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High-frequency electromagnetic radiation and the production of free radicals in four mouse organs

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Abstract

The article studies the amplitude-frequency spectrum of the brain bioelectric activity function within the range of 27–0.13 Hz caused by reading gustatory and visual adjectives. Sixteen women aged 18–20 took part in the experiment. The results showed the range of the greatest change of excitation (maximum) and inhibition (minimum) of brain bioelectric activity function. When reading gustatory adjectives, the main and maximum changes of bioelectric activity function amplitude value are observed in the range of delta and slow rhythms. In case of reading visual adjectives, the changes are observed in theta and fast rhythms. It is peculiar that the number of amplitude maximums of bioelectric activity function in both right and left hemispheres 3 and 5 times higher while reading gustatory adjectives than visual adjectives correspondingly. It is necessary to conduct further research in order to elaborate the processing mechanisms of visual stimuli neuron in detail.

Introduction

The record and analysis of the brain bioelectric activity synchronized with the observed (sensor, motor and cognitive) events represent a very promising tool for studying cognitive processes that ensure perception and organization of a mental task performance. This noninvasive method of monitoring the brain physiological processes allows obtaining objective information about the functioning of the brain and psychological processes in real-time mode (Klochkova *et al* 2016; Quiroz-G 2003).

It is substantiated that multisensory effects improve information processing in the cortex at early stages, supposing that sensory integration is a distributed process beginning in lower sensory areas and continuing in larger associations. Thus, visual stimulus increases the speed and the strength of the response of neurons in the auditory cortex (Kayser *et al* 2010). However, the identity of the stimulus can be decoded only according to the responses to their primary sensory modality during the stimulus period rather than at the processing stages that connect sensation and decision-making. These results indicate that the multimodal decoding and perceptual judgments occur before reaching the sensory areas of the cortex (Lemus *et al* 2010).

Taking into consideration the functional relation and similar evolution of motor and cognitive processes that have dynamic bi-directional influence on each other, which is proved by the data available on how certain brain parts integrate them, there is a development of therapeutic strategies of physical and cognitive training (Leisman *et al* 2016). The results of the studies in this field are widely practically applicable. It is assumed that the combination of physical exercises and cognitive training can enhance benefits of cognition.

The search for general patterns in the realization of cognitive processes through neuron networks is an important task. An ability is proved to modulate different processes initiated by language switch (Van Der Meij *et al* 2011). Hence, there was a study of the question whether verbal memory processing in two non-related languages is mediated by a common neural system or by separate cortical areas (Halsband 2006). Using the subcortial stimulus, some authors managed to trace different pathways of white matter for different languages (Giussani *et al* 2007).

In this set of questions, it is necessary to point out the importance of mental reactivation of the sensations associated with adjectives (Kolbeneva & Aleksandrov 2010), describing not a whole object, but only its properties. Unlike nouns implying a relatively multimodal modeling, adjectives describe various properties of an object perceived by different senses (Wierzbicka 1986). Also, based on the data of previous years, it can be assumed that the processes of differentiation of individual experience are most fully reflected in the characteristics of adjectives (Waxman & Booth 2001). With the help of adjectives included in the specially developed lists of affective (highly-emotional) adjectives, mood, experience in a stressful situation and functional adaptability are studied. In the works mentioned above, it was shown that the presentation of adjectives causing emotions of various signs is accompanied by different changes in the activity of the cerebral cortex.

The objective of the current study is to register and conduct the cluster comparative analysis of the brain bioelectric activity differential spectrum function caused by reading gustatory and visual adjectives from a computer.

The study continues research on the detection of changes in brain processes during the process of controlling certain types of psychological activity (Klochkova *et al* 2016).

Materials and methods

The measurements of the bioelectric activity differential function spectrum were performed in the laboratory of environmental neurocybernetics of the SIC "Arctic" FEB RAS on the diagnostic complex "Registrar of the spectrum of electromagnetic brain activity induction (MS MAGEE-01)" which are multi-turn coils for recording brain biopotentials (Lebedev et al., 2007). The researchers used bipolar leads in frontalis leads according to Kreinlein symmetric scheme (Kovanov *et al* 2001.) with one common vertical electrode located on the sagittal line of the head in the upper part of the fissure of Rolando. The research applied standard biopotential amplifiers with the noise of no more than 1–3 μV, digital filtration with suppression of the signal above 30 and below 0.1 Hz in the investigated area.

