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Changes in Electroencephalogram and Evoked Potentials during Application of the Specific Form of Physiological Training (Meditation)[1]

N. N. Lyubimov[†]

Institute of the Brain, Russian Academy of Medical Sciences, Moscow

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Abstract—Twenty-five subjects between the ages of 30 and 40 years, practising the technique of the specific psychological training (meditation) for 5–6 h every day during 10–12 years, were examined. The amplitude–temporal and topological characteristics of averaged somatosensory evoked potentials (SEP) for stimulation of the median nerve were recorded in symmetrical structures of the cerebral cortex in both hemispheres, as well as the topological characteristics of EEG spectral power for each frequency. SEPs and the spectral power from meditators were recorded before meditation and afterwards. As a result, a duality in the reactivity of cortical structures in test subjects was revealed during meditation. There was a tendency to activation decrease in some neuronal pools in the cerebral cortex together with widening of the power spectrum topology of EEG α and β oscillations and suppression of the late SEP components (N_{82-84}, P_{96-100}, $N_{115-120}$); changes in the opposite direction were simultaneously observed in other neuronal cortical pools: extension of the power spectrum topology of EEG β oscillations and that of some early, i.e., the most reactive, SEP components (N_{27-34}, P_{40-48}, N_{58-62}, P_{71-74}).

"Meditation" is a term being used in some psychological techniques, aimed at the short-term forming of specific mental states. These techniques have been further developed in this and recent centuries due to the achievements in physiology and medicine. Something should be said, first of all, about the techniques of "transcendental meditation", developed by Maharishi Mahesh Yogi [1–5]. The techniques entail the nonverbal (subvocal) stereotype pronounciation by a meditator of a special syllable or sound—a mantra (which is selected individually for every person who practices meditation) while in a comfortable relaxed pose with eyes closed. In Russia, the two simplest techniques of meditation (concentration of attention and contemplation) were modified and recommended by V.M. Bekhterev for activating intellectual human activity [6, 7].

In the previous electroencephalographic studies [8–13], it was found that the spectral power of α and β oscillations in the cerebral cortex of the subjects increase during meditation sessions which were usually accompanied by muscle relaxation and slowing of heart rate and respiration. That is why these central–peripheral changes were assessed as a reflection of a deep "psychic–muscular tranquility" during meditation with a broad spreading of the cortical inhibition process. However, this notion hardly conforms to such heightened mental activity observed after meditation sessions. The activating influence of meditation on mechanisms of perception, as well as on intellectual activity and behavior, testifies at the very least to a dual meditation action on the activity of neuronal brain structures (to the activation of not only inhibitory processes but excitatory ones as well). In fact, the creative upsurge does not appear from "deep tranquility". It necessitates "the struggle of two direct opposite tendencies, two antitheses".

Therefore, the main goal of our research was to find out the cortical activation effects (the second "excitation component") on the neuronal structures of the cerebral cortex arising from meditation. For this purpose, we used two techniques: the research of the topology of the spectral power of different frequencies in cortical electrical activity (EEG) and that of separate components of cortical averaged somatosensory evoked potentials (SEPs) during stimulation of the median nerve in subjects before and after transcendental meditation (TM) sessions.

METHODS

Twenty-five subjects between the ages of 30 and 45 years, who applied the technique of transcendental meditation for 5–6 h every day over 10–12 years, were examined. EEG and SEPs from symmetrical structures of the cerebral cortex in two hemispheres to the median nerve stimulation were recorded with the help of applied electrodes. Electrical reactions were recorded from 22 scalp points according to the 10 × 20 scheme before and during the TM sessions. For recording and

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[1] The Editorial Board of the journal does not fully share the author's views.

[†] Deceased.

analysis of EEG and SEPs, equipment, including a specialized computer "Bio-logic Brain Atlas II" (USA), was used. A computer of this system had not only a set of software for averaging EPs and estimation of the spectral power on-line, but also programs for the topology of EP components in the cerebral cortex of both hemispheres, as well as for the spectral power topology of any EEG frequency; it also had searching programs for current sources of any EP component, as well as statistics programs. The frequency bandwidth for anyone of the 22 amplifier channels of this system ranged from 0 to 10000 Hz. For stimulating the median nerve via applied electrodes in the wrist area of the test subjects, an electrostimulator "Bio-logic" (USA) was used. The median nerve was stimulated with the frequency of 1 Hz. The stimulus value was slightly above the magnitude inducing contraction of the thumb muscles. For SEP averaging about 80–150 stimulations were used with the help of the "Bio-logic" system.

RESULTS

First of all, we tried to repeat the studies of Wallace [9, 14] and of other authors testifying to an increase in the spectral power of EEG α- and θ-oscillations in symmetrical structures of the cerebral cortex and to widening of topology of this phenomenon during TM sessions. The cortical topology (recording from 22 symmetrical points of the cerebral cortex) of the spectral power of α-oscillations during 8-s intervals at three successive stages of testing in test subject 11 (before the TM session and during the 2-min and 6-min meditation sessions) and statistical estimation of this topology are shown in Fig. 1. An increase in the spectral power of α-rhythm in subject 11 during TM was statistically significant (the values of standard deviations were $2.87–3.62 > 0$) in the frontal, central, and parietal structures of the cerebral cortex of both hemispheres.

