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Long-range correlations in heart rate variability during computer-mouse work under time pressure

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ABSTRACT

The aim of this study was to investigate the influences of time pressure on long-range correlations in heart rate variability (HRV), the effects of relaxation on the cardiovascular regulation system and the advantages of detrended fluctuation analysis (DFA) over the conventional power spectral analysis in discriminating states of the cardiovascular systems under different levels of time pressure. Volunteer subjects ($n = 10$, male/female $= 5/5$) participated in a computer-mouse task consisting of five sessions, i.e. baseline session (BSS) which was free of time pressure, followed by sessions with 80% (SS80), 100% (SS100), 90% (SS90) and 150% (SS150) of the baseline time. Electrocardiogram (ECG) and task performance were recorded throughout the experiments. Two rest sessions before and after the computer-mouse work, i.e. RS1 and RS2, were also recorded as comparison. HRV series were subsequently analyzed by both conventional power spectral analysis and detrended fluctuation analysis (DFA). The long-term scaling exponent α_2 by DFA was significantly lower in SS80 than that in other sessions. It was also found that short-term release of time pressure had positive influences on the cardiovascular system, i.e. the α_2 in RS2 was significantly higher than that in SS80, SS100 and SS90. No significant differences were found between any two sessions by conventional power spectral analysis. Our results showed that DFA performed better in discriminating the states of cardiovascular autonomic modulation under time pressure than the conventional power spectral analysis.

1. Introduction

Computers nowadays are widely used in business management, industrial control, scientific research, student education, entertainment, family life and etc. It is difficult to find an area without use of computers. The intensive involvement of computers has also greatly improved the productivity of the work, but computer-based work also requires much higher synchrony in the process, e.g. sometimes people need to complete their tasks within limited time to avoid the piling up from the upstream and the downstream waiting. Such timing commitments are also very popular in computer games. Scientists have noticed that the psychosocial stress, which was linked to kinds of cardiovascular diseases (CVDs), such as cardiac arrhythmias [1], myocardial infarction [2] and sudden cardiac death [3], could be caused by computer work under time pressure. One of the main mechanisms relating to psychosocial stress and CVDs is a rapid increase of heart rate and arterial pressure, induced by increased sympathetic activity, decreased vagal activity, transitory endothelial dysfunction and atherothrombotic activation [4]. Thus, it would be useful to study the influences of computer work under time pressure on the cardiovascular system by quantitative means of assessing sympathetic and parasympathetic activities.

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In previous studies [5,6], power spectral analysis of HRV had been applied to quantitatively assess the functioning of the short-term cardiovascular autonomic activities during computer work under time pressure. Heiden et al. [5], however, found that the spectral characteristics of HRV, e.g. power in low frequency (LF), high frequency (HF), LF/HF ratio and etc., did not differ significantly between the more demanding task (i.e. time pressure and precision demands were imposed during the task) and the less demanding task. Similarly, Wahlström et al. [6] found that there was no significant difference in the LF/HF ratio between control condition and stress condition in the Stroop color and word test (CWT) involving time pressure and stressful verbal provocation. Therefore, alternative methods should be tried to explore the changes of the cardiovascular autonomic modulation during computer work under time pressure.

In recent years, detrended fluctuation analysis (DFA), proposed by Peng to explore the long-range correlations embedded in the data [7], has been successfully applied to a wide range of research fields, e.g. DNA sequences [8], neural signals [9], meteorology [10] and heart rate dynamics [11,12]. Some evidences had demonstrated that modifying the relative importance of sympathetic and parasympathetic nervous systems could lead to changes of the long-range correlations embedded in HRV series [13]. Moreover, scientists found that the long-range correlations by detrended fluctuation analysis of HRV had advantages over the conventional spectral analysis due to its independence of human behavior [13–15] and had been also proved to be useful in diagnosis of cardiovascular diseases [16–18].

The aim of this study is to investigate the changes of long-range correlations in HRV series during computer-mouse work under different levels of time pressure, and how much the relaxation influences on autonomic neural regulation. Additionally, we are going to compare DFA with conventional power spectral analysis in discriminating states of the cardiovascular systems under different levels of time pressure.

2. Materials and methods

2.1. Subjects

Ten healthy university students ($n = 10$, male/female $= 6/4$, age $= 22.3 \pm 2.2$ yrs, height $= 166.4 \pm 5.0$ cm, weight $= 55.6 \pm 5.9$ kg), volunteered to take part in the study after signing the informed consent agreements. All subjects were experienced computer-mouse users and right-handed, and none of them had any history of cardiovascular diseases. They were asked to arrive at the laboratory at least ten minutes before the experiments, and not to participate in strenuous physical exercises immediately prior. All subjects were financially compensated for their participation regardless of their performances in the experiments.

2.2. Protocols

The subjects were seated comfortably about 80 cm in front of a 19 in. computer display (LXM-L19CH, Lenovo, China, resolution 1280×1024 pixels). The ECG signals were continuously recorded with electrodes (Model 2146, Vanwa, China) attached on the inner sides of two forearms and the right ankle according to the driven-right-leg system. The signals were amplified (Dual BIO Amp (ML135), ADInstruments, Castle Hill, Australia) before the A/D conversion by a recording system (Powerlab/16sp, ADInstruments, Castle Hill, Australia) at 1000 Hz. The computer-mouse work task was modified from previous studies [19,20]. A screen shot of the task is shown in Fig. 1. During the computer-mouse work, subjects were requested to input six-digit numbers, displayed on the top of the screen, by clicking the soft keyboard under the edit box. A time bar between the number and the edit box was used to indicate how much time was left in the stress sessions. Some special rules were applied to minimize the possible influences as follows:

(1) To avoid the influences due to the layout of the regular keyboard and the typing skill, the subjects were only allowed to input the digits through the soft keyboard on the screen;
(2) At the beginning of each trial, the mouse was initialized at the center of the soft keyboard;
(3) The digit "0" was not used in order to have a square keyboard;
(4) The numbers were randomly created, and the six digits in a number were dissimilar;
(5) Digit input from the soft keyboard was displayed in real time in the edit box as "*" in the same font size as the digit;
(6) The configuration and control buttons were aligned at the bottom of the screen in a very small area.

Each task consisted of seven 8-min sessions separated by 3-min breaks (see Fig. 2), including two rest sessions (RS1 and RS2), one baseline session (BSS), and four stress sessions (SS80, SS100, SS90 and SS150). The details of each session are:

(1) In rest sessions (RS1 and RS2), the subjects were seated in front of the display without any tasks.
(2) In BSS session, subjects were asked to input the six-digit number displayed on the computer screen using the soft keyboard with their dominant hands. Upon completion of each number, a new six-digit number would be displayed. The average time required by the subject to input one number was used as his/her baseline time. In this session, the subject was not under any time pressure and the time bar was disabled.
(3) In the subsequent four stress sessions (SS80, SS100, SS90 and SS150), the subjects were required to input the six-digit numbers within 80% (SS80), 100% (SS100), 90% (SS90), and 150% (SS150) of the baseline time, respectively. Subjects were asked to complete the input as quickly as possible. The time bar was activated to show the time left.
(4) To evaluate the task performance, the number correct rate (NCR) was recorded in BSS and four stress sessions.