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A Comparative EEG Study in Normal and Autistic Children

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We report here a comparative analysis of spectral power and mean coherence in the alpha, beta, and gamma rhythms in children aged 5–7 years, both normal and with early childhood autism, at rest and in conditions of a cognitive task (counting). In baseline conditions, both healthy children and those with autism showed a marked frontal-occipital alpha gradient. The cognitive task led to increases in the spectral power of the alpha1 range and its displacement into the left hemisphere without any alteration of alpha2; the task also produced a marked increase in spectral power in the alpha3 range. In healthy children, the cognitive task, as compared with baseline conditions, produced significant increases in the spectral power and coherence of the rapid rhythms in the central and frontal areas of the left hemisphere. In patients with early childhood autism, there was a right-sided predominance of spectral power in the alpha range both in baseline conditions and during the cognitive task. Baseline gamma-range spectral power in early childhood autism had greater values than in normal children and did not change during the cognitive task.

Keywords: cognitive tests, early childhood autism, EEG spectral power.

The number of children with dysontogenetic schizophrenia spectrum disorders, particularly early childhood autism (ECA), is increasing. Despite the predominance of signs of dysontogenesis in ECA, positive psychopathological symptoms are also often present and can prevent recovery of functions with aging. This increases the particular need for studies of the factors and mechanisms of this type of mental pathology. The problem of impairments to cognitive processes in adults [6, 9, 10] and children [3] with schizophrenia have been well studied. Impairments to cognitive functions in children with ECA have received less study, though published data suggest some similarity in the mechanisms of these two types of pathology [14]. Developmental impairments of the autistic type affect both sensory [15] and motor [11, 12] functions, though the major problems of adaptation of autism patients are related to the characteristics of information processing, its analysis, generalization, and the search for analogies. Impairments to integrative activity can be caused by loss of connections between specialized local neural networks and superfluous connections within isolated neuronal ensembles. In autism, individual blocks of processed information are not connected with each other [14]. Such impairments to connections are also typical of adult schizophrenia patients [7, 16, 18].

Studies of EEG characteristics in schizophrenia have shown that the process of generalizing information is reflected in the EEG in the form of synchronized high-frequency rhythms – gamma oscillations at 30–60 Hz, though some data give a range of 20–90 Hz [6, 10]. Changes in this high-frequency activity in patients with autism as compared with normal subjects may reflect impairments in the process of binding parts into a whole.

Age-related changes in the EEG in normal subjects lead to decreases in the spectral density (amplitude and index) of the delta and theta rhythms and increases in the spectral power of alpha and beta oscillations. Children with ECA are characterized by higher spectral densities in the beta2 frequency band and lower levels in the alpha frequency bands than seen in normal children of the same age. Some similar-

