

Topographic Variability of the EEG Spectral Patterns

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Abstract—The problem of spatio-temporal variability of the short-term spectral descriptions of multichannel EEG recording is discussed and a technique for estimation of the dynamics of the topographic map of the EEG spectral patterns (SP) is proposed. The SP types were determined using the adaptive classification technique in each of the 16 channels of EEG recording for each analysis epoch. The obtained 16-dimensional sets of SP types, or SP vectors, were compared for successive EEG analysis epochs. The mismatch estimation was calculated for neighboring SP vectors. The moments of significant mismatch between SP vectors testified to a radical reorganization of the spatial map of EEG spectral descriptions. It was shown that the dynamics of the SP vectors of real EEG are characterized by alternation of relative stable periods, the duration of which are substantially different from the respective characteristics of a stochastic process. These periods are caused by formation of the cortical spatial modules, within which steady relations are formed by the character of mutual stabilization between the types of EEG spectral description in each realization independently of their correlation and coherence. The prospects of using the analysis of topographic variability of the EEG SP for diagnosing brain functional states are discussed.

INTRODUCTION

The estimation of the spatial organization of the cortical EEG is one of the most promising approaches to studying the integrative activity of the human brain. The methods of analysis of simultaneous joint coordination of several or many EEG recordings directed toward the study of the integral organization of cortical bioelectric field are of special interest. Some EEG parameters of the global cortical integration, such as a sagittal gradient of the α activity, indices of interhemispheric asymmetry and others have been known since the discovery of EEG. Powerful estimations of the temporal and frequency coordination between local EEG recordings, such as the correlation and coherence coefficients (see [1] for a review) as well as indices of mutual informativity [2, 3], were developed later. However, they are destined predominantly for EEG analysis only in pairs of derivations.

Modern technologies of EEG computer analysis suggest a number of "geometric" estimations of joint coordination of local EEG recordings calculated with the use of factor analysis [4, 5, *et al.*] and multivariate linear regression [6, 7] of the primary EEG characteristics as well as on the basis of three-dimensional dipole decomposition of multichannel EEG [8] and ideas about the chaotic dynamics of an EEG vector composed of simultaneous momentary counts of local EEG recordings [9]. Individual attempts have been made to describe the integral cortical biopotential field by complexes of partial structural and spectro-correlative characteristics of local EEG recordings [10–12].

However, all these approaches inevitably come up against the problem of the nonstationary nature of

EEG. Regardless of how powerful or statistically significant may be different estimations of coordination between local EEG, there are difficulties in their meaningful interpretation if they do not match the EEG piecewise stationary structure. For instance, an assessment of coherence between EEG signals in two derivations in short analysis epochs revealed its rather developed dynamics [13, 14]. In this case, the coherence coefficient calculated without regard for the piecewise stationary EEG segmentation parameter loses a substantial part of its diagnostic value for studying discrete functional states of the brain as a very averaged index.

In this aspect, the so-called spatially oriented segmentation of cortical potentials proposed by Lehmann [15, 16] is a more adequate approach for estimation of global mutual coordination between EEG in different derivations. This technique is based on the calculation of the spatial localization of the vector of the maximal potential difference. In Lehmann's opinion, periods of stabilization of this vector reflect the stable functional complexes, or brain microstates, which at a given moment determine the character of key mental processes [17]. In such a way, the dynamics of the cortical biopotential field can be considered as a sequence of relatively stabilized topographical EEG maps.

Despite the successful approbation of Lehmann's methodology for EEG diagnostics of the different functional state of the human brain in psychophysiological and clinical studies [18–21] it should be mentioned that, in the context of this method, local EEG realizations participate far from equally in the formation of the resulting dipole vector. Its positions are determined only at the peaks of α oscillations [15, 16] and only in the periods of their maximal expression, while the

selection of cortical formations in relation to candidates for the structure-forming basis in the segmentation of the topographic EEG map only by the α rhythm expression is far from being justified from the viewpoint of indubitable neurobiological equivalence of cortical areas.

