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Summery Skin Potential as an Integral Characteristic of the Electrophysiological Status of an Individual

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ABSTRACT
The article presents a final review of some results of experiments in which the properties of the summery skin potential (SSP) were studied in the context of searching for an integral indicator of the electrophysiological status of an individual. Unlike traditional partial indicators - galvanic skin response (GSR), electromyogram (EMG), encephalogram (EEG) in the form of a multichannel recording of its components, electrocardiogram (ECG), - which are recorded upon contact of electrodes with the skin, the SSP, recorded in a wide range of frequencies, already contains a significant part of the information provided by these indicators. The data presented in the article confirm this thesis. In the simplest case, one universal bio-amplifier is enough to register the SSP. After processing the record with a special author's algorithm, it is possible to obtain a number of derivative indicators - a low-frequency component of the SSP, which is an analogue of the GSR, a high-frequency component containing brain frequencies and information on the individual's electro-tonus, the spectral power of the SSP in the range of 1 - 150 Hz, frequency-time dynamics. When diverting a biosignal from a skin area contralateral to the target one and connecting it to a second amplifier, it is possible to obtain a record of a simplified cardiogram, from which, after appropriate processing, information on the heart rate, average amplitude of the systolic R wave, dynamics of intervals between systoles, and vegetative balance is extracted. After Z-transformation of the obtained data, a multidimensional picture of the general state of the electrophysiological status of the individual is obtained when he performs the activity specified in the experiment. Based on these transformed data, an image of this status is constructed in the form of a polygonal figure, the angles of which correspond to the parameters of the SSP. The area of this figure or the sum of the average Z values for each parameter of the SSP allows us to "compress" all the multidimensional information into one integral indicator, which can be considered as a general assessment of the electro-physiological status of an individual.

Keywords: Summery Skin Potential, Whole and Parts, Electrophysiological Status, Electro-Tonus, Multichannel Recording, True Integrity

Introduction

The summery skin potential (SSP) is the total electrical activity of the entire organism, expressed as a time sequence of biopotentials of different amplitudes over a relatively wide frequency range. Such a sequence is recorded by taking electrical signals from any areas of the skin and amplifying them using identical universal bioamplifiers capable of operating in the range of at least 0 - 5 kHz.

The ability to take the total signal from the surface of the skin is ensured by the fact that the skin, having a sufficient percentage of moisture, is a good conductor of living electricity. And the fact that all subcutaneous anatomical organs are also in a humid environment creates conditions for the spread of electrical activity throughout the body, arising in one or another local area of the organism. It is strange that this obvious and long-known to all specialists fact was ignored when analyzing the properties of the recorded biopotentials. By default, it was assumed that only the electrical activity that occurs directly under the electrodes is recorded, and it is practically independent of more distant areas.

In the more than century-long history of psychophysiology, a tradition has developed of recording not the total, but the partial electrical activity of the skin, isolating a signal in a predetermined frequency range using relatively narrow-band

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filters (initially analog, then digital). For example, the GSR has a range of 0–2 Hz, EOG – from 0 to 10 Hz, EEG – from 2 to 45 Hz with less narrow subranges for different brain rhythms, ECG – from infra-low frequencies to 30 Hz, EMG – from 10 to 400 Hz. To record each of these categories of biopotentials, specialized amplifiers and analysis algorithms were created. As a result of such differentiation, the whole (SSP) disintegrated into separate independent parts, disappearing as a special subject of scientific research. True, recently one can often encounter attempts to develop an "integral" approach to the study of psychophysiological phenomena, but so far this is limited to the appearance of integrality, which comes down to multichannel recording of the same partial indicators [1-5]. For example, reactions to films that induce fear and despondency were assessed by the frequency and variability of the heartbeat, the amplitude of the systolic tooth of the cardiogram, the systolic volume of the heart, the ejection of the left ventricle, blood pressure, pulse amplitude, finger temperature, the level, frequency and amplitude of the GSR, breathing parameters, and facial reactions [6]. Meanwhile, in the early and recent history of psychophysiology one can encounter instructive, although not always complete, examples of an integral approach to the study of electrophysiological processes in the human body [7-9].

