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Thinking with images or thinking with language: a pilot EEG probability mapping study

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This pilot EEG mapping study was designed to explore thinking processes using complex mental imagery and thought processes. EEG was recorded with 19 electrodes (10/20 system against averaged ear lobe signals) while volunteers ($n = 42$) performed two separate tasks: visualization of an abstract concept and interpretation of a painting. Average spectral parameters such as amplitude, local and interhemispheric coherences were computed for five frequency bands (theta, alpha, beta 1, 2 and 3). Results indicate that the frontal regions are strongly involved during these tasks as evidenced by coherence changes. Changes are also present in temporal, parietal and occipital regions and are discussed in relation to information processing with the frontal regions considering the different cognitive functions required by the tasks.

INTRODUCTION

Mental imagery refers to the brain's ability to generate and use mental visual images during cognitive processes. These images consist in mental representation of objects or events as if they were actually perceived from the outer world (Howard, 1983; Finke, 1989a). Varied paradigms have been used to study mental imagery such as generating mental images from memory when listening to words (Farah, 1989), memorizing concrete nouns with or without the use of mental imagery (Goldenberg et al., 1987), creating mental images out of memorized topographic information (Roland and Friberg, 1985), and mentally rotating figures (Shepard and Cooper, 1982; Corballis and Sergent, 1988; Ratcliff, 1979; Papanicolaou, 1987; Rappelsberger et al., 1987).

Because thinking with images implies mentally 'seeing', the relation between visual perception and mental imagery has been examined and it was found that the neuroanatomical regions implicated in perception and processing of visuospatial information, namely the occipital, temporal and parietal cortices, are involved in mental image generation (Farah et al., 1988; Farah, 1989). Goldenberg et al. (1987) found that the imagery system was composed of medial occipital and inferior temporal cortices.

Different hemispheric specialization has been described for mental imagery. The ability to generate a detailed image from memory has been ascribed to the left posterior brain regions (Farah, 1989), whereas mental rotation abilities seem to involve predominantly the posterior part of the right hemisphere (Corbalis and Sergent, 1988;

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Ratcliff, 1979; Papanicolaou et al., 1987) In a rCBF study, Goldenberg et al. (1987) found that the imagery system was composed of posterior regions of both hemispheres but that the left hemisphere was predominantly engaged when processing verbally elicited mental images. Other studies do not support a lateralized effect and indicate that both hemispheres are capable of generating mental images (Biggins et al., 1990; see Kosslyn 1988).

Cognitive psychologists have proposed two theories on the mode of representation of verbal and imaginal material in memory. A dual-coding theory (Paivio, 1979) states that verbal and imaginal material are processed by two distinct representational systems whereas the propositional theory (Pylyshyn, 1981 – see Howard, 1983) expresses the view that information in the brain takes the form of abstract propositions which have neither an imaginal nor a verbal form. In a review article, Farah (1989) suggests that imagery and verbal thought depend upon at least partially distinct neural processes and consequently that thinking in images is distinct from thinking in language.

This pilot study tackles the question whether or not differences between thinking with images and thinking with language might show up in the ongoing electrical activity of the brain. It also examines if the brain behaves differently when it self-creates a mental image as opposed to when it generates a mental image from perception of an external event. Self-created mental images are constructed out of memorized images of the outside world and may introduce the subject's own imaginal and creative capabilities to envision reality with new self-formulated images (Finke, 1989b).

Subjects were asked in a first task to create a mental image out of an abstract concept and in a second task, to elaborate a verbal interpretation of a painting seen prior to EEG recording. Both tasks imply the use of mental imagery but also of verbal thinking. The verbal thoughts incite the construction of a mental image in the first case and serve to analyse a generated mental image in the second case. In both tasks a mental image must remain available for cognitive processing by the brain either for further construction of the mental image itself or for further verbal interpretation of it.

Such a project seems worth being carried on since, in previous EEG studies, significant changes of power and coherence were detected during a variety of cognitive tasks such as doing mental arithmetic, reading, listening to a spoken text and to music (Giannitrapani, 1985; Petsche et al., 1986, 1987, 1988a,b; Rappelsberger and Petsche, 1988). This paper is an extension of previous studies and comprises brain processes in which even more elaborate brain work should be involved than in simple cognition tasks; one aim among others was to investigate the limits of the EEG methodology developed by us for the search for traces of mental processes.