Moreover, lack of initial "attachment" of Lehmann's segmentary spatial EEG patterns to EEG spectral characteristics largely makes results of such segmentation ontologically unpromising and consigns them to the status of phenomenological description [22].

Therefore, it was proposed to combine the advantages of the temporal and frequency approaches to analysis of segment-to-segment construction of the cortical biopotential field. The problem of this study was to develop a technique of segmentation of EEG topographic maps on the basis of short-term spectral descriptions of local EEG recordings.

It was suggested that it would be possible to detect periods with more or less generalized stabilization in the dynamics of the spatial mosaic of different types of spectral patterns (SP) of the cortical EEG. Thus, analysis of topographic SP variability would make it possible to trace episodes of the stable cortical interarea cooperations independently of partial correlation or coherency between the local EEG recordings.

METHODS

In order to test the method of estimation of the SP topographic variability, a 16-channel one-minute EEG recording of a 28-year-old man (*ALF01-16*, eyes closed) and a 40-channel EEG recording of a 25-year-old woman (*GTN01-40*, eyes open and closed) were used. In both subjects, the α activity was well expressed.

EEG was recorded in 16 standard Jasper's derivations ($F_3, F_z, F_4, F_7, F_8, T_3, T_4, T_5, T_6, C_3, C_z, C_4, P_3, P_4, O_1, O_2$) in reference to coupled ear-lobe electrodes. After amplification, the EEG was digitized with a sampling rate of 128/s and stored on a computer hard disk. The duration of each EEG recording was 1 min. Individual spectra were calculated in the range of 1–30 Hz with 0.5 Hz discretization using the FFT transform in 2-s analysis epochs overlapping by 50 counts. Thus, 149 sequential individual spectra were calculated for each minute of EEG recording.

Parameters of topographic variability of the EEG spectral patterns were estimated in two stages. At the first stage, the adaptive classification of sequential single EEG spectra was performed in each derivation in reference to a versatile set of 32 standard SP. This procedure has been detailed by us in the previous paper [23]. Here, we only note that this way of SP classification makes it possible to identify up to 97% of individual single spectra in initial EEG realizations.

At the second stage, the set of 16 classified SP in each derivation was presented as a 16-dimensional vector

(i.e., SP vector) for each analysis epoch. Components of this SP vector could vary in the range of 0–32 in accordance with their classification number from the standard SP set (zero is a nonclassified individual single spectrum).

Thus, each minute realization of multichannel EEG was reduced to a matrix of 149 SP vectors by the number of elementary analysis epochs of the EEG signal. The degree of mismatch between any two vectors from this matrix was scored by the number of components distinguishing them (from 0 to 16). The comparison of sequential vectors was of particular interest. The peak values of vector mismatch estimation would indicate the moments of substantial transformation of the spatial organization of the spectral descriptions of local EEG realizations. On the contrary, low mismatch estimations for a series of sequential SP vectors would reflect the periods of relative stabilization of the map of cortical relations between the EEG spectral patterns.

RESULTS

Let us first consider the results of EEG analysis of the subject *ALF01-16*. Notably, the relative incidence of the SP type change during the transition between the neighboring EEG analysis epochs of the same realization varied from 0.41 to 0.51 (0.49 on average) in different derivations (Table 1). Differences in this index were most expressed in the occipital derivations, and

Table 1. Indices of dynamic variability of the EEG spectral pattern types for different EEG derivations in subject *ALF01-16*

Derivation	Relative incidence of SP type change	Diversity of SP types
O_1	0.51 ± 0.01	39 ± 3.4
O_2	0.41 ± 0.02	29 ± 1.8
P_3	0.51 ± 0.01	44 ± 2.0
P_4	0.51 ± 0.02	44 ± 2.6
T_5	0.50 ± 0.01	42 ± 3.2
T_6	0.49 ± 0.01	39 ± 3.0
C_3	0.51 ± 0.02	50 ± 2.1
C_4	0.49 ± 0.01	47 ± 2.2
C_z	0.47 ± 0.02	48 ± 2.3
T_3	0.44 ± 0.02	39 ± 2.0
T_4	0.50 ± 0.01	42 ± 2.7
F_3	0.51 ± 0.01	46 ± 1.1
F_4	0.51 ± 0.02	47 ± 1.1
F_z	0.51 ± 0.01	46 ± 1.3
F_7	0.47 ± 0.01	46 ± 1.4
F_8	0.47 ± 0.01	41 ± 1.8
Mean	0.49 ± 0.02	43 ± 2.1

