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Dynamics of Neuronal Activity of the Parietal Associative Zones of the Cat Cerebral Cortex in Sleep-Wakefulness Cycle

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ABSTRACT. The dynamics of neuronal activity of the so-called association zones of the parietal regions of the cerebral cortex in the sleep-wakefulness cycle has been studied in chronic cats. It is conjectured that the changes in neuronal activity of the association zones of the parietal regions of the cerebral cortex over sleep-wakefulness cycle display the dynamics of cognitive processes, which on their part, are determined just by the transformation (both quantitative and qualitative) of the neuronal activity of the cerebral cortex, in general, and of its association zones, in particular. *© 2007 Bull. Georg. Natl. Acad. Sci.*

Key words: *neuronal activity, sleep-wakefulness cycle, association zones of the parietal regions of the cerebral cortex.*

It is commonly believed that the association zones (AZ) of the cerebral cortex play an exceptionally important role in the regulation of higher psychic functions, such as learning, memory, consciousness, etc. [1-4]. This assertion, alongside with other facts, is supported by the availability of abundant morphological connections both of the specific projection zones of the cortex, and the subcortical structures with the AZ. It can be conjectured that among other integral brain phenomena, the sleep-wakefulness cycle (SWC) is not an exception, in the sense of AZ involvement in its regulation. This assumption is also strongly supported by the fact that it is the psychic activities that undergo the most drastic and typical changes over SWC. Of these latter, the most outstanding one is the process of consciousness, which declines with the onset of slow wave sleep (SWS), and is almost completely blocked as the deep slow-wave sleep (DSWS) sets in. On account of the fact that the AZ plays an essential part in the regulation of the process of consciousness, investigation into the dynamics of neuronal activity over SWC has particular interest. In this respect, the AZ of the parietal regions (AZPR) deserves special attention. Thus, it is assumed that only the AZPR are most actively involved in the organization of cognitive phenomena, as distinct from the frontal region AZ that are directly responsible for the regulation of motivational and emotional processes [5].

The dynamics of neuronal activity of the cerebral cortex has been the subject of numerous publications referring to different periods. However, only the experiments that have been carried out after the discovery of paradoxical phase of sleep are informative [6].

In carrying out the experiments described below, concerned with elucidating the dynamics of neuronal activity of AZPR of the cerebral cortex, we have been motivated, on the one hand, by a presumed involvement of the cortical AZ in the organization of higher psychic functions of the brain, and on the other hand, by the desire to gain an insight into the dynamics of neuronal activity of these structures over SWC, with regard to its complex structure reflecting different levels of the brain integrative activity.

The experiments were carried out with 5 pubertal cats. Preparation of the skull for microelectrodes' manipulations and surgery for insertion of steel electrodes in different brain structures was performed under nembutal (35 ml/kg) anesthesia. A trepanation hole was drilled in the skull, the position of its centre was determined according to the Atlas of Reinoso-Suarez [7]. A cylindrical plexiglas thread bush was inserted in the orifice and fixed in position with noracryl, the thread bush being treated on the inner surface. In order to limit pulsation, the bottom of the thread bush was covered with a plastic film ("Parafilm"). With a view to studying the dynamics of AZPR neuronal activity discharges of individual neurons have been recorded against the background of different cycles. In order to identify the various SWC phases we have recorded: the electroneocorticogram, electrohippocampogram, the electrical activity of the mesencephalic areas from where ponto-geniculo-occipital spikes were generated, as well as the electromyogram from cervical muscles, and eye movements. The neuronal discharges of cortical AZPR have been recorded against the background of: active wakefulness (AW), passive wakefulness (PW), light SWS (LSWS), deep SWS (DSWS) and paradoxical sleep (PS).

The microelectrodes, made of tungsten wire with the diameter of 200 to 250 µm, were sharpened electrolytically. Their entire surface, excepting the tip, was insulated by a special varnish. Resistance of the electrodes equaled 5 to 10 MΩ. The microelectrodes were inserted in the brain with the aid of a manipulator fixed in the thread bush. One step of the micromanipulator shifted the microelectrode by 50 µm.

