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Gender-Dependent Frequency–Spatial Organization of the Brain Cortex Activity during Convergent and Divergent Thinking: II. Analysis of the EEG Coherence

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Abstract—The gender dependence of inter- and intrahemispheric interactions of neuronal assemblies during convergent (CTh) and divergent (DTh) thinking was studied on the basis of analysis of coherence (Coh) of cortical potentials in a broad frequency band. CTh was studied with a model of mental arithmetic, and DTh, with a heuristic task. Right-handed subjects were examined. The distinctive feature of CTh was a functional change in the patterns of EEG Coh in the θ band. Men were characterized by an increase in interactions between the centro-parieto-occipital areas of both hemispheres and between the frontal and temporooccipital regions of the right hemisphere, whereas a similar pattern of coherent connections was shifted to the left temporal area in women, suggesting a predominant use of verbal calculation strategies by women and visuospatial strategies by men. Regardless of the gender, DTh was associated with an increase in interhemispheric Coh and an increase in Coh in the right hemisphere. However, the successful performance of a task in men and women was determined by different degrees of hemispheric interaction: men successfully solved the problem under conditions of a closer interaction of both hemispheres, whereas women efficient in their performance showed a weaker interaction of homologous cortical areas as compared to noncreative subjects.

Gender dimorphism is inherent in various cognitive activities, including convergent (CTh) and divergent (DTh) thinking [1, 2]; however, features of the functional hemispheric lateralization characteristic of men and women [3–5] during solving mathematical (CTh) or creative (DTh) tasks remain unstudied. Considering that gender differences in brain activity have been observed even in the case of equal efficiencies of cognitive performance [5, 6], analysis of the frequency–spatial EEG organization during CTh and DTh may be useful for revealing features of the functional interhemispheric interaction in men and women.

Guilford [7] proposed the model of DTh for describing the creative type of thinking, implying many solutions of a problem, each of which can be correct, in contrast to CTh, with a single correct solution. Investigation of inter- and intrahemispheric interactions by mapping coherent connections between different cortical areas is of special interest with such models because they offer a possibility of direct observation of convergence or divergence of neuronal connections depending on the test conditions.

It is well known that, in general, men perform arithmetic IQ subtests better than women [1, 8, 9]. However, although a number of articles are concerned with the neurophysiological mechanisms of mathematical operations [10–13], their gender-related features are scarcely considered in these works. At the same time, high specialization of the brain hemispheres during the performance of verbal and spatial tasks has been found in men [4, 5]. This fact suggests that convergent processes are more pronounced in men and, consequently, success in solving of mathematical (convergent) tasks by men and women is also associated with gender-related features of interhemispheric interactions.

Analysis of the gender-related features of interhemispheric interactions during DTh (creative thinking) provokes still greater interest. It has been shown that interhemispheric asymmetry is weaker in highly creative than in low-creative subjects [14–18]. At the same time, a closer interhemispheric interaction has been observed in women compared to men [19–21]. Consequently, gender differences in hemispheric interaction may be expected for DTh. Indeed, investigation of the cortical mechanisms of creativity has established that the performance of a verbal task in men is associated with an increase in interhemispheric coherence (Coh) between the right posterior and left frontal cortical areas, whereas a stronger connection between the left posterior and right frontal and mediotemporal areas has been observed in women [22]. Analysis of the EEG spatial organization in two α bands has shown that, during composing a story, intrahemispheric Coh in the α_1 rhythm in the left hemisphere increases only in women. Also, Coh increases between the centroparietal sites in women, whereas a decrease in coherent connections is mainly observed in men [23]. Moreover, mental visualization of an abstract notion produces in women a more pronounced decrease in the interhemispheric and ipsilateral right-hemispheric interaction of the frontal areas than in men. Coh in the left posterior area in the α_1 band decreases in women to a greater extent. The common effect of all variants of creative activity under the given test conditions is an increase in Coh between distant cortical areas, probably, owing to the interaction of cortical neuronal assemblies with subcortical structures [22–24]. This conclusion is based on the existence of two types of neuronal networks and, correspondingly, of two systems: local and more widely distributed cooperation of cortical neurons [25].

Dominance of the right hemisphere in creative thinking has been demonstrated by many authors [26–28]. On the basis of comparative examination of commissurotomized patients and healthy subjects, it has been suggested that creativity is caused by simultaneous symbolization of ideas and their imagery in the right hemisphere, accessible to the left hemisphere via the *corpus callosum* [26]. Thus, the ideas of the right-hemispheric dominance do not contradict the known facts of a closer interhemispheric interaction in creative processes. At the same time, evidence for the gender dimorphism of the *corpus callosum* [20, 29, 30] suggests gender differences in the interhemispheric interaction during DTh.

Thus, the aim of our study was to determine gender-dependent features of inter- and intrahemispheric interaction during CTh and DTh. CTh was simulated by arithmetic operations, and solving heuristic problems was used as an example of DTh. Taking into account the known facts regarding the functional heterogeneity of EEG rhythms [18, 23, 31, 32], it seemed important to analyze EEG Coh between different cortical areas in a broad frequency band.