As part of the study, fast and slow rhythms were recorded. Fast rhythms include beta (more than 12 Hz), alpha (8–12 Hz), theta (4–8 Hz) and delta (1–4 Hz) ranges. Normally, there are 2 types of delta vibrations: the first one has a cortical origin, the second one is generated in the thalamus. It is known that the intracortical delta-rhythm is connected with the slow processes within the cerebral cortex (Kropotov 2010). Slow rhythms are recorded within 1–0.3 Hz. Preparatory activity is an example of slow cognitive activity.

Spectral estimation was carried out with the sampling rate of 0.06 Hz. In the programme spectral analysis, the frequency axis was divided into 840 frequency bands with the width of 3% from the central frequency. Appearing in the frequency band, the amplitudes of the spectral frequencies synergized as a result of FFT. The resulting amplitude set to the central frequency. The logarithmation procedure was applied to equalize the amplitude of the spectral assessment for different spectral frequencies and normalization. A similar approach was applied during the study of long-term reactions of electroencephalogram (EEG) of hippocampus and neocortex in pharmacological studies (Podolskiy *et al* 2000). Only repetitive and stationary oscillations were distinguished. The duration of the analysis period was 160 s.

Adjectives

In this work, adjectives from linguo-psychological dictionary were used (Kolbeneva & Aleksandrov 2010). For the experiment, there was a selection of adjectives associated with highly-differentiated behavior (visual) and low-differentiated behavior (taste) aimed at finding differences by comparing the frequency range of fBA.

Adjectives make up the main part of the affective lexicon (Clore & Ortony 1988). During the selection of adjectives, such a complex criterion as imagery (concreteness/abstractness) was taken into account. To eliminate the analysis of mechanisms of distinguishing between concrete and abstract words, concrete adjectives causing more associations were selected (Appendix 1). As studies have shown, concrete words are perceived and processed easier than abstract ones, since, presumably, the analysis of more comprehensible, concrete words requires less stress of cognitive resources (Il'yuchenok 2007).

The selection of adjectives is also based on the fact that adjectives included in the specially developed lists of affective adjectives are frequently used to study moods (Tiller & Campbell 1986; Nemanick & Munz 1994), experiences in stressful situations (Scott *et al* 2001), lateralization of the cerebral hemispheres during the processing of emotional information (Atchley *et* *al* 2003), as well as personal characteristics of people closely connected with emotions (Pascalis *et al* 2004).

Participants

The experimental group consisted of 16 Russian-speaking women aged 18–20 years without any registered pathologies.The sample size of the subjects is associated with the standard conditions of the pickup and analysis of objective indicators (Ivanitskiy *et al* 2013; Portnova *et al* 2010; Petrov *et al* 2016). Under the conditions of this experiment, it was not planned to identify gender differences and age-related peculiarities of perception. All the participants confirmed their consent to participate in the experiment.

Procedure

In order to identify common patterns, spectral analysis was carried out for all the subjects at once. Each subject had at least six series shot for each type of adjective: 3 measuring without intellectual load (background) and 3 measuring in the process of computer presentation of 20 adjectives (gustatory/visual) connected with senses to a medium and strong degree (Kolbeneva & Alexandrov 2016). Testing started at 13.00 local time. In all measuring similar adjectives (only gustatory or visual) were used in different sequences. The data were analyzed after measuring, as it was in the third cycle when the highest number of maximums and minimums of fBA were recorded.

Next, 6 main clusters were singled out and time dynamics was carried out in the course of reading gustatory adjectives, taking into account the fact that each measuring lasted 160 seconds and there were 3 sequential measuring: the first one lasted 0–160 seconds, the second one lasted 160–320 seconds and the third one lasted 320–480 seconds. The intervals between the measuring did not exceed 40 seconds.

The use of differential fBA allows separating (subtracting) the values of background spectral function. Background measurements are the values of fBA, the last one before the measuring session, when the subject, with his eyes open, sits in front of the notebook with the computer presentation. Normalization and transfer into the nondimensional form of the result, i.e., the differential spectral function of bioelectric activity, as well as the fast Fourier transform (spectral estimate) were performed programmatically on the software-hardware complex ''RS MEGI-01".

Written in large print, there was one adjective placed in the center of the slide and was demonstrated for 5 seconds, after which there was an empty slide in front of the subject for 3 seconds. Measuring methodology allows reliable record of the total (global) activity of the brain singling out the spectral harmonics in the range of 27–0.13 Hz (Rybchenko *et al* 2014; Shabanov *et al* 2011).