A similar picture was observed in the case of a spectral power increase in θ-rhythm in the cerebral cortex of both hemispheres in subject 12 during a TM session (Fig. 2). In this figure, the spectral power increase of θ-rhythm is shown in almost all structures of the convex surface of both hemispheres during meditation by this subject. It was most significant (standard deviations $2.75–5.56 > 0$) in the prefrontal, frontal, and parietal structures in the cerebral cortex of both hemisperes.

We found that parallel with an increase in the spectral power of EEG α- and θ-rhythms in the cerebral cortex of subjects during TM sessions the spectral power of β-oscillations also increased (Fig. 3). The EEG spectral power changes from two symmetrical points of the frontal cortical structures in a real time scale are shown in one of the subjects (13) during four successive 5-min stages of testing: before meditation, when the subject is sitting with eyes closed, during meditation, and after meditation finished. As is seen in Fig. 3, the spectral power of β-rhythm increases during a 5-min TM session. These data testify to the fact, that during meditation, along with changes in the electrical activity towards inhibition (slowing down potential oscillations: an increase in the spectral power of α- and θ-rhythms), parallel changes towards excitation take place (acceleration of potential oscillations: an increase in the spectral power of β-rhythm). This in turn testifies to the duality of changes in the electrical activity in the cerebral cortex of subjects during meditation sessions, and to the coexistent increase in the spectral power of α-, θ-, and β-oscillations during these states.

Our notion of cerebral cortex activation in subjects during TM sessions (parallel with the inhibition of processes of development) was further advanced with reference to the estimation of the dynamic characteristics of somatosensory afferent projections on the cortical structures during stimulation of the median nerve.

As we discovered upon electrical stimulation of the median nerve during meditation sessions, the first two SEP components of the so-called early ones with the peak latencies of 15–16 and 20–22 ms ($N_{15–16}$ and $P_{20–22}$) have no specific features in comparison with the state of quiet wakefulness [15, 16]. Specific characteristics for the meditation process changes in the organization of the somatosensory afferent projections and of the corresponding cortical SEP components began with the next afferent message and with the corresponding surface-negative $N_{27–34}$ component. This component, in contrast to the state of quiet wakefulness, had characteristic topological features; the area of its recording was widened not only in the contralateral hemisphere in relation to the stimulated median nerve, but also included cortical structures of the ipsilateral hemisphere (Fig. 4). In the contralateral hemisphere, this widening of its topology took place in all subjects due to more rostral (frontal) cortical areas. The averaged amplitude of the $N_{27–34}$ component in the contralateral hemisphere varied within the limits of -1.5 to 15.3 μV, and the focal zone occupied its previous position as before meditation—in the inferior third of the central sulcus of this hemisphere. In the ipsilateral hemisphere, the zone of the $N_{27–34}$ component recording during meditation had different configurations in the test subjects: in the majority of them, the zone of the $N_{27–34}$ component recording occupied more rostral (frontal) areas, in other subjects, the zone of the $N_{27–34}$ component recording occupied a larger part of the ipsilateral hemisphere, and in the third this component during its recording dominated in amplitude in the parietal and visual cortical structures all over the ipsilateral hemisphere. The averaged amplitude of the $N_{27–34}$ component in the ipsilateral hemisphere changed within the limits of -1.8 to -3.0 μV, and its focal zone was absent.

The next of the most reactive components of the early SEP complex—the positive $P_{40–48}$ component—changed during meditation in a similar way. As in the case of the $N_{27–34}$ component, the averaged amplitudes characteristics of the $P_{40–48}$ component in the same cor-