METHODS

Right-handed 17- to 23-year-old students (36 men and 30 women) were examined. The EEG was recorded from 16 symmetrical sites of the right and left hemispheres in the state of rest and either during performance of successive operations of arithmetical addition (as a task predominantly involving CTh) or during solving of a special nonstandard task (DTh). The nonstandard task was selected on the basis of the results of a special examination described in detail earlier [33]. It consisted of the following: “Hundreds of poisonous snakes are kept in a zoo. It is necessary to measure the length of each one. How can it be done?” All variants of a subject’s responses were conveyed via a microphone, and a mark was made on the corresponding EEG record. The EEG segments preceding a moment when a hypothesis was generated were used in further analysis.

The EEG was recorded monopolarly with 16 electrodes located according to the International 10–20 System at symmetrical sites of the right and left hemispheres (Fp_1, Fp_2, F_3, F_4, F_7, F_8, C_3, C_4, P_3, P_4, T_3, T_4, T_5, T_6, O_1, and O_2) in reference to a linked earlobe electrode, using a Medicor encephalograph (Hungary) with the time constant 0.3 s and a 30-Hz low-pass filter. Analog-to-digital conversion of the EEG signal and calculation of EEG Coh were performed for each of the six frequency bands (θ_1 (4–6 Hz), θ_2 (6–8 Hz), α_1 (8–10 Hz), α_2 (10–13 Hz), β_1 (13–20 Hz), and β_2 (20–30 Hz)), using an IBM AT-386 personal computer with the software program Neirokartograf (MBN, Moscow). Artifact-free 2-s EEG segments with a total duration of 30 s were analyzed. EEG Coh was calculated for all 120 possible combinations of inter- and intrahemispheric lead pairs. Interpreting the results of the Coh statistical analysis, we considered only the sites of multiple Coh changes (foci, or nodes, of coherent connections) in order to avoid possible errors of types I and II. The informative value of this approach to the analysis of relative Coh changes in comparison of different groups of subjects has been shown in many works [18, 22–24, 34].

Statistical data analysis (Student’s *t*-test and analysis of variance (ANOVA)) was performed with the program Statistica for Windows (StatSoft, 1993).

RESULTS

Changes in interhemispheric interactions during convergent and divergent thinking. At the first stage, ANOVA of EEG Coh was performed with the factors gender (GEN, two levels), test (TEST, three levels: baseline conditions, CTh, and DTh), and frequency band (FB, six levels). Total Coh was averaged over the 8 and 56 pairs of homologous and nonhomologous sites, respectively, in the case of interhemispheric Coh, and over 28 pairs in the case of intrahemispheric Coh. For these 28 pairs, the factor laterality (LAT, two levels) was additionally introduced. Significant factor effects and the results of subsequent planned comparison are presented in Table 1. According to these results, total interhemispheric Coh between the homologous sites (HInterHCoh) increased both during CTh and during DTh as compared to the baseline. During CTh, this increase was observed only in the group of women (GR_W); in the men (GR_M), on the contrary, Coh decreased. Coh in the θ_1 and α_2 bands was higher in GR_W than in GR_M. During CTh, a significant increase in Coh was observed in the θ_1 band ($P < 0.003$). During DTh, Coh increased in the α_2, β_1, and β_2 bands ($P < 0.001$, $P < 0.04$, and $P < 0.000$, respectively). Interhemispheric Coh between nonhomologous sites (HInterCoh) increased in the θ_1 band during CTh and in the β_2 band during DTh independently of the gender. However, according to the effect of the GEN × TEST interaction, changes in HInterCoh in the men and the women were opposite during both CTh and DTh: in the former situation, Coh increased in the women and

Table 1. Results of ANOVA for total Coh

Significant factors and their interaction	*df*	*F*	*P*	Effect
	Interhemispheric Coh between homologous sites			
TEST	2.92	5.66	0.005	Coh↑ during CTh and DTh
GEN × TEST	2.96	3.14	0.048	CTh: Coh↑ in GR_W and ↓ in GR_M
GEN × FB	5.230	7.16	0.0000	In the θ_1 and α_2 bands Coh in GR_W is higher than in GR_M
TEST × FB	10.460	4.85	0.0000	In the θ_1 band, Coh is higher during CTh than in the BS; in the α_2, β_1, and β_2 bands, Coh is higher during DTh than in the BS
	Interhemispheric Coh between nonhomologous sites			
GEN × FB	5.225	2.80	0.002	In the θ_1 and θ_2 bands, Coh in GR_W is higher than in GR_M; in the β_2 band, Coh in GR_W is lower than in GR_M
TEST × FB	10.450	2.34	0.001	CTh: Coh↑ in the θ_1 band; DTh: Coh↑ in the β_2 band
GEN × TEST	2.90	2.57	0.008	CTh: Coh ↑ in GR_W and ↓ in GR_M; DTh: Coh ↓ in GR_W and ↑ in GR_M
	Intrahemispheric Coh			
GEN × LAT	1.48	5.06	0.030	LH: Coh in GR_W is lower than in GR_M; RH: Coh in GR_W is the same as in GR_M
GEN × FB	5.240	3.47	0.005	In the β_1 and β_2 bands, Coh in GR_W is lower than in GR_M
TEST × FB	10.480	2.21	0.016	CTh: Coh ↑ in the θ_1 band; DTh: Coh ↑ in the β_2 band