Statistical processing

In the course of the study, the following statistical methods were used with the use of software Statistica (v 13.0): Ward's method (distance between clusters), Chebyshev distance (dendogram construction), K-means clustering.

Results

Differential spectral function of the bioelectric activity

Using the software of the complex, the differential spectral function caused by the bioelectric activity (fBA) for the left and the right hemispheres was studied. The amount of positive and negative peaks of fBA may be higher in both left and right hemispheres (Figure 1).

Clustering method of differential fBA is applied for the amplitude-frequency detalization of brain bioelectric activity. Frequencies that change the function amplitudes equally are to be studied. In order to find out the amount of clusters, dendograms were used. (Figures 2, 3).

A visual difference between the left and right hemispheres on both dendrograms is notable (Figures 2, 3).

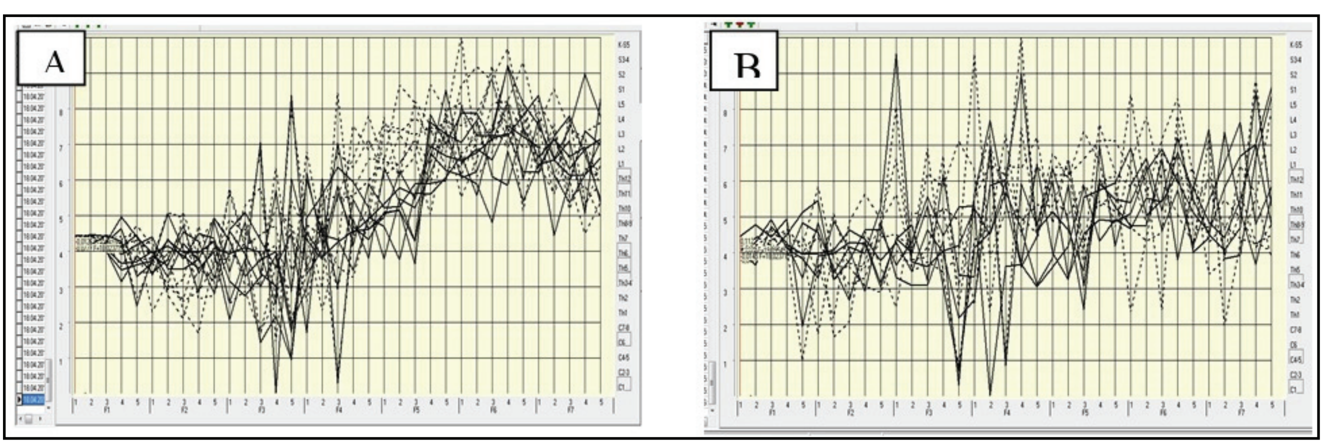

Fig. 1. The graph of amplitude values of the differential spectral function of bioelectric activity recorded in the course of reading adjectives: (A) gustatory, (B) visual. Along the axis of ordinates, the amplitude is in relative units; along the x-axis – frequency functions; the firm line – right hemisphere; the dotted line – left hemisphere.

