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Low-frequency dynamics of autonomic regulation of circulatory system in healthy subjects

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ABSTRACT

The paper is devoted to the analysis of dynamic of interactions between signals of autonomic circulatory regulation. We investigated two-hour experimental records of 30 healthy people. Phase synchronization was studied using the signals of the electrocardiogram and the photoplethysmogram of vessels. We found the presence of long synchronous intervals in some subjects. For analysis of the dynamic we calculated autocorrelation functions. The analysis made it possible to reveal indirect signs of the influence of the humoral regulation system.

Nonlinear dynamics, data analysis, the cardiovascular system

1. INTRODUCTION

The most promising methods in medicine are the methods of revealing the functional interactions of the internal systems of the body. This is because the methods can diagnose structural diseases at an early stage or even before they occur. However, this area of medicine is quite young and requires a lot of fundamental research.

The main aim of this paper was studying the nature of the interaction between two presented systems: the regulation of heart rate and vascular tone. In previously published papers[1-10], we showed the presence of phase synchronization between the studied systems. But previously we used just short data, with a length of about 5-15 minutes. The study of long records will allow us to analyze the dynamics of synchronization of 0.1-Hz rhythms of cardiovascular regulation and to estimate the degree of its reproducibility.

2. DATA

We conducted a series of experiments with 30 healthy people. Subjects were between 18 and 21 years of age with moderate physical activity. The experiments made it possible to obtain simultaneous records of the electrocardiogram (ECG) and finger's photoplethysmogram (PPG) with a length of 2 hours. Figures 1a (photoplethysmogram signal) and 1b (electrocardiogram signal) represent an example of experimental signals, with a length of 5 seconds.

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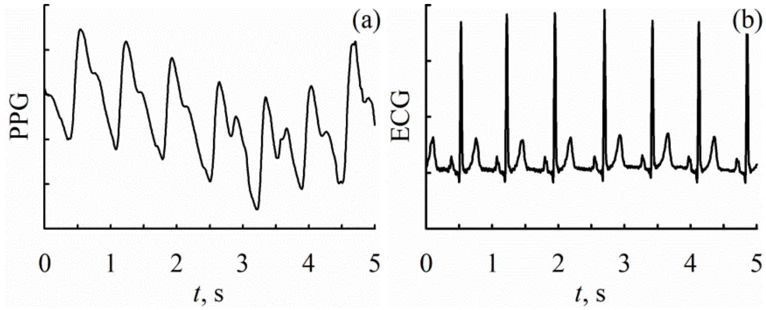

Figure 1. An example of experimental signals, with a length of 5 seconds: 1a – photoplethysmogram signal, 1b - electrocardiogram signal.

The design of the experiment was selected with the help of known recommendations[11]. The signals were sampled at 250 sps and digitized at 14 bits. All subjects were investigated in the afternoon fasting under spontaneous breathing. The signals were recorded in a quiet, temperature-controlled room using a standard electroencephalograph analyzer EEGA-21/26 'Encephalan-131-03' (Medicom MTD Ltd, Taganrog, Russia).

The PPG signal is a source of information about the rhythms of vascular tone regulation. This signal, as we're already noted, is a consequence of sympathetic regulation and has a frequency of about 0.1 Hz. The signal of autonomic regulation of the heart rhythm (also 0.1 Hz) is obtained from the heart rate variability signal. To do this, the experimental ECG signal is analyzed, which allows us to extract information about the length of the cardio intervals. Thus, the variability of the heart rate we examine using a time series of cardiointervalograms (CIG).

3. METHOD

The signals of the PPG and the CIG were used as sources of information on 0.1-Hz rhythms of autonomic regulation of the cardiovascular system. Further preprocessing was a band-pass filtering of the experimental signals in the band from 0.05 to 0.15 Hz. Thus, we have obtained the time series of the signals of autonomic regulation of heart rhythm and vascular tone.