Table 2. Estimations of the SP type variability for sequential EEG analysis epochs at different time shifts between them

	Shift					
	50	100	150	200	250	300
<i>M</i> (ICh) ± <i>m</i>	0.49 ± 0.01	0.66 ± 0.01	0.73 ± 0.01	0.78 ± 0.02	0.82 ± 0.01	0.84 ± 0.02
<i>M</i> (ME) ± <i>m</i>	7.8 ± 0.06	10.34 ± 0.07	11.76 ± 0.08	12.65 ± 0.08	13.09 ± 0.09	13.23 ± 0.09
	Shift					
	350	400	450	500	550	
<i>M</i> (ICh) ± <i>m</i>	0.83 ± 0.02	0.84 ± 0.02	0.84 ± 0.01	0.83 ± 0.02	0.84 ± 0.02	
<i>M</i> (ME) ± <i>m</i>	13.33 ± 0.10	13.4 ± 0.09	13.43 ± 0.08	13.43 ± 0.09	13.48 ± 0.10	

Note: Shift designates the number of counts of a digitized EEG signal between the initial moments of the neighboring analysis epochs; *M* (ICh) is a mean value of the estimation of the relative incidence of the SP type change in the neighboring epochs averaged over all derivations; *M* (ME) is a mean value of the mismatch estimation between the SP vectors for neighboring epochs; *m* is an error of arithmetic mean.

SP types changed more frequently in the left hemisphere.

The diversity of SP types was estimated as a ratio of the number of SP types detected in a given EEG to their total number in the standard set. Diversity for different channels varied in the range of 29–50% (Table 1). The least diversity was observed in the occipital derivations (39 and 29%), with notable dominance of the left hemisphere by this index (Table 1). There was a specific SP set in each channel or small group of channels, since the diversity of SP types in all channels taken together was substantially greater ($78 \pm 1.8\%$) than in each individual channel (Table 1). If not to take into account the SP types which occurred in less than 2% of cases, this value decreased to $34 \pm 1.7\%$. This indicates that more than half of the SP types occur very rarely; i.e., not more than 2–3 times per 149 analysis epochs in a one-minute EEG realization.

The data presented concern the SP variability in the neighboring analysis epochs, which overlap by 80%. It was to be expected that in less overlapping epochs (up to their complete delimitation in time) the estimations of SP variability should increase to a certain value, characterizing a stochastic level of the SP type change incidence. At the equiprobable occurrence of each of the 33 SP types in the EEG, the relative rate of their random alternation should be $1 - 1/33 = 0.97$. In the real EEG, some of its types are very frequent and others are almost entirely absent [23]. Consequently, the level of SP stochastic alternation in the real EEG should be substantially lower than 0.97.

In order to find the value of the relative rate of SP stochastic alternation in the real EEG, it was subjected to a randomized mixing of SP vectors. In such a way, the natural dynamics of SP sequence within each EEG channel were completely destroyed, but the percentage ratio between different SP types characteristic of the real EEG remained the same. After the procedure of randomized mixing of SP vectors was applied to 16 EEG realizations, the relative rate of the SP type alter-

nation at the first and all the following interepoch shifts was 0.825 ± 0.007 . It is apparent that just this value is the estimation of the maximally possible relative SP type alternation rate for a given EEG. Approaching this estimation testifies to the attenuation of mutual SP determination between the neighboring EEG analysis epochs.

Mean values of the relative SP alternation rate in the real EEG for different shifts between the initial moments of the analysis epochs (256 counts) are given in Table 2. The maximal rate of the SP type change, equal to 0.84, was reached at the shift in 300 counts. It remained practically the same during further increase in the time interval between the epochs. Thus, the SP of the neighboring analysis epochs in the individual EEG recording substantially determine each other only in instances of overlapping epochs or at interepoch intervals not longer than 50 counts (Table 2). At greater shifts between the epochs, the estimations of the SP type alternation practically decrease to the stochastic level.

