

SLEEP: A WINDOW TO EVALUATE NEUROPHYSIOLOGICAL CORRELATES OF HIGHER STATES OF CONSCIOUSNESS.

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Understanding consciousness and its underlying psycho-neuro-physiological attributes has been the greatest intellectual challenge across the spectrum of neuroscientists, psychologists, and philosophers. Wake, sleep, and dream are the three distinct states of routine conscious experience. However, the classical literature of contemplative practices (meditation) describes many other conscious states, which are neither completely awake, nor asleep, nor dream. There is experimental evidence which indicates that during meditation practice EEG has a distinct feature of being both “restful and alert” simultaneously. The effect of such a distinct state is also demonstrated during deep sleep. These correlates speak volumes about the other possible ways a neural network (thalamocortical interaction) can take place; thalamocortical systems can integrate information by bringing about synchronization of different areas of the brain, thus modulating the neuronal networks. Earlier studies have demonstrated that expert meditators can bring about such functional integration by inducing a high amplitude gamma synchrony. Emerging evidence has clearly demonstrated that a meditation practice brings about plasticity changes in neural networking. Hypothetically, these plasticity changes induced by meditation practices probably would aid in accessing other neural networks that would otherwise be insulated. Different degrees of thalamocortical communication induced by meditation practices, along with plasticity changes, would aid in accessing

other consciously occult network, thus bringing about a higher conscious state and experience.

P.N. Ravindra: Good afternoon. At the outset, I thank the organizers for giving me this very great opportunity to interact with learned scholars and monks. What I would like to do in the next half hour is to give you an overview of sleep, how the long-term practice of meditation influences sleep, and a hypothesis that studying sleep can unravel the neurophysiological basis of varying states of consciousness brought by meditation practice.

Even though many things have been said about sleep in the ancient text of the Indian traditions, scientifically, the neuropsychological correlates of sleep, and what happens to the brain during the different stages of sleep, are still not fully understood. As to the simple question of why sleep is essential, there is still no definite answer. The field of sleep in neuroscience is new, and to understand sleep in expert meditators is very, very new. Very few people in the scientific community have evaluated sleep in meditators. The outcome of the work is very surprising and has given us clues as to how we might understand consciousness. How can studying sleep, or studying how the brain works during sleep, help us to evaluate, or help us to understand, the neurophysiological underpinnings of consciousness?

Neuro-physiologically speaking, the content of consciousness and degree of subjective experience depends on the capability of an individual to have access to different neural networks. Why is my subjective experience different to someone else's? Why is my subjective experience during different behavioral states different to someone else's? Could this be because I have access to different neural networks? We can take a clue from vision research. When I see you people in the audience, when the light falls on my retina and goes to my visual cortex, how do I consciously perceive and report the same? The answer to this is the feedback connections between different neural networks: when feedback connections, or recurrent connections, or recurrent information processing takes place between different parts

of the brain, conscious perception and its reporting take place. Take vision, for example, where there is a recurrent connection to my language area. From there I have a recurrent connection to my frontal cortex and access to my vocabulary for words to describe what I am seeing. These recurrent connections are the main basis of a conscious experience. The recurrent connections, or feedback connections, are very important in gaining access to different neural networks for the conscious experience. Let me take a clue from meditation practice. During meditation practice—starting from the breath, or starting from a mantra, or whatever it may be—we are conscious of our visceral sensations. What is happening is that the recurrent information from the visceral sensations from my breath is going back to the brain. When this recurrent information is going to the brain, these particular networks become very strong so we try to give our attention to one particular attribute of our consciousness.

