Sleep Neruobiology and Mental Health: A Brief Review

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This review examines the neurobiology of rapid eye movement sleep and non-rapid eye movement sleep as it relates to mental health. The review aims to highlight the importance of sleep health in treating mental illness and discusses how sleep stages broadly impact mood, emotion, and memory. Materials were gathered throughout the sourcing of various research in the MSU Sleep and Development Lab. Results indicate a great level of complexity between the frequency and duration of brainwaves in the sleep-wake cycle. The neurobiology also suggests the need for a larger emphasis on sleep as a potential avenue for understanding and treating a variety of mental health conditions.

Decades of research have demonstrated that sleep is essential to learning, memory consolidation, and behavioral outcomes (Anwer et al., 2019). Sleep problems have also been identified as a major contributing factor to mental health difficulties, such as depression and anxiety (Ioannou et al., 2020). While the literature most commonly examines sleep behaviors such as sleep duration and subjective sleep quality, neurobiological activity during sleep is not uniform across the night. In addition, the type of sleep obtained may vary between individuals and on a nightly basis (Ong, Lo, Gooley, & Chee, 2016). Understanding the complexity of sleep neurobiology and how it relates to mental health introduces the potential for targeted sleep treatments to accompany mental health diagnoses. This brief review will identify several sleep characteristics that have been linked with mental health in prior research.

Neurobiology

Neural activity is commonly observed via the electrical impulses that are transmitted between neurons and used for cell-to-cell communication. Electrochemical gradients across neuron membranes are created when chemical messages sent between cells open channels to change sodium and potassium gradients. Changes in charge across the cell membrane generate action potentials that give neurons the property of conductivity, allowing signals to transmit across the brain and body. Rhythmic fluctuations of voltage across the brain called brain waves are classified by frequency and denoted by the Greek letters a, b, q, d, and g. When measuring brain waves, electrodes are placed on specific locations of the scalp to record the electrical impulses occurring in the brain.

An Overview of Neural Activity during Sleep

Electroencephalography (EEG), facial electromyography (fEMG), and electrooculography (EOG) are methods of observation that are commonly used in sleep studies to track sleep neurobiology. Measurements of electrical impulses in the brain are recorded and then classified into different sleep stages. Sleep is composed of two primary types: Non Rapid Eye Movement (NREM) sleep, and Rapid Eye Movement (REM) sleep. NREM is further broken into three stages, NREM stage 1 (N1), NREM stage 2 (N2), and NREM stage 3 (N3). We cycle through these stages each night, with the majority of N3 sleep primarily occurring during the first half of the night, and REM primarily dominating the second half of the night.

During the transition between wakefulness and sleep, b-waves resting at a frequency between 16- 32 Hz begin to slow and become a-waves (8-13 Hz). This decrease in neuroelectric frequency is associated with the experience of relaxation and sleepiness prior to entering N1. Once the body enters N1, another drop in frequency is observed between 4-8 Hz. N2 sleep is comprised of theta waves, and includes unique defining wave architectures - sleep spindles and K-complexes. Sleep spindles are short bursts of electrical activity between 12-14 Hz, and have been theorized to contribute to neural plasticity and learning, while K-complexes are high-amplitude slow waves that may suppress cortical arousal and may contribute to memory consolidation. From there, electrical frequency decreases again to what is classified as N3, which is also known as slow wave sleep (<1 Hz oscillations) and d-waves (1-4 Hz), which is the deepest and most physiologically restorative sleep stage.

Comparatively, REM sleep accounts for roughly a quarter of a typical sleep time and displays EEG patterns more similar to wakefulness. Brain waves in REM sleep are composed of low amplitudes and include faster rhythms correlating with an increase in cortical activity. REM sleep is also accompanied by ocular saccades and muscle atonia. REM sleep is when most dreaming activity occurs.