Extracellular action potentials of neurons led from gyrus lateralis and gyrus suprasilvius through a miniature cathode follower were fed into the amplifiers of a double oscillograph. The neuronal discharges were recorded on a photo film from the screen of the oscillograph, as well as on a magnetic tape and (following the amplitude discrimination), were read out on paper, in parallel with electroencephalograms. Recordings on the magnetic tape were analyzed by means of a microcomputer. A multichannel discriminator permitted to identify the activity of a single neuron, or of several neurons, at recording multineuronal activity, however, the activity of only one neuron, with the highest amplitude peak, on the paper was read out. While plotting the histograms, impulse sequences of each neuron, isolated by the discriminator were processed. To avoid errors induced by noise, the activity of neurons with the lowest amplitude peaks was not analyzed.

The most typical picture of dynamics of a single unit activity in cortical AZPR is presented in Fig. 1A. As seen in the active wakefulness, neuronal changes are more or less evenly distributed in time (Fig. 1A-AW). However, as SWS gradually sets in, initially there occur quantitative changes in neuronal discharge frequency, expressed in its decrease (Fig. 1A-LSWS, first half of the record), and it is only later that the pattern of activity gets altered, i.e. there occur qualitative changes. These changes manifest themselves in the transition of the activity, that is from evenly distributed in time, to the cluster-pause pattern (Fig. 1A-LSWS, second half). This latter type of activity gets best pronounced with the onset of DSWS (Fig. 1A-DSWS) and persists throughout the entire course of the given phase. With the nearing of PS phase onset, testified by the occurrence of single ponto-geniculo-occipital spikes, as well as by the development of complete atony of the cervical muscle, the cluster-pause type activity gets gradually deranged, and, against the background of PS, it resembles the neuronal activity typical of active wakefulness (Fig. 1A-PS).

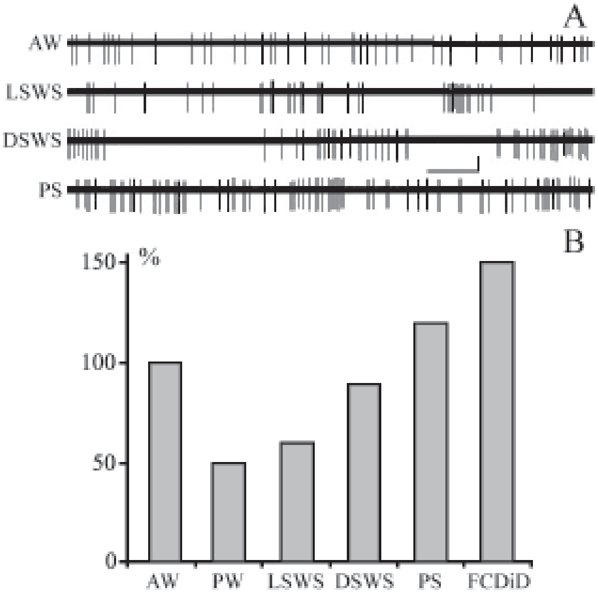

Fig. 1. The character of dynamics of single unit discharges AZPR in different SWC phases (A) and the results of statistical treatment of data (by *t* test) and dynamics of activity of 10 typical AZPR neurons in various phases and stages (within phases) of SWC (B).

AW - active wakefulness, LSWS - Light SWS (first half of the record) and well-developed SWS (second half of the record), DSWS – Deep SWS and PS – Paradoxical sleep in the presence of mean frequency of rapid eye movement, FCDiD - frequency in a cluster during DSWS.

Calibration - time 100 ms, amplitude - 100 µV.

While studying quantitative changes in the neuronal activity of the brain as a whole, and of cortical AZPR in particular, over SWC phases, it is important to identify different levels of wakefulness as well as the sleep phases. Fig. 1B demonstrates statistic results of quantitative changes in the neuronal activity of the lateral gyrus at various phases and stages of the SWC. It is quite clearly seen that if the neuronal activity of the lateral gyrus is considerably elevated at DSWS and PS, in contrast to passive wakefulness, then there occurs rather a different picture when active wakefulness background recording is intended to be compared with. In this case the highest discharge frequency can be viewed against the background of active wakefulness and PS, though a total activity is noticeably lowered even at DSWS, despite a fairly higher frequency of cluster discharges.