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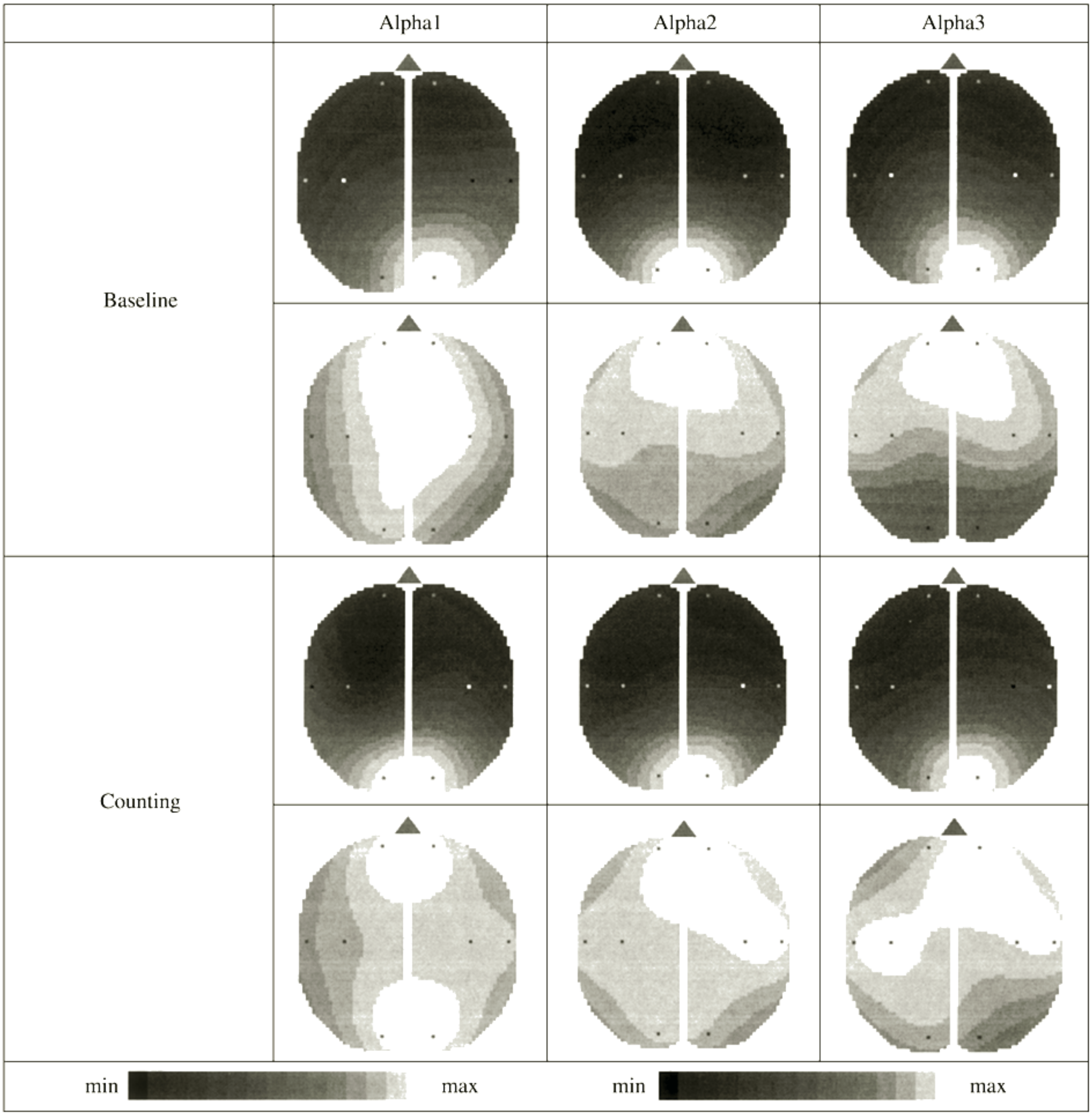

Fig. 1. Maps of alpha-rhythm SP and mean coherence in healthy children in baseline conditions and on counting: rows 1 and 3 show SP ($\mu V^2/Hz$) and rows 2 and 4 show coherence (units). The SP scale is from 3 to 50 $\mu V^2/Hz$ (left calibration scale); the coherence scale is from 0.2 to 1.0 units (right calibration scale).

ity in the age-related changes in these patients and normal subjects have been seen, though the times at which these changes occur are abnormal [2]. The aim of the present work was to identify the individual components of these abnormalities in the neurophysiological mechanisms of cognitive disorders in children with ECA.

METHODS

The study involved two groups of boys aged from 5 years 5 months to 7 years 2 months with predominantly right-sided characteristics: a control group (19 healthy children) and children with a diagnosis of "early childhood autism" (ICD F.85) (27 patients). The subjects were in the stage of preliminary investigation and were not yet receiving medication. The parents of all the children provided informed consent for their children to take part in the study.

EEG recordings were made from 16 electrodes in the standard 10–20% scheme and combined ear electrodes using a CONAN 4.5 computerized electrophysiological system [4]. Rhythms in the range 0.3–70 Hz were recorded at a digitization frequency of 256 Hz on trace epochs of duration 60 sec.

