Sleep & Neurocognitive Performance

A daily adequate dose of healthy sleep is the most effective performance enhancement on the planet.

With Mathias Basner, MD, PhD, MSc

Are Sleep and Cognition Connected?

There is evidence that multiple cognitive domains are affected by not getting enough sleep, or sleep deprivation. Vigilant attention—the ability to attend to the environment and react to stimuli in as timely a manner as needed—is affected early and strongly by sleep loss. This explains why the psychomotor vigilance test (PVT) is considered the most sensitive assay for measuring the effects of sleep deprivation regardless of etiology (Table).

The PVT is based on simple reaction time and does not have aptitude or practice effects that often confound the effects of sleep loss on more complex cognitive tests. Sleep loss also manifests in several physiologic measures (eg, waking EEG frequency, frequency of slow eyelid closures, or heart reate variability), but these are not as easy to measure unobtrusively, espeicially in operational environments. Sleep also influences mood, creativty, and physical ability.

Do People Recognize Impairments From Sleep Loss?

There is a lack of awareness, which is possibly one of the major reasons why our society is chronically sleep deprived. We ran studies, in which subjects only had the opportunity to sleep for 4 or 6 hours for 14 consecutive days. Interestingly, subjective levels of sleepiness increased during the first few days of the study, but then quickly plateaued. Subjects habituated and got used to feeling sleepy. In contrast, objective performance measured with the PVT decreased almost in a linear fashion. For those restricted to 4 hours per night, a level equivalent to 24 hours without any sleep was reached after 1 week of sleep restriction and equivalent to 48 hours without sleep after 2 weeks of restriction. This is rather concerning because it suggests that not getting enough sleep on a chronic basis gradually approaches the effect of getting no sleep at all. We have little research from controlled laboratory studies beyound 2 weeks of sleep restriction, but mathematical models suggest that if sleep is chronically restricted to less than 3.8 hours per 24-hour period, humans are not able to sustain this. The models suggest that performance will stabilize eventually, albeit at a lower level compared to subjects who do get enough sleep if we sleep more than 3.8 hours per day.

TABLE. SOURCES OF SLEEP LOSS

Cause	Defined as:
Acute sleep loss	Being awake for more than 16 hours
Chronic sleep loss	Not getting ≥7 hours of sleep per 24-hour period for multiple days
Circadian misalignment	Being awake when the circadian system is promoting sleep or trying to sleep when the circadian system is promoting wakefulness

The fact that subjects get used to chronic sleep loss likely plays an important role in why society is sleep depriving itself. We don't know how well we can feel and perform if we only get enough sleep. Instead, we engage in chronic sleep loss during the work week, try to keep going during the day with caffeine and other stimulants, and then try to catch up with more sleep on the weekend. However, evidence is increasing that this lifestyle is associated with health consequences.

The mismatch between objective and subjective assessments of the effects of sleep loss becomes more evident during the biological night. That is, people are more likely to overestimate their performance capability in the night, a period with increased risk for sleep loss-related traffic accidents.

Are There People Who Really Don't Need as Much Sleep or Who Are Less Impaired by Sleep Loss?

There is a great deal of heterogeneity in how resilient people are to sleep loss. Some will be severely affected by sleep loss early on, and others can go for 3 nights without any sleep without appreciable cognitive effects. Studies that repeatedly expose subjects to sleep loss, as well as studies in twins, suggest sensitivity to sleep loss is a phenotypic trait, likely polygenic (ie, caused by multiple genes). We and others have tried to identify variables like age, sex, education level, and other characteristics that would predict resilience to sleep loss but without much success. The entire field of sleep research is currently looking for sensitive and specific biomarkers that would predict sensitivity to sleep loss, on

the one hand, and acute level of impairment from sleep loss on the other. Imagine if we could objectively assess how affected a person is from sleep loss the same way we can measure if someone had too much alcohol with a breathalyzer.

How Much Sleep Do We Need to Perform Well?