Now let us consider the total SP dynamics over all the channels. In a single analysis epoch, there were $31 \pm 1.4\%$ of the SP types from their total number in the standard set on average. The mean estimation of the mismatch between the successive SP vectors of the EEG realization was 7.83 (Table 2). This signifies that at the shift of the neighboring vectors by 50 counts, i.e., by 20% of the analysis epoch duration (2 s corresponds to 256 counts), the SP type changes, on average, in 8 of 16 local EEG derivations. At longer shifts between the compared EEG analysis epochs, the mismatch estimation increases and reaches its maximum in 13.4 at the shift in 300 counts (Table 2).

On closer examination, these data turn out to be the regular result of parameters of SP variability for the neighboring epochs in each individual EEG channel. In fact, if the relative SP change rate at transition from one epoch to another in each EEG channel is equal, for instance, to 0.49 and 0.84 on average (respectively, for

interepoch shifts in 50 and 300 counts) (Table 2) and SP change in one channel is scored as 1, the total mismatch estimation for 16 channels should be on average $1 \times 0.49 \times 16 = 7.84$ or $1 \times 0.84 \times 16 = 13.4$, which precisely fits the experimental data (Table 2).

Thus, the mean estimation of the mismatch between the neighboring SP vectors over the whole EEG recording is completely determined by the SP variability parameters in each individual channel, which is why this estimation does not contain information about cooperative properties of the dynamics of the SP spatial map. At the same time, such information may be presented by parameters of the distribution of individual values of the SP vector mismatch estimation. If there is no interchannel synchronization of the SP type change at transition from one analysis epoch to another, the distribution of the SP vector mismatch estimations should apparently adhere to the standard law.

In order to simulate a situation with full temporal mismatch, 16 channels of the initial EEG were mixed in such a way that in each of the newly synthesized 16-channel blocks there was no pair of channels that would belong to the same EEG realization.

The distributions of the mismatch estimations between the neighboring SP vectors for real and "mixed" EEG are presented in Fig. 1. As can be seen, this distribution for the "mixed" EEG actually approaches the standard, and that for the real EEG is markedly different from the standard distribution. About 90% of these estimations for the real EEG are grouped in the range from 4 to 12, and about 55% are evenly distributed in the range from 6 to 10 (Fig. 1). This appears to conform to the dynamic range of SP vector variability, which contains estimations of the functional lability of the SP map.

Thus, at the indicated parameters of digitizing and spectral analysis of the EEG signal, the characteristics of topographic SP variability fall within a rather wide dynamic range for neighboring analysis epochs overlapping by about 80%. Such conditions make it possible to estimate temporal heterogeneity of the spatial SP map with sufficiently good temporal resolution in 50 counts, i.e., 0.39 s. In particular, it is possible to trace the periods with more or less spatially variable EEG SP by the index of the mismatch between sequential SP vectors. If to specify the threshold of the SP vector mismatch, it is possible to assess the periods of relative stability of the SP map. Within these periods of relative stability, the SP type change at transition from one analysis epoch to another would occur only in a limited number of cortical areas.

What is the mean duration of the relative stabilization of the SP map? The mean duration of the segment of relative SP map stabilization as a function of a specified threshold of SP vector mismatch estimation is presented in Fig. 2.

It is evident that the period of relative SP map stabilization increases almost 10 times from 2.9 to 27.8 sequential epochs (i.e., from 2.8 to 12.5 s) with the