All the somatic sensory information comes into the thalamus and from here information goes to the cortex. We call this the thalamocortical network. However, visceral sensation is relayed via a small part of the brain called the insula. This thalamocortical network, and the connections of the insula, plays a very important role in meditation practice. When I am awake and conscious, my thalamocortical network is in an active state. When I go to sleep, my thalamocortical network is in an inactive state that we call a hyperpolarized state. When I first started meditation classes, I would start meditating and after few minutes would generally feel very drowsy. Then I would consciously say, “focus on my breath” or “focus on my mantra” and I would become very active. This “on and off” of the thalamocortical network is common during the initial days of meditation practice; once practice is established we tend to be in a meditative state for longer periods of time and there will be minimal or no intermittent active or drowsy/sleepy states. The maintenance of this particular state for considerable lengths of time, where the thalamocortical network is neither fully active nor fully depolarized, is of paramount importance. Sensory information is coming to the thalamus but the expression of the same

at the cortex is different. How such practices bring about this delicate balance in thalamocortical oscillations, neither active nor inactive, is a great and critical question in understanding the neurophysiological correlates of meditation practices. We do not know how it actually happens. When such a delicate balance is maintained should there be a different type of connection that should take place from the thalamus to the cortex?

Taking a clue from basic sleep neurophysiology, a number of studies have shown that during sleep those neuronal networks, which were predominantly active during waking hours, reactivate. If I learn something or focus too much on one particular subject during my waking hours, some of my brain network is very active; when I go to sleep the same neural network is reactivated. This is the basis of memory consolidation. There are many studies that have shown that meditation practice can have a tremendous effect on the waking state, on waking behavior, on cognition, on perception. But does meditation practice bring about any change in my sleep? That's the question that we have asked.

Sleep is a very complex behavioral state. It is not a single state, and it is not a uniform state. We know that we have two types of sleep: REM sleep and NREM sleep. REM sleep is rapid eye movement sleep, and NREM is non-rapid eye movement sleep. If you look at a person who has been asleep for at least one and a half hours you can see their eyeballs starting to oscillate. We call this REM sleep. At other times there will be no eye movement. This is NREM sleep. So, during a whole night of sleep, we go through different stages of sleep. When I go to sleep at 10.30 pm I'll be very drowsy for a few minutes, and then I'll enter NREM sleep and pass through Stage 1, Stage 2, Stage 3, and Stage 4. Stage 3 and Stage 4 are called deep sleep, or slow-wave sleep. Later REM sleep starts. This is when we dream, and in this dream the emotional component is predominant. This cycle of NREM and REM sleep is called the sleep cycle. One sleep cycle will last for 90–120 minutes and normally we will have four or five sleep cycles during the night. In NREM Stage 3 and 4 there is a complete sensory cut off, and

the brain is by itself. During my waking hours my brain is bombarded and is always busy sorting information. During deep sleep, when all our sensory input is blocked, the brain is by itself. In this particular state, when thalamocortical oscillations are almost hyperpolarized, we experience slow-wave sleep, when no other information is coming into the brain. During this state cortical networks talk to each other (cortico-cortical oscillations), which is recorded as a very slow-wave sleep, less than 1 hertz. This plays an important role in bringing about plasticity changes in the neuronal network, which has a critical role in many physiological functions, including how I feel when I get up the next morning—how fresh I feel. It brings about memory consolidation, and helps brain growth and repair.

Another important aspect of sleep is that it is the one physiological function that first changes with aging. The first thing that changes with age is the reduction of slow-wave sleep. When a person is around 20 or 25 years their slow-wave sleep starts to reduce. When the person is around 50, 55, or 60 years their slow-wave sleep completely disappears, and when the person crosses 65 or 70 years their REM sleep starts coming down. This reduction of slow-wave sleep has an effect on what happens in the neural network. Probably no cortico-cortical dialogue takes place, which means that there could be less plasticity changes in the neuronal network. We have studied and evaluated the sleep of expert meditators, ages 30 to 70 years, and have found that even the 70-year old person who has been regularly meditating for a long duration of time has a slow-wave sleep equal to that of a much younger adult. This result speaks volumes about how the thalamocortical network, or the cortical neural network, interacts in meditators. It suggests that more plasticity changes should take place in meditators even in their old age. This brings about greater changes in the functions of different neuronal networks of the brain. We have also found that the REM percentage is significantly more in meditators. As I mentioned earlier, REM is the stage of sleep in which we dream. Decades of research have shown that NREM is the non-dream state. However, there are a few reports that say we dream even