TABLE 1. Comparison of the Spectral Powers of the Alpha and Gamma Rhythms ($\mu V^2/Hz$) in Normal Children and Children with ECA; Average Values

Lead	Baseline (α_{mean})		Counting (α_{mean})		Baseline (γ)		Counting (γ)	
	normal	ECA	normal	ECA	normal	ECA	normal	ECA
Fp1	4.79	7.8	7.828*	7.423	0.154	1.042	1.00	1.01
Fp2	4.98	6.65	7.041	6.488	0.16	0.75	0.70*	0.82
F7	3.66	2.54	4.42	2.60	0.04	0.14	0.04	0.26
F8	4.74	2.88	5.62	2.91	0.08	0.12	0.11	0.26
F3	5.65	3.35	6.16	3.39	0.07	0.08	0.05	0.08
F4	4.91	3.08	4.56	3.09	0.04	0.07	0.02	0.09
T3	5.67	10.84	10.5**	11.06	0.127	0.95	0.92*	1.05
T4	8.13	10.45	10.52	11.26	0.142	0.63	0.69*	0.57
C3	8.30	6.936	9.964	5.813	0.160	1.82	0.77*	0.89*
C4	8.84	9.551	12.88	8.557	0.170	1.12	0.68*	0.72
T5	15.99	4.29	10.4	4.10	0.05	0.23	0.02	0.15
T6	8.39	4.36	8.20	3.95	0.151	0.17	0.01	0.29
P3	17.06	6.86	15.37	5.71	0.09	0.19	0.02	0.09
P4	15.01	6.17	17.17	4.79	0.07	0.26	0.02	0.08*
O1	19.28	11.78	26.33*	12.92	0.160	0.68	1.01**	0.74
O2	21.24	21.81	29.13	26.85	0.142	0.79	0.53	1.02

Note. Significant differences between baseline and counting within groups (normal–normal and ECA–ECA), χ^2; *$0.01 < p < 0.05$; **$p < 0.01$.

Baseline EEG was recorded in the state of rest with the eyes closed. The cognitive task, consisting of "counting" silently with the eyes closed, consisted of addition and subtraction of numbers up to 30 for healthy children and 10 for patients with ECA. EEG traces were processed and analyzed using the CONAN 4.5 program. Spectral and phase parameters were also calculated using specific programs [6]. Spectral power (SP) and mean coherence were studied in the alpha (7.5–13 Hz), beta (14–45 Hz), and gamma (45–60 Hz) ranges by averaging and comparing the results between groups of subjects. Mean coherence was calculated as the mean value of all paired coherences at the point of interest. This measure addresses the extent of involvement of different cortical zones in information processing and allows the results to be presented as isopotential fields rather than as paired connections. Significant differences were identified by unifactorial analysis of variance (ANOVA) with the nonparametric χ^2 test.

RESULTS

Spectral power values in the alpha1, alpha2, and alpha3 subranges in healthy subjects were maximal in the occipital areas and gradually decreased towards the frontal, showing the usual alpha gradient (Fig. 1). SP of the alpha-rhythm range increased on counting as compared with baseline (Table 1). The cognitive task produced the most significant changes in power in the form of increases in the alpha3 range. Mean coherence in the alpha range showed no significant zonal differences in calm waking, maximal values being recorded in the frontal leads. The cognitive task led to minor and insignificant redistribution of the zones of maxima, with tendencies to increases during counting in the alpha1 range in the occipital regions and in the alpha2 and alpha3 ranges in the right temporal and central areas, and in the alpha3 range in the left central area (Fig. 1).

Measures of the SP of gamma oscillations in baseline conditions showed significant predominance in the left occipital and right central areas (Table 1, Fig. 2). During the cognitive task, high SP in the occipital lead persisted, while SP decreased in the central area and increased in the left frontal and temporal leads. The "counting" test markedly altered the pattern of mean coherence. The greatest changes, which were increases, were seen in the central and particularly the temporal area of the left hemisphere.

