Attentional and emotional tasks: gender differences in heart rate variability detected by short-term detrended fluctuation analysis

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***Abstract*—In this study we analyzed the heart rate variability of 21 subjects, 12 females and 9 males performing a two-step task. The subjects were requested to watch a relaxing movie for 30 minutes and, in a different day, to watch a stressful movie again for 30 minutes. The electrocardiographic signal was recorded for all the duration of the sessions. The series of the beat-to-beat time intervals were analyzed by detrended fluctuation analysis. The short-term variability index $\alpha 1$ clearly indicated a significant gender difference independently of the specific movie, while $\alpha 2$ did not reveal any significant difference of gender and task. This finding contrasts with the results of physical stimulation, which abolishes the gender differences observed in resting conditions. The discrepancy may depend on lower autonomic engagement in cognitive/affective than in physical tasks as well as on a possible different balance of the sympathetic and parasympathetic activities.**

***Index Terms*—heart rate variability (HRV), detrended fluctuation analysis (DFA), attentional task, emotional task.**

INTRODUCTION

Since its first appearance in 1994, Detrended Fluctuation Analysis (DFA) [1] has been widely employed to study the fractal-like characteristics of time series recorded in many different fields: finance, environment, biology, medicine, physiology, to cite a few. One of the most analyzed physiological time series is the heart rate recorded in different pathophysiologic conditions. DFA proved to be useful in characterizing different physiological conditions and in supplying diagnostic and prognostic indices in various cardiac diseases [2]-[9]. Originally DFA was aimed at investigating long-range correlations and, in cardiological studies, was applied to heart rate time series derived from 24-h electrocardiogram (ECG) recordings (ECG Holter monitoring). These studies clearly demonstrated that the heart rate variability (HRV) can be indifferently characterized by unique dynamics along all the scales investigated or by the presence of a crossover separating two different dynamics, one for small scales, up to about 11 cardiac beats (short-term dynamics), and a second for higher scales (long-term dynamics). In particular, DFA short-term index, usually indicated as $\alpha 1$, seems to yield prognostic information on post-infarction and cardiac arrhythmias and to be a risk marker of cardiac death in elderly people [3]-[8]. Besides that, studies on healthy subjects showed that the gender difference observed in resting condition disappeared during various *physical tasks* (supine rest, sitting, exercising) [9]. In this study we investigated whether gender differences can be detected also during tasks where attention and emotion are involved.

METHODS

Subjects and experimental procedure

Data from 21 healthy, drug-free students of the University of Pisa (12 females and 9 males, age 19–30) were recorded during an experimental procedure approved by the Ethics committee of the University of Pisa. The procedure included 2 separate sessions consisting of an attentional task (AT: watching an emotionally neutral movie, duration 30 min) and of an emotional task (ET: watching a stressful movie, duration 30 min). AT and ET had been previously administered to 50 subjects not included in the present study and had been judged as relaxing and stressful, respectively, by all of them. Both movies, previously unknown by the participants, were shown on a computer screen (15 in.) positioned 150 cm far from the subjects, at head level, in a light- and sound attenuated room. The two experimental sessions took place in the morning (9.00–12.00), separated by at least 3 days. Females were tested during the second week after their last menses. Participants were comfortably seated in an arm-chair and asked to be silent and avoid movements as much as possible. During both sessions the ECG signals was recorded through Red Dot™ Ag/AgCl disposable electrodes placed according to the standard D1 lead. The tachogram, that is the series of the interbeat intervals (RR) was obtained using a QRS complex detector based on threshold on derivative signal [10]. Artifacts due to false positive were removed through a predictive filter with a threshold on prediction error [11].

Detrended fluctuation analysis

Detrended fluctuation analysis is a technique aimed at investigating the fractal-like properties of a time series even in presence of nonstationarities, when classical correlation analysis cannot be correctly applied. The DFA can be accomplished according to the steps briefly described below. The time series $\{x_t\}$ is first integrated and then divided into equal, nonoverlapping windows of length *n*. Next, least-squares linear regression line fit, which represents the local trend, is computed in each window. The integrated series is detrended by subtracting its local trend. The local detrended functions are then averaged over all the windows of length *n*. This procedure is repeated for increasing window sizes to obtain a relationship between the averaged detrended function *F(n)* and the window size *n*. For fractal-like signals, a power law relation exists between *F(n)* and *n*, that is $F(n) \sim n^{\alpha}$. The value α ranges in the interval $0< \alpha \leq 1$. A value of $\alpha=0.5$ indicates a completely uncorrelated dynamics (i.e. white noise). When $\alpha<0.5$, the dynamics is antipersistent, that is high values alternate with low values, while persistence, where high values are likely to be followed by still high values, is present when $0.5< \alpha<1$. The value $\alpha=1$ corresponds to the special case of *1/f* power law behavior. Values ranging between $1<\alpha<1.5$ characterize fractional Brownian motion while a value $\alpha=1.5$ is obtained for Brownian motion. Fig. 1. shows the typical DFA behavior for autocorrelated fractional Gaussian noise, generated with Hurst exponent H=0.85 (upper panel), and white noise with Hurst exponent H=0.5 (lower panel). In both examples the dynamics is unique and therefore it is characterized by a single α exponent very close to H, as expected. Usually the analysis of heart rate variability with DFA is performed by computing two slopes: one ($\alpha 1$) for small window sizes, i.e. for $n\leq 11$ cardiac beats, and the other ($\alpha 2$) for larger windows, generally not exceeding N/4 (N=series length). In this study the RR time series were analyzed using DFA and the slopes $\alpha 1$ and $\alpha 2$ were computed in the windows of length $4<n\leq 11$ and $12\leq n\leq 180$, respectively.

