Sleep, Emotions, and Visceral Control

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Abstract—It is known that sleep is connected with sensory isolation of the brain, inactivation of the consciousness and reorganization of the electrical activity in all cerebral cortical areas. On the other hand, sleep deprivation leads to pathology in visceral organs and finally to the death of animals, while there are no obvious changes in the brain itself. It is still unclear how the changes in the brain activity during sleep could be connected with the visceral health. We assumed that the same brain areas and the same neurons that, in wakefulness, process exteroceptive information, switch, during sleep, to the processing of the interoceptive information. Thus, the central nervous system is involved in regulating the life support functions of the body during sleep. The results of our experiments supported this hypothesis, explained many observations obtained in somnology, and offered mechanisms of several pathological states connected with sleep. However, at the present level of the visceral sleep theory, there is no understanding of the well-known link between the emotional reactions of the body and transition from wakefulness to sleep, and sleep quality. In this study, an attempt is undertaken to combine the visceral theory of sleep with the need-informational theory of emotions proposed by P. Simonov. The visceral theory of sleep assumes that in living organisms there is a constant monitoring of the correspondence of the visceral parameters to the genetically determined values. Mismatch signals evoke the feeling of tiredness and the need of sleep. This sleep need enters the competition with other actual needs of the body. In accordance with the theory of Simonov, emotions connected with a particular need play an important role in their ranking for satisfaction. We propose that emotional estimation of the sleep need based on visceral signals occurs in the same brain structures which undertake this estimation for other behavioral needs in wakefulness. During sleep, the same brain structures involved in estimating emotions continue to rank visceral needs and define their order for processing in the cortical areas and in the highest centers of visceral integration. In the context of the proposed hypothesis, we discuss the results of the studies on the link between sleep and emotions.

Keywords: visceral theory of sleep, need-informational theory of emotion, visceral control

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1. INTRODUCTION: THE MAIN PARADOX OF THE SLEEP STATE

There is probably no other sphere of physiological science where the word “paradoxical” is mentioned as frequently as in sleep physiology. Everyone has heard about the paradoxical sleep phase and legends around this state of the body. However, in our opinion, the most paradoxical sleep phenomenon is that, despite numerous studies in the last century, there is still no generally acknowledged theory capable of explaining the functional purpose of this state. As for the difficulty of developing such a theory, it is obviously connected with the main sleep paradox, which consists of the contradictions among the following phenomena that, at first glance, are difficult to combine.

Transition from wakefulness to sleep is connected with pronounced changes in the electrical activity of the brain, first of all, of the cerebral cortex. In the periods of slow-wave sleep, cortical neurons pass to periodic burst activity reflected in the slow waves of EEG. Both humans and animals choose, for sleep, quiet and dark places with a soft bedding to decrease the level of activation of proprio- and extero-(distant) receptors. In addition special neuronal mechanisms raise the thresholds for sensory information on its way to the cortex [1, 2]. All this makes an impression of the informational isolation of the brain during sleep. At this time, cortical output motor commands are also blocked (so-called sleep atonia) [3]. In combination with bright images of dreams, these observations led to conclusion that sleep is a state needed, first of all, to support the brain’s efficient functioning. Reviews of these studies are presented in several publications [4–6].
A striking finding was that, in rats, the only organ that did not suffer from sleep deprivation was the brain [10]. This observation was frequently doubted, since it is well known that sleep deprivation in humans is accompanied by a decrease in attention and ability to solve complex tasks [11]. This apparent contradiction was solved by the discovery of the local sleep phenomenon [12, 13]. It was shown that in some cases sleep development in some cortical zones can take place during behavioral wakefulness. Thus, it was natural to explain the cognitive consequences of sleep deprivation by turning off of several cortical zones rather than by the deterioration of brain efficiency.

It remained a puzzle how the informational isolation of the brain from the external world, which accompanies the transition from wakefulness to sleep, could be connected with visceral health.

Attempts to find a solution to this issue, we advanced a rather simple hypothesis. According to this hypothesis, during sleep, the brain is actually isolated from exteroceptive information. However, the same brain neurons that, in periods of wakefulness, analyze exteroceptive information of different modality switch over to the analysis of interoceptive information coming from different visceral systems. Thus, the central nervous system during sleep is involved in the process of visceral regulation.

Despite the attractiveness of this approach, the main obstacle—the generally recognized concept that cerebral cortex is a system of specialized processors tuned to the analysis of signals of definite sensory modality—was in its way. This concept reflected itself also in the adopted nomenclature of cortical zones, such as visual, auditory, and somatosensory zones. However, one should remember that during the creation of computers, the development of specialized processors was very soon given up, and all modern machines are based precisely on universal processors. There is no doubt that the construction of computers created by human is far simpler than the organization of the most powerful devices of information processing known to us, namely, an animal’s brain. It is difficult to imagine that the principles of universal processors were not used in the process of creating a living brain. This consideration urged us to conduct a series of experiments to check nontrivial predictions of the visceral sleep hypothesis.

The results of experiments that would never have been made in the absence of this hypothesis confirmed this proposal [14–18]. A detailed review of these studies, whose results allowed us to speak about the visceral sleep theory, has been recently published [19]. In terms of the suggested theory, many observations of experimental somnology were explained, and the mechanisms of a number of pathologies related to the sleep state became clear.

However, there remained phenomena that did not find explanation at the level of the development of the visceral sleep theory. There were numerous indications of the connection of the sleep state with the emotional reactions of the body. To a certain extent, all of them concerned the mechanism of transition from wakefulness to sleep. The negative effects of acute emotional sensations on the quality of subsequent sleep and shifts to the negative side of the emotional background after sleep deprivation were described. We consider the results of these analyses in detail below, in the concluding section.

In this study, we searched for a logical connection between mechanisms of sleep triggering, control of visceral systems, and mechanisms of the formation of emotional reactions. The visceral sleep theory opened an approach to understanding the relation between the sleep state and the working of the visceral systems of the body. In the sphere of the physiology of emotions, the need-informational theory of emotions elaborated by P. Simonov and his coworkers remains the most developed [20, 21]. Both discussed approaches are based on the analysis of information flows in the nervous system. Although, at first glance, these theories concerned different issues of physiological activity, we tried to bring these two directions together.

In the second section of this paper, we shall consider the main elements of the visceral sleep theory and present the picture of changes of the main information flows in the nervous system in the sleep-wakefulness cycle suggested by this theory.

In the third section, we shall try to combine Simonov’s propositions of the need-informational theory of emotions with concepts of neurophysiological mechanisms and the functional purpose of this state emerging from the visceral theory.

Finally, in the fourth section, we shall briefly review the papers on the relation between sleep and emotional states and discuss these results in the approach suggested by us.

2. ASSUMPTIONS OF THE VISCERAL SLEEP THEORY

The visceral sleep theory is based on the suggestion that the same cortical zones and the same neurons that in wakefulness analyze signals from exteroceptors in the state of sleep switch over to the analysis of interoceptive information. To test this hypothesis, responses of different cerebral cortical regions to extero- and interoceptive stimulation in sleep and in wakefulness were compared. It was shown that neurons of the visual and somatosensory cortex of cats that in wakefulness responded to visual and somatic stimulation in