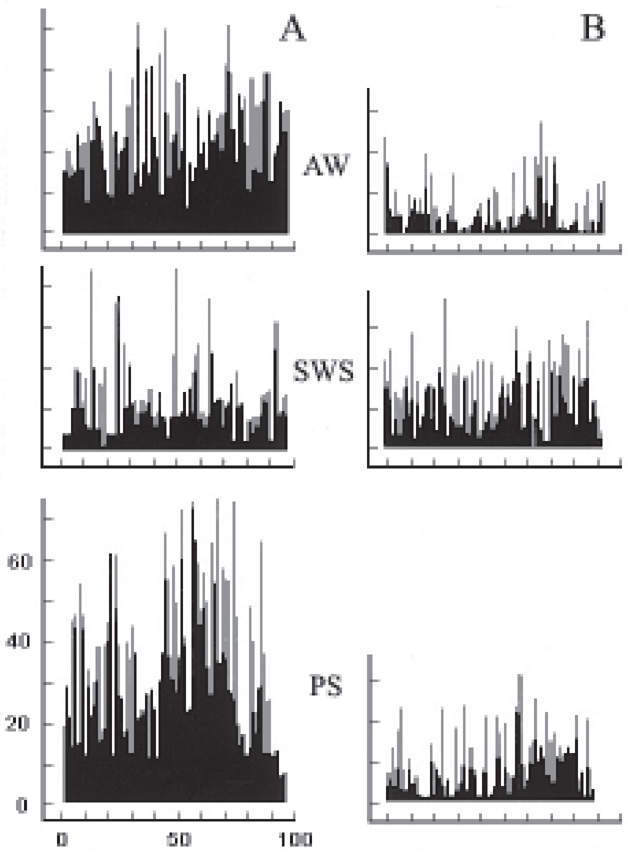

Fig. 2. Frequency histograms of neuronal activity in the cortical association zones (gyrus lateralis) in SWC. On the axis of abscissa - time in sec, on the axis of ordinate - frequency in sec. Designations: AW - active wakefulness, SWS - slow wave sleep, PS - paradoxical phase of sleep.

This fact can certainly be explained by a predomination, in time, of pauses over clusters. Very often, however, though there are clearly expressed pauses between the clusters at DSWS, the increase in the average cluster amount is so important that a total activity of single neurons of cortical AZPR exceeds their activity against the background of active wakefulness and PS.

Figure 2 represents the histogram-like data illustrating the dynamics of the discharges of two neurons, registered from the lateral gyrus in the SWC. It can be seen that with the onset of SWS, if one neuron (Fig. 2A) significantly brings its activity down as compared to the wakefulness, and especially, against the background of PS, the other one (Fig. 2B) is discharging at a comparatively lower rhythm and, on the contrary, gets more activated, most of all against the background of SWS. However, it should be noted that neurons of the second type are rarer than those of type one.

An interesting picture can also be observed in those cases when the activities of two or three neurons of the cortical AZPR are tracked through one and the same recording microelectrode. Fig. 3 shows the activity dynamics of two neurons of lateral gyrus. As demonstrated, their discharges are more or less evenly distributed in time against the background of active wakefulness (Fig. 3-AW), whereas in passive wakefulness (Fig. 3-PW), similar to LSWS (Fig. 3-LSWS), both of the neurons display the cluster-pause activity. However, their active episodes and pauses are asynchronous, as a result, the cluster activity of one of the neurons coincides with the pause of the other. With the change to DSWS, active and silent episodes of both neurons set in synchronously (Fig. 3-DSWS), but with the development of PS, the activity type which is characteristic of active wakefulness is restored (Fig. 3-PS). A similar picture could be found looking more attentively through the recordings of the dynamics of multineuronal activity of motor cortex [8] and Gyrus Cingulus of cat's brain [9].