during NREM sleep, but that the content of the dream is different. In REM sleep, the content of the dream is more emotive in nature; in NREM sleep, the dream is more of a working memory. During slow-wave sleep, delta and theta waves, which are slow frequency waves, are produced. The power of delta and theta, which indicates the approximate amount of neurons that are working to bring about a particular stage, can be measured. We have seen that even though meditators spend a very large percentage of time in slow-wave sleep their delta power is less. What does this mean? It means that fewer neurons are required to bring about a particular stage, which means more economy, or conservation of energy, for the brain. Conservation of energy and the recruitment of fewer but efficient neurons for a task is a great benefit for the brain. Cognitive studies have shown that the combination of theta waves and gamma frequency correlates to the memory processing that is taking place and the combination of alpha and gamma supports the attention process. When I pay attention to one particular task my alpha and gamma increases, and when I try to rehearse it, and put it into my memory bank, then theta and gamma is predominant. We also heard Dr. Roy say that there is a 40-hertz frequency that happens in our neural network; we call it the gamma frequency. The gamma frequency tries to glue the different areas of the brain together so that my sensory perception of the external world is perceived as a single unit. In other words, you are seeing me, you are hearing me, and even though the information processing capacity of these two neural networks is different, the overall experience, you seeing and hearing me, is happening simultaneously. It is not that you see me first and then you hear me. This binding of different areas of the brain is brought about by this gamma activity, the 40-hertz gamma activity.

The presence of this continuous gamma activity in any state, whether a waking state or a sleep state, especially a REM sleep state, brings about a unity of experience, or a conscious experience. Whenever there is an interruption in the gamma activity of communication between the different neural networks, it will be non-conscious. In

terms of neurophysiological correlation, the conscious experience is about how different neural networks integrate themselves and get overall integrated information. Does this integration of information happen during sleep? If you analyze a non-meditator during REM sleep, gamma activity is very minimal. But we have observed that an expert meditator, a very senior experienced meditator, will have an increase in gamma activity during REM sleep. This is an important aspect because meditators report that they are either a lucid dreamer—a person who knows they are dreaming—or, if not, when they wake they are able to narrate their dream sequence by sequence. So what happens during sleep? There are no external stimuli. The brain is by itself with its own intrinsic activity, and this intrinsic activity is largely dependent on how my neural networks interact with each other during my waking state.

How do we neuro-physiologically correlate whether someone does or does not dream? There could be error in a subjective experience or report. Studies have shown that during REM sleep there will be more eye movement. One of the explanations for this eye movement is that it is a saccade, a rapidly jerky movement of the eye that will try to scan the visual image during dreaming. This saccade means that dreaming may be taking place. We have seen that the saccade of a control subject, a non-meditator, is less than that of a novice meditator and that the experienced meditator has the highest number of saccades. This suggests that long-term meditators are likely to dream a lot. Their subjective experience is also likely to be different to non-meditators; as there is more gamma during REM sleep there should be more synchrony between neural networks from different areas of the brain.

Other events that occur during sleep are also very important. In Geshe Nyima's presentation, we heard that just as there are connections between the thalamus and the cortex there is also interaction between the cortex and the hippocampus. The hippocampus is the main area in the brain where memory consolidation takes place. During sleep, whatever information we have gathered during our waking hours is exchanged between the cortex and the hippocampus and from the

hippocampus back to the cortex. This occurs at the frequency range of theta-gamma. It is in this theta-gamma dynamic where these memory processes takes place. It is likely that the activity of the neural network, which is generated by consistent and recurrent thought during waking hours, gets reactivated and consolidated during sleep. I have no definite proof of this but in principle it should happen. I'm not well versed in traditional texts, but I overheard somebody saying that memories are rooted in sleep. I don't know whether we can correlate this or not. I will have to get input from the Buddhist scholars and the monks who are here.

My overview suggests that sleep provides a good paradigm to study the neurophysiological correlates of consciousness because during sleep the brain is not bombarded with the noise that comes from sensory input. The brain is by itself and the state of neural networks during sleep is more dependent on what our mental state is during waking hours. So during sleep we can study the function of the brain by itself without any noise from external stimuli. Even though these ideas are very new, and there have not been many experiments, I thought I would share them with you. Your input from the Buddhist perspective will help to deepen our understanding.