Notes: Here and in Table 2: Coh, coherence; GR_M, men; GR_W, women; BS, baseline state; TEST, test; GEN, gender; FB, frequency band; LAT, laterality; GR, group; LH, left hemisphere; RH, right hemisphere; ↑ and ↓, Coh increases or decreases, respectively.

decreased in the men; in the latter situation, this relationship was opposite. Total intrahemispheric Coh (IntraCoh) increased in the θ_1 band during CTh and in the β_2 band during DTh. Thus, total Coh of all types increased in the θ_1 band during CTh and in the β_2 band during DTh.

According to these results of ANOVA, topographic maps of the Coh changes during CTh and DTh were constructed for the most informative bands, θ_1 and β_2, respectively (Fig. 1).

During CTh, an increase in Coh in the θ_1 band was observed in the men, predominantly, in the right hemisphere, and coherent connections were focused in the sites O_2, T_6, and F_4. In the left hemisphere, an increase in Coh was most evident for the occipital lead. In the women, the nodes of coherent connections were shifted to the left hemisphere (F_3, C_3, P_3, T_3, and T_5). Simultaneously, interhemispheric interactions strengthened owing to an increase in Coh both between the fronto-centro-parietal cortical areas (F_4, C_4, and P_4 along with the above Coh foci) and between the homologous sites F_3–F_4, C_3–C_4, P_3–P_4, O_1–O_2, T_3–T_4, and T_5–T_6.

During DTh, the most pronounced changes in the EEG were revealed in the β_2 band by ANOVA (Table 1). Whereas HInterHCoh was to a greater extent increased in GR_W (Fp_1–Fp_2, F_3–F_4, C_3–C_4, P_3–P_4, and O_1–O_2), the increase in HInterCoh was more evident in GR_M (Fig. 1). This increase was observed for all sites except Fp_1, F_7, and T_3. We can say that DTh in men is associated with the increased interaction of the right hemisphere with the posterior regions of the left hemisphere, whereas the increased interaction of the left frontal regions (foci in F_3 and F_7) with the right-hemispheric regions (except the left temporal areas) is to a greater extent pronounced in women.

Changes in interhemispheric interactions as dependent on the efficiency of divergent thinking. At the next stage, analysis of the gender-related differences in the organization of interhemispheric interactions during DTh was carried out with regard to performance efficiency. To this end, the men and the women were subdivided into groups of those who had (GR1) and those who had not (GR0) solved the problem. Fifteen of 36 men and 11 of 27 women successfully coped with the problem. ANOVA was performed as at the first stage of the study, but the factor of performance efficiency (group (GR), two levels) was introduced and only two levels (baseline and DTh) were considered for the factor TEST.

The results of ANOVA for total Coh after the introduction of the factor GR (GR1_M, GR1_W, GR0_M, and GR0_W were the groups of men and women who had and who had not coped with the task, respectively) are presented in Table 2. Functional changes in Coh associated with successful divergent performance differed between the men and women, predominantly, in two frequency bands, α_1 and β_2. In parallel, we detected general gender-unrelated effects, which were caused only by the DTh efficiency. Thus, HInterHCoh increased in GR0 but decreased in GR1, so that total