The distributions of power and mean coherence of the beta rhythm in cortical zones, both in baseline conditions and during the cognitive task, generally repeated the main characteristics of the distributions for the alpha range (Fig. 3). Averaged power maps showed clear frontal–occipital gradients for the beta1 and beta2 ranges which persisted on performance of the "counting" test. The distribution of the beta3 range changed during the cognitive task: the frontal-occipital gradient disappeared and SP increased in the frontal and temporal leads of the left hemisphere (Fig. 3). Mean coherence in the beta1 and beta2 ranges remained essentially identical during the cognitive task to that in

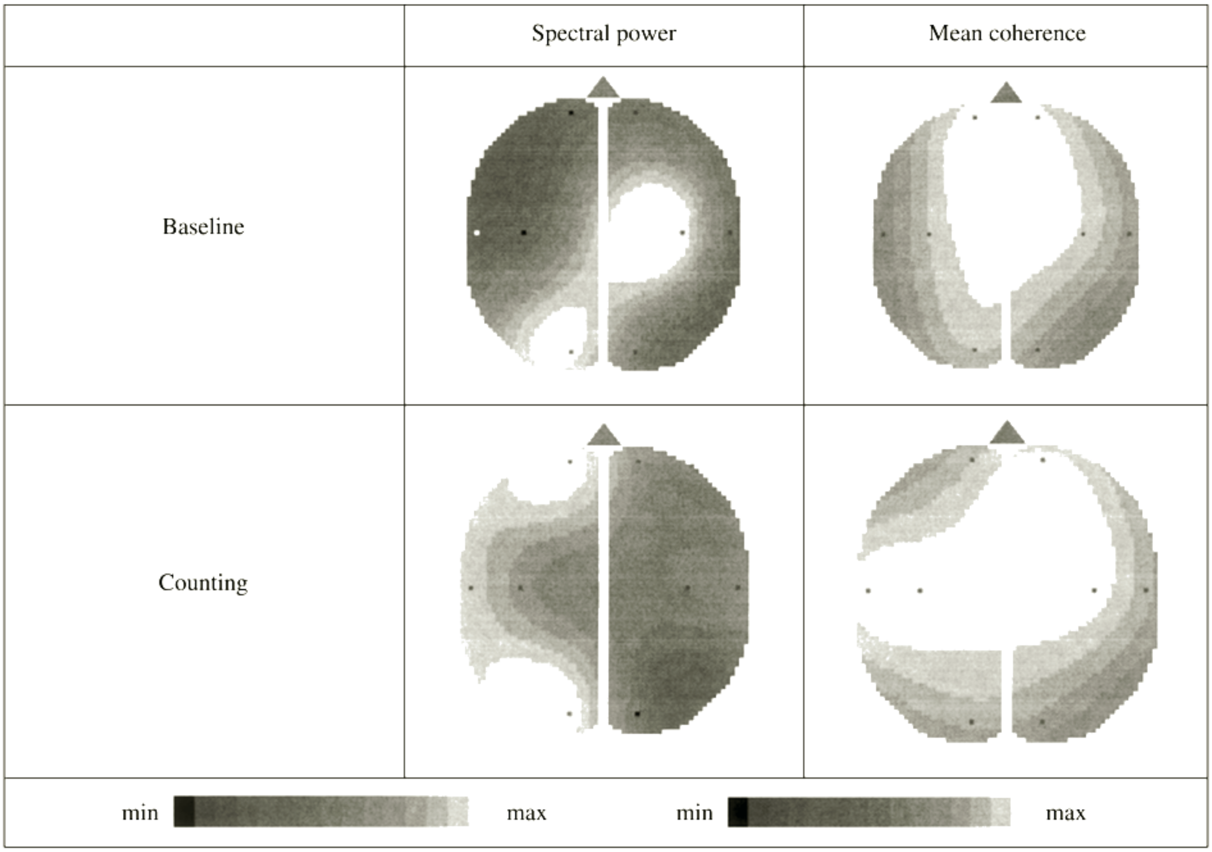

Fig. 2. Maps of gamma-rhythm SP (μV^2/Hz) and mean coherence (units) in healthy children in baseline conditions and during counting. The SP scale is from 0.05 to 0.4 μV^2/Hz; the coherence scale is from 0.2 to 1.0 units.

baseline conditions. Mean coherence in the beta3 range (27–40 Hz) showed the same pattern as that seen for the gamma range: values increased almost two-fold from baseline in the left central area (Fig. 3).