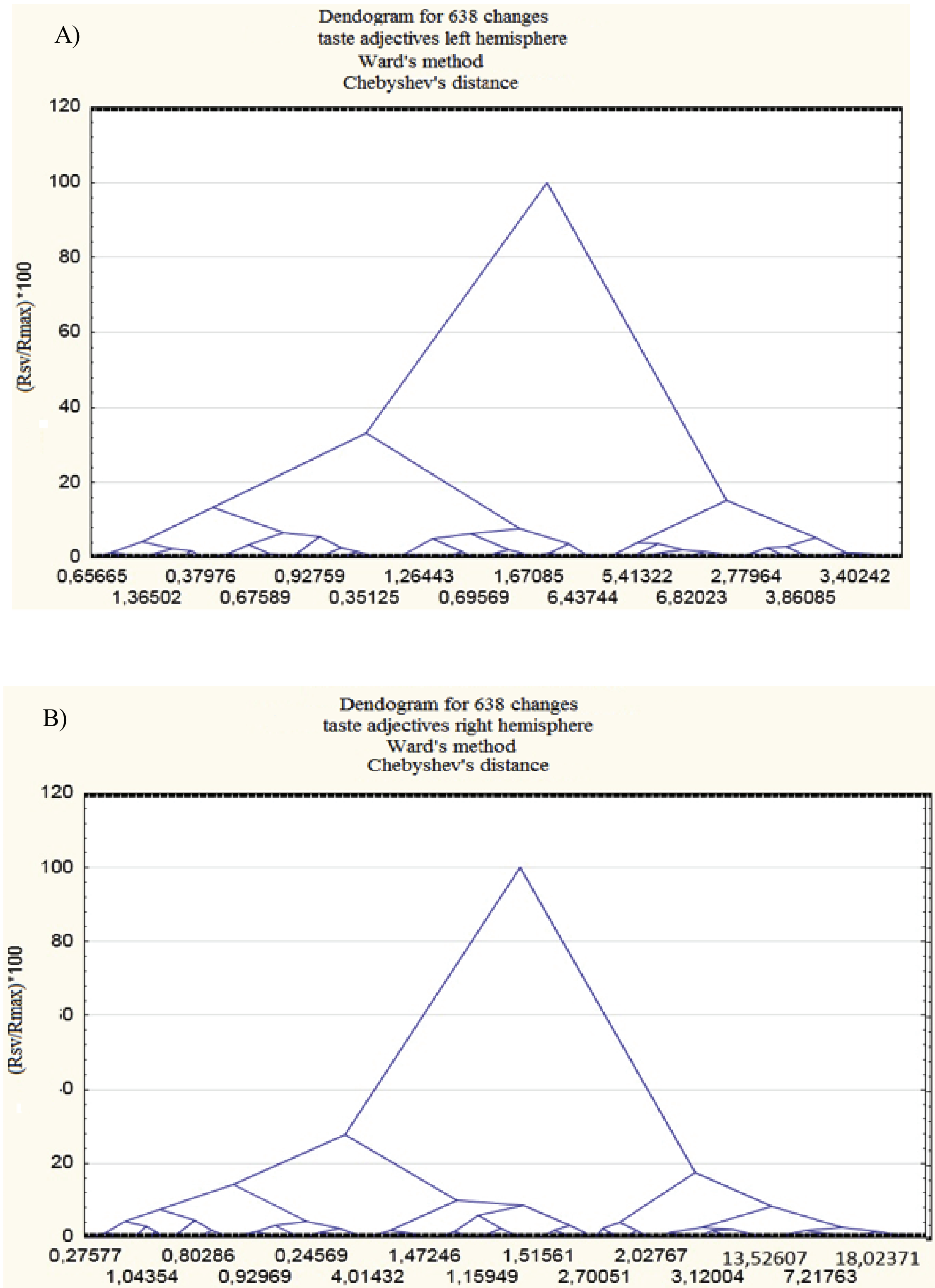

Fig. 2. Dendogram of the clustering of amplitude-frequency characteristics of the differential fBA during the process of reading gustatory adjectives: (A) left hemisphere, (B) right hemisphere. The x-axis shows the filtered 'RS MEGI-01' spectra of bioelectric activity of frequencies (Hz) grouped into clusters.