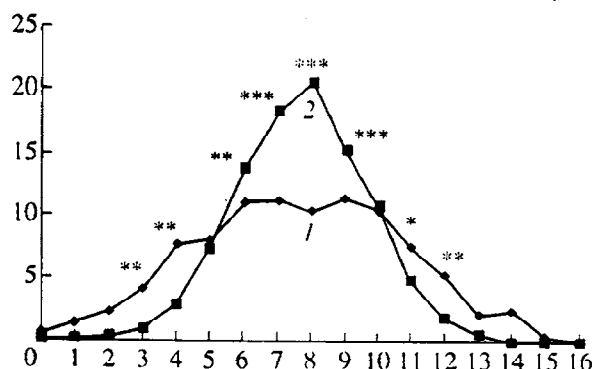


Fig. 1. Distribution of SP vector mismatch estimations for (1) the real EEG recording and (2) the "mixed" one, in which all the channels are completely mismatched in time. Abscissa: SP mismatch estimations from 0 (full identity of the SP vectors) to 16 (full mismatch between the SP vectors). Ordinate: relative representation (in percent) of each mismatch estimation in total data array for 16 EEG derivations. Student's levels of statistically significant differences: ***, $p < 0.001$, **, $p < 0.01$, *, $p < 0.05$.

increase in the threshold level of difference from 8 to 13, and at the next step of threshold change the stabilization period already comprises almost half of the whole EEG recording, i.e., 70.9 epochs (29 s). If to stop, for example, at the levels of 50, 62.5, or 75% SP map transformation (the SP vector mismatch estimations 8, 10, and 12, respectively), the mean duration of the relative stabilization of this map would be 2.8, 3.6, and 8.3 s, respectively (Fig. 2).

To what extent are these estimations indicative of the functional cortical interregional cooperation? It is shown that even in the absence of any correlation between the EEG channels there should be a certain stochastic level of the SP map stabilization, which would reflect merely occasional combinations of SP types in different channels. The duration of periods of such occasional stabilization of interarea relations would probably be substantially lower than in the presence of functional interaction between the areas of EEG derivations.

Figure 2 depicts the mean duration of the SP map stabilization periods for the "mixed" EEG, in which the interchannel correlation is completely absent in contrast to the respective data for the real EEG. The regularities of SP sequence within each channel remain unchanged. It is evident that, in the range of threshold mismatches between the SP vectors from 10 to 15, the "mixed" and real EEG recordings were in fact substantially different in terms of the duration of the periods of relative SP map stabilization (Fig. 2). An important practical conclusion from this observation is that the estimations of the mean duration of the SP map stabilization associated with the functional correlation between the local EEG realizations should be calculated at the threshold SP vector mismatches from 10 to 12. At this particular threshold range, differences

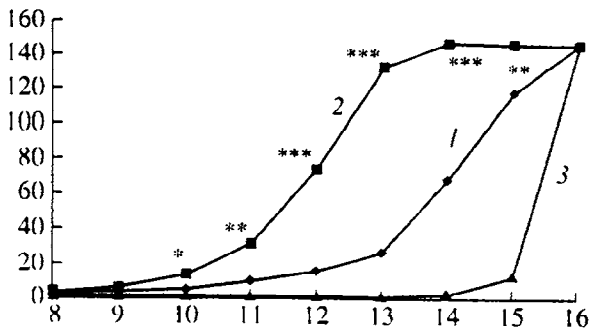


Fig. 2. Dependence of the SP map stabilization period on the threshold (specified) of the SP vector mismatch for (1) the real, (2) "mixed between the derivations", and (3) "mixed within derivations" EEG recordings. Abscissa: the mismatch thresholds; ordinate: mean duration (for 16 derivations) of the period of relative stability of neighboring SP vectors (at the shift of 50 counts) corresponding to a given mismatch threshold. Student's levels of statistically significant differences between (1) and (2): ***, $p < 0.001$, **, $p < 0.01$, *, $p < 0.05$.