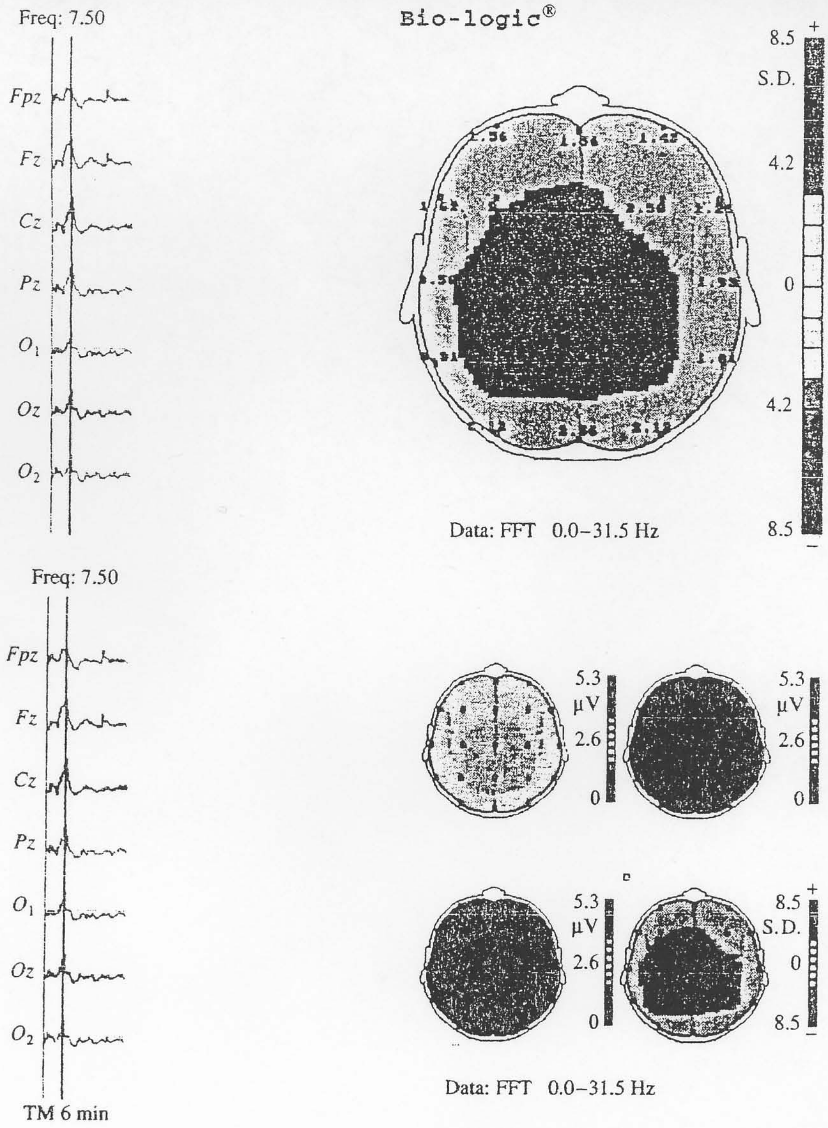

Fig. 1. On the left: comparison of the EEG α-rhythm spectral power topology in the cerebral cortex during the second meditation session in subject 11 with the averaged topology of spectral power of the same EEG rhythm in 70 normal subjects, sitting in a comfortable pose with eyes closed. The information about the spectral power topology of EEG α-rhythm in the cerebral cortex of these subjects was stored in the computer memory *"Bio-logic Brain Atlas II."* On the right: in the upper part of the figure: statistical estimation (standard deviations) of the spectral power topology of EEG α-rhythm in the cerebral cortex during the second meditation session; in the lower part: the spectral power topology of EEG α-rhythm in the cerebral cortex before the meditation session, during the first and second meditation sessions, and statistical estimation of the spectral power topology of EEG α-rhythm in the cerebral cortex during the second meditation session.

tical structures of both hemispheres during meditation were increased as compared to the state of quiet wakefulness, and the topology was widened in the contralateral hemisphere and included the ipsilateral hemisphere as well (Fig. 5). The averaged amplitude of the P_{40-48} component varied within the limits of +1.5 to +3.9 μV during meditation. The zone of the maximal expressiveness of this component was found in the contralateral hemisphere, as it was observed in the state of quiet wakefulness—to the front from the inferior third of the central sulcus, in the region of the C_4 and P_4 points.

The third of the most reactive SEPs components—the negative N_{58-62} component—had the same tendencies towards averaged amplitude characteristics and topology as the two previous components. The averaged amplitude characteristics of the N_{58-62} component during meditation were increased in comparison with the state of quiet wakefulness not only in the zone of its maximal expressiveness, but also beyond this zone, in