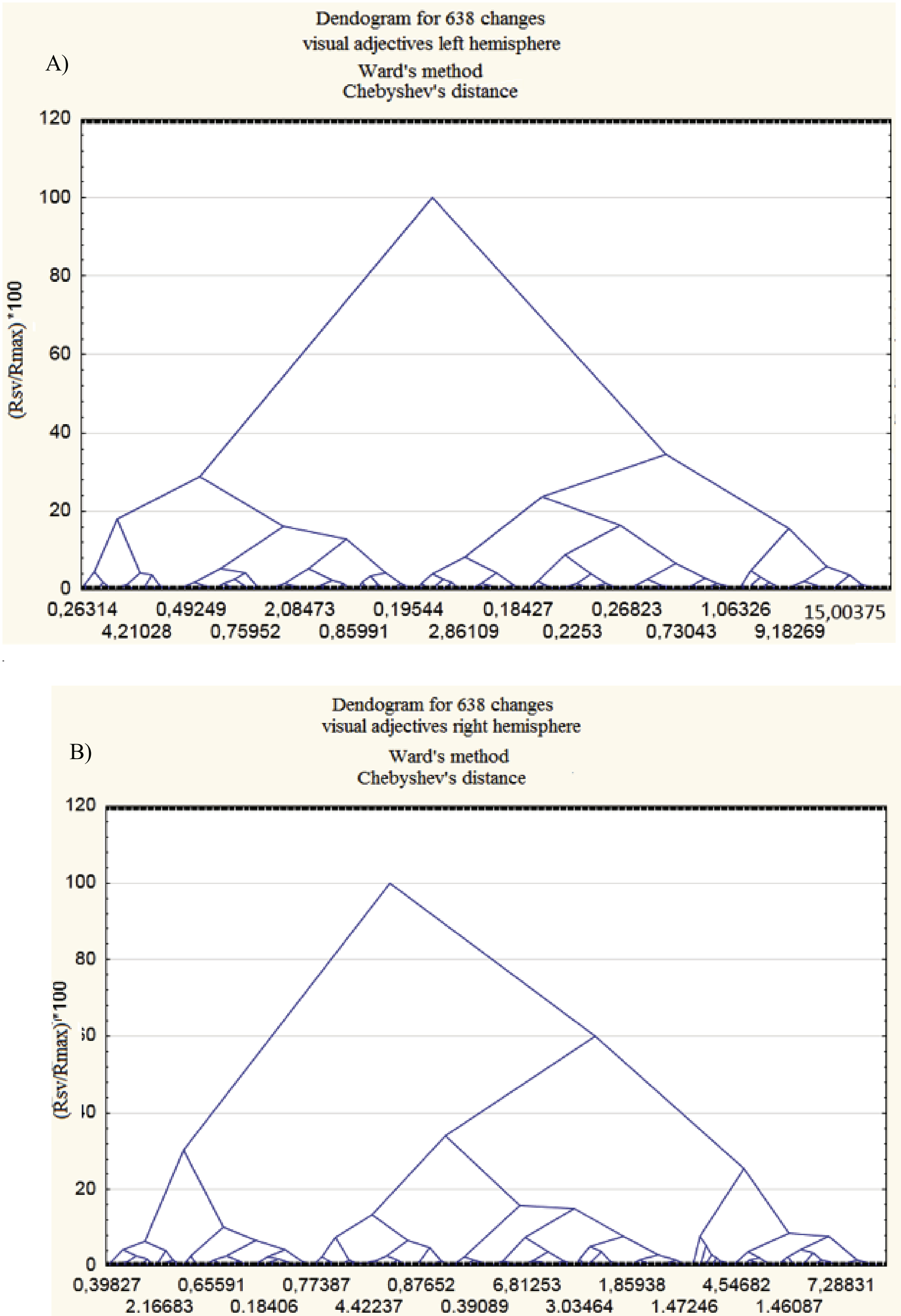

Fig. 3. Dendogram of the clustering of amplitude-frequency characteristics of differential fBA during the process of reading visual adjectives: (A) left hemisphere, (B) right hemisphere.

Tab. 1. The content of clusters fBA gustatory adjectives.

Rhythms	3rd left/1st right null	Brake-left/right	Brake changeable left/right	3rd Maximum-left/right	paral 0 left/ right	Changeable left/ 6th changeable right
slow (<1 Hz)	2/5	0/0	0/0	73/56	77/78	96/109
delta (1-4 Hz)	54/71	21/27	9/21	10/22	68/65	54/10
theta (4-8 Hz)	29/49	37/48	25/7	1/0	17/5	0
alpha(8-12 Hz)	13/17	13/20	11/0	0/0	0/0	0
beta (12-27 Hz)	20/19	2/9	6/0	0/0	0/0	0
In total	118/161	73/104	51/28	84/78	162/148	150/119

Tab. 2. The content of the clusters fBA visual adjectives.

Rhythms	1st left/3rd right null	Brake left/right	Max left /right	MaxRise left/right	paral 0 left/ right	Changeable left/ changeable right
slow (<1 Hz)	37/18	6/0	33/83	44/59	60/53	69/35
delta (1-4 Hz)	61/47	19/16	4/36	52/25	55/51	25/41
theta (4-8 Hz)	46/40	37/7	0/2	9/3	10/29	7/28
alpha(8-12 Hz)	15/19	21/2	0/1	0/0	1/9	0/6
beta (12-27 Hz)	26/18	2/0	0/0	0/0	0/7	0/3
In total	185/142	85/25	37/122	105/87	126/149	101/113

Based on the obtained results, 6 groups can be picked out, that is, set a limitation of 6 clusters of fBA to be studied during the processes of reading both gustatory and visual adjectives (Figures 2, 3).

Frequencies were grouped into clusters with the method of k-means clustering. Each cluster contains objects with close amplitudes. Chebyshev distance was calculated as the distance between the average amplitudes of separate clusters. Figures 4, 5 show the changes in the average values of the amplitudes of clusters between measuring.

