Development and investigation of the nanosensor-based apparatus to assess the psycho-emotional state of a person

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Abstract. Psycho-emotional state is one of the factors effecting human health. Its evaluation allows revealing hidden psychological trauma which can be reason of chronic stress, depression or psychosomatic disorders. Modern techniques of objective psycho-emotional state assessment involve a device which detects electrophysiological parameters of human body connected with emotional reaction and psychological condition. The present study covers development and testing of psycho-emotional state assessment device. The developed implement uses three methods of electrophysiological activity evaluation: electrocardiography, electroencephalography and galvanic skin response detection. The device represents hardware-software complex consisting of nanosensors, measuring unit, lead wires and laptop. Filters are excluded from the measuring circuit due to metrological parameters and noise immunity of implemented nanosensors. This solution minimizes signal distortion and allows measuring signals of 0.3 μV and higher in a wide frequency range (0-10000 Hz) with minimal data loss. In addition, results of preliminary medical studies aimed to find correspondence between different psycho-emotional states and electrophysiological parameters are described. Impact of filters on electrophysiological studies was studied. According to the results conventional filters significantly distort EEG channel information. Further research will be directed to the creation of complete base of electrophysiological parameters related to a particular emotion.

1. Introduction

The relentless pace of modern life – the amount of information perceived and processed, mental and physical work performed, unfavorable environment, and emotional stress – can negatively affect the nervous system and the entire body of a person. These lead to the repeated or protracted stressful impact on the nervous system that can develop into chronic events and negatively affect the brain and its functions [1].

Emotional fatigue and stress syndrome triggered by psycho-emotional stress have a negative impact on the cardiovascular and endocrine systems, gastrointestinal tract, reproductive organs, musculoskeletal system, etc. Improper functioning of these system significantly increases the risk of complications in patients with chronic diseases (asthma, diabetes, etc.), and may cause pathologies in healthy people [2]. Due to the negative emotional somatization [3], protracted stresses or strong emotional responses may provoke depression, phobia, paranoia [4], and psychosomatic disorders. For this reason, the study of psychological problems associated with the psycho-emotional state of a person is relevant to diagnostic medicine.

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One of the factors hindering the analysis of the psycho-emotional state of a person is the suppression of negative memories and concomitant emotions, which can lead to the subsequent formation of complexes or chronic stresses. The suppression is especially dangerous since it is not evident to others and the person himself. Thus, some people suffer from depression caused by complexes and unexpressed emotions, but they are unaware of the problem and therefore cannot be provided with medical support. The problem can be solved by monitoring the subconscious response of the body at the physiological level, namely, by studying changes in the psycho-physiological state of a person.

2. Hardware and software complex

The psycho-physiological state of a person can be assessed by the methods widely used in diagnostic medicine: electrocardiography, electroencephalography, galvanic skin response, muscular tremor recording, electromyography, electrosomnography, plethysmography, measurement of changes in thoracic breathing, measurement of blood pressure, etc. [5, 6] Most of the methods are related to electrophysiological methods.

Electrophysiological methods are based on the measurement of bioelectric potentials of various organs and tissues or on the measurement of their resistance. These methods are appropriate for studying the psycho-emotional state of a person, since the measured electrical characteristics allow an objective assessment of physiological changes. The obtained characteristics can be subjected to the component analysis to identify common features that can provide useful data. The features are further analyzed to develop criteria for assessing the psycho-emotional state of a person. This approach enables an objective stratification of patients using the data obtained by a special apparatus, but not the opinion of psychologists based on conversations with a patient. This is especially important for those who suppress their emotions and thus hinder the psycho-emotional state assessment.

The apparatus to assess the psycho-emotional state of a person is a complex that examines the described electrophysiological characteristics. The approach allows us to expand the number of these characteristics and to increase the accuracy of determination of the emotional transition and stress caused by suppressed negative emotions.