Maps of the spectral-power characteristics of the alpha rhythm in children with ECA showed significant variation in the distributions of values by area. The SP distribution map showed an asymmetric distribution of the alpha rhythm in the occipital areas with a predominance on the right (Fig. 4). The cognitive task in ECA patients did not induce any increases in the power of the alpha rhythm in any lead apart from the right occipital; the central and parietal leads showed some decrease in SP during counting (Table 1). Mean alpha-rhythm coherence in patients showed insignificant changes during counting: there were minor changes in the temporal and frontal areas of the right hemisphere (Fig. 4). The gamma range in baseline conditions had higher values than in normal children, particularly in the left temporal lead. Overall measures of SP showed no significant changes from baseline characteristics on counting in terms of either locations or power values (Fig. 5; Table 1). Total coherence also showed no significant changes during the cognitive task as compared with baseline. Results obtained for the beta rhythm in ECA are not presented here.

DISCUSSION

The first question arising on analysis of EEG characteristics in children with ECA is that of the extent to which the deviations from normal seen in this disorder are due to delays in development. An answer to this question requires the patterns of normal development to be compared with those in patients with abnormalities. The main rhythms reflecting maturation of different areas of the cortex and their interaction with subcortical structures develop asynchronously [8]. In normal children aged 3–5 years, the alpha rhythm is most marked in the right occipital area; on maturation, its focus shifts to the left by age 6–9 years and is located more or less symmetrically; by 10–14 years of age, this rhythm shows some predominance in the left occipital zone [1]. At the same time, the right hemisphere has been shown to have a greater deficit in nonspecific activation of the alpha rhythm [5]. Our data on the spectral

