Heart and Brain Activity Correlation

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Abstract: *Study of various psychophysiological states (PPS) was done by the parallel measurements of cardiac activity by heart rate (HR), heart rate variability (HRV) and brain activity by vibraimage (VI) technology. The correlation between HR and VI signals was established for task free state. Correlation between HR and VI is violated for PPS caused by imposed stimuli. No correlation between HRV and brain activity period (BAP) in very low frequency range (VLF) was detected. The advantages of vibraimage technology for brain activity study were presented.*

Keywords: *vibraimage, heart rate (HR), heart rate variability (HRV), fast Fourier transformation (FFT), very low frequency (VLF), brain activity period (BAP), task free state, imposed stimuli.*

Currently, there are several technologies for studying brain activity and neuroimaging. Most of the methods used are based on structural visualization or functional analysis (Bunge & Kahn, 2009). There are several different approaches to the study of brain activity used in medicine, psychology and neurophysiology. The developers of some technologies for the study of brain activity claim close success in understanding the processes of consciousness (Farah et al., 2014), however, in our opinion, it still very far from a complete understanding of brain activity physiology. The first technology used to study brain activity was electroencephalography (EEG). The rhythmic activity of the brain was first discovered by the great Russian physiologist Ivan Sechenov back in 1882 and described in the publication «Galvanic phenomena on the medulla oblongata of a frog» (Sechenov, 1965). The German physiologist and psychiatrist Hans Berger recorded the first human EEG in 1924 (Millett, 2001). Traditionally, EEG studies the electrical activity of the brain in a frequency range above 1 Hz, but EEG rhythms below 0.1 Hz, called DC-EEG or slow-change potentials, are also known (Murik, 2005).

When developing vibraimage technology (Minkin, 2017; 2020), was established the correlation between the parameters of high-frequency vibraimage signals and EEG signals for a person in an active state, such as stress or aggression. In a comparative analysis of vibraimage (VI) and EEG, it is necessary to take into account that VI signals are lower frequency than electrical signals due to mechanical inertia of movements. The time constant of any biomechanical movements in humans determined by Nikolai Bernstein in 0,1 seconds limits the upper frequency in the spectrum of vestibular movements of 10 Hz (Bernstein, 1967). At the end of the last century, Soviet scientists developed a new scientific field — space medicine, combining science and practical research for training astronauts. Several developers, including cardiologists R. M. Baevsky, L. V. Chireikin and A. N. Fleishman (Baevsky et al., 2001), together with their teams, developed a two-circuit model of heart regulation based on the study of heart rate variability (HRV).

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The main goal of space medicine was to assess the activity, behavior and functional capabilities of a person in various conditions, including in the absence of gravity. One of the elements of the study of cardio intervals is spectral analysis. Through fast Fourier processing of HRV signals, various maxima were established in the resulting spectrograms. Each of the maxima obtained by spectral processing of cardiac activity signals indicates the presence of chronobiological rhythms of cardiac activity in certain frequency regions. One of the most pronounced rhythms of cardiac activity as a chronobiological signal (Halberg, 1987) was detected in the region of very low frequencies, the period of such fluctuations is approximately 30–60 seconds. Most of the previous studies on the relationship between cardiac and brain activity have been performed in the analysis of the cardiac signal and EEG (Billones et al., 2018). Despite a considerable amount of work in this direction, no clear correlation between brain and cardiac activity was previously revealed, although it is known that the brain is the main consumer of oxygen in the human body. One explanation for the lack of results is that EEG technology has significant limitations in the study of brain activity, as it is not intended to study a person in a free state. Most of the comparative studies of EEG and ECG signals were carried out in sleep or other restricted conditions of a person (Ako et al., 2003; Messik et al., 1987; Billones, 2018).

The aim was a comparative study of human brain activity under normal working conditions while working at a computer and a desktop while synchronously recording physiological signals of HR, HRV and VI.