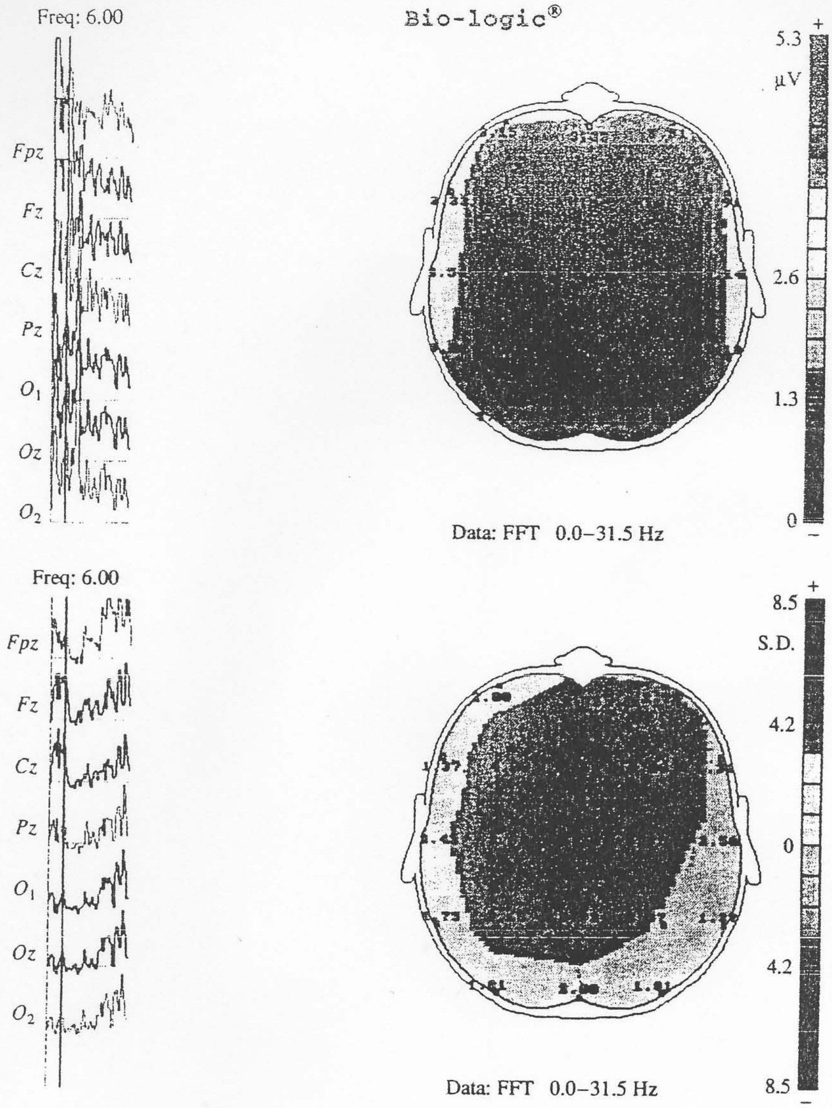

Fig. 2. Spectral power topology of EEG θ-rhythm in the cerebral cortex and its statistical estimation in subject 12 during 10 min-meditation.

the cortical structures of both hemispheres. The topology of the N_{58-62} SEP component during meditation sessions was broadened in both the contralateral hemisphere and ipsilateral one in all subjects (Fig. 6).

In the contralateral hemisphere, widening of a zone of the N_{58-62} component recording in the test subjects had two variations: in some of the subjects it occupied more rostral (frontal) structures, and in others it largely involved the parietal, temporal, and even visual cortical areas. The focus of maximal expressiveness of the N_{58-62} component during meditation was found in the inferior third area of the central sulcus of the contralateral hemisphere in the region of the point C_4, as was the case before meditation. In the ipsilateral hemisphere, relative to the stimulated median nerve, the topology of the N_{58-62} component during meditation had also two variants of development, corresponding to two topology types of this component in the contralateral hemisphere. In the case of more rostral localization of the zone of the N_{58-62} component recording in the contralateral hemisphere, the zone of its recording in the ipsilateral hemisphere also occupied a more rostral position, involving the frontal, central, and partly parietal areas of the cerebral cortex. In the case of a more caudal location of the zone of the N_{58-62} component recording in the contralateral hemisphere, the zone of its recording in the ipsilateral hemisphere was located caudally, occupying correspondingly the central, parietal, and partly visual areas in the ipsilateral hemisphere.

The fourth of the most reactive early SEP components—the positive component with the peak latency of 71–74 ms (P_{71-74})—also demonstrated the main feature