METHODS

Subjects and tasks to be performed

This study was conducted on 42 right-handed subjects (20 males, mean age 17.8 ± 1.0, and 22 females, 17.4 ± 0.5). The tasks to be performed during EEG recordings were as follows (see Schmidt-Henrich, 1990): (1) visualization of an abstract concept: the subjects were asked to give four abstract concepts of their own choice, to select one of them, and to try to visualize it during EEG recording knowing that, thereafter, they would be requested to draw their imagination on a piece of paper with coloured pencils. The sketches were interpreted by them and demonstrated that the volunteers had tried to fulfill their tasks to their best conscience; and (2) interpretation of a painting: the subjects were shown three paintings (C.D. Friedrich, Landscape on Ruegen, F. Goya, The Carnival Procession and A. Brauer, The Last Ray of Sun) and were requested to select one of these pictures to try to interpret it during EEG recording knowing that, thereafter, they would be requested to write down their interpretation.

Each EEG run consisted of the following sequence: EEG control before each task, EEG during the tasks (1) or (2), and EEG control after each task. The sequence of the cognitive activation tasks was changed at random. Before and after each task, EEG at rest was recorded for 1 min. The eyes were closed during EEG recordings. All subjects were paid for the examination.

During visualization of an abstract concept, the following abstract concepts were chosen for visualization by the volunteers: love (3), belief (1), death (1), tolerance (1), art (1), unity (1), listening (1), anarchy (1), holidays (1), hate (1), magnitude (1), mentality (1), stability (1), justice (1), sadness (1), anxiety (1), heaven (1), religion (1), solitude (1); by the female volunteers: love (4), hate (4), sadness (1), joy (1), aversion (1), friendliness (1), freedom (1), desperation (1), friendship (1), reality (1), self-confidence (1), fate (1), life (1), pain (1), fantasy (1), war (1).

Electrophysiological methods

The EEG was recorded with respect to linked ear electrodes from 19 gold cup electrodes according to the 10/20 system and stored on analogue tape for off-line data processing. The subjects were in a reclined position in a comfortable chair and had their eyes closed. They were given enough opportunity to move and relax between the runs.

After digitization at 256/s, artifacts were eliminated by visual inspection. For spectral analysis, about 15 epochs of 2 s each were chosen from the EEG records during the tasks for computation. After Fourier transformation of the 2 s epochs, averaged power and cross-power spectra were computed, the latter between adjacent electrodes and between electrodes on homologous locations of the two hemispheres. Data reduction was achieved by extracting broad-band parameters for five frequency bands: theta (4–7.5 Hz), alpha (8–12.5 Hz), beta 1 (13–18 Hz), beta 2 (18.5–24 Hz) and beta 3 (24.5–31.5 Hz). The parameter 'coherence', hardly yet considered in mapping techniques, was included as it proved to give hints as to the degree of the instantaneous functional electrical coupling of two brain regions. By this concept, the largely used and very diffuse concept of 'synchronization' in clinical electroencephalography may be comprised quantitatively.

The baselines for the evaluation of task-dependent power and coherence changes were obtained from averaged spectra over all 2 s epochs of the control records of each subject at rest with eyes closed.

Statistical evaluation and presentation of data as EEG probability maps

For the evaluation of significant differences of absolute power and coherence, the paired Wilcoxon test was applied to the differences between the corresponding parameters of the control and task situations. The obtained error probabilities were presented as topographic probability maps. The statistic approach is purely descriptive, i.e., statistics is not used to confirm or to reject null hypotheses but rather to yield hints at those of the various comparisons for which possible differences exist.

RESULTS

The visualization of an abstract concept (Fig. 1)

Effect on amplitude. This task provoked a reduction in amplitude in the theta, alpha and beta 1 ranges affecting almost all electrode locations.

Effect on coherence. Changes in local coherence were almost exclusively localized in anterior regions of both hemispheres but involved mostly the right hemisphere in the theta, alpha and beta 3 ranges and the left hemisphere in the beta 2 range.

A decrease of local coherence was present in the theta and alpha ranges mainly in the right frontal regions extending to the right anterior-medial temporal electrode and from the latter electrode to the right central area. In these ranges, interhemispheric coherence was slightly increased between anterior-medial temporal regions.

