EFFECT OF THE STATE OF SLEEP AND WAKEFULNESS ON TRANSMISSION OF THE AFFERENT SIGNAL THROUGH THE POSTERIOR VENTRAL NUCLEUS OF THE THALAMUS

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The effect of the state of sleep and wakefulness on transmission of afferent stimuli and subsequent inhibitory processes in the posterior ventral nucleus of the thalamus was studied in chronic experiments on unanesthetized cats. In a drowsy state and in a state of superficial sleep stimulus transmission is reduced, whereas in an active state (during the arousal reaction, movement, eating, etc.) it is increased. In paradoxical sleep stimulus transmission is at the same level as in a state of quiet wakefulness. In a drowsy state and in the first phase of sleep marked fluctuation of transmission is observed. The level of stimulus transmission is most stable in active states. The intensity of the after-inhibition following transmission of the afferent signal depends on the level of anesthesia, of wakefulness, and of natural sleep. Processes following transmission of the afferent stimulus in the posterior ventral nucleus of the thalamus during barbiturate anesthesia differ radically from those in the unanesthetized animal. After-inhibition, so characteristic of anesthesia, is manifested in the drowsy state only to a slight degree, and in the waking state it is not exhibited at all.

KEY WORDS: *transmission of afferent stimuli; posterior ventral nucleus of the thalamus; sleep; waking state.*

The characteristics of transmission of afferent stimuli through the specific nuclei of the thalamus in relation to the level of sleep and wakefulness have been investigated chiefly in the visual system [5-7, 9, 10]. The workers concerned concluded that thalamic transmission is greatest during the arousal reaction, decreases during the oneset of sleep, and is considerably reduced during sleep itself, which is accompanied by slow activity in the EEG. In the state of deep paradoxical sleep, accompanied by fast EEG activity, a marked increase in thalamic transmission is observed [9, 10].

Under conditions of barbiturate anesthesia after-inhibition develops in the relay cells of the posterior ventral nucleus (NVP) after transmission of the afferent impulse. According to Andersen et al. and to the present writers' own observations [1-4], this phenomenon is due to internal thalamic mechanisms. The actual character of the after-inhibition in NVP following transmission of somatic impulses, as it depends on the level of natural sleep and wakefulness, has not yet been explained.

In the investigation described below the character of transmission of somatic sensory impulses through NVP was investigated in relation to the level of sleep and wakefulness in chronic experiments on cats. After-processes taking place in the relay cells of NVP after transmission of the afferent signal also were studied in the state of sleep and wakefulness and also in the stages of transition from anesthesia to the waking state. The amplitude of the response of the thalamocortical fibers (TCF) to stimulation of the medial lemniscus (ML) was used as the indicator of transmission. The indicator of the after-processes developing in NVP after passage of the afferent impulse was the cycle of recovery of excitability of TCF to paired stimulation of ML under appropriate conditions.

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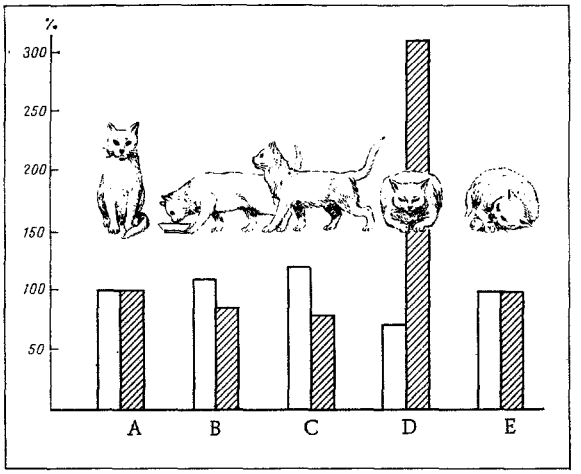

Fig. 1. Mean values of amplitudes of responses of TCF to stimulation of ML and corresponding coefficients of variation for different states of the animals. Unshaded columns show mean values of amplitudes of responses of TCF to stimulation of ML; shaded columns coefficients of variation of responses. A) Waking state; B) active movements, state of eating and drinking; C) reaction of attention; D) state of drowsing and initial phase of sleep; E) state of deep sleep.