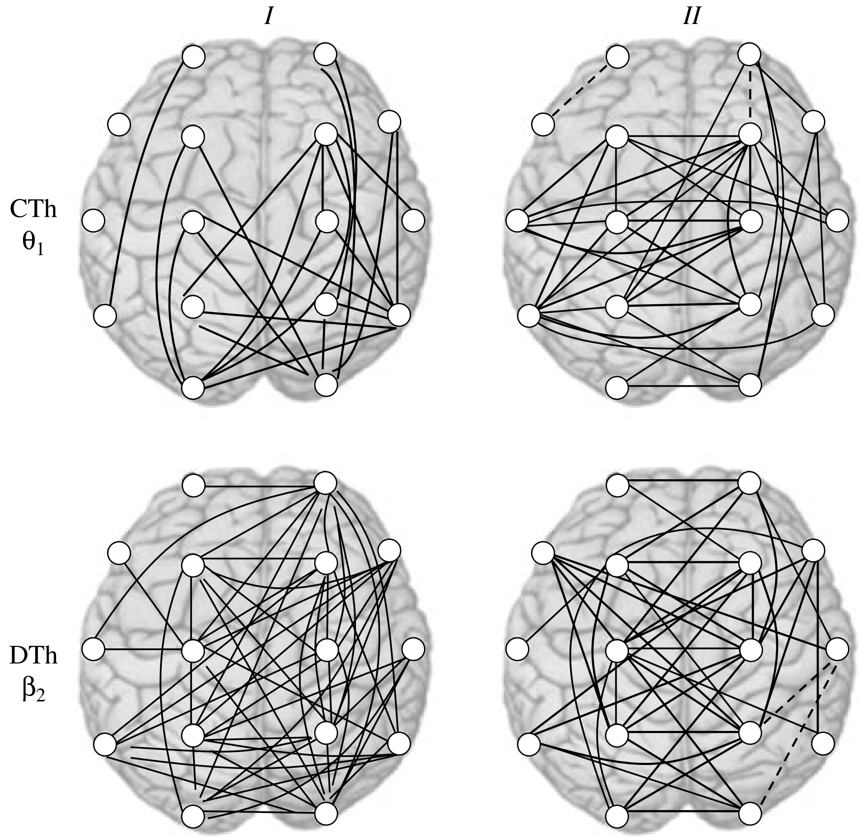

Fig. 1. Maps of Coh changes in the θ_1 and β_2 bands in (*I*) men and (*II*) women during CTh and DTh. Here and in Fig. 2: solid lines point to an increase in EEG Coh, and dashed lines point to a decrease in Coh; $P < 0.05$ for thin lines; $P < 0.01$ for thick lines.

HInterHCoh for the α_1 band in GR0 became higher than in GR1. This relationship was inverse in the β_2 band: Coh in GR1 was higher than in GR0. At the same time, during the DTh, total IntraCoh in the right hemisphere decreased in GR0 and increased in GR1, so that IntraCoh in GR1 became higher than in GR0. Total IntraCoh for the left hemisphere did not differ significantly between GR0 and GR1.

Effects of the interaction GEN × GR in the α_1 band are shown in Fig. 2a: GR1_M was characterized by an increase in HInterCoh, whereas a decrease took place in GR1_W. As a consequence, HInterCoh became higher in GR1_M than in GR1_W.

Maps of coherent connections in the α_1 band as dependent on the gender and success in the divergent task are presented in Fig. 2b. More prominent differences in Coh changes (as compared to the baseline level) were observed in this band in the women: Coh predominantly increased in GR0_W with a focus in F_7 and decreased in GR1_W with a focus in T_3. In the men, only isolated changes in Coh were significant in GR1_M, whereas a decrease in HInterCoh with a focus in Fp_2 was characteristic of GR0_M. However, comparison of maps of the Coh difference between GR1 and GR0 showed that an increase in coherent connections with foci in Fp_1, F_7, P_3, and O_1 was characteristic of GR1_M, whereas a decrease in interhemispheric Coh in the frontal cortical areas with foci in F_7, F_8, T_3, and C_4 was observed in GR1_W.

Taking into account that EEG changes caused by DTh were observed predominantly in the β_2 band and the interaction GEN × GR × TEST for HInterHCoh was near significant for all frequency bands, we performed ANOVA with the factor electrode location (EL, eight levels) separately for the β_2 band. This analysis revealed the significant interaction GEN × GR × TEST (Table 2), which was caused by the fact that Coh in the β_2 rhythm increased in the men ($P < 0.035$) and decreased in the women during successful divergent performance (Fig. 3a).

Maps of Coh in the β_2 band for GR1 and GR0 as dependent on the gender and the results of Coh subtraction (GR1 – GR0) (Fig. 3b) illustrate the ANOVA results. Gender differences during DTh were observed both in GR0 and in GR1. GR0_M was characterized by an increase in interhemispheric Coh with multiple foci, so that the interaction of cortical areas involved almost all regions of both the left (except F_7) and the right (except F_8 and T_4) hemispheres. One more area of weaker cortical interaction in GR0_M was the connec-

Table 2. Results of ANOVA with the factor group (performance efficiency) for total coherence during DTh

Significant factors and their interaction	*df*	*F*	*P*	Effect
				Interhemispheric Coh between homologous sites
GEN × GR × TEST	1.51	3.66	0.06	During DTh: Coh in GR0_M is lower than in GR0_W and in GR1_M is higher than in GR1_W
GR × TEST × FB	5.255	3.50	0.004	In the θ_2 and α_1 bands: during DTh, Coh ↑ in GR0 and ↓ in GR1
GR × FB	5.255	3.98	0.02	In the α_1 band: Coh in GR0 is higher than in GR1; in the β_2 band: Coh in GR0 is lower than in GR1
				Interhemispheric Coh between nonhomologous sites
GEN × GR × FB	5.225	2.33	0.04	In the α_1 band: Coh in GR0_M is lower than in GR0_W and in GR1_M is higher than in GR1_W; in GR_W: Coh in GR0 is higher than in GR1; in GR_M: Coh in GR0 is lower than in GR1
				Interhemispheric Coh between homologous sites in the β_2 band
GR × TEST × LAT	1.56	6.36	0.015	During DTh in RH: Coh ↓ in GR0 and ↑ in GR1; in LH: Coh in GR0 is the same as in GR1; in RH: Coh in GR0 is lower than in GR1
				Interhemispheric Coh between homologous sites in the β_2 band
GEN × GR × TEST	1.52	5.32	0.025	During DTh, Coh ↑ in GR_M and ↓ in GR_W; in GR_M: Coh in GR0 is lower than in GR1