Materials and Methods

To determine the correlation between the signals of cardiac and brain activity, ECG and VI signals were studied in four different PPS of one subject. The ECG signal was obtained using 4 leads of the ECG Dongle electrocardiograph (ECG Dongle, 2020). The signal of brain activity based on the vestibular-emotional reflex (Minkin&Nikolaenko, 2008) was recorded by the Vibraimage PRO10 vibraimage system (Vibraimage PRO10, 2020). The duration of physiological signals measurement in each PPS was 600 seconds. All PPS characterized different brain activity of the user at one workplace at the computer. In each PPS, 10 measurements of physiological signals were performed. The first PPS (1PPS) characterized the user in the active mode of working at the computer. The second PPS (2PPS) characterized the rest mode of the user looking out the window at the courtyard with a slowly changing environment, passing cars and walking pedestrians. The third PPS (3PPS) characterized the subject sitting in the workplace with his eyes closed. The fourth PPS (4PPS) characterized the subjects being tested on a computer with periodic stimulus presentation by the VibraMI program (Minkin&Nikolaenko, 2017; VibraMI, 2020).

Results

Consider the data of a comparative analysis of ECG and VI signal spectrograms captured from one subject placed in various psychophysiological states. Capturing of the both ECG and VI signals practically do not limit the physical activity of a person;

therefore, it can be captured under any conditions. The ECG signal was captured using an ECG Dongle electrocardiograph (ECG Dongle, 2020), and the vibraimage signal was captured using the Vibraimage PRO10 system (Vibraimage PRO10, 2020).

Figures 1 and 2 show examples of Fourier spectrograms processed from HRV cardio signal (fig. 1) and VI signal (fig. 2) for a programmer who is actively working on a computer. Figure 3 shows a typical histogram of heart rate distribution (HR) during 600 seconds testing and the average value of the HR and the standard deviation of HR.

Note that the maximums of HRV and VI spectrum signals obtained simultaneously for one PPS do not coincide along the horizontal axis (the period of physiological process) and the general character of curves is different, also a maximums shift along the time axis.

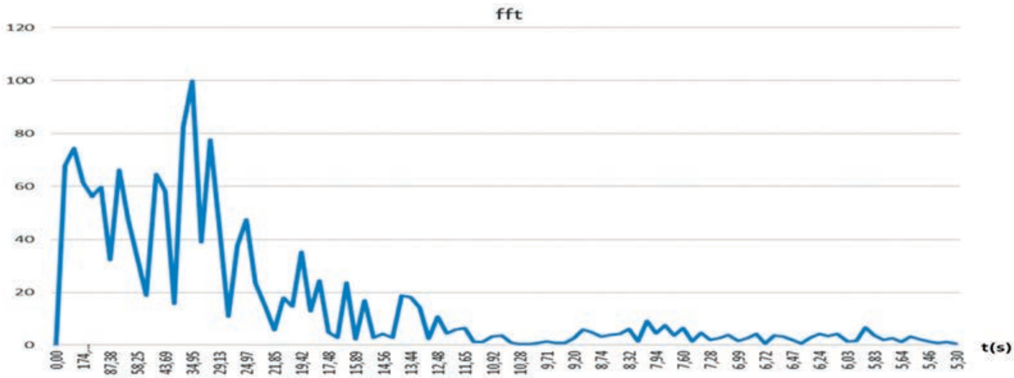

Fig. 1. Spectrogram sample obtained by fast Fourier transformation (FFT) of cardio signal HRV

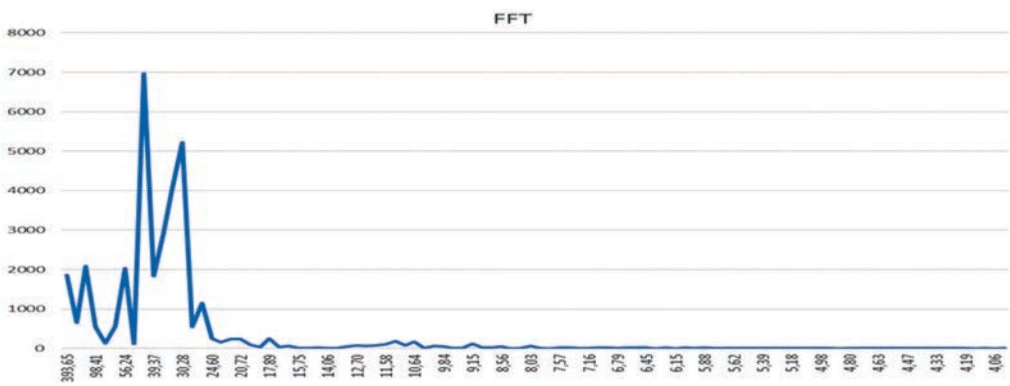

Fig. 2. Spectrogram sample of fast Fourier transformation for a PPS signal obtained by VI technology

