Sleep, Fatigue & Risk of Accidents

The Importance of Objective Sleep Measurements to mitigate Fatigue Risk
“Sleep is not a luxury – it’s a necessity – and should be thought of as a ‘vital sign’ of good health”

www.cdc.gov/sleep
Fatigue Risk Management

A data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles and knowledge as well as operational experience, that aims to ensure relevant personnel are performing at adequate levels of alertness.
The Scientific Principles

- Physiological need for sleep
  - Quality
  - Quantity

- Circadian biological clock

- Recovery from sleep loss
  - Transient
  - Cumulative
How we fall asleep

• Our bodies provoke us to sleep by sending messages from our circadian clock- our inner time-keeping, temperature fluctuating, enzyme and hormone controlling devices.

• The circadian clock works in tandem with adenosine, a neurotransmitter that “turns down” many of the bodily processes that make us feel awake.

• Adenosine builds up in our brains as our cells create the power needed to move us through the day.

• **Adenosine causes sleepiness** and along with corresponding messages from the circadian clock, **alerts us that its time to sleep.**
How we fall asleep

- The circadian clock also promotes release of melatonin from the pineal gland, a hormone that affects the modulation of sleep patterns.

  - Melatonin peaks around midnight, enters area in hypothalamus called Suprachiasmatic nucleus (SCN) and slows down the brain, allowing neurons and the nervous system to heal. A very important process for learning and memory function.
How much sleep is needed

- Sleep is a **behavioral state** that is a natural part of life, we should spend about one-third of our life sleeping.

- Sleep is a **required activity** and is important for a healthy life. The National Sleep Foundation recommends 7-9 hours of sleep every 24 hours for individuals age 24-64 years old. (1)

- How much sleep is needed depends on:
  - Individual sensitivity to sleep loss (2,3)
  - Sleep Quality
  - Age
  - Daily activities and exercise
Sleep & the Autonomic Nervous System (ANS)

Poor sleep causes frequent micro/macro arousals that lead to repeated surges in the sympathetic nervous system activity and changes in hormonal and immune control. \(4\)

- **Good Quality Sleep** generally decreases sympathetic activity and increases parasympathetic activity. \(5\)
- **Poor Quality Sleep** generally increases sympathetic activity and decreases parasympathetic activity. \(5\)
Sleep Deprivation

- Relatively modest daily reductions in sleep time can accumulate across days to cause a sleep debt or sleepiness.

- Sleepiness has been defined as the drive to fall asleep. (6)

- If the sleep debt becomes too great, it can lead to dangerous sleepiness or fatigue.

- Although the individual may not realize his or her sleepiness or fatigue, it can have dramatic effects on daytime performance, health, safety, thinking and mood. (7)
Sleep Restores the Brain \(^{(8,9,10,11)}\)

- **Memory and Learning** – sleep organizes and helps to recover memories.

- **Mood enhancement and social behaviors** – the parts of the brain that control emotions, decision-making and social interactions slow down during sleep, allowing optimal performance when awake.

- **Nervous system** – neurons used in the brain during the day enter into a cleaning mechanism during the night, without adequate sleep this mechanism is disrupted.
Sleep Restores the Body

- **Growth and development** – growth hormones are released during sleep and are an important function for rebuilding bones and muscles.
- **Immune system** – without adequate sleep the immune system becomes weak and the body becomes more vulnerable to infections and disease.
- **Hormone homeostasis** – regulated by the Hypothalamic-Pituitary Axis is affected by sleep deprivation changing secretion of insulin, cortisol, thyroid-hormone, growth hormone, estrogen, progesterone and testosterone secretion, all hormones vital for the body to function properly.
- **Appetite hormones** – leptin and ghrelin regulation is affected by sleep deprivation causing increase in prevalence of obesity.
Fatigue
(ICAO Definition*)

“....A physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair alertness and ability to safely operate or perform safety related duties”

* International Civil Aviation Organization (13)
Fatigue & Sleepiness

Fatigue is the inability or unwillingness to continue an activity that has been going on for an extended time. (14)

- It is not normal for a person to be sleepy at times when the person expects to be awake.

- Lifestyle factors and undiagnosed or untreated sleep disorders can cause fatigue.

- Fatigue may be associated with difficulty concentrating, memory lapses, loss of energy and emotional instability.