Note: Subjects were not (GR0) or were (GR1) successful in solving a divergent task.

tion between the prefrontal and other cortical areas. In GR0_W, an increase in HInterHCoh was most pronounced in Fp_1–Fp_2, F_3–F_4, C_3–C_4, and P_3–P_4 and an increase in HInterCoh focused, predominantly, in F_7 and O_2. A topographically generalized increase in HInterCoh and a prominent increase in IntraCoh between all eight sites of the right hemisphere were observed in GR1_M. In GR1_W, an increase in Coh was less pronounced and embraced mainly T_5, C_3, P_3, C_4, and F_4. In this group, IntraCoh increased only between the frontal and temporal cortical areas. Maps of the Coh differences between GR1 and GR0 illustrate the general result according to ANOVA: strengthening of the interhemispheric interaction during successful divergent performance in the men and its weakening in the women. At the same time, regardless of the gender, successful performance of the divergent task was accompanied by an increase in intrahemispheric Coh in the right hemisphere. However, in GR1_W, this analysis additionally revealed a topographically more extensive increase in IntraCoh between the temporal areas T_4 and T_8 and other cortical areas of the right hemisphere.

DISCUSSION

Convergent thinking. In our study, the strongest changes in EEG Coh during CTh in both men and women were observed in the θ_1 band; however, significant gender-related differences were revealed in the topography of cortical interactions. Patterns of the regional CTh-related increase in Coh correspond to the known facts of the functional interaction of the right frontal cortex and temporo-centro-parietal cortical regions during performance of mathematical operations [35]. At the same time, comparison of the Coh patterns in the men and the women suggests gender-related differences in CTh strategies, which are predominantly verbal (the dominance of the left-hemispheric temporal areas) in women and visuospatial (an increase in the interaction in the posterior cortical areas with a shift of foci to the right hemisphere) in men. These two ways of calculation performance—linguistic and visuospatial encoding of numerical stimuli—were inferred from the results of brain activity mapping by means of positron emission tomography [10, 11].

Our analysis of the functional changes in EEG power during CTh revealed different asymmetry of the θ_1-rhythm amplitude in the men (right-hemispheric dominance) and the women (left-hemispheric dominance) [33]. According to data in the literature, changes in the power of the θ_1 rhythm are associated with adequate concentration of attention under passive conditions [36, 37]. Consequently, our results can testify that CTh in men is to a greater extent performed under conditions of automated sustaining of attention, whereas the left frontal areas, responsible for the organization of voluntary attention, are to a greater extent involved in women. Moreover, it is interesting that CTh was associated with a general frequency-nondifferentiated increase in interhemispheric Coh in the women and its decrease in the men, whereas DTh was characterized by the inverse relationships between Coh changes (Table 1). These findings are in agreement with the suggestion about a more specific localization of cognitive functions in men and their more diffuse bilateral representation in women [3–5, 38]. If so, CTh in men may be associated with less pronounced Coh changes in different frequency bands and DTh may activate extensive