Three diagnostic electrophysiological methods were used to develop the apparatus: electrocardiography, electroencephalography and galvanic skin response. The electrophysiological characteristics were determined using bipolar leads. Since the study aimed to develop an optimal apparatus for the psycho-emotional state investigation, the number of leads was minimized to three to eliminate the impact of electrodes and to reduce the amount of simultaneously processed data.

The lead for the ECG channel was placed according to Holter (Figure 1a), and the electrodes for the galvanic skin response measurement were placed on the middle phalanges, which correspond to the index and ring fingers (Figure 1b). For the electroencephalographic channel, the leads were placed above the limbic center of the brain at points F7–T3 of the 10–20 lead system (Figure 1c). The lead placement for the electroencephalographic channel is due to the direct participation of the limbic system in the formation of emotions associated with memories and experience [7].

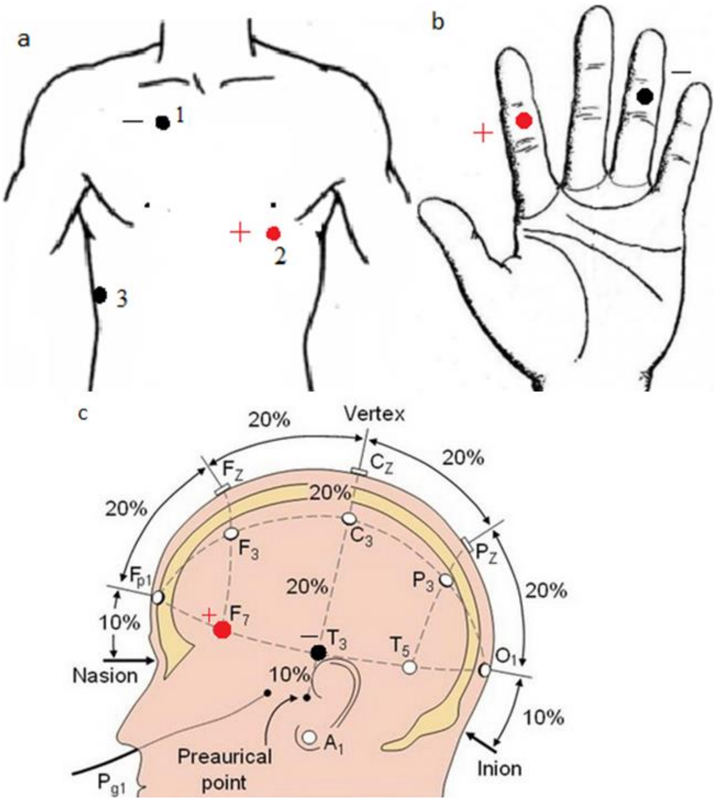

Figure 1. Lead placement for ECG channel (a), galvanic skin response channel (b) and electroencephalographic channel (c): 1 – negative, 2 – positive, 3 – ground.

The developed apparatus is a hardware and software complex (HSC) for the electrophysiological studies. The complex comprises 7 Ag/AgCl nanosensors, a measuring unit, lead wires, and a laptop.

Nanosensors are porous ceramic structures, which contain silver nanoparticles and exhibit good metrological parameters: DC electrode potential difference is no more than 2.0 mV; DC voltage drift does not exceed 0.005 μV/s; self-noise voltage does not exceed ± 200 nV in the frequency range from 0 to 10 kHz. In addition, the electrodes are not polarized under the DC impact and are characterized by high noise immunity that enables implementation of a hardware part of the measuring unit without filters in the input circuit [8]. Technical parameters of the developed complex are given in Table 1.

Table 1. Technical parameters of the developed apparatus.