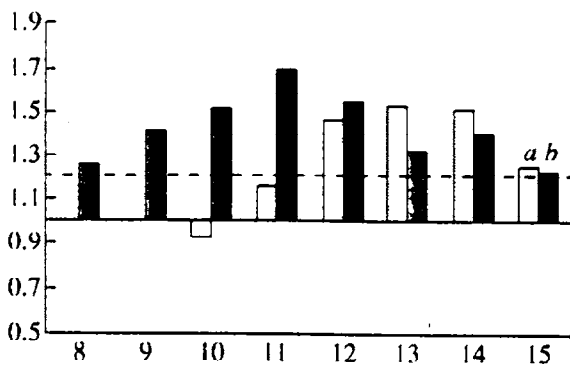


Fig. 3. Ratio between the mean stabilization periods of the EEG SP map under the CE and OE conditions (a) in the same subject *GTN01-40* (CE/OE) and (b) under the CE conditions between two subjects *ALF01-16* and *GTN01-40* (CE1/CE2). Abscissa: thresholds of mismatch between the SP vectors. The student's level of significance 1.23, above which the estimations are statistically significant ($p < 0.05$), is shown by the dashed line.

between the real and "mixed" EEG recordings occur along with a sufficiently fine (from 3.6 to 8.3 s) temporal structure of the SP map and statistically are highly significant (Fig. 2).

However, the above assumption about longer periods of the SP map stabilization in the real EEG was not justified. It turned out that, in a rather wide range of threshold differences between the SP vectors, the native EEG recordings were characterized by notably shorter periods of the SP map stabilization than the corresponding estimations for the "mixed" EEG (Fig. 2). At the same time, these estimations did not even approach the possible minimum characteristic of the EEG with a fully destroyed natural sequence of the SP types in each individual channel (Fig. 2).

Thus, the location of estimation of the mean period of SP map stabilization of real EEG in "coordinates" of factors of inter- and intrachannel coordination of the SP sequence allows this EEG to be characterized from the viewpoint of more or less general coordination between its short-time local spectral descriptions.

Note that the data presented above were derived from the file containing 16 EEG realizations recorded in the same subject (*ALF01-16*) under conditions of closed eyes.

For initial estimation of the data spread caused by interindividual differences, 40-channel EEG was recorded in the second subject (*GTN01-40*), which was also characterized by well expressed α activity. To assess the possible influence of the factor of α rhythm expression on SP variability, the EEG in the second subject was recorded under conditions of open (OE) and closed eyes (CE).

The data obtained from this subject under CE conditions practically fit the principal estimations of the "intrachannel" SP variability for the first subject (Tables 1 and 3) in the incidence of SP change in sequential epochs (0.55 ± 0.02) and in diversity of the SP types ($42 \pm 2\%$). This was true both for individual derivations and for all the channels together ($76 \pm 1.5\%$).

Concerning the SP map variability, the set of SP types in SP vectors was somewhat wider in *GTN01-40* ($39 \pm 1.9\%$) than in *ALF01-16* ($31 \pm 1.4\%$; $St(15.19) = 3.6$; $p < 0.001$). Moreover, the subjects also differed in the mean duration of the SP vector stabilization period, but only for high thresholds of mismatch between the vectors (Fig. 3).

Comparison of SP variabilities under CE and OE conditions in subject *GTN01-40* showed that, while the differences between the estimations averaged over all the channels were absent (Table 2), there was a pronounced sagittal gradient of the SP diversity index at the OE: this index reached its maximum (0.48–0.49%) in the occipital and parietal derivations (Table 3).

EEG under CE and OE conditions virtually did not differ in estimations of the mean mismatch between the neighboring SP vectors (8.82 and 8.91, respectively), in the number of the SP types participating in formation of SP vectors (39 ± 0.7 and $37 \pm 1.1\%$), and in the number of the SP types which were "engaged" in all the channels (76 ± 1.7 and $78 \pm 1.4\%$).

At the same time, characteristics of the temporal organization of the SP map for the CE and OE conditions were statistically significantly different (Fig. 3); for example, for the thresholds of the SP vector mismatch of 13–15, the mean stabilization period of the SP map was 50% longer under CE than under OE conditions (Fig. 3). This is an additional demonstration that, in contrast to SP alternation in the frames of one channel, parameters of topographic SP variability are sufficiently sensitive both to interindividual differences and to changes in the brain functional state.