In other cases the change in the neuronal activity is mainly manifested by quantitative, rather than qualitative shifts. An illustrative example is given in Fig. 4A, involving registration of two neurons, whose spikes differ from each other in their amplitude. As demonstrated, discharges of both neurons were more or less evenly distributed in time against the background of active wakefulness (Fig. 4A-AW), while in passive wakefulness (Fig. 4A-PW) their discharge frequency decreased drastically, without being transformed into the cluster-pause activity. A clear-cut cluster type activity was not in evidence even during DSWS (Fig. 4A-DSWS). In PS the activity of either neuron got enhanced, reaching the level typical of active wakefulness. Consider also that the highest discharge frequency was observed at the so-called emotional stage of PS (Fig. 4A-EPS) [10], whereas in the non-

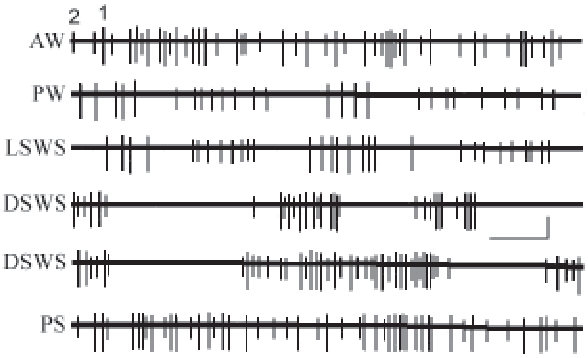

Fig. 3. Dynamics of activity of two neurons led through one and the same microelectrode from AZPR in the SWC. AW - active wakefulness, PW - passive wakefulness, LSWS – light SWS, DSWS – deep SWS, PS – paradoxical sleep. Calibration - time 100 ms, amplitude - 100 μV.

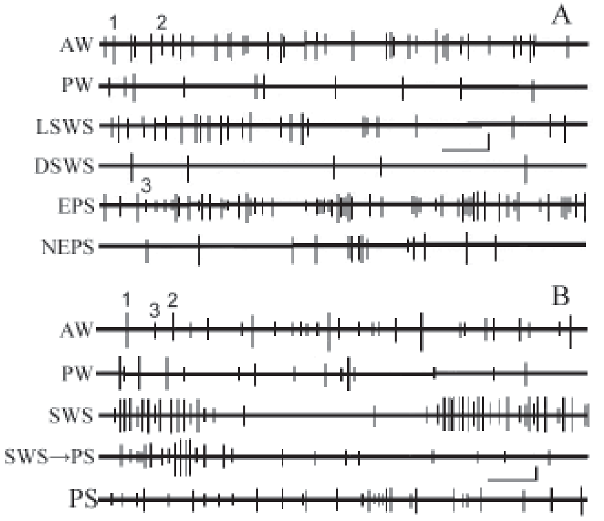

Fig. 4. Dynamics of activity of three neurons led through one and the same microelectrode from the suprasylvian gyrus in different phases of SWC (A) and from the cortical association zone in SWC (B). AW - active wakefulness, PW - passive wakefulness, LSWS – light SWS, DSWS – deep SWS, PS – paradoxical sleep, EPS - emotional stage of PS, NEPS - nonemotional stage of PS, SWS – slow wave sleep and SWS’!PS - transition from SWS to PS Calibration - time 100 ms, amplitude - 100 µV.

emotional stage the discharge frequency decreased considerably (Fig. 4A-NEPS). Attention is also drawn to the fact that in the PS emotional stage, there appeared discharges of a third neuron (with small spike amplitude) whose activity was hardly traceable under other sleep phases or stages. Such selective activation of some AZPR neurons in specific SWC phases, though not very frequently, but is still observable.

Figure 4B illustrates a curious example of behavior of three neurons recorded through the same microelectrode from the AZPR. As can be seen, under active wakefulness all the three neurons discharge at more or less regular pace. However, in the other SWC phases that follow, there occur disparities in their behavior. Activity of the neuron with the greatest spike amplitude in DSWS, undergoes qualitative changes, i.e. the neurons start to discharge in a cluster-type manner. Despite fairly lengthy pauses between the clusters, owing to the drastic rise in the mean number of discharges in clusters, the level of the overall activity in DSWS tangibly exceeds the one observed at passive or active wakefulness. As for the other two neurons, they display only quantitative changes, i.e. their discharge frequency decreases over passive wakefulness and DSWS, as compared with active wakefulness, and with PS in particular. An obvious difference in the behavior of the three neurons is that the neuron with the highest spike amplitude almost stops discharging at PS (Fig. 4B-PS), while the remaining two neurons enhance their activity to the level even excelling the one corresponding to active wakefulness.