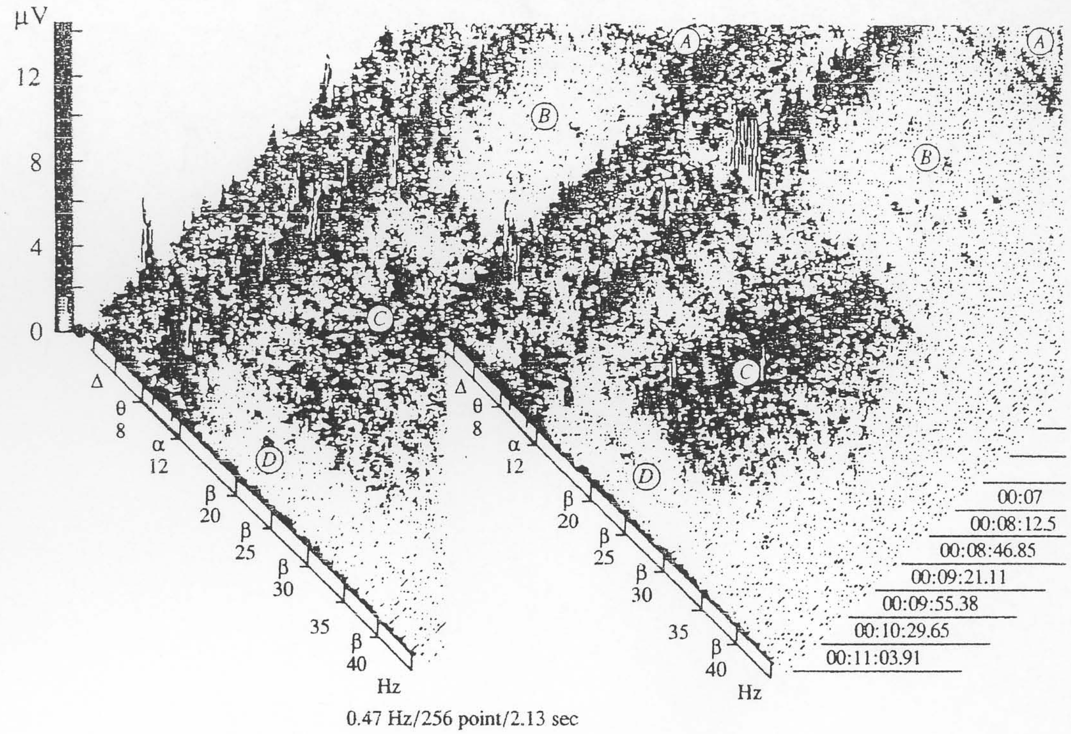

Fig. 3. Changes in EEG spectral power in two symmetrical points of the frontal cortical area in subject 13 during four 5-min. stages of testing (from top to bottom): *A*: before meditation, when the subject is sitting in a comfortable pose with the eyes opened; *B*: when the subject is sitting with eyes closed; *C*: during meditation, and *D*: after it. Ordinate: EEG spectral power, abscissa: EEG frequencies. On the right: time.

of the three previous SEP components: widening of the topology of its recording in both cerebral hemispheres.

The functional mobilization of additional projections and transcomissural afferent projections is not the sole prerogative of the somatosensory system under the action of meditation; similar changes were found in the auditory system as well.

The subsequent (late) three SEP components (N_{82-84}, P_{96-100}, $N_{115-120}$) of the median nerve stimulation during meditation took a fundamentally opposite progression in the cerebral cortex of all subjects compared with four previous early, i.e., the most reactive, EPs components. They either disappeared, or the topology of their recording was diminished compared with the state of quiet wakefulness. This effect is demonstrated in Fig. 7, where one can see a sharp weakening and decrease in the topology of one of the averaged SEP late components with the peak latency of 117 ms (N_{117}) during meditation (Fig. 7).

DISCUSSION

Therefore, the results of our study testify to the fact that in structures of the central nervous system TM initiates not only inhibition processes conforming to the data of studies [9, 14], but also activation processes. According to these results, during meditation sessions spectral power of EEG β-rhythm in the brain cortex increases. There is also an increase and widening of cortical somatosensory and auditory afferent projections due to the functional mobilization of additional projection and transcomissural connections of analyzers; i.e., a part of the neuronal brain structures experiences a functional shift towards excitation during meditation. Notably, parallel with these changes an increase in the spectral power of α- and θ-rhythms occurs in the cerebral cortex, as well as a reduction or even disappearance of the late (N_{82-84}, P_{96-100}, $N_{117-120}$) SEP components. Similar behavior was also revealed in the late components of auditory EPs during meditation. The complex of the latter EEG and EP changes may be interpreted as a parallel change in the functional activity of certain brain structures towards inhibition. Consequently, the general complex of EEG and EP changes in the brain cortex of subjects during meditation demonstrates spatial and temporal duality in the reactivity of brain neuronal structures.

What are the neurophysiological mechanisms of these changes?

According to the TM technique, a meditation process proceeds during monotonous repetition of a syllable (mantra), having no semantic meaning in the context of the relaxed state of a subject. This procedure causes the state of inhibition in brain structures, which