In general, to overcome the narrow analytical approach in psychophysiology, there is no need to invent a special integrating paradigm, since the integration of local electrical signals in a living organism occurs automatically due to the "organ structure", and it is expressed in the SSP indicator. The latter, as will be shown below, includes almost all of the above-mentioned particular indicators, combining them into a single broadband structure (gestalt), just as multi- colored brushstrokes on a canvas form a holistic picture (at least in the genre of realistic painting). But, being a holistic formation, the SSP has its own specific properties, which I have been studying for several years, and they are described in this article. The main attention in it is paid to methodic aspects, and not to the methodology, which says a lot of general words about "how it should be", and not about how to specifically achieve this.

GSR and EMG as components of the SSP

Following the principle of analysis from the general to the specific, we will first select the SSP recorded monopolarly from any area of the skin surface, using the standard procedure for ensuring contact of the silver chloride electrode with a diameter of 8 mm with this area. We will call this electrode active. It is connected by a shielded cable to the positive input of the differential amplifier. Another electrode placed in a cup with ordinary water will serve as a reference. This electrode is connected to the common input (GND, or 0) of the differential amplifier. The tip of any finger of the left (or right) hand of the subject is also dipped into the water with the reference electrode. Connecting it to the common input of the amplifier through a water contact with the reference electrode provides a sufficiently low resistance (< 5 kOhm) between the subject and the zero input of the amplifier, which is necessary, in particular, to reduce the level of incoming external signals, in particular, 50-Hz "noise". In most experiments I used this method to effectively "ground" the subjects, and sometimes to connect them to the active input of the amplifier.

Figure 1 shows a fragment of the recording and partial processing of the SSP of a subject at rest while he or she was perceiving a sports scene. For this and all other SSP recordings, a universal broadband amplifier DA-100C (BIOPAC, USA) was used. The active electrode was located on the left forearm in the area of the ulnar flexor of the left wrist. Simultaneously, using another amplifier (GSR100C, the same company), which had a common zero input with the first one, the GSR was recorded using the Feret method [10]. The first channel from the top shows the "raw" SSP recording in the range of 0.05-300 Hz, the third channel shows the same recording processed with a digital bandpass filter in the range of 0.05-2 Hz. The latter is the low-frequency (LF) component of the SSP, which does not contain the high-frequency (HF) component, reflected in the previous recording as a thickening on the curve. The low-frequency component of the SSP is a very close, if not complete topological analogue of the GSP, which is shown in the second channel from the top. Topological, because in different subjects the amplitude of the low-frequency component of the SSP may differ from the amplitude of the GSR, and the shapes of the corresponding graphs may not only be in-phase (as in Figure 1), but also antiphase (mirror) even in the same subject.

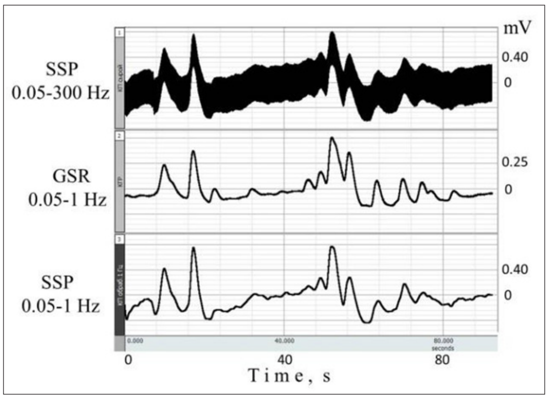

Figure 1: Fragment of recording and partial processing of the SSP during the subject's perception of images of familiar and unfamiliar faces. Explanations in the text.