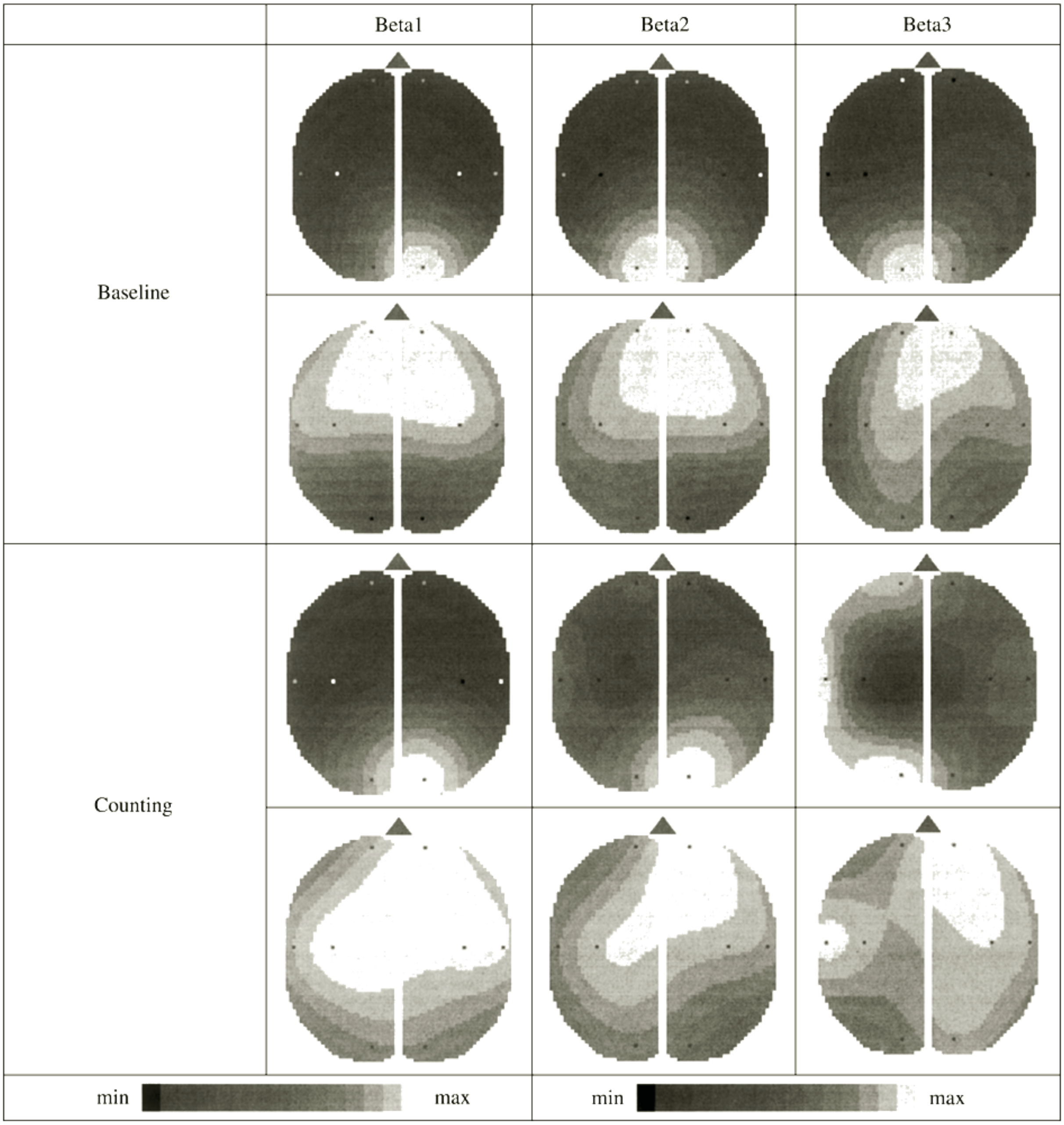

Fig. 3. Maps of beta-rhythm SP and mean coherence in healthy children in baseline conditions and during counting. The SP scale is from 1.0 to 3.0 μV^2/Hz; the coherence scale is from 0.2 to 1.0 units. For further details see caption to Fig. 1.

power of the alpha rhythm in studies of healthy children of a control group aged 5.5–7 years supported the view of the alpha rhythm as the “cognitive” range. Spectral power in the alpha1, alpha2, and alpha3 subranges were maximal in the occipital areas and gradually decreased towards the frontal area, showing persistence of the alpha gradient and lateralization typical of this age. Children of this age with ECA showed a predominantly right-sided alpha rhythm, which may provide grounds for suggesting a delay in the maturation of the basic rhythm. Thus, the asymmetrical distribution of the alpha rhythm seen here in the occipital areas, with a predominance on the right, in ECA patients aged 5.5–7 years, which is characteristic of healthy children aged 3–5 years, evidences a delay in the functional development of the cortex associated with the diagnosis of ECA. At the same time, a right-sided predominance of the alpha rhythm has been described in adult patients with schizophrenia with negative symptoms [6]. The view has been