- The prevalence of fatigue is high and has serious consequences, such as drowsy driving, erred judgment and the risk of workplace or other accidents.
Objective Fatigue Science Approach

• **Fatigue**
  - A “common, almost universal feature of modern life”, but when in excess, it is a real concern.
  - Associated with some of the most devastating accidents of all time.
  - Increased hazard rates of workplace injury and accidents.
  - Can be predicted based on **Sleep Quality and Quantity**.

• **Accident Risk**
  - Can be predicted based on levels of **fatigue**.
  - Has been quantified and is built into several mathematical models for prediction of sleepiness and of accident risk. (15)

• **Self evaluation of fatigue is not accurate**
  - Scientific Research shows that it is not possible for people to accurately assess their own level of fatigue. (7)
  - Fatigue is the key symptom of the Burnout Syndrome.
Sleep, Fatigue and the Workplace

Fatigue is linked to impaired performance and safety – it is essential to ensure that employees performing high risk jobs are “fit for duty” to be able to safely perform their duties.

• There is a clear evidence for sleep homeostatic effects causing impaired performance and increase in accidents. (16)

• Research suggests that a person’s sleep need is a joint function of a homeostatic process (that increases with time awake and recovers with time asleep) and an innate circadian process that fluctuates reliably across the 24-hour day. (17)

• “State instability”, the effects of sleepiness include longer reaction times, fewer discovered stimuli, a larger variability of performance and long response lapses. (18,31)
Sleep Quantity & Fatigue

The effects of accumulated sleep loss – studies of two weeks of partial sleep loss showed: (19)

- Sleep duration less than 7 hours
  - Lower boundary for sleep duration in order to avoid accumulation of fatigue or behavioral impairment.

- Sleep duration less than 6 hours
  - Small and gradual increase of performance impairment.

- Sleep duration less than 4 hours
  - Steep increase in performance impairment.

Operator fatigue is a function of the sleep quality and quantity and the body clock. (20)
The brain adapts to chronic sleep restriction \(^{(21)}\)

- In mild to moderate sleep restriction this adaptation is sufficient to stabilize performance, although at a reduced level.
- The adaptive changes are hypothesized to restrict the brain operational capacity and to persist for several days after normal sleep duration is restored, delaying recovery.
- Day-after-day of sleep restriction often is a bigger problem than long periods of continuous wakefulness. \(^{(22)}\)
- Sleep loss results in the choice of low-effort tasks that helps maintain accurate responding. \(^{(23)}\)
Sleep Quality & Fatigue

Things that affect Sleep Quality

• Sleep fragmentation (arousals per hour) prevents the restorative effects of sleep and causes fatigue.
• Amount of Slow Wave Sleep (Stable Sleep) is the best marker of Sleep Quality.
• Sleep latency (the time it takes to fall asleep in a dark room) is a good indicator of Sleep Quality:
  • 5 minutes or less is a sign of excessive sleepiness and poor sleep.
  • Excess of 30 minutes can be a sign of insomnia.
Circadian Clock

- Circadian rhythm is generated within the neurons of the suprachiasmatic nucleus (SCN) of hypothalamus - the genetically tuned pacemaker of sleep.

- Output signals from SCN modulate daily rhythms in sleep and alertness, but also the rhythms of core body temperature, blood pressure and the secretion of various hormones such as melatonin and cortisol.
  - Intrinsic rhythm of the clock is slightly longer than 24 hours, so precise synchronization to a 24-hour day depends on exposure to environmental time signals most importantly the solar light/dark cycle. (24)
Circadian Clock

Sleep need is a joint function of a homeostatic process (increases with time awake and recovers with time asleep) and an innate circadian process that fluctuates reliably across the 24-hour day. (17)

- Prior sleep loss normally causes a homeostatic response during the next sleep opportunity, characterized by increased amounts of Slow Wave Sleep (Stable Sleep).
- Recovery sleep becomes deeper and less fragmented.
- Recovery aims first at recovering slow wave sleep then to a lesser degree REM sleep.
Circadian Rhythm Sleep Disorders (CRSD)

The circadian system generates a clock dependent alerting process during the waking hours.

Consequently, attempting sleep at the “wrong circadian phase” (during the “circadian day”) undermines sleep quality and shortens its duration because of the competing circadian arousal process.