As indicated above, apart from analyzing the quantitative, as well as qualitative changes in the neuronal activity in AZPR, we also focused on studying such parameters as: variation of the mean values of neuronal discharges in clusters over SWS phase.

Fig. 1A-DSWS and Fig. 1B-FCDiD demonstrate a clear-cut increase in the mean frequency of discharges in clusters over SWS, as compared with active wakefulness and PS. Very often, the increase in the mean frequency of neuronal discharges in clusters against the background of DSWS is so significant that it results in the considerable enhancement of the neuronal activity over SWS, as compared both to active wakefulness and PS.

It should be noted that the cluster-pause activity of neurons of AZPR is exclusively typical of SWS, and by no means of PS. The reason why we focus on this fact is that after Evarts’s classical works [6] bearing on the neuronal activity of the brain over SWC, it became habitual to think that the cluster-pause neuronal activity was typical of both SWS and PS, though in this latter, discharge clusters, as well as pauses, might be longer. Later on quite a few scientists have reported that neurons of the cerebral cortex, as well as of other brain structures [9,13] discharge at regular intervals in PS, i.e. their discharges are more or less evenly distributed in time. Nevertheless, at considering the general mechanisms of brain work over SWC, many authors typically refer to Evarts’ original publications [see 4]. And the data described therein, presumably bear only on motor neurons who start discharging in groups of clusters in response to the development of the phasic motor components of PS, thereby giving an impression that the neuronal activity proceeds according to the cluster-pause pattern. In our experiments, not in a single case did the neuronal activity of cortical AZPR change from cluster-pause pattern to more or less regular discharges at the transition from SWS to PS, as characteristic of active wakefulness. A true cluster-pause activity developed only against the background of SWS. Though, not infrequently, in AZPR there can be detected such neurons whose discharges in PS correlate with the phasic components of this particular physiological process, such as rapid eye movements, isolated contraction of the somatic muscles, accompanied by limb movements or vibris. In all probability, such distribution pattern of neuronal discharges is qualitatively different from the cluster-pause activity, typical of SWS. This contention is also strongly supported by the fact that at recording the activities of two neurons in the lateral gyrus during PS through one and the same electrode during PS, only one of them, with larger spike amplitude, was discharging in clusters, while the other, with smaller spike amplitude, continued to display regular excitation. As for SWS, in this phase clusters and pauses in discharges of both the neurons develop synchronously, which is indicative of the alternation of active episodes and inhibition, rather than of the occurrence of discharge clusters in response to the development of the phasic motor components of PS. In this respect, it is also informative that over the so-called non-emotional stage of PS [10], in the absence of clear-cut phasic motor components, activity of the neuron with the larger spike amplitude does not only follow the cluster-pause pattern but is even decreased to zero. This also testifies to the fact that the occurrence of cluster discharges in the described phase is related to the motor phasic components of PS.

At studying the dynamics of various neurophysiologic parameters over SWC, one can readily identify the clear-cut transition moments from one phase to another. In this connection, it is also of interest to run down the dynamics of the neuronal activity in cortical AZPR at the change from SWS to PS, and from PS to wakefulness or SWS. Logically, in the sequence of SWC phases, SWS, as a rule, should be followed by PS, however, this regularity is often broken, presumably for various reasons, and before PS sets in, against the background of SWS there may appear more or less long episodes of wakefulness, which occasionally develop into a full-fledged phase, judging from all the behavioral and EEG parameters.