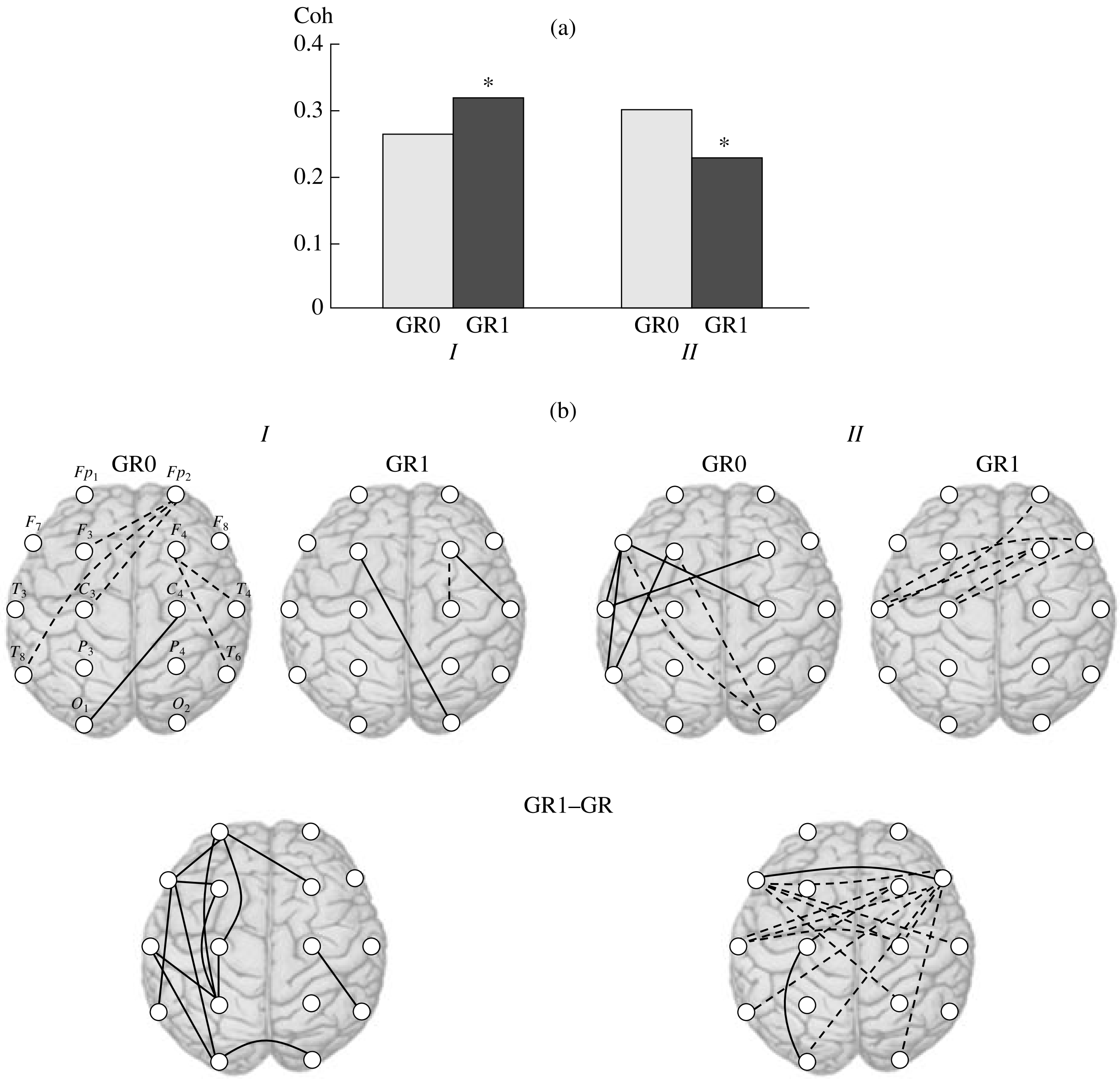

Fig. 2. Changes in EEG Coh in the α_1 band in (*I*) men and (*II*) women during DTh as dependent on its efficiency. (*) The difference was significant at $P < 0.024$. Here and in Fig. 3: (a) changes in mean interhemispheric Coh between nonhomologous sites of both hemispheres; (b) maps of changes in Coh in subjects who were (GR1) or were not (GR0) successful in solving the task and of the difference in Coh between GR1 and GR0.

functional connections of neuronal networks. The opposite pattern may be expected for women; i.e., successful DTh may be associated with a weakening of "excess" connections.

Divergent thinking. The increase in the interaction of cortical areas in the β_2 band was a common EEG correlate of DTh in the men and the women, but it was substantially less pronounced in the women. Consequently, this finding supports the above assumption. Creative solving of a problem calls for consideration of many hypotheses with possible stepwise convergent analysis of individual levels of a problem, retrieval of verbal and imagery memory traces, and use of various analogies and metaphors [34, 39]. All these mental operations recruit many cortical areas of the right and left hemispheres with activation of both closely spaced and distant neuronal networks. As indicated by these data and the results of our previous study, such integration of the cortical areas during DTh is performed predominantly by means of a increase in the activity of high-frequency β_2 oscillators [33]. The functional significance of the β band is still incompletely understood; this band is only known as an indicator of many cognitive processes [40]. Hence, it is unclear of which process the β_2