An increase of local coherence was observed in the beta 2 range mainly in the left frontal regions extending to the central area and in the beta 3 band mainly in the right frontal regions extending to central and anterior-medial temporal areas. Interhemispheric coherence values were increased between posterior temporal areas in all beta ranges but most strongly in the beta 2 range where increases were also observed between all frontal areas and between central regions.

Local coherence and interhemispheric coherence values were completely unaltered in parietal regions and were slightly increased between left posterior temporal and occipital electrodes in beta 1 and beta 2.

The interpretation of a painting (Fig. 2)

Effect on amplitude. This task provoked a global reduction in amplitude in all ranges. This decrease was lateralized to the left hemisphere in the beta 1 range and was localized in posterior regions in the beta 3 range.

Effect on coherence. Local coherence was decreased mainly in the right anterior regions in the alpha range and in the right posterior regions in the beta ranges and was increased mainly in the left hemisphere of most frequency bands.

The decrease of local coherence was present in the alpha band between all electrode sites in the right frontal regions and reached the right anterior-medial temporal and right central electrodes. A notable decrease was also present between polar and parasagittal frontal electrodes on the left hemisphere in both lower ranges. These changes were associated with an increase in interhemispheric coherence between frontal polar areas in the theta range. In the beta ranges, the decrease of local coherence was mostly concen-