Usually, when analyzing relatively low-frequency biopotentials (EOG, ECG, EEG), the HF component is considered as unwanted "noise" and is excluded from registration using appropriate filters if it goes beyond the frequency range adopted for a given type of biopotential. These filters, different for each type of biopotential, are built into the hardware recording system, which thus becomes highly specialized, so that, for example, a device for recording GSR cannot be used to record ECG or EMG. The use of universal broadband amplifiers allows us to significantly expand the scope of use of a single-type device for recording different biopotentials.

The HF component of the SSP has an amplitude an order of magnitude smaller than the LF component, and a frequency in the range from 5 to 150 Hz. The average frequency range of the myogram is also in this range [11]. My colleagues have often pointed out this similarity, noting that this is not some kind of SSP, but a myogram; this similarity is even stronger when, at a different time scale (for example, 0.2 s/div), the recording becomes more extended.

Indeed, it is difficult to find a place on the human body where muscles are not located under the skin surface, and they apparently contribute to the overall picture of the SSP, even when they are at rest. But the SSP is also recorded at complete muscular rest, when a zero line is drawn in the EMG. It is more correct to consider EMG as an integral part of the SSP and not to identify these categories. Additional arguments in favor of this thesis will be given below.

And in connection with the myogram, it would be useful to take into account the following circumstance, which is not clearly articulated in EMG studies, but is of great importance for its adequate interpretation. EMG recording is usually carried out bipolarly using two closely spaced (about 20 mm) electrodes, which are connected to the differential inputs (+ and -) of the amplifier [3,12-14]. This means that the signal from one electrode of the bipolar pair is subtracted from the signal from the other. This generally accepted method allows for a significant reduction in the level of common-mode interference. This is its "advantage" over the monopolar recording method. The word "advantage" is in quotation marks because it is burdened with a significant, in my opinion, disadvantage. The fact is that with this recording method, two closely spaced electrodes of a bipolar pair transmit practically the same information. This can be easily verified by recording the signal from one electrode (M1) using one amplifier, and the signal from the other electrode (M2) using another amplifier, the parameters of which are identical to the first, with simultaneous recording of the bipolar signal. That is, three identical amplifiers are used here. A fragment of such recording is shown in Figure 2. The fourth channel shows the result of arithmetic subtraction of the second channel from the first, that is, M1 - M2. It is clear, firstly, that the records M1 and M2 are practically identical: the positive correlation between them is 0.98; secondly, the output signal of the differential amplifier of the bipolar lead (3rd channel from the top) and the result of the software subtraction of monopolar records (4th channel) are practically identical.

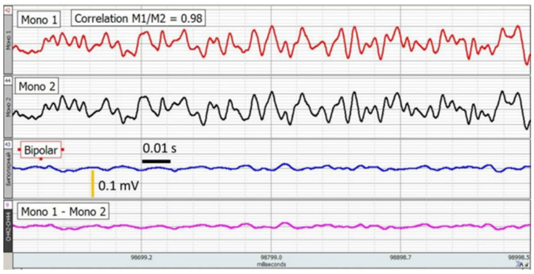

Figure 2: Comparison of mono- and bipolar recording. Mono 1 and Mono 2 are monopolar leads from the 1st and 2nd electrodes of the bipolar pair (Bipolar) connected to the inputs of the differential amplifier (blue line). Mono 1 – Mono 2 is a difference, calculated by the program.

All channels are presented in the same scale.

It is also evident that the amplitude of the bipolar signal is much (almost an order of magnitude) smaller than the monopolar signals, which indicates an extremely small difference between M1 and M2 (the time and amplitude scales are the same in all channels). Moreover, as the spectral analysis of the bipolar and monopolar leads showed, in the first case the frequency range of the upper part of the spectrum is almost two times smaller than in the second. That is, with bipolar leads, frequencies located in the high-frequency segment of the spectrum disappear from the signal. The above-mentioned drawback of bipolar recording did not bother researchers very much, who probably did not even suspect it, because EMG was used mainly to diagnose disorders in the functioning of the neuromuscular apparatus, which, as it turned out, can also be detected using bipolar recording. However, in the context of the wider use of the SSP, the choice of monopolar recording seems more adequate, given its advantage in amplitude, frequency-time and spectral relations.