Analysis of the obtained experimental data leads to the following conclusions: 1. Activity of the majority of neurons in AZPR throughout SWC undergoes qualitative changes that manifest themselves in the transformation of their discharge pattern from regular type, i.e. evenly distributed in time, characteristic of the state of wakefulness, to the cluster-pause type, characteristic of SWS. And the neuronal activity, typical of wakefulness, is restored in the PS phase. 2. Against the background of DSWS, the mean frequency of neuronal cluster discharges, in AZPR of the cortex, is appreciably higher than that in active wakefulness. This fact provides evidence for the postsynaptic inhibition of neurons during pauses, which upon termination, are immediately followed by the rebound of activity and the respective rise in the frequency of neuronal discharges. 3. A smaller portion of neurons in AZPR, exhibits only quantitative changes in SWC, without transforming their activity to the cluster-pause type. 4. In AZPR there can also be detected such neurons that are activated selectively in one or another SWC phase. 5. Most neurons in the cortical AZPR abruptly, sometimes down to a full stoppage, reduce their activity immediately after termination of PS, as well as with the occurrence of short episodes of EEG desynchronization without signs of behavioral arousal against the background of DSWS. 6. It is conjectured that the changes in neuronal activity of AZPR of the cerebral cortex over SWC display the dynamics of cognitive processes, which, for their part, are determined just by the transformation (both quantitative and qualitative) of the neuronal activity of the cerebral cortex, in general, and of its AZ, in particular.

ადამიანისა და ცხოველთა ფიზიოლოგია

კატის თავის ტვინის ქერქის პარიეტალური ასოციაციური უბნების ნეირონული აქტივობის დინამიკა ძილ-ღვიძილის ციკლში

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შესწავლილია კატის თავის ტვინის ახალი ქერქის პარიეტალური ზონის ასოციაციური უბნების ნეირონული აქტივობის დინამიკა ძილ-ღვიძილის ციკლში. მიღებულ მონაცემთა ანალიზი იძლევა შემდეგი დასკვნების საშუალებას: 1. ნეირონთა უმეტესობის აქტივობა ძილ-ღვიძილის ციკლში განიცდის როგორც რაოდენობრივ, ისე თვისებრივ ცვლილებებს. ეს უკანასკნელი გამოიხატება აქტიური ღვიძილისათვის და ძილის პარადოქსული ფაზისათვის დამახასიათებელი ნეირონების რეგულარული განმუხტვების ტრანსფორმაციაში ჯგუფურ-პაუზურ ფორმაში, რაც დამახასიათებელია ძილის ნელტალღოვანი ფაზებისათვის და განსაკუთრებით ღრმა ნელტალღოვანი ძილისათვის. 2. აღსანიშნავია, რომ ღრმა ნელტალღოვანი ძილის ფონზე ნეირონების განმუხტვის საშუალო სიხშირე ჯგუფებში შეიძლება მნიშვნელოვნად მეტი იყოს ვიდრე მათი რეგულარული განმუხტვების სიხშირე აქტიური ღვიძილისა და პარადოქსული ძილის ფონზე. 3. ნეირონების შედარებით მცირე ჯგუფი ძილ-ღვიძილის ციკლში განიცდის მხოლოდ რაოდენობრივ ცვლილებებს ჯგუფურ-პაუზურ აქტივობაში ტრანსფორმაციის გარეშე. 4. აღნიშნული უბნების ზოგიერთი ნეირონი აქტივობას იწყებს შერჩევითად ძილ-ღვიძილის ციკლის მხოლოდ ამა თუ იმ ფაზაში. 5. აღნიშნული ასოციაციური უბნების ნეირონთა უმეტესობა წყვეტს ან მკვეთრად ამცირებს აქტივობას როგორც ძილის პარადოქსული ფაზის სწრაფი გადასვლისას ღვიძილის ფაზაში, ასევე ნელტალღოვანი ძილის ფონზე განვითარებული იზოლირებული ელექტროენცეფალოგრაფიული შეღვიძებისას. 6. საბოლოოდ შეიძლება დავასკვნათ, რომ თავის ტვინის ახალი ქერქის ასოციაციური უბნები აქტიურად მონაწილეობენ როგორც ძილ-ღვიძილის ციკლის სტრუქტურის ფორმირებაში, ასევე მასში მიმდინარე ფსიქოფიზიოლოგიური პროცესების დინამიკაში.

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