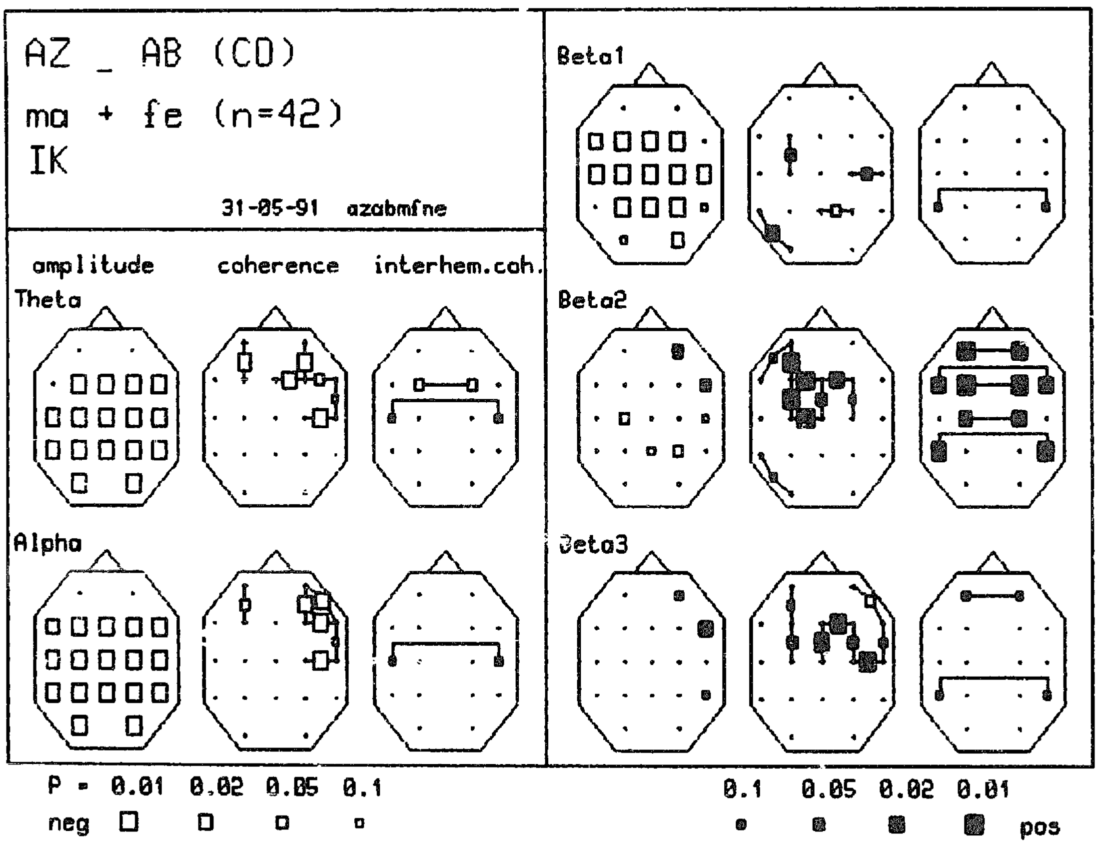

Fig. 1. Probability maps. The maps show the error probabilities according to statistical evaluations of the EEG spectral parameter differences between visualization of an abstract concept (AB/CO) and the control situation (AZ/Eyes closed). The five rows relate to the five frequency bands examined. The three columns concern: mean amplitude per frequency band, local coherence, i.e., coherence between adjacent electrodes along the transverse and longitudinal rows, and interhemispheric coherence, i.e., coherence between corresponding sites of both hemispheres. Significant amplitude differences are indicated by squares at the corresponding electrode positions. A significant transverse or longitudinal coherence change is presented by a square drawn between the two electrodes involved. A significant interhemispheric coherence change is marked by squares at the two electrode locations of homologous sites of both hemispheres connected by a line. Black squares indicate amplitude or coherence increase and empty squares amplitude or coherence decrease provoked by the cognitive task.

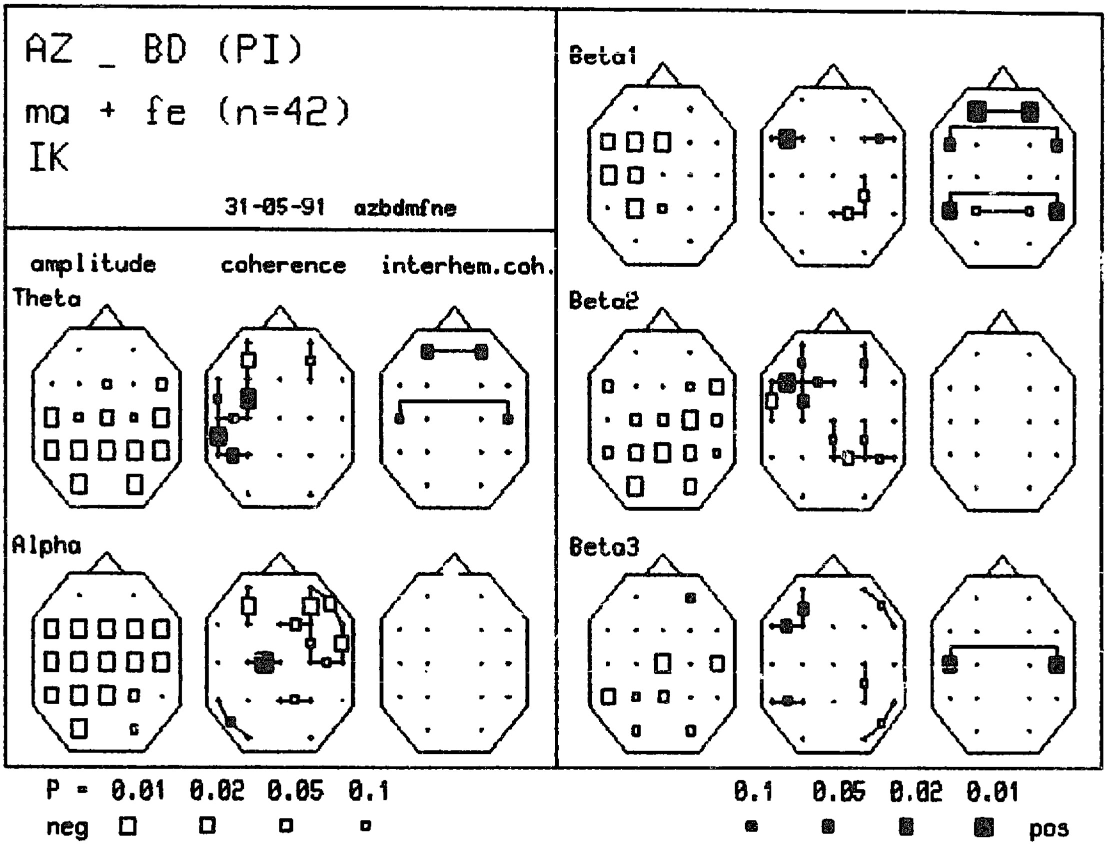

Fig. 2. Probability maps. The maps show the error probabilities according to statistical evaluations of the EEG spectral parameter differences between interpretation of a painting (BD/PI) and the control situation (AZ/Eyes closed). The arrangement of the maps is as in Fig. 1. Black squares indicate amplitude or coherence increase and empty squares amplitude or coherence decrease provoked by the cognitive task.

trated around the parietal region of the right hemisphere. An interhemispheric coherence decrease was slightly present between parietal regions in the beta 1 range.

