

# **Scaling in heart rate and speed dynamics of runners in the marathon race.**

Running Head: Heart rate and speed dynamics in marathon running.

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## **Abstract**

We report the modification of the scaling dynamics of human heart rate (HR in  $\text{beat}\cdot\text{min}^{-1}$ ), speed (S in  $\text{km}\cdot\text{hour}^{-1}$ ) and cardiac cost (the Heart Rate / Speed ratio, HRS in  $\text{cardiac}\ \text{beats}\cdot\text{m}^{-1}$ ) was investigated in ten male subjects ( $35\pm 5$  yrs) who ran a marathon. The scaling power law was observed using the detrended fluctuation analysis (DFA) and the wavelet structure function. The corresponding scaling law exponents  $\alpha$  and  $\tau$  were estimated as the slope of the segment lines which fit respectively the DFA function graph and the wavelet structure function graph in a log-log representation. For all the signals, two distinct regions of DFA scale invariance, [0.4 -1.8] and [1.8-2.3] with the corresponding short-range ( $\alpha_1$ ) and long-range scale ( $\alpha_2$ ) exponents were identified in both half marathon races and  $\alpha_1$  was significantly higher than  $\alpha_2$  ( $p<0.0001$ ).  $\alpha_1$  and  $\alpha_2$  of HR increased as the race progressed ( $p<0.01$ ) and only  $\alpha_1$  (short scaling) for S. The HR wavelet scaling exponent ( $\tau$ ) increased significantly during the race ( $p<0.01$ ). These results demonstrate that a long exhaustive run affects the fractal short scaling of heart rate and speed.

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## Introduction

Cardio respiratory dynamics have revealed fractal scaling in the organization of heart rate, blood pressure and respiration rate [29, 36, 40, 44, 47, 62, 63, 64 ]. Dynamical systems are driven by competitive forces, e.g. parasympathic versus sympathetic stimuli [21, 37, 39, 49, 72,]. To investigate the nonstationarity of the heart rate which changes when a subject rises to a standing position, methodologies such as detrended fluctuation analysis (DFA) and wavelets scaling behaviour have been developed [11, 14, 36, 37, 38, 39, 61]. The distribution of the HR variation in healthy subjects has been described by a DFA function over a wide range of time-scales and the observed fractal scaling behaviour indicates the presence of long range (power law) correlations [1,14, 36, 38]. The detrended long memory process of a time series is estimated by a scaling behaviour exponent ( $\alpha$ ) which is the slope of the linear regression fit of a scale dependent quantity versus the scale in logarithmic representation and  $\alpha$  is usually close to 1. This long-range HR correlation behavior is shown to breakdown in older persons or in persons with severe congestive heart failure [30, 36, 40, 64, 69 ].

However, while more and more cases of sudden cardiac death have been reported during exercise, only a limited number of publications have focused on the effects of exercise on the statistical properties of the heart rate signal. For example, myocardial injury and ventricular dysfunction related to training levels among non elite participants in the Boston Marathon has recently been reported [55]. Twenty years ago, cardiac fatigue in subjects who completed the Hawaii

Ironman Triathlon (2.4 mile swim, 112 mile bike, and 26.2 mile run in  $28\pm 9$  hr) was demonstrated [25]. However, researchers are still unsure about how fatigue, induced by exercise, modifies the heart rate beat to beat variability in the context of exhaustive long exercise such as the marathon where there is an increase in the occurrence of sudden death in participants [51, 66 ]

A multifractal analysis of heart rate time series during 10 km races and marathon was presented in an attempt to unveil the scaling law behaviour using the Wavelet Transform Modulus Maxima (WTMM) method proposed by Arneodo et al. [9], which estimates the spectrum of singularities of the Hölder exponents using multifractal formalism [74]. This work previously undertaken by the present research group demonstrated that the distribution of the variations in the beat-to-beat intervals in healthy subjects was described by a structure function over a wide range of scales and that fatigue did not significantly alter the scaling behaviour of the HR time series [75].

However, this study by Wesfreid and co-workers [75] did not apply the DFA method which has been reported to be a particularly robust estimator [60] for small series and for signals with superimposed linear trends as reported in the heart rate time series (the so-called “cardiovascular drift”) reported in long and intense exercise [22, 23, 68] Furthermore, the speed time series was not examined. We suggest that speed regulation could be one of the major causes of the absence of HR drift in free pace exercise. Indeed, some studies have suggested that humans might regulate their effort during competition based on

practice and prior competitive experience and on feedback from a variety of receptors that monitor the physiological responses to the demands of the activity [57, 68]. Recent reports have suggested that the rate of development of peripheral locomotors muscle fatigue was a “regulated” variable (20). Researchers have also suggested that sensory feedback from the fatiguing muscle would modulate central motor output [2, 3, 4, 67].

The present study aimed to test the possible alterations of the scaling dynamics of speed and heart rate during a marathon event. We compared the two half marathon and we hypothesized that as for pathologic conditions, the long exhaustive exercise, as the marathon, decrease the heart rate scaling.