In 2014 an American Academy of Sleep Medicine and Sleep Research Society expert task force reviewed the relevant literature and reached consensus that adults should sleep 7 or more hours per night regularly to promote optimal health. Yet, as we discussed, sleep needs differs considerably among individuals. Some truly need only 6 hours per night and others truly need 8. There are also people who can go even a few days without sleep and not be severely affected, but this is rare. If someone says they are functioning well with only 4 hours per night, I would be skeptical. We are driven as a society to keep going, and people may talk about not needing sleep because sleep is perceived as a weakness (eg, "why can't you work 18 hours?"). Also, people who say they sleep only 4 hours per day are often referring only to nighttime sleep and not counting sleep they catch in transport between meetings or even in meetings. Because we have no way yet to predict how much sleep each person needs to be healthy, we can only give the recommendation for an average adult. Children and adolescents need much more sleep than adults, and separate guidelines exist for this important developmental stage depending on the child's age.

What Happens If We Are Very Sleepy?

We call this wake-state instability, when 2 drives are competing with each other, a top-down drive trying to stay alert and a bottom-up drive trying to initiate sleep. If the latter wins, we can fall asleep uncontrollably—a so-called lapse of attention or microsleep. It is currently impossible to exactly predict when a microsleep will occur; we only know that the likelihood increases with sleep loss, during the biological night, and in sensitive subjects. About 25% of all car accidents in the US result from wake-state instability. These fatigue-related crashes tend to be worse because they typically occur at high-speeds without the driver trying to avoid the crash during the microsleep period. During drowsy driving, people will try all sorts of countermeasures to keep them alert (eg, coffee, lowering the window, increasing the volume of the radio), but the drive to fall asleep is so powerful that these countermeasures are inefficient or only work for brief periods of time (Box 1).

Do Those Average 7 Hours Need to Be Consecutive?

Experiments show that total sleep time per 24-hour period is what matters, not how the sleep time is distributed across the day. An issue to be careful about, however, is that of sleep inertia—a period of decreased performance capacity lasting up to 1 hour or more after we wake up. The brain takes some time to transition into sleep at night and out of sleep in the morning. The latter is what we call sleep inertia, and it is among the reasons many people get coffee as soon as they wake—trying to jumpstart themselves into the wake state. Another reason for early morning coffee is that, although we have slept for a full night and are fully recuperated in the morning, the circadian system is still mostly promoting sleep in the early morning, and coffee helps this too.

Multiple sleep periods also create multiple transitions into and out of sleep. This can be problematic for people working overnight shifts who have to respond quickly to emergencies. In a study of medical interns during extended overnight shifts, we found that interns who got some sleep during the night shift performed worse in the first hour after waking up than those who did not get any sleep. Consuming caffeine immediately before the nap can relieve some of the sleep inertia symptoms.

Can You Bank Sleep?

Several studies suggest it is indeed possible to "bank" sleep, or get more sleep to prepare for a period of sleep restriction. Prophylactic napping before extended shifts can help prevent some of the worst effects of sleep loss. Studies show, however, that a longer period of chronic sleep loss (eg, during the workweek) cannot be made up by sleeping more for 1 or 2 days (eg, on the weekend). There is growing evidence for a physiologic "sleep memory", a mechanism that is currently poorly understood. Importantly, several studies show chronic sleep loss, acute sleep loss, and circadian timing interact in a nonlinear fashion. Effects of acute sleep loss will be much worse if preceded by a period of chronic sleep loss and during the biological night. If alcohol is added to the mixture (think of going out on a Friday night after a hectic workweek), the combination quickly gets lethal.

Box 1. The Danger of Drowsy Driving

- Driving after 24 hours without sleep is equivalent to driving with a blood alcohol level above the legal limit (1.0% blood alcohol).
- 37% of adults in the US admit to having fallen asleep at the wheel.
- Sleep deprivation may cause 20%-25% of car accidents.
- Accidents during microsleep are higher speed, higher impact, and more dangerous.
- Annually ~83,000 crashes and ~1,000 fatalities result from drowsy driving.