An increase of local coherence was present in the lower frequency ranges mostly in the theta band in the left hemisphere extending from frontal to central, to temporal and to parietal regions with interhemispheric coherence being slightly increased between anterior-medial temporal areas. In the alpha band, a major increase of local coherence was observed in the left central region. In all beta bands, increases of local coherence were mostly localized in the left frontal regions involving lateral and parasagittal electrodes in all cases. Interhemispheric coherence values were mostly increased in the beta 1 range between polar and lateral frontal areas and between posterior temporal areas.

Differences between sexes

In both tasks, a difference between males and females occurred. During interpretation of a painting, the decreases of local coherence in the lower frequency bands involving the right frontal, anterior-medial temporal and central regions were not present in the female group. During visualisation of an abstract concept, these changes were present in both sexes but were most pronounced in the female group.

DISCUSSION

This pilot study permits formulation of hypothesis regarding the relation between regional neurophysiologic changes and cognitive processes involved in thinking and in complex form of mental imagery as shown by EEG probability mapping.

Further studies need to be conducted to better discriminate the different cognitive components being activated during such complex mental processes and to further analyse dynamic electrical interactions between different brain areas.

The present results indicate that during visualization of an abstract concept and interpretation of a painting, the most significant changes occur in the frontal regions. Frontal regions have been shown to be involved in executive functions such as planning and sequencing of behavior and cognition (Luria, 1973; Roland, 1984). These functions imply neurophysiologic interactions between prefrontal cortex and other brain areas, a fact supported by neuroanatomical interconnections between prefrontal, posterior parietal, temporal and occipital cortices as described by Goldman-Rakic (1988).

Mnemonic and attentional functions of the frontal lobe

One frontal lobe function is to memorize results of each step performed during a cognitive task in order to decide how to further execute a task, thus playing a role in temporal ordering of recent events and in self-organizing behavior (Milner and Petrides, 1984; Goldman-Rakic, 1984). Patients with lesions localized in the right frontal lobe showed impairment in a recency-discrimination task involving representational drawings as opposed to a verbal material (Corsi, 1972 – see Kolb and Whishaw, 1990). Sustained attention has also been related to right prefrontal activity (Roland and Friberg, 1985; Pardo et al., 1991).

In the theta and alpha frequency ranges during both tasks of our study, the decrease in local coherence localized in the right frontal regions extending into the anterior-medial portion of the temporal lobe may be related to such mnemonic and attentional functions of the frontal lobe. The extension of these changes into the right temporal lobe and the increase, although slight, of interhemispheric coherence between anterior-medial temporal regions, support this hypothesis considering the recognized role of these regions in mnemonic functions (Mishkin and Appenzeller, 1987), especially the specific role of the right temporal lobe in non-verbal memory (Milner, 1970).

These right fronto-temporal local and interhemispheric coherence changes may reflect the necessity for the brain to maintain 'visible' a mental image during visualization of an abstract concept and interpretation of a painting in order to further act upon it implicating mnemonic, arousal and attentional components.

These local coherence changes were present in both sexes during the visualization of an abstract concept, a task in which maintenance and organization of a mental image is central. However, differences between sexes were observed during interpretation of a painting: females did not present these changes. One explanation may be that, when analyses of written sentences were conducted following EEG recording, males had a strong tendency to provide descriptions and not interpretations of the painting whereas females as a whole provided definite interpretations. This may indicate a different cognitive style between sexes with males remaining fixed on the painting's image when engaging more in a descriptive process and females drifting towards verbal thinking unbounded to this image in an interpretive process.