Frequency content of the clusters can be seen in Tables 2 and 3. The titles of the clusters are related to the differential function average value, that is, in the cluster marked 'null' the differential fBA value is close to zero (functions in case of frequency clusters do not differ from those in case of the background). 'Brake' title is connected with the negative value of the function: in the background mode in case of cluster frequencies the values of the function are higher compared to the process of the hotoshoot. The cluster in the background mode of which the differential function gets to the highest value is logically titled as 'maximum'. The titles of the other two clusters are connected with the behavioural dynamics. During the second measuring, the differential fBA of certain clusters obviously decrease and hence the title of such clusters – 'changeable' (Figures 4, 5). On each graph, there is a cluster which is parallel to the null, but the value of the differential function is higher than zero. Such clusters are entitled as 'parallel to the null' (abbreviated as 'paral. 0').

As concluded from Figures 4 and 5, frequency cluster (null) is identified. This cluster's amplitude fBA is the same as the background function, i.e., with null differential amplitude. This cluster contains almost all the fast beta rhythms and most of the alpha rhythms (Tables 1, 2).

Table 1 shows the details about the amount of bioelectric activity frequency function that makes up the content of the clusters in the course of reading gustatory adjectives for the left/right hemispheres.

Table 2 shows the frequency amount content of the clusters fBA during the process of reading visual adjectives for the left/right hemispheres. Alpha rhythms partially make up the content of the 'brake' cluster with negative differential amplitude, i.e., amplitudes in the background fBA are more in case of these frequencies compared to the amplitude during the process of reading adjectives (which slow down). It is necessary to point out that during the measuring of taste adjectives there are 2 brake clusters, one of which has the null mark of the differential amplitude during the second series in the left hemisphere.

In the course of reading visual adjectives, there is one brake cluster (Figure 5, Table 2). However, in the left hemisphere, one of the two clusters that greatly change the amplitude in the second measuring, also crosses the null mark. The highest value of frequency in this cluster is 6.61 Hz (theta-rhythm).

The second cluster that greatly changes the average amplitude has only delta and slow rhythms. In the right hemisphere, during the process of reading visual

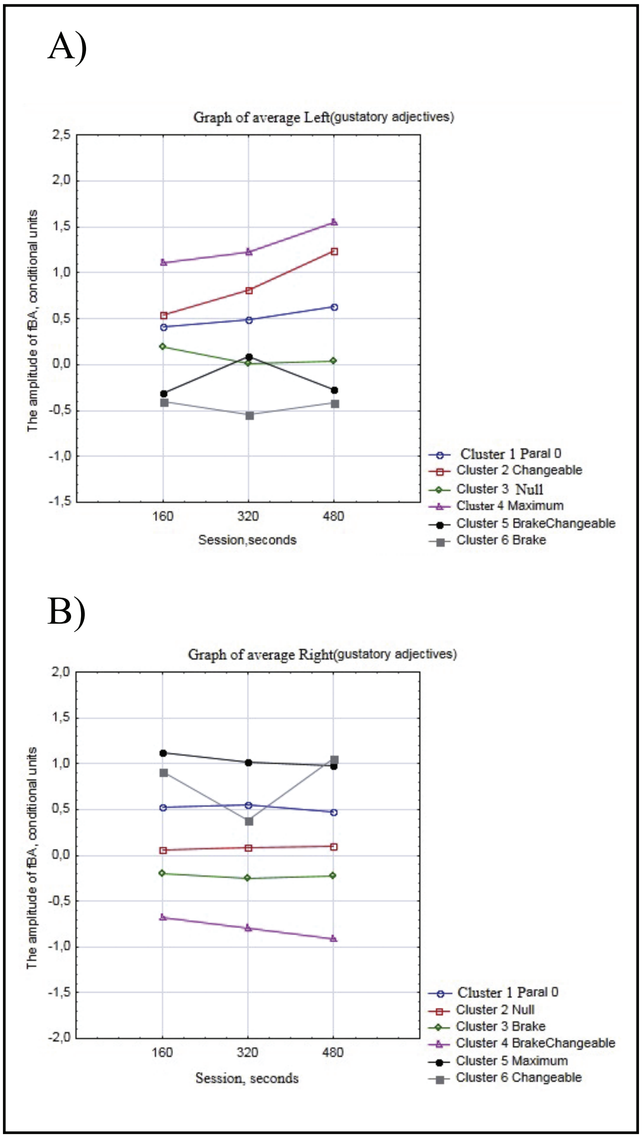

Fig. 4. The dynamics of changes in fBA clusters in the course of reading gustatory adjectives: (A) left hemisphere, (B) right hemisphere; the Y-axis represents the average amplitude in dimensionless units, the X-axis represents the finishing time of the measuring.

