

EXPERIMENTAL APPROACH TO AUDITORY SENSORY PROCESSING IN SLEEP AND WAKEFULNESS

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ABSTRACT

Sensory information about the environment and the body continuously modulates central nervous system (CNS) activity during the sleep/wakefulness cycle. It was proposed that the sensory input participates in waking and influences sleep. A landmark paper by Bremer [1] postulated that wakefulness was supported by the sensory systems and that a lack, or decreased level, in their activity would lead to sleep. In addition, interactions were reported between sleep and sensory input in general [12], and a surgical *quasi*-total deafferentation revealed significant changes in the characteristics of sleep and wakefulness [15].

Although profoundly modified, the processing of sensory information is still present during sleep. While all sensory systems show some influence on sleep, they are also reciprocally modulated by the sleep or waking state of the brain. Moreover, every sensory system presents an efferent pathway with centrifugal fibers reaching its own receptors and nuclei of the afferent pathway, introducing a base for reciprocal interaction between the sensory input and the CNS state. Thus, the incoming sensory information may alter sleep and waking physiology, and, conversely, the sleeping brain imposes rules on information processing [13].

Although we do not completely understand how the brain processes sensory information, it is currently accepted that neuronal networks can change depending on the information they receive throughout life [5, 11]. We postulate that neural networks can also change during the 24-hour cycling from wakefulness to sleep and *vice versa*. Cell assembly coding is a tenable aspect on how the brain may operate in sleep and waking.

The auditory system

Several reasons support our approach relating sleep and auditory physiology. First, hearing is the only tele-receptive modality relatively open during sleep in micro-osmotic animals, acting as a continuous monitor of the environment, e.g., predators detection, a baby's cry during the night that awakes his parents. Second, while auditory stimuli can affect sleep, e.g., a noisy night will reduce the total sleep time and will be followed by a sleep normalization once the noise is reduced [6]; the total lack of auditory input after bilateral lesion of the cochleae alters the sleep architecture of guinea pig by increasing the total sleep time [7]. Third, the link between auditory perception and sleep is also expressed by the presence of auditory images in 65% of recalled dreams [4]. Finally, the local blood flow is significantly increased in auditory *loci*, such as the auditory cortex, medial geniculate, inferior colliculus, superior olive, and particularly, the cochlear nucleus, with a $\approx 170\%$ increase during paradoxical sleep [10].

Sleep

Sleep is a distinct physiological state in which the brain and the body show major changes of most physiological parameters compared to wakefulness. The brain is a different one, i.e., its networks have changed from a *waking mode* into a *sleeping mode*. General phenomena such as brain metabolism and blood flow, brain oxygen availability distribution, energy metabolism, autonomic functions, temperature control, and the endocrine system, illustrate how striking sleep-related shifts widely change brain and body functions [12, 13,14].

The guinea pig -our experimental animal- sleep/waking cycle is not a circadian one and has been described as either diurnal or nocturnal, sleep/waking occurs throughout the 24-hour period with a light/dark ratio of 1-1.1. This particular non-circadian condition is quite similar to the human neonate sleep-waking cycle.

Processing approaches

The present report analyzes sensory processing during sleep and wakefulness from a single neuronal viewpoint in the context of neuronal networks or cell assemblies. Our premises are that processing changes throughout the sleep-wakefulness cycle may be at least partially evidenced in single neurons by: 1. changes in the phase-locking between the unit and the hippocampal theta rhythm The stimuli were presented rhythmically or at random, tone bursts or natural guinea pig calls. 2. changes in the discharge rate and firing pattern of the response to artificial or natural sounds. 3. neurotransmitters involved in the afferent and efferent pathways.

