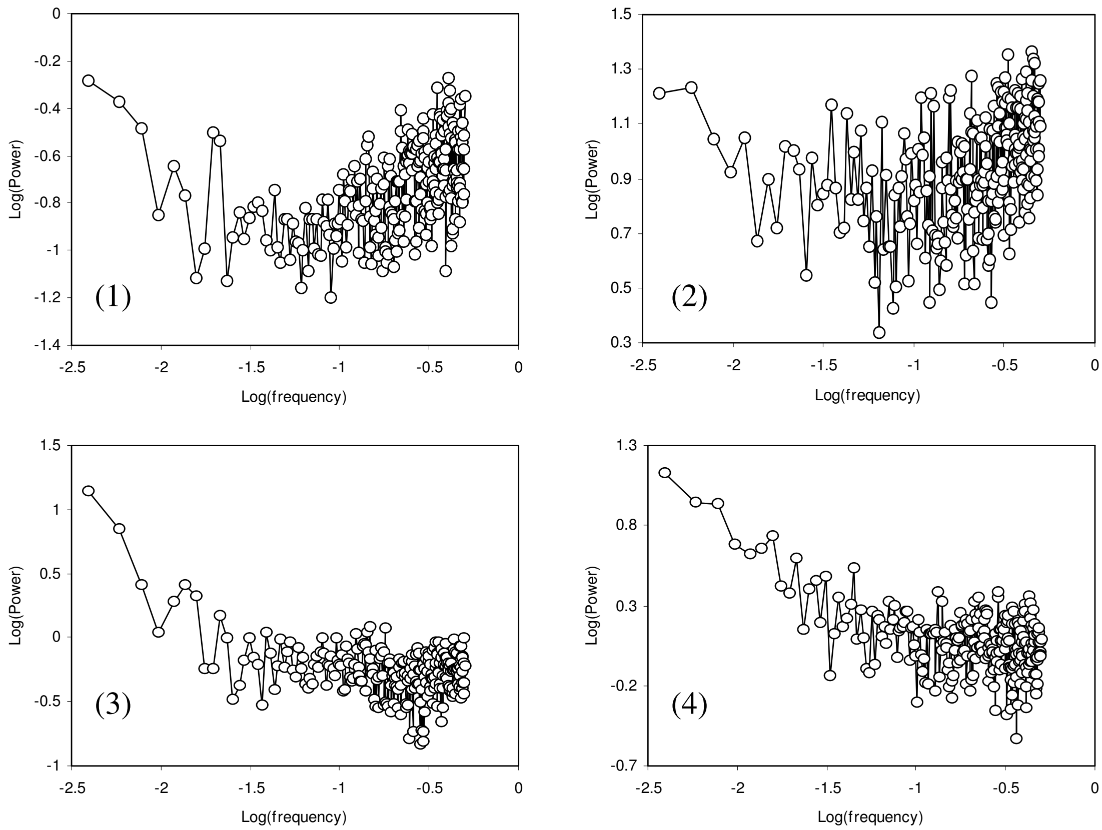

Figure 1: Log-log power spectra obtained (1) in a tapping experiment, (2) with the shifting strategy model, (3) in a uni-manual oscillation experiment, and (4) with the hopping model.

These two models provide believable solutions for simulating simple timing behaviors. They could in the future allow a better understanding of more complex process, and notably the control of relative timing in coordination tasks. On a more theoretical point of view, both models show that fractal fluctuations could arise from the combination of an auto-regressive process and a random walk, suggesting a possible universal source for 1/*f* noise in natural systems.

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