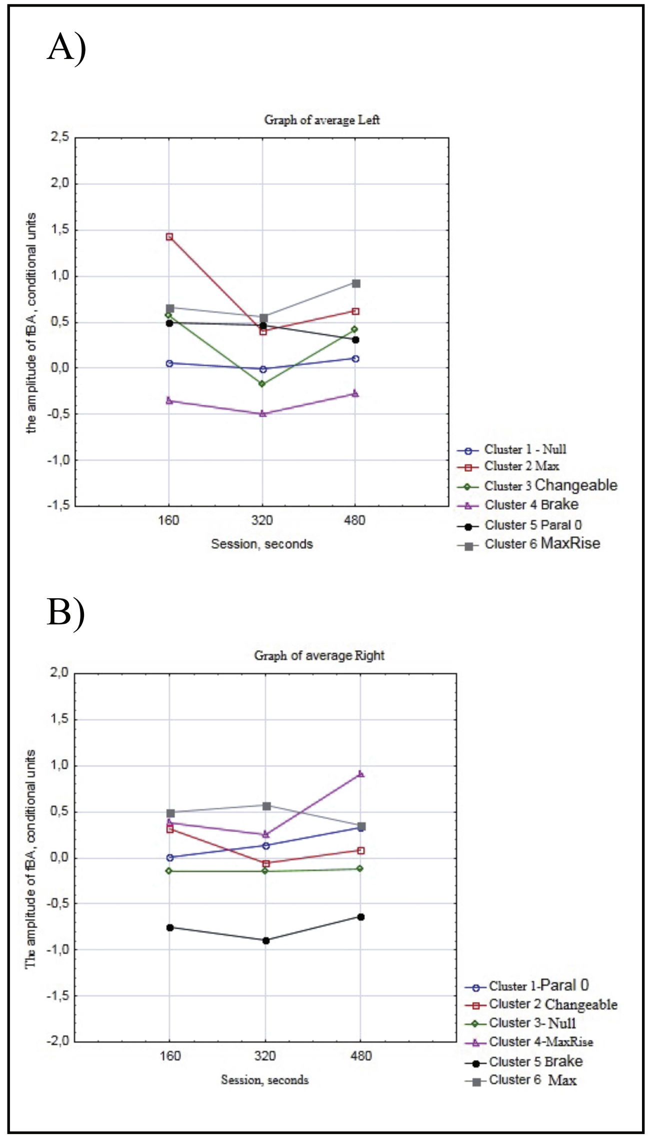

Fig. 5. The dynamics of fBA clusters change in the course of reading visual adjectives: (A) left hemisphere, (B) right hemisphere, the Y-axis represents the amplitude in relative units, the X-axis represents the number of the measuring.

adjectives, the greatly changeable cluster, where the amplitude reduces upon crossing the null mark in the second measuring and later remains almost unchanged, contains 9 fast rhythms, with 3 of them being in the range of beta. During the measuring of gustatory adjectives, in the differential function of the bioelectric activity, there is a cluster named parallel 0 that goes parallel to the null cluster (Figure 4). This cluster does not contain fast rhythms (Table 2), however, there are frequencies in it that are in the range of theta. The greatest number of theta rhythms is within brake and null clusters. The differential average amplitude fBA remains almost unchanged in the course of measuring of gustatory adjectives. The measuring of visual abstract adjectives has a completely different pattern (Figure 5). In the right hemisphere, one can observe a gradual growth in average amplitude fBA from series 1 to series 3. Apart from theta, both alpha and beta rhythms compose the frequency content of this cluster. At the same time, in the left hemisphere the amplitude decreases and except theta, there is also one frequency of alpha range (Table 2).

In the course of reading gustatory adjectives, the cluster with maximal values of bioelectric activity function (Figure 4) does not include fast rhythms. It mainly contain delta and slow rhythms (Table 2). In the left hemisphere, the amplitude of each rhythm grows steadily in the cluster. The amplitude of the cluster, which is called 'changeable' due to its behaviour in the right hemisphere as the amplitude significantly decreases in the second series, then it even exceeds the one of the maximum cluster in the third series, is virtually parallel to the low value. Although the content of the frequencies is rather similar (Table 2), there are considerably less delta rhythms in the right hemisphere than in the left one.