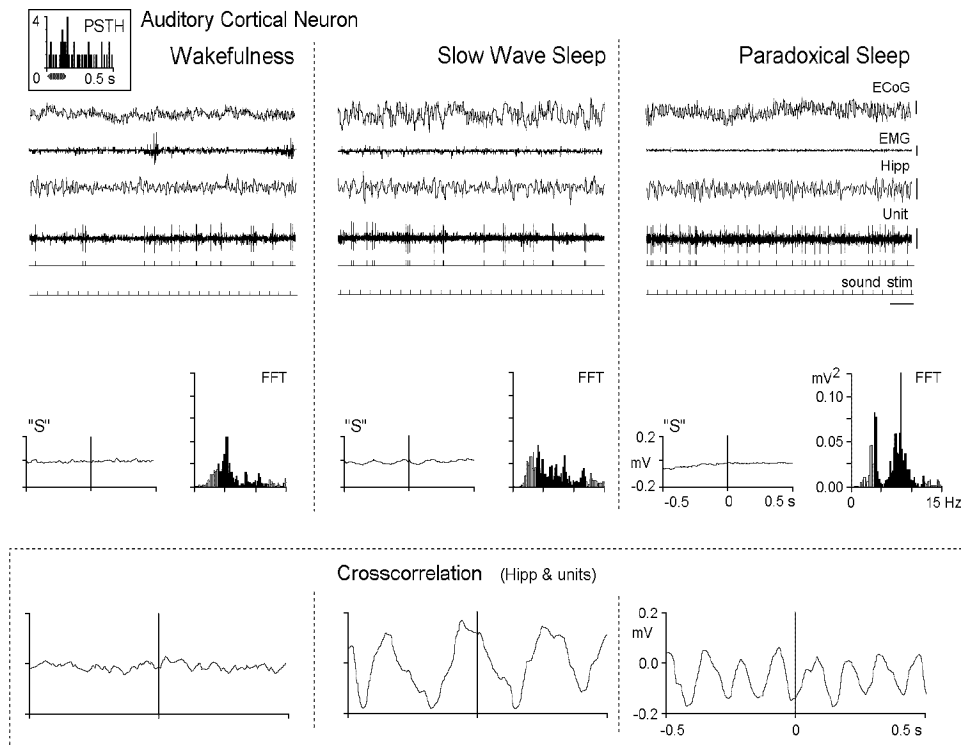


Fig. 1. Auditory cortical A1 neuron. In this particular example the crosscorrelation (phase-locking, lower traces) between the unit and theta rhythm was present during Slow Wave and Paradoxical Sleep, while disappeared in Wakefulness in spite of a theta rhythm presence (FFT). The theta waves frequency changed in sleep while the unit continuous to be phase-locked. "S", shuffling of the inter-spikes intervals produced flat crosscorrelation. Stimuli, tone burst 50 ms, 2/ s. FFT, Fourier Transform. PSTH, Post-stimulus time histogram. ECoG, electrocorticogram; EMG, eletromyogram; Hipp, hippocampal theta; Unit, raw recording and digitized. Modified from [9].

The first part of our report is based on the hypothesis that the encoding of sensory information needs a timer in order to be processed and stored, and that the hippocampal theta rhythm could contribute to the temporal organization as an internal low frequency *zeitgeber*. We have demonstrated that the guinea pig's auditory and visual neuronal discharge exhibits a temporal relationship (phase-locking) to the hippocampal theta waves during wakefulness and sleep phases, with regular or at random stimulation using artificial tones or natural calls [8, 9, 13, 14].

The second. During sleep the evoked firing of auditory units increases, decreases or remains similar to that observed during quiet wakefulness. However, there was not auditory unit yet that stopped firing when the guinea pig enters sleep. Approximately half of the cortical neurons studied did not change firing rate when passing into sleep while others increased or decreased. Thus, the system is continuously aware of the environment. We postulate that those neurons that changed their evoked firing during sleep are also related to cell assemblies of still unknown sleep processes [14].

The third. Excitatory amino acid neurotransmitters participate in the synaptic transmission of the afferent and efferent pathways in the auditory system. In the inferior colliculus, however, the effects of glutamate mediating the response to sound and the efferent excitation evoked by auditory cortical stimulation failed to show differences in sleep and wakefulness [3].

Considering that neonates and also infants spend most of the time asleep, the continuous arrival of sensory information to the brain during both sleep phases may serve to 'sculpt' the brain by activity-dependent mechanisms of neural development, as has been postulated for wakefulness. Moreover, these basic approaches may contribute as a first step towards the possibility of auditory learning, as it was suggested in sleeping newborns [2].

Keywords: Auditory processing, Unitary activity, Hippocampal theta rhythm, Phase-locking, Sleep, Wakefulness

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