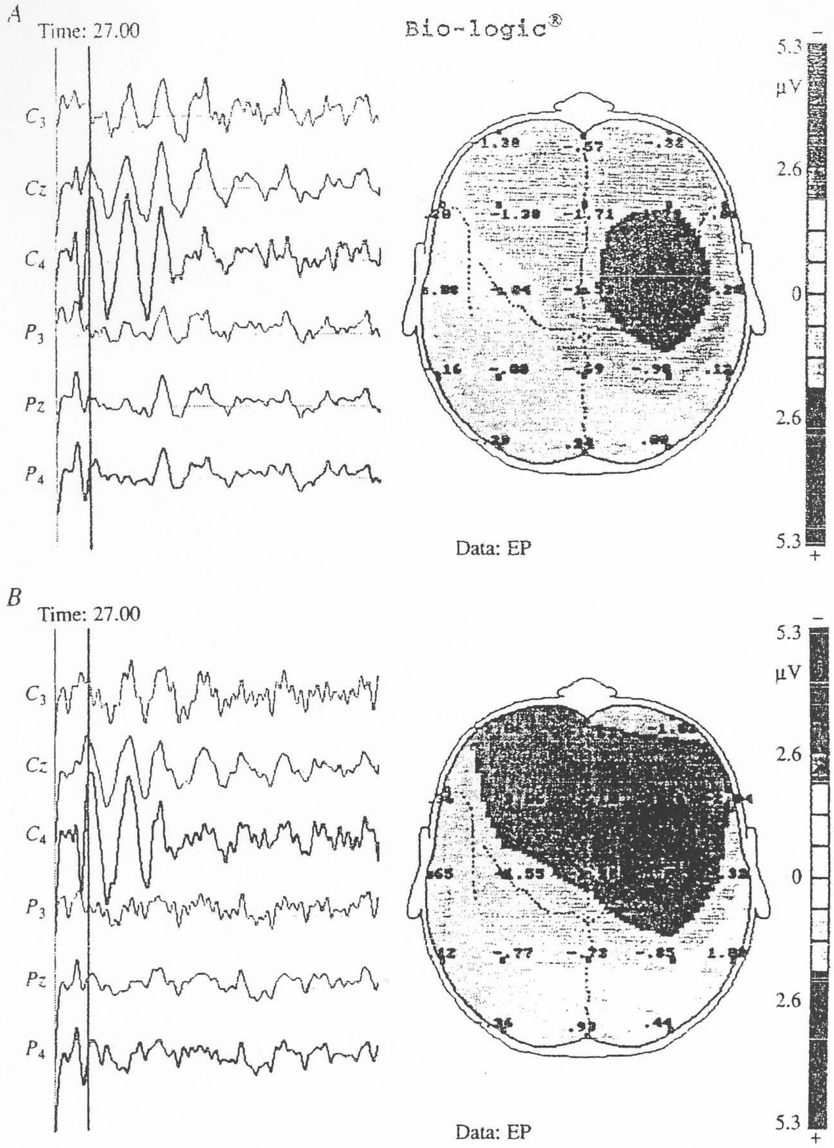

Fig. 4. Widening of the recording area (topology) of one of the early, most reactive components of averaged SEPs with the peak latency of 27 ms (N_{27}) in the cerebral cortex of subject 2 during meditation. *A*: topology of the component N_{27} after the stimulation of the left median nerve before meditation, *B*: during meditation.

via inhibitory central mechanisms [17–23] organizes a complex of corresponding central–peripheral changes (weakening of muscular tone, deceleration of heart rate, and respiration rate and blood pressure drop and increase in the spectral power of α- and θ-rhythms, and weakening of late components of somatosensory and auditory EPs in the cerebral cortex).

Supposedly the same mechanisms of central inhibition become either weaker (at least with regard to somatosensory and auditory analyzers) or increase relatively to inhibitory neurons of the second order, controlling the activity of inhibitory neurons of the first order that are directly connected with relay neurons of these brainstem centers. In either case, the excitability of the relay neurons of brainstem centers increases, and activation of these centers by the corresponding somatosensory and auditory stimulations becomes stronger and more effective. This conforms to our data concerning an increase in the amplitude characteristics of certain SEPs components in the dorsal column nuclei of the spinal cord in subjects during meditation, parallel with stimulation of the median nerve [24]. That is why activation of brainstem somatosensory centers in these conditions is accompanied by strengthening and widening of certain specific somatosensory projections and probably of afferent projections of other modalities towards the cerebral cortex. For the same reason, an