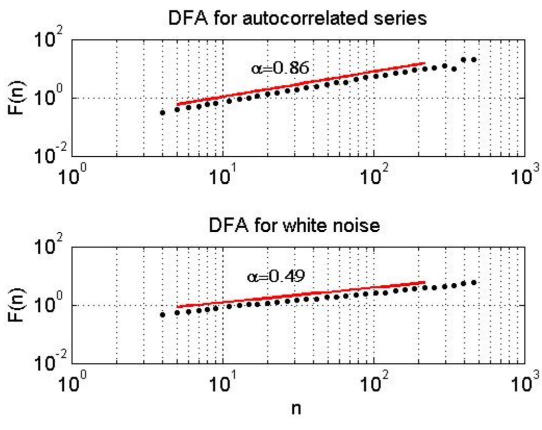

Fig. 1. Log-log plot of DFA of two simulated series of 2048 data: fractional Gaussian noise (upper panel) and white noise (lower panel), both showing a unique linear relationship.

A. Statistical analysis

The values $\alpha 1$ and $\alpha 2$ were analyzed according to a 2 Genders (Females, Males) x 2 Sessions (AT, ET) repeated measures ANOVA design (SPSS.15). Statistical significance was set at $p<0.05$.

RESULTS

Significant gender difference was observed for $\alpha 1$. In fact females showed significant lower $\alpha 1$ values with respect to males ($F(1,19)=6.772$, $p<0.0018$). This gender difference was independent of the specific session (Fig. 2).

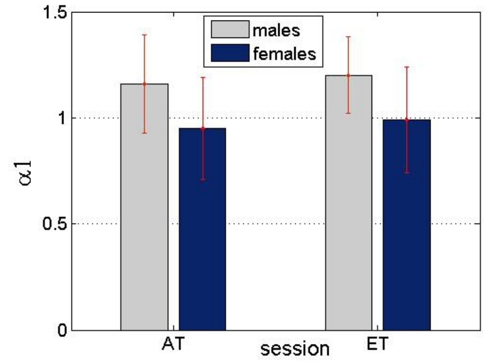

Fig. 2. Mean of $\alpha 1\pm$sd for males and females in sessions AT and ET

The value $\alpha 2$ did not show any significant effect; its value approached the one detected in 24-hour heart rate variability studies, probably indicating that longer-term variability is modulated by the same actors (neurologic, chemical, hormonal) in both genders. The DFA behavior of one female (upper panel) and one male (lower panel) is shown in Fig.3. Table I reports the values of $\alpha 1$ and $\alpha 2$ for males and females for session AT and session ET.

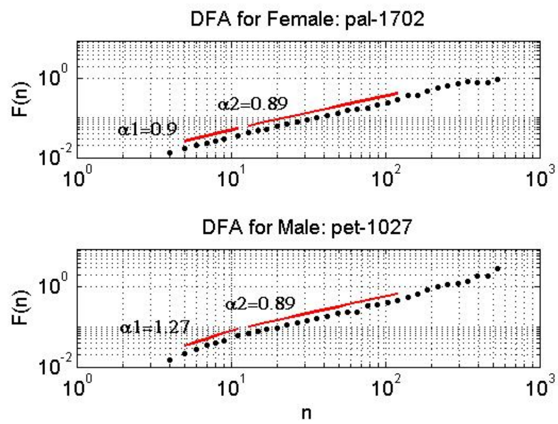

Fig. 3. Log-log plot of DFA of a female (upper panel) and a male (lower panel). The female exhibits a linear relationship with a unique slope, while the male exhibits a crossover at about 11 beats. Above the crossover both subjects have the same α value.

CONCLUSIONS

Although DFA was originally introduced for the investigation of long-term dynamics, guidelines do not exist suggesting the time series minimum length necessary for DFA to be correctly applied: it strictly depends on the dynamical characteristics of the series (e.g. slow dynamics necessitates of longer length to be captured) and the object of investigation (either long- or short-term variability).