EXPERIMENTAL METHOD

Chronic experiments were carried out on cats with implanted electrodes. The concentric bipolar electrodes (interelectrode distance 1-1,5 mm) were introduced in accordance with a system of stereotaxic coordinates taken from the atlas of Jasper and Ajmone-Marsan [8], into the medial lemniscus on the left and right sides (F 5.0, L 4.5-5.0, B -2) and identical recording electrodes were inserted into TCF on both sides (F 16, L 8,0). The electrodes and socket with contrasting connections were fixed to the animal's skull with acrylic glue; ML was stimulated by square pulses (0,1 msec, 0,1 Hz) from a stimulator with radiofrequency output. During paired stimulation of ML the interval between stimuli varied from 3 to 500 msec in 26 ranks: from 3 to 10 msec by 1msec, from 10 to 100 msec by 10 msec, from 100 to 200 msec by 20 msec, from 200 to 300 msec by 50 msec, and from 300 to 500 msec by 100 msec. The potentials were recorded and measured on the screen of a cathode-ray oscilloscope with a memory. The subsequent mathematical analysis of the data was carried out on a computer of the FACOM-R type by means of a special program. In this way it was possible to calculate from a large number of observations the dynamics of the change in the testing response of TCF to paired stimulation of ML depending on the animal's condition.

During measurement of each bioelectrical response of TCF to stimulation of ML the animal's behavior was recorded simultaneously. For each interval between stimuli the mean values of the responses, standard deviations, and variation coefficients were calculated on the basis of responses recorded while the animal behaved in a uniform and definite manner. These mean values of the testing responses of TCF, characteristic for different states, were compared at the appropriate intervals in order to determine the significant difference between them. Significance of differences was judged on the basis of Student's criterion ($P < 0,01$).

The results described are based on the measurement of 102,000 responses recorded from TCF of five cats in the course of 85 experiments. The cycle of recovery of the testing response of TCF to paired stimulation of ML was recorded altogether 68 times in five experimental animals.

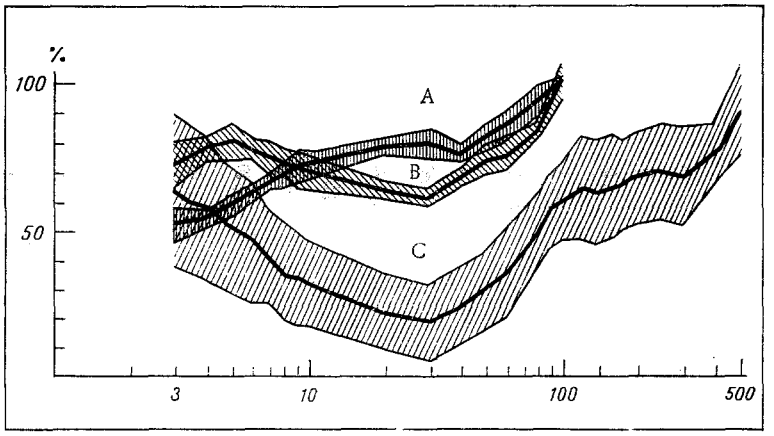

Fig. 2. Recovery cycles of testing response of TCF to paired stimulation of ML (averaged curves). Thick black line indicates relative mean values of responses of TCF to testing stimulus of ML; shaded bands correspond to standard deviations. A) Animal in active states; B) in state of drowsiness and in first phase of sleep; C) during barbiturate anesthesia. Abscissa, intervals between stimuli (in msec; logarithmic scale); ordinate, amplitudes of testing responses expressed as percentages of conditioning response.