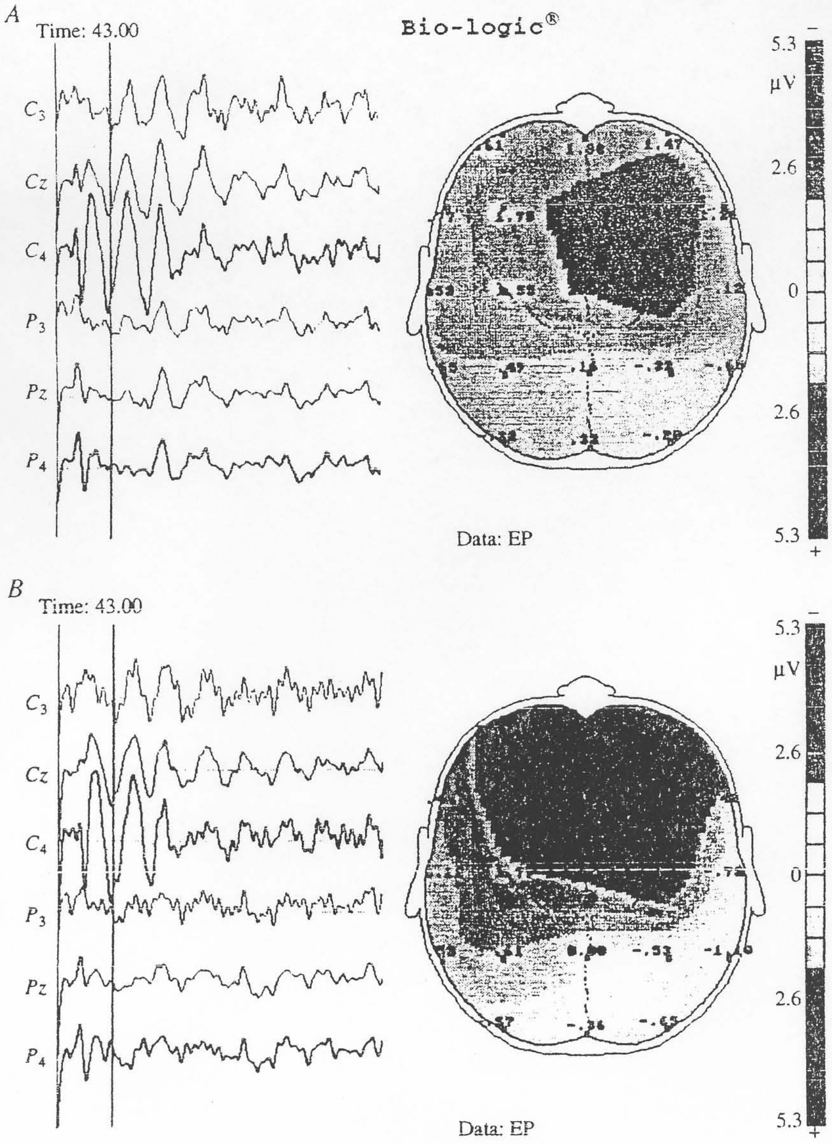

Fig. 5. Widening of the recording area (topology) of one of the early, most reactive components of averaged SEPs with the peak latency of 43 ms (P_{43}) in subject 2 during meditation. *A*: topology of the component P_{43} after the left median nerve stimulation before meditation, *B*: during meditation.

increase in the spectral power of EEG β-rhythm occurs in the cerebral cortex of subjects during meditation.

Evidently, initial somatosensory influences towards the cerebral cortex, which are accompanied by the generation of the first two SEP components in the thoracic nuclei and in the cerebral cortex, which are not changed compared with the state of quiet wakefulness, by reaching the cortex involve feedback connections in the process, which act to decrease or increase (see above) central inhibition relative to other (corresponding) neuronal unit pools of brainstem somatosensory centers. The calculation of conduction excitation velocities in the neuronal fibers of a middle diameter in the lemniscus system and in human pyramidal connections [25] admits temporal characteristics of excitation circulation from the thoracic nuclei to the cortex and back to the thoracic nuclei for "facilitation" of subsequent afferent messages through an increase in the excitability of the corresponding relay neuronal units of the thoracic nuclei.

All this taken together testifies to the fact that meditation initiates not only a deep rest of the central nervous system, but also prepares it for a more keen and precise perception of sensory signals. Widening of the range and effectiveness of perception mechanisms during meditation, which corresponds to many psychological observations [8, 9, 11, 26] and to our data concerning an increase and widening in cortical somatosensory

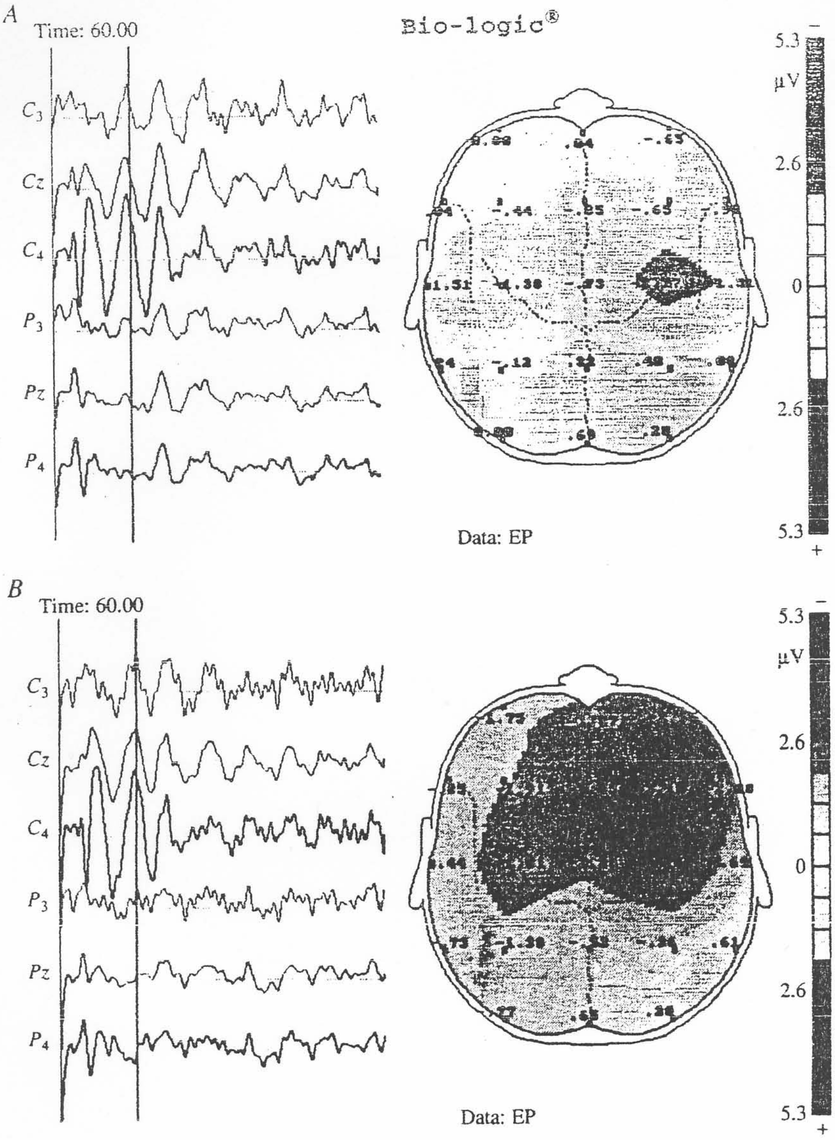

Fig. 6. Widening of the recording area of the third of early most reactive components of averaged SEPs with the peak latency of 60 ms (N_{60}) in subject 2 during meditation. *A*: the topology of component 60 after the left median nerve stimulation before meditation, *B*: during meditation.

and auditory afferent projections during meditation, is in conformity with the theoretical conception of Maharishi Mahesh Yogi [1–5] of "conscious broadening" during meditation.