Parameter	Value
The current consumed by the HSC during ECG recording	no more than 300 мA
Input voltage range for ECG recording	from ± 0.3μV to ±10 mV
Frequency range	from 0 to 10000 Hz
Sampling frequency	32,000 Hz
Input impedance	no less than 10 MΩ
Frequency response unevenness in the range from 0 to 10,000 Hz	from ± 20 % to ±10 %
DC in the volunteer's circuit	no more than 0.1 μA
Range of the measured durations of micropotentials	from 0.3 ms to 100 ms

The absence of filtering input circuits makes it possible to obtain the data undistorted by filters. Since the HSC uses highly stable low-noise and noise-immune nanosensors, it is capable of measuring signals of 0.3 μV and higher in the frequency range from 0 to 10,000 Hz. The sampling frequency of the signal equal to 32,000 Hz enables recording micropotentials with a duration of 0.3 ms. The apparatus uses a wide frequency range in contrast to other apparatus in which the signal is limited within the range from 0.5 Hz to 50 Hz to eliminate muscular and high-frequency noise [9]. The HSC allows us to noninvasively obtain a maximum of data on electrophysiological processes and to investigate the majority of frequency characteristics of the brain electrical activity.

3. Results of the preliminary studies

The apparatus efficiency and the rationality of using three leads were verified during the preliminary medical studies of the psycho-emotional state of a person. Volunteers aged 23 to 27 years were involved in the preliminary studies. Each of 14 volunteers involved in the study had a preliminary conversation to reveal the topics associated with a bright, negative or positive experience from the past. Based on these data, a set of questions was developed to elicit emotional responses.

Each volunteer was connected to the apparatus and then asked some questions. The changes in electrophysiological parameters and the chronogram of this process were accurately recorded to reveal the correlation between the fragments of recordings and responses to the questions. Figure 2 illustrates the electroencephalogram, electrocardiogram and galvanic skin response of one of the examined volunteers.

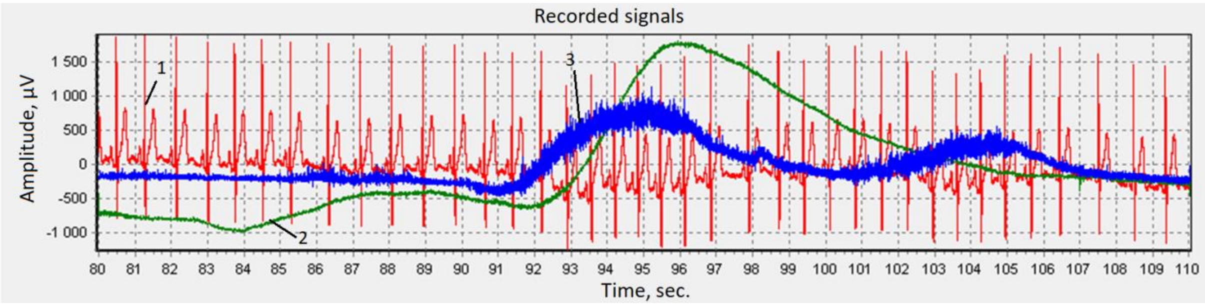

Figure 2. ECG (1), galvanic skin response (2) and electroencephalogram (3).

A sharp voltage jump in the galvanic skin response channel, increase in the heart rate, PQRST complex parameters and the curve constant component in the ECG channel indicated the beginning of psycho-emotional response. When answering emotionally colored questions (the chronogram period varies from 89 to 109 seconds), the heart rate (Figure 3) and cardiocycle duration increased. In addition, the signal constant component shift and dramatic change in the galvanic skin response potential could be observed. At the same time, responses to neutral questions were insignificant and resulted in slight fluctuations of the GSR potentials and the brain electrical activity associated with memories. The questions were asked with an interval of 20 seconds.

Figure 3. Changes in the heart rate.

In addition, the effect of bandpass filtering on the measured signal shape was investigated for each of the channels. The filtering effect was simulated using digital bandpass filtering. The frequency band from 0.002 to 100 Hz, which is typically used for the study of human emotions, was chosen for the ECG channel [10], a bandpass filter with the cutoff frequencies of 0.5 and 50 Hz was used for the EEG channel, and the cutoff frequencies of the filter used for the galvanic skin response channel were 0.05 and 5 Hz [11].