Main properties of the SSP

By digitally processing many SSPs obtained in different behavioral experiments, it was possible to establish, in addition to the LF component, three more of its main characteristics: 1) electro-tonus, 2) frequency dynamics, 3) spectral power profile. An example of the first two is shown in Figure 3. The third will be considered separately.

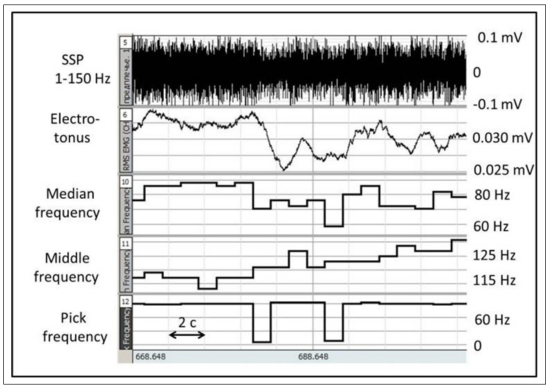

Figure 3: A fragment of the recording of the SSP (online mode) and its derivatives (offline mode) – electro-tonus, median, average and peak frequencies. The subject was at rest and listened to a musical melody. Explanations are in the text.

Electro-tonus (ET) is the amplitude characteristic of the SSP as a function of time. Since the SSP has a quasi-sinusoidal shape, its average value is very close to zero. Therefore, the ET value is measured by the root-mean-square value of the distribution of all its amplitudes over a certain observation interval within the set width of the sliding time window. In the given example, the window width was 1 s. The measure of ET is the value of the integral of the root- mean-square values over the selected observation interval; alternatively, the average of these values can be used. As can be seen in Figure 3, ET has a certain minimum base level (in this case - 0.025 mV), above which its oscillations of different amplitudes are observed. I note that when analyzing EMG, root mean square (RMS) processing of the myogram is also sometimes used under different muscle loads or for diagnosing disorders of the neuromuscular system. But in our case, the subject was at rest, when his muscular apparatus is completely relaxed and muscle tonus remains normal throughout the experiment and does not change significantly. Therefore, there is reason to consider the observed ET oscillations to be extramuscular in nature.

The frequency dynamics of the SSP is represented by three types of frequencies - median, average and peak. The median and average are the usual indicators of descriptive statistics, which were calculated within a sliding window of 1 s; in Figure 3, this is exactly the width of the smallest step on the corresponding curves. The peak frequency is the maximum frequency within this sliding window. Usually, I take the cumulative frequency (Cf) as a measure of frequency dynamics - the average of the sum of the average indicators of each of the three frequencies. Based on the definition of the SSP given above, its frequency is the result of summing up all the frequencies generated in different anatomical structures of the body, and the frequency dynamics reflects the time distribution of the activity of these structures. That is, a cumulative frequency of, for example, 30 Hz corresponds to one structure, and at 80 Hz - to another. Figure 3 shows how quickly these structures can change. This bears little resemblance to the familiar images of EEG "rhythms," each of which is in a narrow and relatively constant frequency range, with only the amplitude of the signal changing. It seems to me that EEG rhythms are of purely technical origin, being isolated from the general brain activity by a series of adjustable filters. Incidentally, it is interesting that even the dynamics of median frequencies do not reflect the frequencies common to EEG (from 10 to 45 Hz). Apparently, the latter "disappear" during averaging, which occurs within the time boundaries of a sliding window, in which greater weight falls on higher frequencies. As will be shown below, "brain" frequencies, however, are widely represented in the spectral power profiles of the SSP.