Table 3. Indices of the dynamic variability of the types of the EEG spectral patterns in different EEG derivations in subject GTN01-40

Derivation	Closed eyes		Open eyes	
	relative incidence of the SP type change	diversity of the SP type	relative incidence of the SP type change	diversity of the SP type
<i>O</i> ₁	0.54 ± 0.02	40 ± 2.8	0.57 ± 0.01	49 ± 2.1
<i>O</i> ₂	0.51 ± 0.02	38 ± 2.8	0.55 ± 0.02	46 ± 2.4
<i>P</i> ₃	0.57 ± 0.01	45 ± 2.5	0.56 ± 0.02	48 ± 1.6
<i>P</i> ₄	0.57 ± 0.02	45 ± 2.3	0.55 ± 0.02	49 ± 1.8
<i>T</i> ₅	0.57 ± 0.02	43 ± 2.4	0.57 ± 0.02	49 ± 2.5
<i>T</i> ₆	0.53 ± 0.02	43 ± 2.5	0.57 ± 0.02	48 ± 1.9
<i>C</i> ₃	0.57 ± 0.02	44 ± 2.1	0.54 ± 0.01	47 ± 2.0
<i>C</i> ₄	0.55 ± 0.01	42 ± 1.9	0.55 ± 0.01	45 ± 2.1
<i>C</i> _z	0.56 ± 0.01	43 ± 1.8	0.57 ± 0.01	45 ± 1.6
<i>T</i> ₃	0.55 ± 0.02	42 ± 3.0	0.51 ± 0.03	41 ± 2.2
<i>T</i> ₄	0.56 ± 0.02	50 ± 2.3	0.55 ± 0.02	41 ± 2.0
<i>F</i> ₃	0.55 ± 0.02	42 ± 1.7	0.57 ± 0.02	38 ± 1.9
<i>F</i> ₄	0.55 ± 0.02	40 ± 1.6	0.56 ± 0.01	33 ± 2.1
<i>F</i> _z	0.55 ± 0.01	42 ± 1.8	0.56 ± 0.02	37 ± 1.8
<i>F</i> ₇	0.53 ± 0.02	40 ± 2.4	0.57 ± 0.02	31 ± 2.2
<i>F</i> ₈	0.53 ± 0.02	38 ± 2.9	0.56 ± 0.02	28 ± 2.0
Mean	0.55 ± 0.02	42 ± 2.3	0.56 ± 0.02	42 ± 2.0

DISCUSSION

Spectral expansion is one of the most informative ways of the compact representation of the dynamic variability of the EEG signal [24]. Thus, the features of integral dynamics of tens and hundreds of thousands of neurons in a given cortical area at the local time moment are reflected in parameters of a single EEG spectrum. Invariability of single spectra in the course of several analysis epochs is obviously indicative of the maintenance of the same general mode of operation of the neuronal systems in a given cortical area within a given time period. In this case, the EEG SP stabilization in several cortical areas may simultaneously reflect formation of steady integrations between the cortical areas independently of the specific characteristics of these SP in each channel of EEG recording. In contrast to Lehmann's stabilization of the map of peak EEG potentials, the invariability of the EEG SP map testifies to correlated temporal stabilization of the dynamic processes per se in the tested cortical areas.

What are the regularities of such spatial stabilization of the EEG SP? It was found that even in strongly overlapping (by 80%) 2-s analysis epochs of the real EEG there are virtually no cases when the unchanged SP type simultaneously persists in all 16 EEG derivations at transition from one analysis epoch to another (Fig. 1). Obviously, global stabilization of the functional state within several seconds is an exception rather than a rule for the normal operation of the brain.

It is likely that the pattern of the functional stabilization of the interregional cortical relations can be presented as a mosaic of dynamic constellations of different brain formations, which exist simultaneously but differ in the moments of their generation and termination. These constellations can be involved in realization of certain macrooperations of nervous activity. The lifetime of such spatial "operational modules" is determined by the duration of the period of joint stabilization of the main dynamic parameters of neuronal activity, which are included in these cortical modules. At the level of integral EEG, these processes are reflected in stabilization of the SP in corresponding derivations [23].

By specifying the threshold of the maximal mismatch between the neighboring SP vectors, it is possible to set the spatial scale of operational modules for which the mean duration of stabilization period of interregional relations is to be determined. As is seen from the obtained data, for a set of operational modules comprising from 8 to 16 cortical areas the mean duration of stabilization period is only 2.6 s (2.4 sequential epochs).