Does Sleep Loss Cause Irreversible Neural Damage?

Long-term effects of sleep deprivation are not fully understood, but we currently assume that effects of a limited period of acute or chronic sleep loss are fully reversible. However, comparable to so many lifestyle effects, long-term health consequences are primarily determined by cumulative exposures over time. Just as 1 opulent meal will not make us obese, a single night without sleep likely has no long-term health consequences. Chronic sleep loss, however, is associated with a number of negative health outcomes, including cardiovascular disease, diabetes, obesity, and premature death. Chronic sleep loss is also increasingly linked to neurodegenerative diseases including Alzheimer's disease (AD), although because sleep itself is a symptom of AD it is difficult to distinguish cause and effect. Several recent studies suggest that sleep plays a crucial role in clearing metabolic byproducts that may play a role in neurodegenerative disease from the brain. For example, cerebrospinal fluid Aβ and tau levels were increased by ~30% and > 50%, respectively, after 1 night of sleep loss in humans.

How Does Caffeine Affect Sleep Physiology?

Caffeine acts as an adenosine receptor antagonist. Although it clearly promotes attention and alertness, higher cognitive functions may not benefit as much. This may be among the reasons political deals reached well after midnight can turn out to be the worst ones. In addition, caffeine interferes with sleep onset and sleep architecture and, thus, sleep recuperation. This can lead to more caffeine use during the day, and, ultimately, start a vicious cycle. To prevent caffeine effects on sleep, it is best to stop consuming caffeine by about noon.

What Can We Do to Compensate for Lost Sleep?

In the end, there is no substitute for sleep. Researchers once thought sleep was a purely passive process, a way to conserve energy. But now we know the opposite is true. Sleep is a very active mechanism, with hormones secreted exclusively while we sleep, memories consolidated, and new insights gathered during sleep. The sleeping brain uses almost as much energy as the awake brain.

In the field of sleep, the biggest question is still why we sleep. Tononi and Cirelli spearheaded the *synaptic homeostasis hypothesis* (Box 2) that suggests as we gather new experiences during wakefulness, we form new connections between neurons. However, this can't go on forever because space in our heads is limited. Therefore, there has to be a time where we shut out the environment so the brain can compare new knowledge to old, strengthen some connections, and prune back others to make new room for new experiences during the next day.

How Would You Advise People Who Must Go Without Sleep for a Period of Time?

There are ways we can prepare for lost sleep and prevent some of the consequences of sleep deprivation. As discussed, it is possible to bank sleep by getting extra sleep in the days leading up to a period of expected lost sleep. Daytime naps to supplement shorter than usual sleep periods can also be helpful. In our study of medical interns, we found that those who lost sleep during overnight shifts were able to recuperate most of the deficit by sleeping longer on days off or before normal day shifts. Caffeine and bright light can be used strategically and, as discussed, it can make sense to have caffeine before napping. Naps should not be much longer than 30 min to avoid slipping into deep sleep, which increases sleep inertia.

What Else Promotes Healthy Sleep and Cognition?

We recently published a study on the relationship between sleep and exercise suggesting that, although both are healthy behaviors, they can compete for time. The typically recommended 30 minutes of exercise per day is compatible with sufficient sleep, although exercise and sleep influence each other positively in the sense that exercise does have a positive effect on sleep quality. High-quality sleep of sufficient duration improves athletic performance and reduces injury risk. Thus, exercise may help people with insomnia improve their sleep. In contrast to older sleep hygiene suggestions, exercise immediately before going to bed does not seem to affect sleep or falling asleep. I think we, as health professionals, should encourage both exercise and sufficient sleep. For those who like to go to bed and get up early it probably makes sense to exercise in the morning, perhaps even before work (although that was associated with the greatest decreases in sleep time in our study). For those who like to go to bed late and get up late, evening exercise may make more sense. ■

Box 2. Why Might Sleep Be Neuroactive Time?

Proponents of the synaptic potentiation theory argue that sleep is the price we pay for the brain's plasticity—its ability to modify its wiring in response to experience.

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