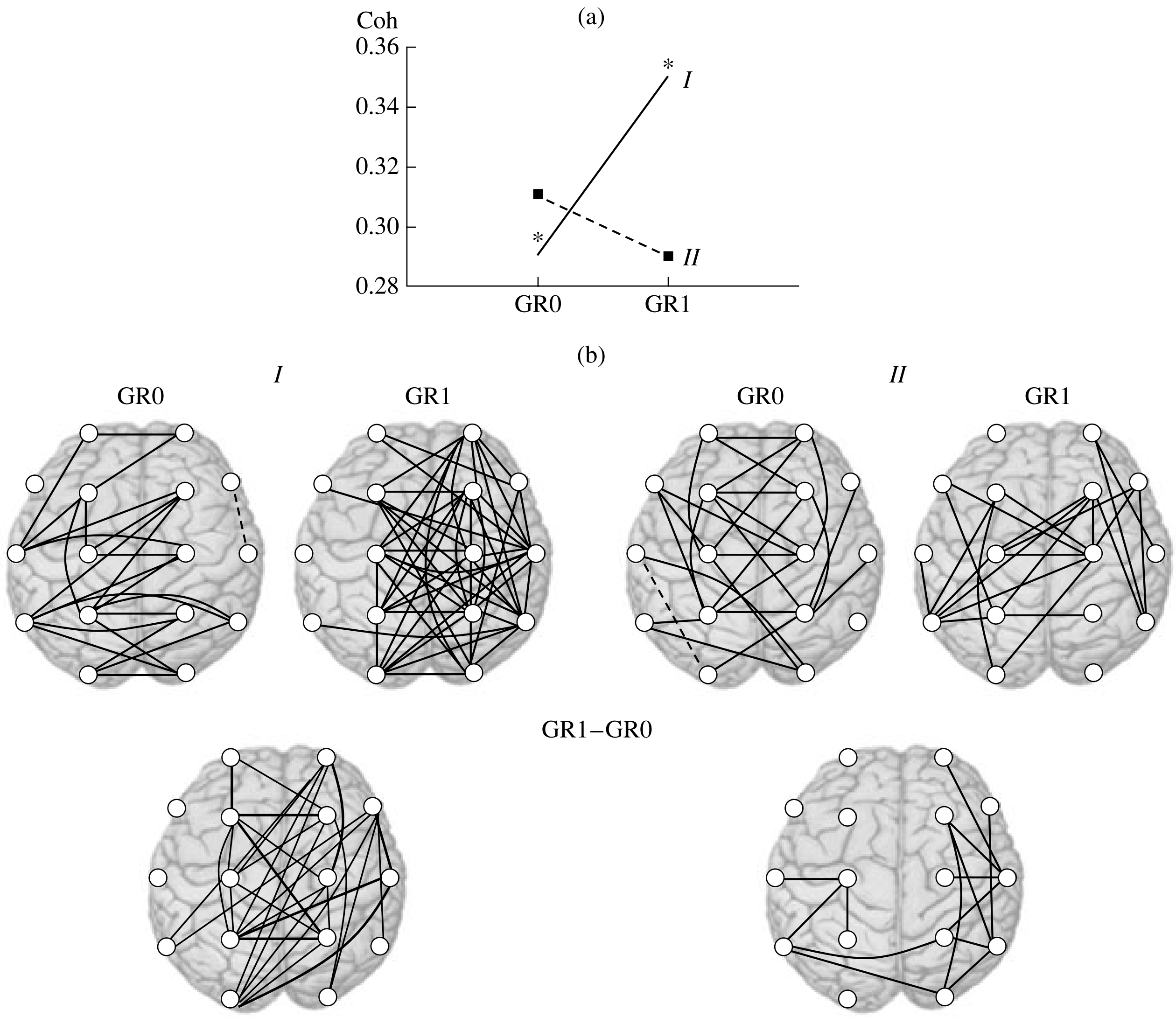

Fig. 3. Changes in EEG Coh in the β_2 band in (*I*) men and (*II*) women during DTh as dependent on its efficiency. (*) The difference was significant at $P < 0.035$.

rhythm is the correlate in our study. Low-creative persons are known to use mainly analytical verbal strategies and semantic memory while solving a divergent task, while highly creative subjects use the visuospatial strategy and episodic memory [16, 34]. Ample evidence has been obtained for right-hemispheric dominance in creative thinking [26–28]. In our study, these findings were confirmed by the maps of coherent connections in the β_2 band: more active involvement of the left hemisphere in DTh was observed (along with a predominantly left-hemispheric location of Coh foci) in GR0, while a stronger interaction of the cortical areas in the right hemisphere was detected for GR1. However, these phenomena were to a greater extent characteristic of the men. In the women, in addition to the right-hemispheric increase in Coh, the left-hemispheric focus in the posterotemporal area was observed in GR1, whereas in GR0 the right-hemispheric interaction was characterized by foci in the frontal and parietal areas. Thus, the Coh patterns in GR0_M may be considered as an EEG correlate of the verbal and successive organization of the mental process and the Coh patterns in GR1_M may be associated with visuospatial and simultaneous thinking. Thinking strategies seem to be more variable and, consequently, not so evident in women. However, the increase in the interhemispheric Coh revealed during efficient DTh sites to a more intimate hemispheric interaction in creative subjects and agrees with the known facts of an increase in Coh during performance of creative tasks [15, 22, 34].

