



Auditory-Vestibular Control of Sleep: Understanding Neurosensory Sleep Algorithms

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February 8, 2013

Overview:

Understanding sleep is one of the great challenges to biomedicine of the 21st century. Sleep is as important to life and health as breathing, eating or drinking, and yet despite decades of research by thousands of dedicated scientists and physicians, it is still one of the least-understood behaviors. It is estimated that 40 million people in the US have chronic sleep problems, and 20 million more experience temporary sleep problems at some point in their lives. As of today, there are more than 70 separately described sleep “disorders”; some irritating and temporary, some literally life threatening. These broadly include:

- Insomnia, the inability to fall or stay asleep
- Disturbed sleep, in which the sufferer fails to achieve all required stages of sleep
- Excessive sleepiness, such as narcolepsy or chronic fatigue syndrome.

However, simply lumping sleep problems into diagnostic categories does very little to help figure out their underlying causes. Sleep can be affected by factors as fleeting as the amount of coffee or tea consumed, or by those as basic as age, gender, genetics or health. Discovering ways to allow everyone to get the sleep they need at every stage of their life requires a major rethinking of how we approach sleep and sleep disorders.

What is Normal Sleep?

Sleep is a complex neurological behavior dependent on interactions between the master biological clock, the suprachiasmatic nucleus, and numerous regions in the brainstem and forebrain that comprise a “global sleep system.” Interactions between these centers give rise to global changes in electrical activity of large populations of neurons that can be detected by electroencephalography (EEG). EEG data shows that sleep is broken into four stages: three progressively deeper non-REM stages (drowsy, spindle, deep) and one of Rapid Eye Movement (REM) sleep. Normal sleep in adult humans usually progresses through several cycles of these stages each night. Proper sleep is required for behaviors ranging from cognitive function and memory consolidation to adequate immune responses and metabolic maintenance. Failure to achieve proper sleep has been implicated in health issues as wide ranging as dementia, delayed wound healing, obesity, and diabetes.

Treatments

Early treatments for insomnia primarily focused on the administration of sedatives to induce relaxation or unconsciousness, and this technique is still widely used. However, more recent studies have demonstrated that sedatives and hypnotics not only do not induce normal sleep, they can cause more long term problems than they solve, including dependence, reactive insomnia or even drug-related deaths due to improper dosage and mixing with alcohol or other drugs. Drugs

that target sleep-related biochemical systems such as Ambien or Lunesta can have greater efficacy without some of the side effects of more general sedatives, but also have mixed effectiveness in the greater population. Over-the-counter dietary supplements are often effective for some people for short periods of time, but their unregulated nature allows for wide variance in strength and purity, as well as the fact that users are taking very complicated compounds whose mechanisms are poorly understood.

On the other hand, hundreds of thousands of people suffer the reverse problem of daytime sleepiness; sometimes as a by-product of insufficient night time sleep, others due to underlying medical conditions such as narcolepsy or chronic fatigue syndrome. In many cases, the typical stimulant-based treatments given for excessive daytime sleepiness can be as much of a problem as the disorder they are trying to fix, with pharmaceutical and natural stimulants having effects that last much longer than the daytime period and interfering with normal sleep patterns at night. This is why many people who begin trying to medicate their way out of sleep issues end up in a long term roller-coaster of inappropriate sleepiness and wakefulness, leading often to serious psychological and medical problems.

Sound and Vibration Based Sleep Aids

A common means for helping people fall asleep is by using sound. Hearing (and its related sense, balance) are two sensory systems that easily penetrate the brain's natural sensory damping during deeper sleep stages. Hearing is the only sensory system that remains truly active during sleep (Velluti, 1997). This sensitivity to sound even while trying to sleep is a two-edged sword. While it means that sounds are the most likely distracters to interrupt or prevent sleep, it also provides a way to mask environmental events.

In addition to hearing, there has been continuous interest in the relationship between the sleep and vestibular systems for more than 40 years (Leslie et al. 1997). Parents know that you can rock your baby to sleep. Regular, low-amplitude vestibular stimulation, such as rocking or exposure to engine vibration can induce Sopite syndrome, characterized by drowsiness, lethargy and reduced attention (Lawson & Mead, 1998). On the other hand, everyone has experienced being shaken awake. Both of these are vestibular responses. Between these two extremes is a psychophysical curve — with sleep on one end and wakefulness on the other — mediated by the inner ear. Thus, both auditory and vestibular systems have impact on sleep, and research over the last decade has demonstrated that they can cross talk under certain conditions.

- The auditory system is the sensory system most able to affect arousal under sleep and near-sleep conditions and has substantial functional and anatomical overlap with the vestibular system.
- The vestibular system is profoundly interconnected with, and effects substantial control over, sleep processes.
- Complex, broadband harmonic sounds are capable of synchronizing large populations of neurons in the brain from the brainstem through the cortex. This allows sound or music to be used as a carrier to induce and modulate neuronal responses in regions of the brain that

mediate arousal, and interact with targets of the vestibular system that have a similar function.

We have developed sound-deliverable neurosensory algorithms that drive sleep-inducing auditory and vestibular responses. These algorithms allow us to use any spectrally -rich music as microsecond-accurate modulators of neural activity, using the brain's natural pathways from the ears to sites in the global sleep systems of the brain. The algorithms use three basic techniques:

- Low-frequency, low-amplitude rumbling noise drives vestibular Sopite responses, instead of whole body vibration or rocking, inducing sleep.
- Binaural beating – structured stereo sounds that synchronize large regions of the cortex – can be used so that the beating frequency oscillates at the rates observed in different stages of sleep, simulating normal neural processes for maintaining sleep, and driving the sleeper from one stage to another.
- Finally, overall arousal can be reduced by auditory facilitated relaxation. This involves the use of calming sounds such as low amplitude pink noise convolved with cardiac and respiratory sound envelopes, which decrease in repetition rate across a physiologically appropriate range to lower the listener's heart and breathing rates.

Our sleep-inducing technology embedded within the acoustically modified music created for The Listening Program® SLEEP programs uses all three methodologies. Ad-hoc clinical testing has demonstrated the effectiveness of our algorithms in inducing sleep by reducing sleep latency and increasing efficiency in subjects ranging in age from 1 to 62, and has been shown to decrease sleep latency, increase sleep efficiency, or both, in up to 77% of people with normal binaural hearing.

References

- Lawson, B.D., Mead, A.M. (1998). The Sopite syndrome revisited: drowsiness and mood changes during real and apparent motion. *Acta Astronaut.*, 43: 181-192.
- Leslie, K.R., Stickgold, R., Dizio, P., Lackner, J.R., Hobson, J.A. (1997). The effect of optokinetic stimulation on daytime sleepiness. *Arch. Ital. Biol.*, 135: 219-228.
- Velluti, R.A. (1997). Interactions between sleep and sensory physiology. *J. Sleep Res.* 6:61-77.