Spectral power is a general characteristic of the frequency composition of the SSP on a certain observation interval. Each frequency is presented together with the amplitude of the signal associated with it, which allows us to judge the degree of energetic expression of this frequency in the general frequency spectrum. An example of a smoothed profile of the spectral power of the SSP of one of the subjects is shown in Figure 4.

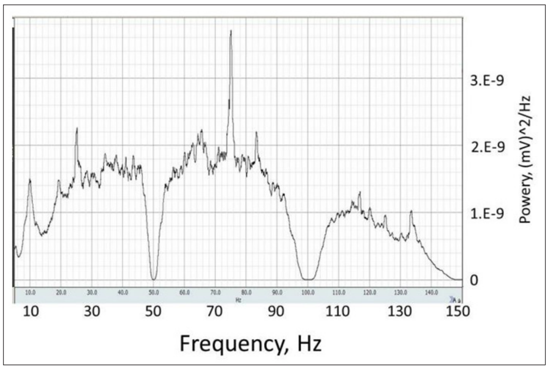

Figure 4: An example of the spectral power of the SSP of a subject whose spontaneous SSP activity was recorded during 5 minutes of complete rest. Monopolar signal recording was made from the elbow flexor of the left forearm.

Zero dips in the profile at frequencies of 50 and 100 Hz are explained by the operation of rejection filters tuned to these frequencies. Positive peaks of different amplitudes with a maximum peak at a frequency of 75 Hz are observed at frequencies of 10, 25, 75, 82 and 132 Hz.

In different subjects and when they performed different perceptual actions (perception of facial images, happy and sad pictures, musical melodies), the configurations of the spectral profiles differed in several ways: the number (density), amplitudes and frequency localization of peaks, as well as the integral power indicator in the range of 5-150 Hz.

My interest in the spectral power profile is based on the idea that its constituent frequencies reflect the distribution of energy across various functional structures of the body, formed in an individual throughout his or her life and differently involved in one or another specific activity. But this hypothesis still awaits confirmation on more voluminous material.

In some experiments conducted by me with the participation of students of different courses and areas of study at Dubna University, a simple cardiogram was recorded in parallel with the SSP (Figure 5). I consider it a symbolic projection of the heart's work onto the electro-skin potential, that is, as an integral part of the SSP. To record a simplified ECG, a separate universal amplifier was used, to which an electrode was connected, fixed on any part of the subject's body, contralateral to another, grounded part (according to the Eithoven triangle). By placing electrodes, for example, on the left and right hand, it is possible, after appropriate processing of the recording and in addition to the parameters of the SSP, to obtain derivative information sufficient for psychophysiological studies: heart rate (HR) as a function of time (intervalogram), maximum amplitude of the systolic R wave, vegetative balance, scatterogram. Such cardiograms with some results of their processing can be seen in more detail in my publications (see the list of references).

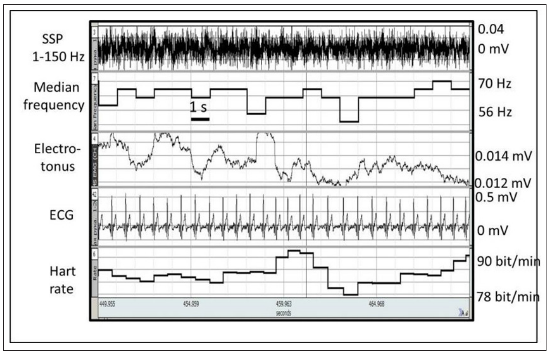

Figure 5: shows a fragment of the simultaneous recording of the SSP and ECG while the subject was listening to a musical melody.