Comparison of the cortical spatial organization for the subjects who did or did not successfully perform the divergent task shows that the same efficiency of performance is achieved in men and women by means of different variants of interactions between the brain hemispheres. We established earlier that efficient performance in men is associated with a greater power of the β_2 rhythm, whereas this power is lower in successful women as compared to inefficient groups [33]. In accordance with these data, we suggested a greater involvement of the system of "differential" attention (in terms of [24]) in men than in women. According to the results of this study, another gender-related feature of efficient neuronal organization in DTh is the extent of the interhemispheric interaction: it weakens in women and substantially strengthens in men. This active interhemispheric interaction is sustained in GR1_M both by the *corpus callosum* (the increase in Coh between the homologous sites of the left and right hemispheres) and by subcortical structures (the increase in coherent connections between distant sites, for example, F_3–O_2, F_3–T_6, F_4–O_2, etc.). The legitimacy of this assumption is confirmed by studies of the correlation of local and long-distance Coh with the activities of the cortex and subcortical structures [25, 41]. It is worth noting also that the interaction GEN × FB for HInterHCoh sites to higher total Coh in the lower frequency bands ($\theta_{1,2}$) in women and in the high-frequency β_2 band in men. This finding and the gender differences demonstrated for the changes in power and Coh of the α_1 rhythm during DTh [23, 33, 34] testify to different mechanisms of information selection in men and women. In this case, such mechanisms imply "inner" attention processes such as selection of information retrieved from memory and integrated into complex associative structures. There is evidence of a close interrelation between attention and arousal, which have a similar neural substrate, i.e., the thalamus and frontoparietal areas of the right hemisphere [37]. We suggested earlier that activation processes based on the thalamocortical connections are to a greater extent characteristic of women and that the system of voluntary information selection (activation of the frontal areas) is characteristic of GR0, whereas the system of involuntary attention (a posterior system) activates in GR1 [33]. A weakening of the intracortical interaction in the anterior areas in the α_1 band in GR1_W confirms this hypothesis because the decrease in both the amplitude and the Coh of the α_2 rhythm may be considered as an index of the strengthening of the thalamocortical connectivity [24, 42]. In men, desynchronization of the α_1 rhythm in the frontal cortical regions [33] together with an increase in left-hemispheric Coh suggests cooperation of cortical neurons in convergent stepwise analysis of a divergent problem. Another type of information selection (differential attention) can be represented by a synchronous interaction of high-frequency cortical oscillators in the β_2 band, which is indicated by the Coh patterns in this band. This kind of attention, in general, is characteristic of DTh but seems to operate more efficiently in GR1_M. It has already been mentioned that the results of testing are more variable in women and that their right and left hemispheres are involved in mental operations in a more flexible way [43–45]. The interhemispheric interaction in women is more intimate, which has been confirmed both by analysis of interhemispheric Coh in men and women and by morphometric data [19–21, 46]. For example, during testing for verbal, spatial, and abstract abilities, Coh is higher in women than in men in the central, parietal, and occipital sites [47]. During the performance of a verbal creative task, an increase in interhemispheric Coh was observed between the right posterior and left frontal cortical areas in men, whereas a closer functional connection of the left posterior with the right frontal and mediotemporal areas was observed in women [22]. These findings agree with our observations made for GR1, though in the higher frequency β_2 band. According to the hypotheses of many authors [48–50], the principles of information selection differ between men and women: the former rely more on self-determined impulsive global strategies, whereas the latter use more complete but reflective successive approaches to information processing with comprehension of the information and its adaptation to available notions, including social stereotypes. Indeed, only in GR_W were socially oriented hypotheses (for example, to call for a snake charmer or to invite a hunter) put forward, whereas in GR_M the idea of a solution could arise, for example, from a well-known cartoon where a monkey measures the length of a boa in parrots. It is women (and also GR0_M) who appear to predominantly recruit left-hemispheric verbal analytical cognitive mechanisms, whose operation results in seemingly reasonable but unoriginal solutions, such as the above invitation of an assistant (GR0_W) or a killing of all snakes with their subsequent measurement with a ruler (GR0_M).

It is of interest that efficient DTh is associated with a close interaction of both hemispheres in men and a weaker interaction in women. This fact is probably related to an asymmetric character of interfering inhibition in men and a more symmetric character of this process in women. This proposal was put forward in order to explain the gender differences in memorizing dichotically presented verbal information [21]. Based on this hypothesis and our findings, it can be suggested that interhemispheric connections, which are more evident in men, allow the left hemisphere to exert an inhibitory influence on the right-hemispheric functions to prolong the period of intuitive thinking and generation of right-hemispheric imagery and metaphoric concepts. After a certain latent period, these concepts can be assessed by the left frontal cortex, responsible for decision selection and solution initiation [51]. At the same time, it is possibly due to a more symmetrical and weaker inhibitory effect in information processing in women [52] that a less close interaction between the left and right hemispheres is optimal for efficient DTh, although the right hemisphere still dominates in the creative process. In this case, it is a narrowing of the interaction channel that probably makes a creative solution more likely because such a narrowing sites to a greater lateralization of mental processes and prevents a raw idea from being realized.

CONCLUSIONS

(1) The distinctive feature of CTh (the performance of arithmetic operations) is a functional change in the patterns of EEG Coh in the θ_1 band. A bilateral strengthening of the interactions in the centro-parieto-occipital cortical areas and between the frontal and the temporooccipital regions of the right cortex is more characteristic of men, whereas a similar pattern of coherent connections is to a greater extent shifted to the left temporal area of the cortex in women. This sites to a predominant use of verbal calculation strategies by women and visuospatial strategies by men.

(2) DTh (solving a nonstandard task) is associated with a gender-independent increase in interhemispheric EEG Coh and in Coh in the right hemisphere. However, efficient task performance is determined by different degrees of hemispheric interaction in men and women: the former solve the problem with a closer interaction of both hemispheres, whereas the latter are characterized by a weaker interaction of homologous cortical areas (as compared to noncreative persons).

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