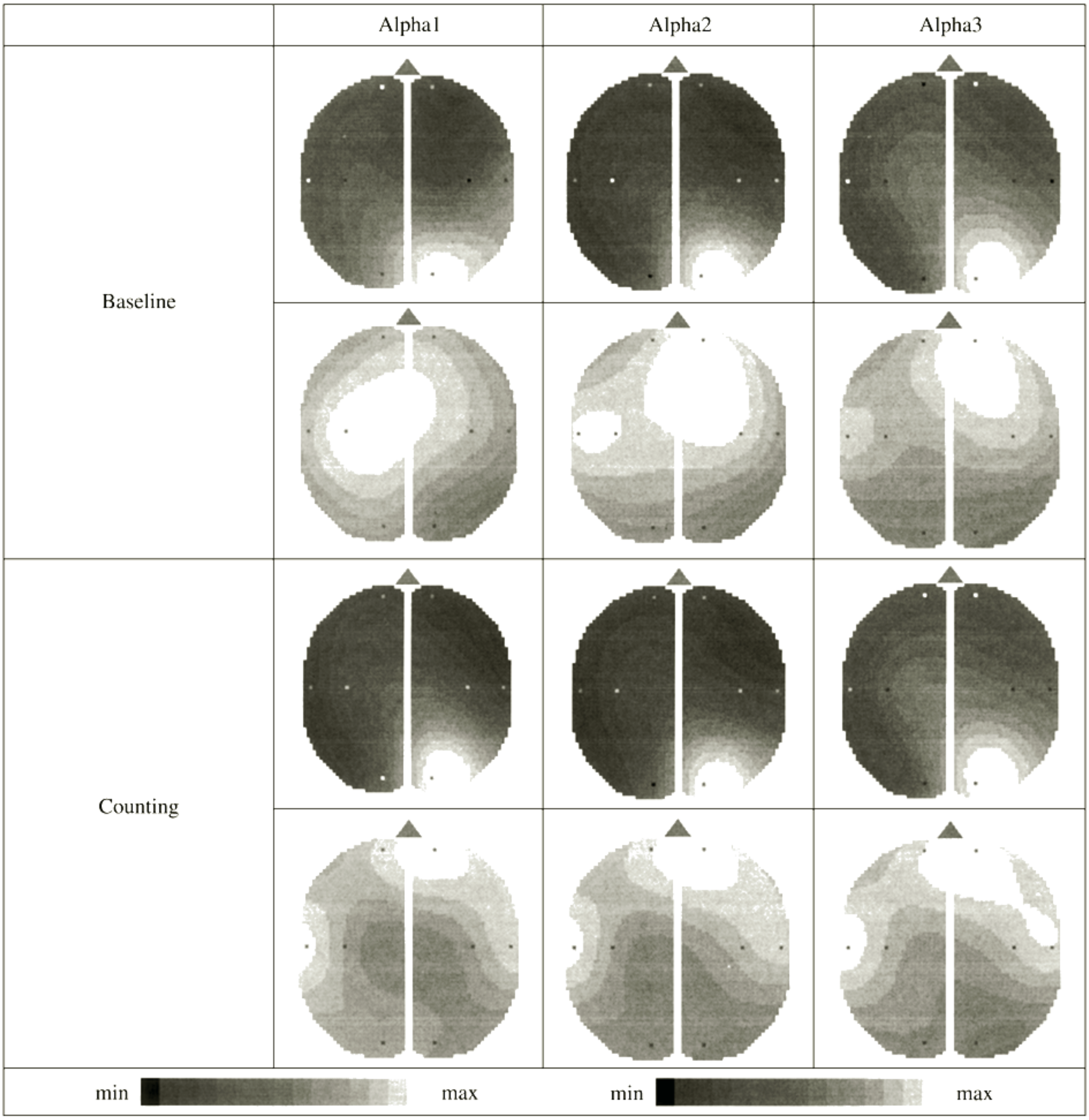

Fig. 4. Maps of alpha-rhythm SP and mean coherence in children with ECA. For further details see caption to Fig. 1.

taken that atypical EEG lateralization of rhythms in patients with autism may point to a decreased capacity of neural networks in the right hemisphere to generate EEG rhythms [17].

Analysis of the data obtained here on the contributions of alpha-rhythm subranges to the overall pattern of maturation of brain electrical activity indicates that the greatest contribution is made by alpha3 oscillations (Table 1), which is not entirely consistent with the concept that the slow components of alpha oscillations mature first and with aging are substituted by the fast components [2]. In addition, the functional involvement of all alpha-rhythm subranges, including the predominant alpha3 subrange, is consistent with the views of the same author that each narrow spectral band in this range has its own course of development. It should be noted that while in normal conditions, alpha-rhythm power levels increase significantly from baseline during the cognitive task, this was not seen in children with ECA.

In terms of the distribution of power and mean coherence, the beta1 and beta2 ranges were found to show similarity with the alpha range, while the beta3 range was similar to the gamma range. Evidently, the high-frequency region starts at 30 Hz, which is of particular interest to us