The study has shown that the use of an open measuring channel enables measuring ultra-slow changes in the electroencephalographic signal that cannot be recorded by conventional electroencephalographs (Figure 4). In this case, the delta rhythm and the impact of the psycho-emotional state on slow bioelectric processes in the brain, which can show a person's inclination to aggression and antisocial behavior, cannot be analyzed [12].

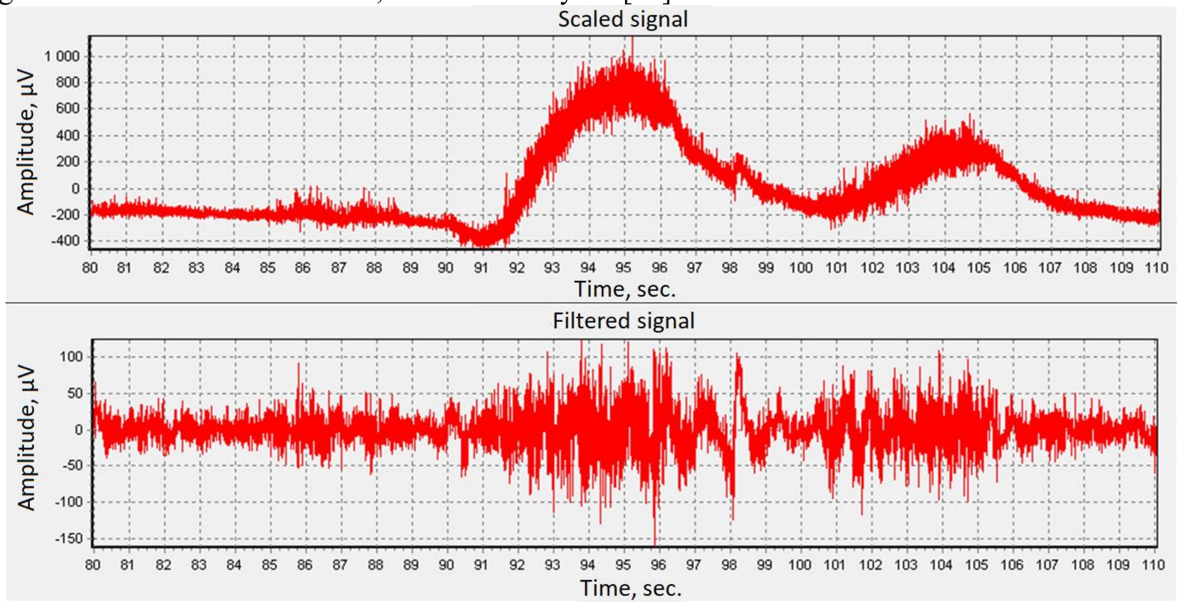

Figure 4. EEG before (a) and after (b) filtration.

The obtained results show that the low-pass or high-pass filtering used in the channels reduces the amount of data initially available for the analysis. For this reason, it is necessary to record the electrical activity in a wide frequency range from 0 to 10,000 Hz and to perform a detailed analysis of the recorded activity in order to identify the required signal fragments. Thus, it will allow us to identify new features that indicate the body's response to both the psycho-emotional state and possible pathologies.

4. Conclusion

The psycho-emotional state of a person requires further investigation in the field of subjective analysis, psychology, and the objective study of electrophysiological factors. Thus, the development of diagnostic electrophysiological systems is crucial [13-20].

The developed hardware and software complex enables the investigation of three different electrophysiological characteristics that enable us to assess the state of the central nervous system. The apparatus exhibits insignificant effect on the psyche due to its non-invasiveness, high noise immunity, and high resolution, which makes it possible to obtain data in a wide frequency range (from 0 to 10 kHz).

The developed apparatus will be further investigated and improved to create a complete database of templates, which will show the correlation between the brain and heart electrical activity and the galvanic skin response and certain types of emotions and stress. This will enable accurate identification of psychological triggers that affect people's health and indicate their suppressed emotional experiences.

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