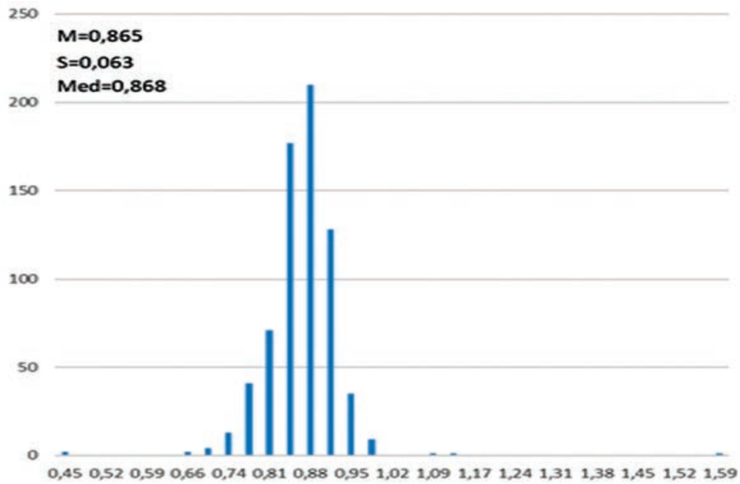

Fig. 3. HR density distribution in 600 seconds testing

Mathematical data for comparative studies of brain and cardiac activity are shown in tables 1–3.

Table 1

Change in heart rate parameters in a study of 4 various PPS

HR	Avg(M), s	**ϭ(M), s**	Avg(ϭ), s	**ϭ(ϭ), s**	Min(M), s	Min(ϭ), s
1PPS (Synchro)	0,921	0,022	0,062	0,006	0,921	0,921
2PPS (Active)	0,893	0,021	0,061	0,007	0,865	0,865
3PPS (SCE)	0,929	0,017	0,049	0,002	0,909	0,909
4PPS (SOE)	0,964	0,028	0,058	0,007	0,927	0,927

Table 2

Change in HRV parameters in the study of 4 various PPS

HRV	Avg(max)	**ϭ(max)**	Avg(fft)	**ϭ(fft)**	Min(max)	Min(fft)
1PPS Synchro	17,100	7,342	26,635	0,897	17,100	26,635
2PPS (Active)	83,347	64,676	46,168	2,143	34,950	44,652
3PPS (SCE)	137,489	41,333	44,401	7,669	78,680	35,585
4PPS (SOE)	87,174	56,437	31,103	4,438	30,260	25,217

Table 3

Change in BAP parameters in the study of 4 various PPS

VI	Avg(max)	**σ(max)**	Avg(fft)	**σ(fft)**	Min(max)	Min(fft)
1PPS (Synchro)	28,100	4,293	35,981	1,832	28,100	35,981
2PPS (Active)	49,726	5,114	41,401	2,608	43,739	39,104
3PPS (SCE)	63,593	18,055	50,875	3,522	39,325	46,974
4PPS (SOE)	62,596	11,937	51,950	5,209	39,325	45,764

Table 1 clearly enough shows that each of PPS is characterized by its own HR period, estimates Avg (M) and Min (M), and various mathematical estimates of the HR period confidently confirm the differences between the PPS.

Discussion

Figures 4 and 5 show the results of measuring the parameters of cardiac and brain activity in the form of graphs of the average values of the signal parameters from tables 1–3.