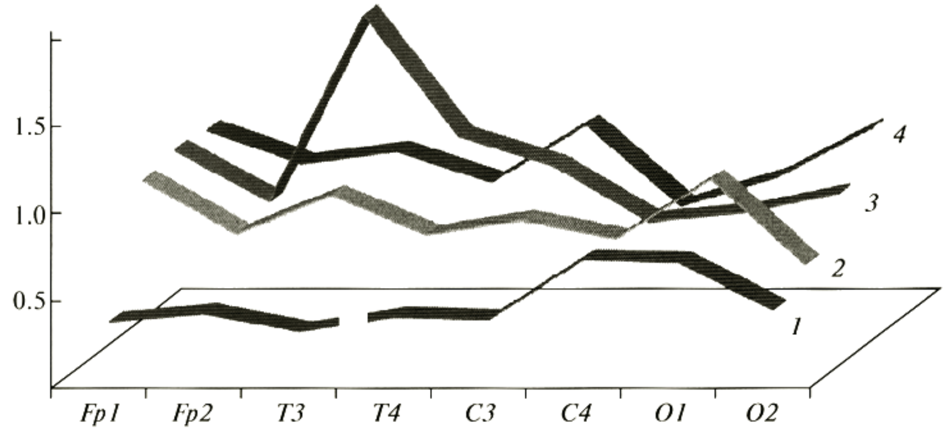

Fig. 5. Spectral power in baseline conditions and during the cognitive task; gamma range; comparison of normal and ECA groups. The ordinate shows SP ($\mu V^2/Hz$). *1*) Baseline in healthy children; *2*) counting in healthy children; *3*) baseline in patients with ECA; *4*) counting in patients with ECA.

in relation to ECA. Thus, the beta2 rhythm was not analyzed at the first stages of the study of ECA; attention was paid mainly to the gamma rhythm. The fact that the SP of the gamma range in healthy children was maximal in the left occipital and right central areas and was weak in the left central and temporal areas, as well as in the left and right frontal areas, is evidence for complex interactions between different cortical zones not only in performing tasks, but also in the resting state. An analogous picture has been described for healthy adult subjects [6]. At the same time, the decreases in SP in the right central area and the increases in SP in the left frontal and left temporal areas in healthy children during the cognitive task provided evidence of topographical rearrangements of the involvement of different zones in performing the cognitive task. The "counting" test produced marked changes in mean coherence in the high-frequency range: the central and temporal areas of the left hemisphere showed the greatest increases in measures of coherence, to a level twice that in the right hemisphere. Our data showing significant increases in power and coherence in the high-frequency range in the left central-temporal area during the cognitive task in healthy subjects indicate that these rhythms are involved in mediating verbally controlled mental activity. In healthy subjects, the central and frontal areas of the right hemisphere also showed significant changes in power and phase characteristics during the cognitive task as compared with baseline in the fast-rhythm range, 27–60 Hz, and this may indicate the functional involvement of these rhythms in forming adaptive behavior. Unlike normal subjects, overall SP in the gamma range in patients with ECA was increased, though there were no significant changes during the cognitive task in terms of either location or power and coherence. These data suggest the conclusion that increased SP values in baseline conditions prevent normal reactivity.

Thus, our data indicate that there were significant differences in the organization of the alpha rhythm in autism, both in baseline conditions and during the cognitive task, and importantly, in the involvement of the rapid oscillations of the beta and gamma rhythms. These data are consistent with published results showing increases in spontaneous high-frequency activity in autism, correlating with the extent of delayed development assessed on the basis of clinical and psychological parameters [13]. It is possible that our data showing increases in baseline activity and decreases in the reactivity of high-frequency rhythms in autism identify one of the physiological mechanisms of impaired integrative brain activity in this disease.

CONCLUSIONS

1. Both healthy subjects and patients aged 5–7 years showed a marked frontal-occipital alpha gradient in baseline conditions. The cognitive task led to an increase in the spectral power of the alpha1 range and shifted it into the left hemisphere, without altering values in the alpha2 range; spectral power in the alpha3 range was markedly increased.

2. In healthy children, the spectral power and coherence of rapid rhythms changed significantly in the central, temporal, and frontal areas of the left hemisphere during the cognitive task as compared with baseline.

3. Patients with ECA showed right-sided predominance of spectral power in the alpha range both at rest and during the cognitive task.

4. In ECA, the spectra power of the gamma rhythm in baseline conditions was characterized by higher values than in normal subjects. During the cognitive task, the spectral power and mean coherence of fast rhythms in patients did not change.

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