Image and thought assembling functions of the frontal lobe

Divergent thinking processes tested with tasks requesting numerous and varied self-generated responses have been associated to frontal activity. These tasks include word listings (verbal fluency) and non-sense drawings (non-verbal fluency) with left frontal lesioned patients being more sensitive to the former task and right frontal lesioned patients being more sensitive to the latter (Milner and Petrides, 1984; Jones-Gotman and Milner, 1977). Motor cortices have been shown to play a role in mental programming of motor behavior before the actual display of the behavior (Luria, 1973; Roland, 1984). In our study, both tasks requested a self-generated mental construction of an image or of a sequence of thoughts which had to be drawn or written on a sheet of paper following the EEG recording. Our results in frontal regions in the beta ranges may reflect an assembling function of the frontal lobe required for construction of a mental image during visualization of an abstract concept or for organization of thoughts during interpretation of a painting.

During visualization of an abstract concept, the fact that local coherence is increased in the left anterior quadrant, a region recognized for its role in language production, in beta 2 range and in the right anterior quadrant, a region more related to non-verbal functions, in the beta 3 range may indicate the presence of an interactive association between thinking with language and thinking with images, i.e., between the verbal thoughts related to an abstract concept chosen and the visual mental image being constructed. This view is in agreement with a relative asymmetry of functions described in the frontal lobes (Kolb and Whishaw, 1990) and therefore, thinking with language would be more related to left frontal activity whereas thinking with images would imply a right frontal contribution.

Different results are observed during interpretation of a painting where the main increase of local coherence in the beta ranges is present in the left anterior regions and only slight increases are observed in the right anterior regions. This task involves mainly analysing a fixed mental image of the painting with verbal thoughts. The subject only needs to keep the image present in his mind in order to elaborate an interpretation. This verbal thinking may thus be related to these left anterior changes. The absence of a constructive process of an image would explain the relative absence of changes in the right anterior quadrant as in the first task and would thus support the previously expressed view of a relative right frontal predominance in certain non-verbal functions. The local coherence increase in the left hemisphere of the theta range may also be associated with language function as was shown in previous language activation experiments (Lacroix et al., 1991).

Interactive information processing between frontal lobe and posterior regions

In the beta ranges during the visualization of an abstract concept, an assembling function of the frontal lobe may involve a functional connection with the posterior regions in order to have access to visual memory storage. Farah (1989) attributed the ability to generate a detailed image from memory to the left posterior brain regions and Goldenberg et al. (1987) found that medial occipital and inferior temporal cortices of both hemispheres were engaged during mental imaging with predominance of the left hemisphere when verbally elicited mental images were used during memory tasks. During visualization of an abstract concept, changes were observed in these particular regions as local coherence was increased between the left occipital and posterior temporal electrodes in beta 1 and beta 2 ranges and interhemispheric coherence was increased between posterior temporal regions in all beta ranges. These changes may reflect a retrieval of visual data from memory storage. During a route imagination task, Roland and Friberg (1985) also attributed changes in occipital and temporal regions to retrieval of visual information.

Information processing may also be present between the frontal and the parietal regions. Coherence involving parietal sites showed differences between both tasks. Local and interhemispheric coherence of these sites were almost completely unaffected by visualization of an abstract concept and local coherence showed a slight decrease during the interpretation of a painting mostly in the right hemisphere and in the beta ranges. These results are in sharp contrast with important changes observed in local coherence of parietal regions during a mental figure rotation task (Rappelsberger et al., 1987) and in silent reading (Petsche et al., 1987), observations related to visuo-spatial analytic functions involved during these tasks. The results of the present experiments may indicate that interpretation of a painting involves visuo-spatial analytic functions of the right parietal area whereas visualization of an abstract concept does not.

Conclusion

Roland and Friberg (1985) related thinking processes to changes present in prefrontal regions. Our results suggest that sustained and elaborated verbal or imaginal thinking such as in the present experiments involves strongly the frontal regions. They also suggest that, when no reference to external events takes place and self-generated thinking is performed, then the electrical changes are predominantly located in the frontal regions.

As to the neuroanatomical regions involved in mental imagery, our results point to the presence of functional connections implicating many brain regions and show the difficulty in defining specific lateralizing or localizing effects when using complex forms of mental imagery which incorporate many cognitive sub-tasks.

In this study, during self-formulated mental images or thought processes which implied a creative activity on the part of the subject through subjective selections of elements from memory storage and sequential organization of these elements, the EEG underwent task-dependent changes of the parameters power and coherence, changes of varying intensity, location and frequency. So, the question as to whether tasks involving thinking may provoke detectable changes in the background EEG can generally be answered positively.

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