From figures 4 and 5 it follows that when testing without external synchronized stimuli. the dependences of heart rate and VI on different PPS states are quite close and change unidirectional. However, the presentation of periodic external stimuli violates this trend, the heart rate period increases, and the period of the vibration image signal decreases. While the change in the HRV signal period in the VLF range is completely opposite to the change in the heart rate period. That is, in the experiment, there is no relationship between the variability of the pulse and its average value. Thus, with the free functioning of the human body, heart rate is proportional to PMA. So the increasing of brain activity frequency in the VLF range imposes more active work on the heart. Moreover, the human brain recognizes the external rhythm of presentation of information imposed on it and adapts to it independently, but in this case, it does not require activation of cardiac activity, since these artificially imposed rhythms do not require more energy for the brain to work.

The result obtained is new and quite interesting, at least previously, researchers engaged in a comparative analysis of brain activity by comparing EEG and ECG signals could not get a clear correlation between the studied physiological signals (Billones et al., 2018). We believe that the period of brain activity is one of the most informative chronobiological human rhythms. The frequency and period of brain activity in the VLF range depend on the brain load, conscious and unconscious processes in the human body. The adaptation of the rhythm of brain activity to the stimulus evoked requires more detail study. The established relationship between cardiac and brain activity opens up new possibilities for the study of human physiology and psychophysiology.

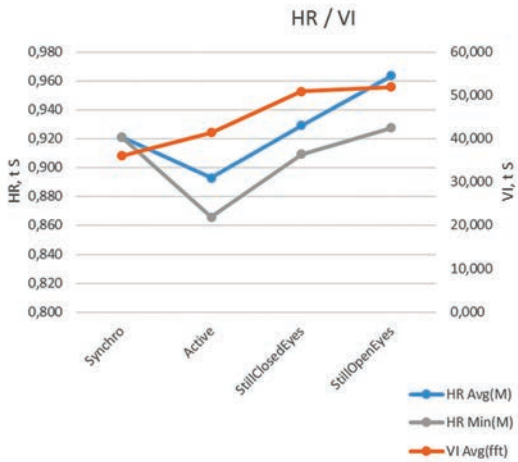

Fig. 4. Comparative analysis of the period of brain activity, defined by VI and HR for 4th various PPS

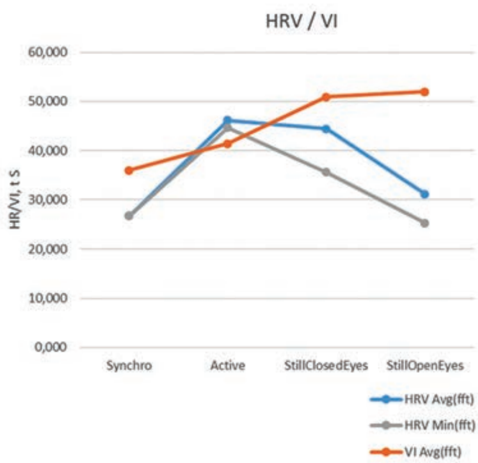

Fig. 5. A comparative analysis of brain activity period, defined by VI and HRV for 4th various PPS

One can discuss various options why vibraimage is more informative in indicating brain activity than other neuroimaging technologies. We believe that vibraimage allows better detection of brain activity in the VLF range, due to mechanical filtering of high frequencies from head vibration and high physiological information content of vestibular signals, so high-frequency processes have less noise impact on the VLF range for vibraimage compared to other technologies. Studies have shown the objective capabilities of vibration imaging technology to study not only physiological processes, but also the work of human consciousness. The results obtained need confirmation, but probably make it possible to refute well-known statement of Penrose (Penrose, 1994) that the development of new physics is necessary to understand the processes of consciousness. Most likely, the continuation of work on the study of consciousness and brain activity by vibraimage technology is sufficient for this.

Conclusion

1. Vibraimage technology informatively detects the chronobiological processes of brain activity and changes in PPS in the VLF range.
2. Presentation of evoked stimulus in the VLF range forms the brain activity frequency close to the frequency of the evoked stimulus.
3. The correlation between the period of brain activity and heart rate allows revising well-known schemes of cardiac activity regulation.
4. The study of brain activity using the analysis of vestibular signals by vibraimage technology has strong advantages over the well-known technologies of EEG and ECG signals processing.
5. Vibraimage technology is just beginning its journey in biomedical applications. It is necessary to expand research and confirm the data by independent researches.

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