The regulation and maintenance of the sleep cycle is heavily dependent upon neuromodulatory milieu. Some of the largest neuro-orchestrators include the lateral hypothalamus, basal forebrain, and the ventral tegmental area. Within each of these regions, collections of dopamine, GABA, and acetylcholine neurons are responsible for the activation and suppression of wakefulness (Gottesmann, 2002) . Accompanying these regions, chemogenic and optogenetic regulation occur via extensions of neuromodulators in the dorsal raphe nucleus, parabrachial nucleus, and locus coeruleus, as well as complexly integrated neural tracts of the thalamus. The parabrachial nucleus, for example, is a node responsible for relaying visceral sensory information such as temperature, pain, and touch. Chemogenic inhibition or legion of this area will result in a coma- like state and suppress wakefulness (Sulaman, Wang, Tyan, & Eban-Rothschild, 2023) . Molecularly, specific neuro-orchestrating regions and neuromodulators contribute to the physiological conditions experienced during the sleep cycle.

REM Sleep

Some theories posit that dreaming plays a role in memory consolidation and emotional regulation, thus highlighting REM sleep as a potential target in treating mental illness (Maquet et al., 2000). For example, the sleep architecture of depressed individuals consists of a shorter REM latency, the time it takes to fall asleep or enter a specific sleep stage (Gottlieb, Goel, Chen, & Young, 2020) and a distinct increase in theta frequency bands in REM sleep (Steiger & Pawlowski, 2019). REM sleep density-the frequency of eye movements observed while sleeping- has also shown to be a factor in post-traumatic stress disorder (PTSD) causing a greater risk for hypersomnolence and lower thresholds for stress (Mellman, Bustamante, Fins, Pigeon, & Nolan, 2002). The sleep to remember, sleep to forget hypothesis (Walker & van der Helm, 2009). states that during REM sleep, there is an increase in cholinergic activity and hippocampal activity, resulting in memory recollection and consolidation. At the same time, activity of aminergic systems is inhibited or greatly reduced, resulting in suppressed norepinephrine. This can result in sleep-dependent emotional memory consolidation, where memories are preserved, but the emotional tone associated with the memory is blunted.

NREM Sleep

NREM sleep disturbances have also been hypothesized to impact the restorative properties of N1 and N2 when cortical abnormalities are observed (Germain, Nofzinger, Kupfer, & Buysse, 2004). For example, decreases in glucose metabolism differing between healthy individuals and depressed individuals has shown to support the overarousal hypothesis for depression, and therefore sleep deprivation, as an accompanying treatment to antidepressants (van den Burg, 1975). Similarly, brain activity of arousal-targeted regions such as the locus coeruleus and raphe nuclei as well as increases in blood flow and metabolism in the mesophilic brainstem, thalamus, and basal forebrain are abnormal and often characterizes sleep of a depressed individual. Further, disturbances to bistable pattern of slow-wave oscillations and d-waves have been shown to contribute to a variety of mental health disorders (Aquino et al., 2024). Slow-wave sleep not only plays a role in endocrine regulation and physical health, but also is credited with homeostatic mechanisms of neuroplasticity and regulation of glymphatic flow. Delta activity has also been observed to reflect neural synchrony to regions of the prefrontal cortex (Scholes, Santisteban, Zhang, Bertone, & Gruber, 2020), suggesting greater significance between behavioral regulation, mood-based disorders, and sleep neurobiology.

Summary

In addition to the potential decrease of emotional regulation as a result of inhibited or impaired REM sleep, disturbances to NREM sleep, the frequency of micro-arousals, and successful regulation of neuromodulators all play a much larger role in sleep health than previously understood. Thus, complexity of the sleep-wake relationship and its impact on symptomatic consequences in mental health diagnosis require much greater emphasis and attention.

About the Author

Emma Howard is a junior at Montana State studying Cell Biology and Neuroscience with a concentration in Biomedical Science and a minor in Biochemistry. She joined the MSU Sleep and Development Lab in Fall 2023 under Dr. Cara Palmer aiding in sleep and social behavioral studies before beginning to investigate the neuroscience of sleep and its applications to mental health. Originally from Colorado Springs, Emma moved to Bozeman in Fall 2022 and has since enjoyed hiking and camping under the big sky. She hopes to attend medical school shortly after graduating where she will continue to investigate applications of Neuroscience.

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