The next step was determining the intervals of phase synchronization between the studied signals. To do this, we used the methods which we developed for detecting instantaneous phases, including, with the aid of the Gilbert transform[10]. For each of the subjects we formed an array with successive lengths of synchronous intervals. Fig. 2 is an example of such the sequence for the subject *N*. As can be noted in the figure, a sufficiently long period of phase synchronization between the studied systems (more than 100 seconds) was observed during two hours for most of the subjects. The maximum value was recorded about 150 seconds.

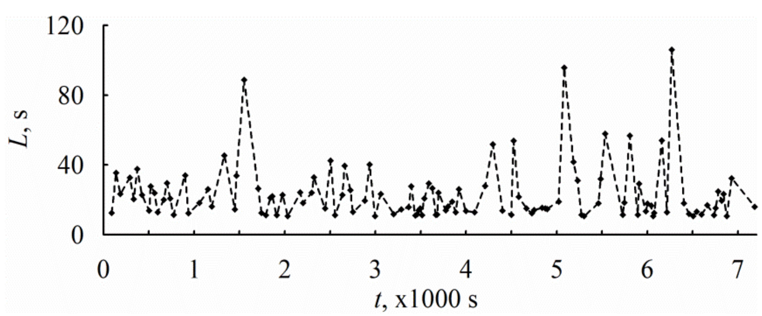

Figure 2. An example of the array with successive lengths *L* of synchronous intervals for the subject *N*. The points indicate the length of the synchronous interval.

The non-equidistant time series were interpolated. The equidistant arrays of sequences of synchronous intervals lengths became the basis for calculating autocorrelation functions with lag from -2000 seconds to 2000 seconds. Fig. 3 shows typical autocorrelation functions for some subjects. As can be seen, the figure notes the different character of the received signals. For example, Fig. 3a and 3c show a signal with a near-periodic character, but Fig. 3b is more like a random process. It is also worth paying special attention to the group of records that have a sharp increase in the magnitude of autocorrelation on large lags (Figure 3c), which may be due to the humoral regulation of systems.

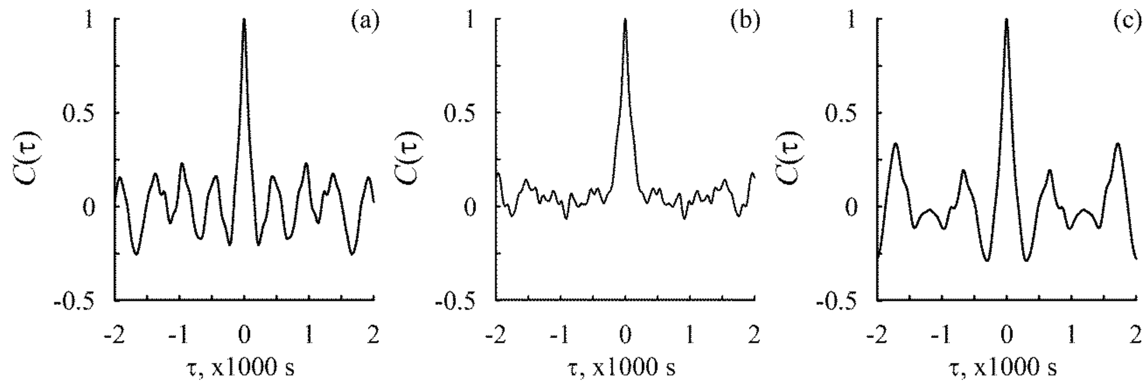

Figure 3. The autocorrelation functions with lag from -2000 seconds to 2000 seconds for some subject.

For analyzing a periodicity of the calculated autocorrelation functions, we calculated the total level of significance (95%) with the help of surrogate data pairs. For creating a surrogate signal, an array of lengths of synchronous sections was randomly generated on the basis of experimental sequences. Fig. 4 represents autocorrelation functions with full significance level. These graphs confirm the existence of a significant amount of autocorrelation on large lags in some subjects.