EXPERIMENTAL RESULTS

The mean values of the responses and the corresponding variance coefficients were analyzed for the following states of the animal: 1) the waking animal peacefully sitting with eyes open; 2) responding to sound, ears turned in the direction of the source of sound; 3) combing itself; 4) licking itself; 5) drinking milk; 6) eating; 7) walking about the cage; 8) sitting with eyes shut, drowsing; 9) lying asleep, cervical muscles still in a contracted state; 10) lying with head on the floor, cervical muscles relaxed, eyes moving, whiskers and ears shaking (external signs of paradoxical sleep observed).

In the active states of the animal (points 2-7) and also during drowsing and in the slow phase of sleep the mean values of the amplitudes of the response of TCF to stimulation of ML differed significantly ($P < 0,01$) from the amplitudes of the response of TCF in a state of quiet wakefulness. The mean value of the amplitude of TCF during the arousal reaction was 121%, in other active states (points 3-7) 113%, and during drowsing and in the slow phase of sleep 75% of the amplitude of the response in a quiet waking state. The mean value of the amplitude of TCF to stimulation of ML in a state of paradoxical sleep was close to the mean value of the amplitude of TCF ($P > 0,05$) in the waking state (Fig. 1).

The coefficients of variation of the responses of TCF to stimulation of ML in active states (during eating, drinking, movement, and the arousal reaction) were 80-84% of the coefficient of variation of the responses of TCF during a state of quiet wakefulness (Fig. 1). In a drowsy state and in the slow phase of sleep the coefficient of variation of the responses was 308% of that of the responses in a quiet waking state.

The extremely high value of the coefficient of variation in a state of drowsiness and during superficial sleep can be explained on the grounds that the decrease in amplitude of the responses of TCF during the change from wakefulness to sleep took place by alternation of high amplitudes (characteristic of the waking state) with very low amplitudes. In a state of drowsiness and in the first phase of sleep the distribution of the responses of TCF to stimulation of ML was thus bimodal; the modal values of this distribution differed from each other by 35%. Analysis of the coefficients of variation suggests that the character of thalamic transmission in a state of drowsiness and in the first phase of sleep is fluctuating.

Curves showing recovery of the testing response of TCF to paired stimulation of ML with the animal in different states are shown in Fig. 2. Curve A characterizes the active state

of the animals (based on responses of TCF recorded in five experimental animals in states described in points 2-7). Curve B characterizes the drowsy state and the state of slow sleep. For clarity, the curve C of recovery of the excitability of TCF during nembutal anesthesia is drawn in the same figure.

The testing response of TCF to paired stimulation of ML in the active state increased gradually and, toward the interval of 30 msec between stimuli, it reached 82% of the conditioning level; toward an interval of 40 msec between stimuli it again decreased slightly, then increased again, and was fully restored toward the interval of 100 msec between stimuli.

In the drowsy state for 5-msec intervals the testing response was reduced to 80% of the conditioning response, then diminished, reaching maximal retardation for intervals between stimulation of 30 msec. In the drowsy state, as well as in the waking state, response of TCF for stimulation of ML was completely reduced 100 msec following the conditioning response. In contrast to this, for nembutal anesthesia the testing response of TCF for stimulation of ML, even for intervals of 500-msec stimulations, constitutes in all 85% of the conditioning response.

After-processes following afferent transmission at the thalamic level in unanesthetized animals under free behavior conditions differed radically from those under anesthesia. In an active waking state, excitability of the relay neurons of NVP was gradually restored after transmission of the afferent signal without any sign of the inhibition that is so characteristic of anesthesia. Under barbiturate anesthesia the excitability of the relay cells of NVP 30 msec after transmission of the stimulus was reduced to a minimum, whereas in the waking, active state, there was actually slight facilitation in this interval between stimuli. In the drowsy state and in the first phase of sleep, although inhibition of the relay cells could not be observed to the same degree as under barbiturate anesthesia, nevertheless some decrease in excitability was observed, and was most marked 30 msec after transmission. Rudiments of the after-inhibition in NVP, which are seen to an extreme degree under anesthesia, are thus also observed under conditions of natural behavior of the animal with a low level of activity of the reticular formation (drowsiness, sleep).

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