

Sleep Fragmentation as an Early Biomarker for Alzheimer's Disease and Cognitive Impairment

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DESCRIPTION

Sleep fragmentation represents one of the most insidious yet underappreciated disruptions to human health in modern society. Unlike total sleep deprivation, which is obvious and easily recognized, sleep fragmentation works quietly, eroding the quality of rest without necessarily reducing the total number of hours spent asleep. It is characterized by frequent brief awakenings or arousals during the night that prevent the body from progressing smoothly through the normal stages of the sleep cycle. While a person experiencing sleep fragmentation may believe they have slept for a full night, the body and brain fail to achieve the deep, restorative phases essential for physical and cognitive recovery.

The structure of human sleep is a finely tuned biological rhythm composed of cycles that alternate between Non-Rapid Eye Movement (NREM) and Rapid Eye Movement (REM) stages. NREM sleep, particularly the deeper stages, is responsible for physical restoration, energy conservation, and immune system strengthening, while REM sleep plays a critical role in memory consolidation, emotional processing, and creativity. In healthy sleep, these cycles flow naturally, with each one lasting about 90 minutes. However, when sleep is fragmented, this continuity is repeatedly broken. Even brief awakenings that may last only seconds can reset the sleep cycle, preventing the brain from reaching or maintaining the deeper stages. Over time, this leads to cumulative sleep debt and neurophysiological dysfunction, similar to what is observed in chronic sleep deprivation.

The causes of sleep fragmentation are multifaceted and can stem from both physiological and behavioral factors. One of the most common physiological causes is sleep apnea, a disorder characterized by repeated pauses in breathing due to airway obstruction or neurological dysfunction. Each apnea episode triggers a micro-arousal as the body instinctively resumes breathing, resulting in severely disrupted sleep architecture. Periodic limb movement disorder and restless legs syndrome are

other frequent contributors, as involuntary muscle jerks or sensations interrupt sleep continuity. Beyond these medical conditions, lifestyle factors such as stress, irregular sleep schedules, and excessive consumption of caffeine or alcohol can fragment sleep by interfering with the body's ability to relax and maintain consistent sleep stages. Environmental influences like noise, light exposure, and temperature fluctuations also play a significant role, particularly in urban settings where sensory disruptions are constant.

The consequences of sleep fragmentation extend beyond mere tiredness. At the cognitive level, fragmented sleep impairs attention, memory, and decision-making. The brain relies on consolidated sleep to clear metabolic waste products such as beta-amyloid, which accumulate during waking hours. Disruption of this clearance process due to fragmented sleep has been linked to neurodegenerative diseases like Alzheimer's. Moreover, fragmented sleep compromises neuroplasticity, the brain's ability to form and reorganize neural connections, which is vital for learning and emotional regulation. Individuals suffering from chronic sleep fragmentation often experience heightened irritability, mood swings, and even symptoms resembling anxiety or depression. This is partly because disrupted sleep affects the balance of neurotransmitters such as serotonin and dopamine, which govern mood stability and motivation. The mind becomes trapped in a loop of fatigue, low resilience, and emotional dysregulation, further exacerbating sleep difficulties.

Physiologically, the repercussions are equally severe. Sleep fragmentation activates the sympathetic nervous system, the body's fight-or-flight mechanism, leading to elevated heart rate and blood pressure during sleep. This constant activation of stress pathways undermines cardiovascular health and has been strongly associated with hypertension, arrhythmias, and an increased risk of heart disease. The endocrine system is also disrupted, as fragmented sleep alters the secretion patterns of hormones like cortisol, insulin, and growth hormone.

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