This means that stable combinations of SP types in eight and more EEG derivations predominantly persist not longer than for two–four sequential SP vectors, and scatter into smaller spatial modules at the next step of the analysis of SP vectors. At the mismatch threshold of 12–13 (i.e., if to take into account compact combinations of three–four cortical areas in the total array of the

stable SP combinations in different derivations), the total stabilization period of the operational modules would last for 16–30 analysis epochs (7.9–13.3 s).

These results would be difficult to interpret without comparing them with similar data obtained for EEG with complete temporal mismatch between all 16 derivations. It turned out that for such “mixed” EEG the stabilization periods for threshold mismatches from 10 (i.e., for the modules comprising from 16 to 6 cortical areas and less) are markedly longer than for the real EEG. In other words, a random combination of components of a 16-dimensional SP vector “creates” substantially longer segments of stabilization of this vector than is observed under conditions when the EEG channels are functionally correlated.

Meanwhile, theoretically it is possible to obtain a chain of successive SP vectors with mismatch not more, for instance, than 10 for as long as desired, relative to the incidence of interepoch SP type change in each of 16 EEG channels equal to 0.5. However, any deviation of the mean period of SP vector stabilization from its stochastic level will testify to the existence of a certain correlation between cortical areas during SP alternation.

The obtained results testify that the interchannel coordination in the real EEG manifests itself in a downward deviation from the stochastically determined level.

It may be suggested that shortening of the EEG SP map stabilization periods fits the conditions of the more dynamic performance of cooperative brain operations. The above evidence for the increase in the mean lifetime of the spatial modules at CE (Fig. 3) is in accord with this suggestion.

Notably, the spatially oriented EEG segmentation by Lehmann demonstrated a substantial increase in the duration of periods of stabilization of a 16-channel EEG map in schizophrenic patients [25]. Similar effects are achieved during application of neuroleptics [19]. At the same time, stationary segments of the EEG map shorten under the action of nootropic drugs [22] and benzodiazepines [19].

The observations of the decreased duration of Lehmann’s spatial EEG segments in depressions [20] and Alzheimer-type dementia [26] are somewhat dissonant from the presented evidence. Most likely, the dynamics of the operational cortical modules become more expressed as a means of compensation for the basic memory and attention processes that have been destroyed.

Apart from the assumption about the intensification of the dynamics of interarea cortical relations, the phenomenon of a sharp shortening of the SP map stabilization periods may have another explanation. In the “mixed” EEG, the total duration of the period of spatial SP stabilization for a given minimum n cortical areas is summed up from the elementary lifetime periods of spatial modules constructed from all possible combina-

tions of n derivations from 16 channels of EEG recording. In contrast to the “mixed” EEG, far from all combinations of SP types can be present in a real EEG recording within the same analysis epoch. Exclusion of a number of such “forbidden” spatial combinations of SP types from a theoretically possible set naturally shortens chains of successive SP vectors, which differ no more than in a given number of components. In such a case, a decrease in the duration of the SP map stabilization periods can testify to a narrowing of possible SP menu of these maps. A similar effect in connection with EEG segmentation by Lehmann was indeed described as a result of neuroleptic drug application [18].

CONCLUSION

Analysis of topographic variability of the short-term spectral patterns of human EEG showed that the dynamics of the spatial EEG SP map appear to reflect the piecewise stationary process of functional integration of cortical structures into operational modules of different size and lifetime. Stabilization parameters of the real EEG SP map substantially differ from the corresponding estimations for the “stochastic” EEG.

Thus, the method of analysis of topographic variability of the EEG SP makes it possible to trace the global dynamics of interarea cortical relations independently of the extent of temporal and frequency similarity between the recorded EEG derivations, but with regard for mutual stability of their spectral descriptions.

However, for more meaningful analysis of the parameters of topographic SP variability, their estimation is required for different functional states, for example, during different stages of a subject’s mnemonic activity. This problem will be the next for exploration.

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