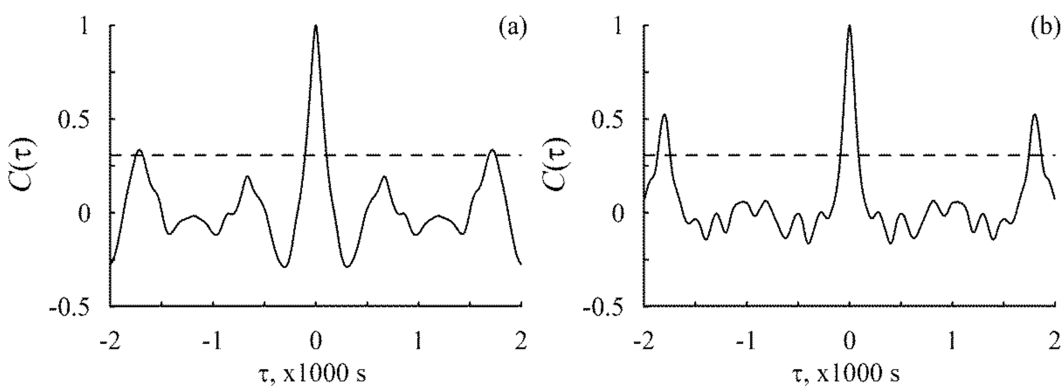

Figure 4. An example of autocorrelation functions with the total level of significance – 95% (marked by dashed line).

4. RESULTS

The experimental long signals were studied and we analyzed the dynamics of interaction between the systems of autonomic regulation of the heart rhythm and vascular tone. The analysis of long signals made it possible to investigate the nature of the interactions of the studied systems for large times. We have received information about the presence of sufficiently long intervals of phase synchronous signals (more than 150 seconds).

We discovered signs of a periodic nature of the interaction between the systems when we have analyzed the autocorrelation functions of sequences of synchronous interval lengths. An interesting result was the presence of significant large magnitudes in autocorrelation functions at large lags.

5. CONCLUSION

In the paper, we investigated the dynamics of interactions between the autonomic systems of circulatory regulation. The presence of significant large values of the autocorrelation functions at large lags requires further investigation and an increase in the experimental sample. However, it is supposedly a consequence of the influence of humoral regulation on systems.

Based on the results of the analysis, a model of interactions between the autonomic regulatory system and the humoral system was proposed (Fig.5).

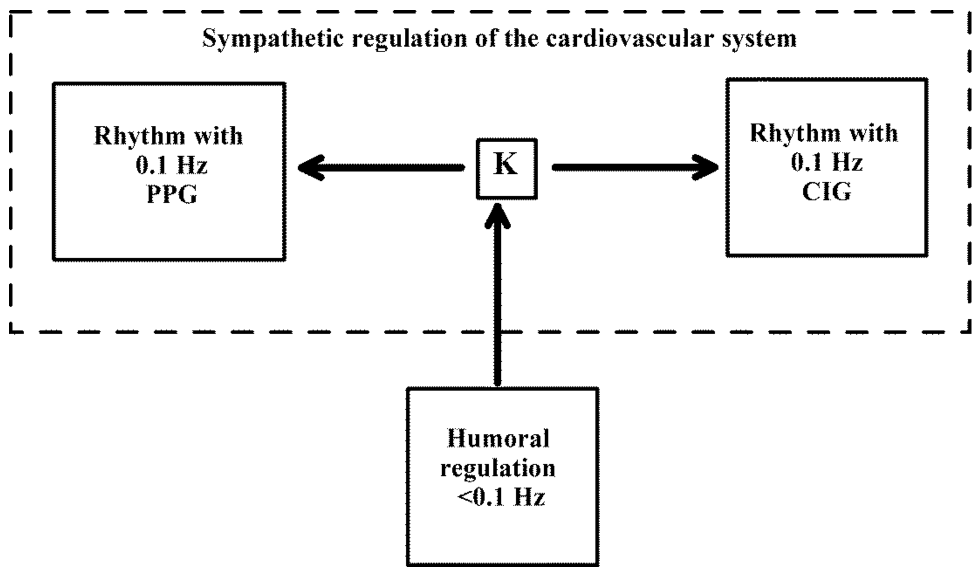

Figure 5. Model of working of autonomic and humoral regulation on the cardiovascular system.

6. ACKNOWLEDGEMENTS

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