Given that during meditation, as Maharishi Mahesh Yogi indicates, inhibitory locks of central inhibition, controlling brainstem sensory centers, open up, the afferent excitation inflow to the central nervous system structures increases, owing to which many activation foci are formed in it. And it is the latter activization tendency of brain neuronal pools that testifies to the fact that during meditation our intellect "organizes" nontrivial functional connections between brain centers (new functional "Bahnungs") that enrich the creative activity of a meditator in postmeditation periods. In accordance with ideas disseminated by Maharishi Mahesh Yogi [1, 5], during transcendental meditation our intellect investigates our knowledge; i.e., during meditation our intellect (brain) not only rests, but also organizes the peculiar creative process. It should be said that it was not by accident that we used the terminology of I.P. Pavlov's teaching of conditioned reflexes [27]. From our point of view, there are no principal differences between the creative component of the conditioned reflex and the creative component of meditation. During the conditioned reflex formation, when two foci of brain structure activity arise, the Bahnung of functional connections occurs not only between these acti-

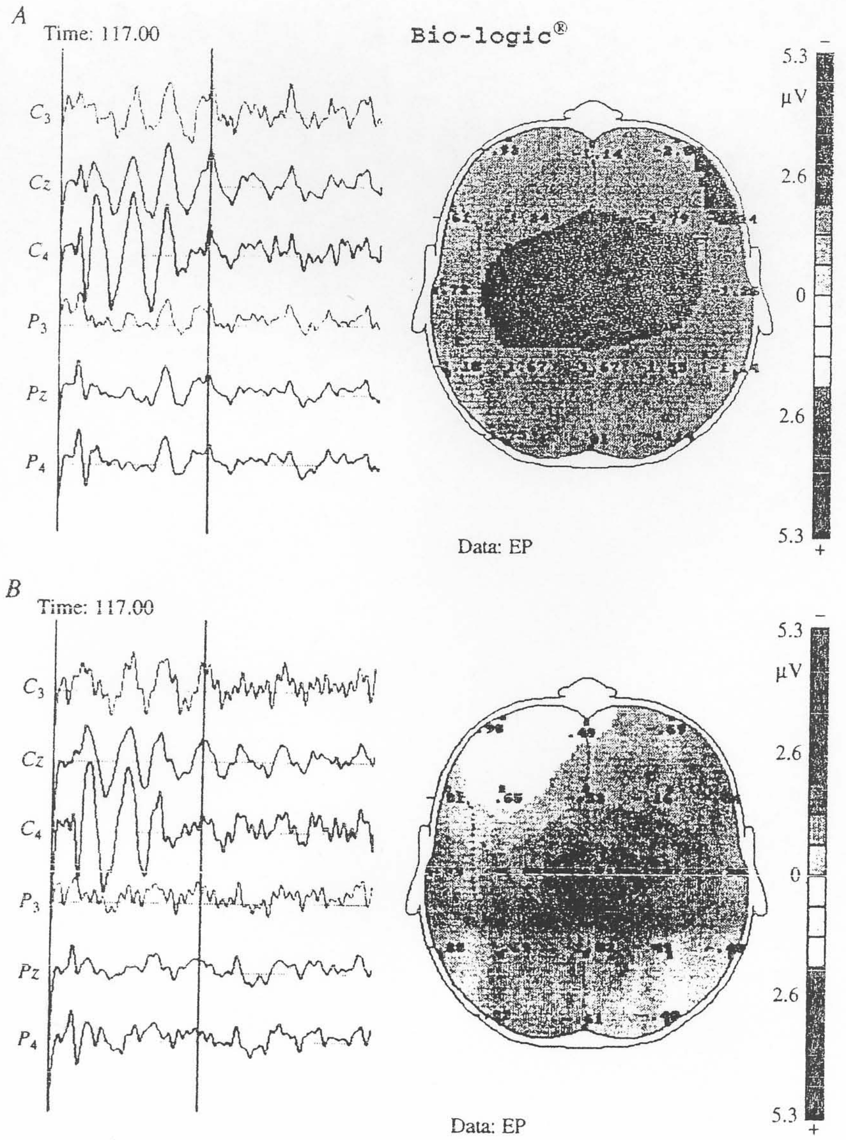

Fig. 7. Weakening and reduction of topology of one of the late components of averaged SEPs (N_{117}) in subject 2 during meditation. *A*: topology of the component N_{117} after the left median nerve stimulation before meditation, *B*: during meditation.

vation centers, but to a much greater extent the same occurs during meditation sessions, when multiple activation foci of brain neuronal structures are created.

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