During the process of reading visual adjectives, fBA of the right hemisphere has the low amplitude. The maximum ('Max' in Table 2) cluster has a slight decrease in amplitude in the third series (Figure 5). Among 122 frequencies of the cluster, there is one frequency of alpha rhythm 10.22 Hz and two frequencies of theta range 6.13 and 5.10 Hz. The rest are delta and slow rhythms. In series 3 of the right hemisphere, there is a sharp increase in the amplitude of 'maximum' cluster, which contains 87 frequencies 3 of them representing the fast rhythms, namely 5.06 Hz, 4.81, and 4.77 Hz. The amplitude of the 'changeable' cluster has similar pattern with lower values (Table 3). 37 out of 113 variables belong to the range of fast rhythms, mainly theta, however, there are 3 frequencies of beta-range 13.24–13.64 Hz.

The highest amplitude of the left hemisphere function in the first series belongs to the cluster that includes 37 delta frequencies and slow rhythms (Table 2). However, its great decrease during the process of the second measuring results in the fact that the highest value belongs to the amplitude of the cluster including 104 frequencies, with 9 of them being within theta-spectrum. Practically parallel to the last one is the behaviour of amplitude fBA of the 'changeable' cluster (104 variables Table 2) 9 of which are within the frequencies of theta-rhythm.

Discussion

The results of the study show that during the process of reading gustatory adjectives, the main and maximum changes in the values of fBA amplitude are observed within delta ranges and slow rhythms. During the process of reading visual adjectives, the changes are observed in theta and fast rhythms.

While reading both gustatory and visual adjectives, the main part of the fast beta and alpha range rhythms were located in the null cluster with zero amplitude difference between the measuring and background of fBA.

During cognitive reactivation of senses while reading gustatory adjectives the growth in the fBA amplitude of the left hemisphere is consistent with the location of verbal centres of association areas, i.e. the left hemisphere of the cerebral cortex (Luriya 2008). The participants felt hunger, which explains a burst of bioactivity in the area of slow rhythm associated with the metabolic, especially while reading gustatory adjectives like 'bouillon' or 'ham'.

While reading visual adjectives, which are mainly abstract (such as 'combed' or 'heavy-faced') and associated with non-dangerous concepts, the reaction is weaker (Figure 5, Table 2) in the area of frequencies less than 2 Hz.

It is necessary to point out that the number of amplitude maximums of bioelectric activity function in case of reading gustatory adjectives is 5 times higher in the left hemisphere and 3 times higher in the right onecompared to those in the process of reading visual adjectives (Table 2). This may be associated with the fact that experience formed during early development of senses is less differentiated than that connected with senses developed later (Aleksandrov 2009), which is why the former should be cognitively repeated faster than the latter.

The assumption that the experience developed earlier is predominantly associated with taste and is less differentiated than the experience developed later predominantly associated with vision is consistent with the data obtained in the work (Chernigovskaya, Arshavsky, 2003; Hoffman & Lambon 2013; Kolbeneva & Alexandrov 2016). The differential spectral fBA caused by visual adjectives shows a lower amplitude than the gustatory ones. This way, the obtained data are consistent with the analogous study and shows that more differentiated experience should cause more frequencies of the lower amplitude fBA (Baars 2003; Kolbeneva & Alexandrov 2016). Further study of response mechanisms and factors affecting the changes of the bioelectric activity of the brain with modern methods has an important theoretical and practical application.

Conclusion

The obtained findings prove that the experience predominantly connected with taste is characterized by a low degree of differentiation, while that predominantly connected with vision has a high degree of differentiation. The number of amplitude maximums of the function of the bioelectric activity varies in the course of reading gustatory (predominance in the left hemisphere) and visual adjectives (predominance in the right hemisphere).

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Appendix 1. Adjectives

<u>List of gustatory adjectives</u>

Bouillon, ham, pomegranate, mushroom, strawberry, raisin, caviar, fig, cabbage, potato, kefir, onion, mandarin, oil, honey, almond, milk, meat, cucumber, olive, sturgeon.

<u>List of visual adjectives</u>

Crimson, whitened, snow-white, faded, shiny, velour, grape, wavy, hairy, gigantic, glossy, naked, hunchbacked, burnt, long, flabby, smoky, curled, green, muzzle, fiery, brushed.