TABLE I. MEAN VALUES ± STANDARD DEVIATION OF $\alpha 1$ AND $\alpha 2$ OF MALES AND FEMALES

Session	Slopes (mean±sd)	males	females
AT	$\alpha 1$ $\alpha 2$	1.16±0.23* 0.89±0.11	0.95±0.24 0.84±0.11
ET	$\alpha 1$ $\alpha 2$	1.20±0.18* 0.92±0.09	0.99±0.25 0.88±0.11

*, p<0.01

Some recent studies, in fact, demonstrated the reliability of DFA when applied also to short periods of ECG recordings of 15 [8] or even 10 minutes [9]. In our study the DFA was applied to 30-min RR time series recorded in a group of young healthy subjects during an attentional and an emotional task. Even though the present findings must be considered preliminary owing to the low number of subjects, it is noticeable that $\alpha 1$, which reflects the dynamics of the fast variability of the heart rate, is sensitive to gender during both tasks. This indicates that attention is associated with gender-related heart rate variability independently of emotion. However, gender modulation is not elicited by the attentional requests, as they have been detected by DFA also in resting conditions [9], and should be considered a simply gender related trait. The present results on attentional/emotional stimulations contrast with those obtained during physical stimulation, which abolished the gender differences observed in resting conditions [9]. The discrepancy may depend on a higher autonomic engagement in physical tasks as well as on a possibly different balance of the sympathetic and parasympathetic activities in response to the different nature of stimulations. In support of the last hypothesis it can be observed that gender differences, with lower $\alpha 1$ values in females, as occur in our subjects, have been observed in response to a physical stimulation (supine rest) characterized by high parasympathetic and low sympathetic tone. Finally, the current findings support the feasibility of using DFA over short intervals of heart rate time series, thus increasing its potential role in clinical settings, in which long-term experiments are not always practical to perform.

ACKNOWLEDGMENT

The authors wish to thank Giulia Paoletti and Eliana Scattina for helping in data acquisition.

REFERENCES

[1] C.K. Peng, S.V. Buldyrev, S. Havlin, M. Simons, H.E. Stanley & A.L. Goldberger, "Mosaic organization of DNA nucleotides," Phys. Rev. E, vol. 49, pp. 1685–1689, 1994.

[2] C.K. Peng, S. Havlin, H.E. Stanley & A.L. Goldberger, "Quantification of scaling exponents and crossover phenomena in nonstationary heartbeat time series," Chaos, vol. 5, pp. 82–87, 1995

[3] H. V. Huikuri, T. H. Mäkikallio, C. K. Peng, A. L. Goldberger, U. Hintze, & M. Moller, "Fractal correlation properties of R-R interval dynamics and mortality in patients with depressed left ventricular function after an acute myocardial infarction," Circulation, vol. 101, pp. 47–53.', 2000.

[4] T. H. Mäkikallio, S. Hoiber, L. Kober, C. Torp-Pedersen, C. K. Peng, A. L. Goldberger, & H. V. Huikuri, "Fractal analysis of heart rate dynamics as a predictor of mortality in patients with depressed left ventricular function after acute myocardial infarction. TRACE investigators. TRAndolapril cardiac evaluation," Am. J. Cardiol., vol. 83, pp. 836–839, 1999.

[5] T. H. Mäkikallio, J. Koistinen, L. Jordaens, M. P. Tulppo, N. Wood, B. Golosarsky, C. K. Peng, A. L. Goldberger & H. V. Huikuri, "Heart rate dynamics before spontaneous onset of ventricular fibrillation in patients with healed myocardial infarcts," Am. J. Cardiol., vol. 83, pp. 880–884, 1999.

[6] J. M. Tapanainen, P. E. Thomsen, L.Kober, C. Torp-Pedersen, T. H. Mäkikallio, A. M. Still, K. S. Lindgren & H. V. Huikuri, "Fractal analysis of heart rate variability and mortality after an acute myocardial infarction," Am. J. Cardiol., vol. 90, pp. 347–352, 2002.

[7] H. V. Huikuri, J. S. Perkiömäki, R. Maestri and G. D. Pinna, "Clinical impact of evaluation of cardiovascular control by novel methods of heart rate dynamics," Phil. Trans. R. Soc. Vol. A367, pp. 1223–1238, February 2009.

[8] R.G. Yeh , J.S. Shieh , G.Y. Chen, C. D. Kuo, "Detrended fluctuation analysis of short-term heart rate variability in late pregnant women, " Autonomic Neuroscience: Basic and Clinical, vol. 150, pp. 122–126, 2009.

[9] P. Castiglioni, M. Di Rienzo, "Gender related differences in scaling structure of heart-rate and blood-pressure variability as assessed by detrended fluctuation analysis", Computing in Cardiology vol. 37, pp. 137−140, 2010.

[10] A. Taddei, C. Marchesi, L. Landucci, "Performance comparison of fast QRS detection algorithms," in Journal of Ambulatory monitoring, C. Marchesi, Eds. The Hague: 1984, pp. 189–207.

[11] M. Varanini, A. Taddei, R. Balocchi, A. Macerata, F. Conforti, M. Emdin, C. Carpeggiani, C. Marchesi, "Adaptive modeling of biological time series for artifact detection," Computers in Cardiology, vol. 20, pp. 695–698, 1993.