Full processing two main recording channels - SSP and ECG - according to the algorithm described in [15], contain the following derivative indicators, each of which is reflected in analog form on the corresponding channels: 1) high-frequency component of the SSP in the range of 1 - 150 Hz; 2) low-frequency (LF) component of the SSP in the range of 0.05 - 1 Hz; 3) derivative of the low-frequency component of the SSP; 4) electro-tonus (ET); 5) median, average and peak frequencies of the SSP as functions of time; 6) ECG, 7) HR. By connecting an additional amplifier with the same parameters as the first two, it is possible to simultaneously record a local (single-channel) EEG with the two main ones (for the SSP and ECG), using a monopolar lead, for example, from point Fp 1 .

When simultaneously recording a local EEG (Fp1) and the SSP in the frequency band of 1 - 45 Hz, a high positive correlation was found between them. In different subjects, it was in the range from 0.55 to 0.89. This is an amazing fact, if we take into account that point Fp1 is located on the upper-anterior part of the subject's forehead, and the electrode for the SSP was placed on the upper side of his right forearm. It turns out that the signal from Fp1, which, according to the generally accepted point of view, reflects the activity of the corresponding area of the brain, is simultaneously present in a place far from it on the right hand! This at least partially confirms the above-mentioned thesis that the SSP can be considered as an integral indicator of the electrical activity of the entire organism.

Thus, using only 3 universal bio-amplifiers with electrodes connected to them, which take away biopotentials in a monopolar mode from three different areas of the skin surface, it is possible to simultaneously obtain initial information on three psychophysiological indicators, and after subsequent digital processing - more expanded information, derived from its common carrier - the SSP.

It was noted above that multichannel recording cannot be considered as a sign of an integral approach to the study of some integral phenomenon in its psychophysiological reflection. Multichannel is only the first necessary step to obtaining a real, and not illusory, integral picture of this phenomenon. This picture cannot be obtained with the help of any sophisticated statistical processing of data, which by their nature remain partial, and the whole point of multichannel recording is reduced only to establishing pairwise correlations between them. Integrity must first be in the mind of the researcher, using for this purpose the appropriate means of material construction based on an integral ideal image. I described an example of such construction in recent articles [15,16]. The integral picture of the characters of the average subject was presented in the form of visual figures (gestalts), several particular features of which corresponded to the parameters of the SSP (Figure 6). The symbol of character as a whole, presented in the form of a figure, and its parts, reflected in the parameters of the SSP, are given here simultaneously, which constitutes the essence of true integrity.

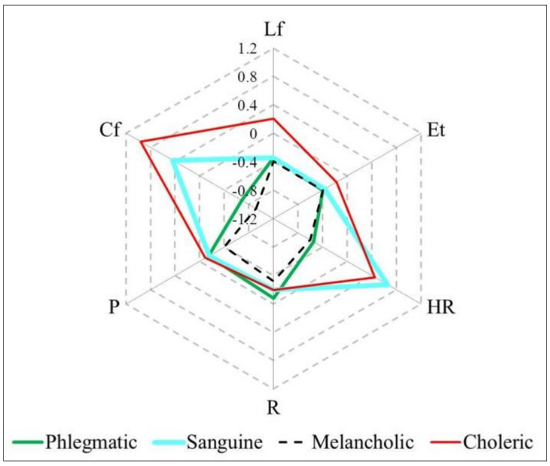

Figure 6: Integral presentation of the experimental results of experiment on the types of temperament [15]. Lf, Et, HR, R, P, Cf – parameters of the SSP (see text). To the left of the vertical radius of the Lf there is a dimensionless scale Z, the isometric points of which at different radii are connected by a dotted line.

Individual data for different subjects can be presented in the same format (Figure 7). This allows you to almost instantly see both the similarity and the difference between them, symbolized in the form of different figures. The contours of these figures are defined by the normalized values (Z) of the corresponding parameters. A single integral indicator for different characters of the "average" (Figure 6) or individual subjects (Figure 7) can be the area of the corresponding figures or the sum of the Z-values (S) for all 6 parameters of the SSP.

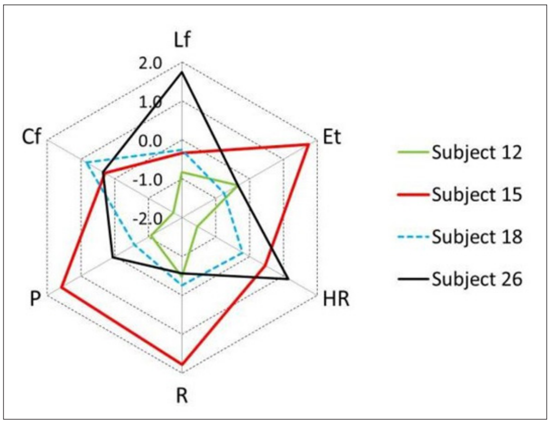

Figure 7: Individual character figures of 4 cholerics. The notations are the same as in Figure 6. Thus, for phlegmatic, sanguine, melancholic, and choleric people S = -4.6; 1.3; -5.7; 3.9, respectively, and for different cholerics S = -6.0; 5.5; -1.2; 2.4 for the following subjects: 12, 15, 18, and 26, respectively [15]. In other words, S can be considered as a general assessment of intergroup or intragroup energy differences, since each parameter of the SSP reflects one or another aspect of the electro-physiological status of the individual.

Conclusion

1. The total skin potential together with its derivatives is a multidimensional characteristic of electrical processes in a living organism. Usually this multidimensionality looks like a set of individual indicators, each of which is recorded on a separate channel. Such multidimensionality, however, does not in itself provide an integral idea of the studied functional status of the individual. After all, each indicator has its own dimension, which is expressed in units of measurement different from other indicators. Therefore, it is very difficult, if not impossible, to directly see the connection between them. To eliminate this difficulty, the Z-transformation of the original or averaged data is used, which allows them to be brought to a "common denominator". As a result, we obtain isomeric values of the parameters of the phenomenon under study, for example, average Z for GSR, average Z for EEG, average Z for HR, average Z for blood pressure, and so on. But in order to obtain a truly integral representation of the phenomenon characterized by the selected partial parameters, they must be presented as features of a certain whole. We see an example of this kind of integrality in visual perception, in which a figure and its parts are given simultaneously and as a single whole. It is therefore no coincidence that in science, when possible, visual (essentially symbolic) means of representing abstract concepts are often used. The psychophysiological status of an individual is an abstract concept. It can be described

verbally, using a set of certain parameters, but due to their objective discreteness, combining words or numbers into a single semantic image is (usually with difficulty) made by the subject, so that true integrality remains his personal secret.

Modern graphics have a fairly large set of visual means that allow you to depict something abstract in the form of a specific symbol. For this purpose I used a petal diagram, which allows one to represent the psychophysiological (or rather, electrophysiological) status of an individual as a closed figure (gestalt), in which the whole and its parts are simultaneously given, which is the essence of true integrality. Moreover, since all the parameters of the SSP are presented in an isometric format, it is possible to "compress" the multidimensionality to a one- dimensional indicator S, which can be considered as a general assessment of intergroup or intragroup differences in the energy status of individuals.

2. The nature of the frequency dynamics of the SSP, derived from the latter using frequency-time analysis, allows us to conclude that the focus of electrical activity in the nervous system quickly moves in a fairly large area, involving the resources of the central and vegetative subsystems necessary for it in the execution of the current action. The movements of this focus are very fast, as evidenced by the records of frequency dynamics, but the overall picture of activity, which is drawn over a long period of time, looks as it is presented, for example, on modern maps of the states of various parts of the brain. We see frozen colored spots on them, although extremely fast-flowing processes are behind them. This suggests that the nervous mechanism for the implementation of the operational composition of the current activity is built in the process of its execution, and does not exist in the form of a pre-prepared template stored in memory.

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