The shortened sleep duration may in turn lead to an accumulation of homeostatic sleep drive. (25)
Circadian Rhythm Sleep Disorders (CRSD)

“A persistent or recurrent pattern of sleep disturbance due primarily to alterations in the circadian timekeeping system or a misalignment between the endogenous circadian rhythm and exogenous factors that affect the timing or duration of sleep”. (26)

- Diagnosis of CRSD requires that the disorder is not “better explained” by another primary sleep disorder, like obstructive sleep apnea (OSA) or any other primary sleep disorder. (29)
- Some individuals appear to have phase tolerance, meaning that their sleep is relatively unaffected by circadian misalignment, while others may be very sensitive. (18,27)
Circadian Phase Indicators

The sleep-wake cycle itself is a rough indicator of circadian phase and is strongly influenced by homeostatic sleep drive as well as many other factors. It has been shown that wake up time provides a fair estimate of circadian phase in subjects who are allowed to sleep on a “free-schedule” but held to a 24-hour day. (28,29)

- Less effective and inaccurate markers to know “what time it is in the brain” are:
  - Core Body Temperature: is easily masked by activity, food intake and sleep and is therefore unsuitable for clinical use.
  - Melatonin Rhythm: use immunoassays to time melatonin secretion by the pineal gland. Melatonin secretion is suppressed by light exposure, so samples need to be obtained under dim light conditions that makes sampling difficult. Posture and some drugs can also influence melatonin secretion.
Circadian Phase Indicators

- The more accurate marker to know “what time it is in the brain” is to track Sleep Quality and Sleep Quantity.

- **SleepImage is:**
  - easy to use, cost effective, clinically validated and FDA cleared sleep screener.
  - objectively and effectively measures sleep onset, sleep quality, sleep duration and sleep fragmentation.
  - makes it easy to objectively track sleep over time.
Physical and Mental affects of Sleep Deprivation

- Poor performance on the job.
- Poor decision-making, poor judgment, increased risk-taking.
- Lack of impulse control, irritability and lack of concentration.
- Impaired memory, concentration and ability to learn.
- Anxiety, depression and other emotional problems.
- Physical impairment, poor coordination, delayed reaction time.
- Impaired driving performance and more car accidents.
- Magnification of the effects of alcohol on the body.
- Increased incidence of obesity, diabetes 2, high blood pressure, heart diseases and increased risk of stroke, depression and illness in general.
Sleep deprivation and Work performance

• Sleep deprived brain opts for Deep Sleep (Stable Sleep) and consequently less REM Sleep.
  • Later sleep cycles tend to have longer REM periods than earlier in the night; short sleep periods that have only one or two sleep cycles, causes REM sleep to be disproportionately affected.

• Brain deprived of REM sleep.
  • Concentration on a single activity becomes challenging; multitasking becomes exponentially more challenging.
  • It becomes more difficult to pick up on nuances in discussions or negotiations.
Sleep Debt

- The more sleep debt increases, the more the capability to recognize it decreases.

- As the sleep debt mounts, the poor health consequences increase, increasing the risk for chronic diseases. (30,31)

- Settle short-term debt. Add three to four extra hours of sleep on the weekend for lost sleep during the week and an extra hour or two per night the following week until the sleep debt has been fully repaid.
Sleep Debt (cont’d)

• Address long-term debt. Plan a vacation with a light schedule and few obligations. Turn off the alarm clock and sleep every night until waking up naturally.

• Avoid backsliding into a new debt cycle. Once you’ve determined how much sleep you really need, factor it into your daily schedule.

• Try to go to bed and get up at the same time every day – at the very least on weekdays.
Sleep Deprivation & Chronic Diseases

Sleep Deprivation is a major risk factor for developing chronic diseases. (32)

- Cardiovascular Disease
- Diabetes 2
- Weight gain/Obesity
- Weaker immune system
- Depression
- Alzheimer disease (increased amyloid), decreased mental performance and memory loss
CardioPulmonaryCoupling (CPC) & Fatigue management

• CPC captures the dynamics of a homeostatic process. The key is to get a “sleep print”, a baseline for an individual, recommended to measure three nights during stable condition (like a fingerprint of sleep).
  – An abrupt increase is either from sedative intake or recovery of sleep debt, assuming steady total sleep time.
  – An abrupt decrease could be caused by pain, drugs, anxiety or stress.
  – A decrease in stable sleep exceeding:
    10% is a yellow flag
    20% is a red flag
Autonomic Nervous System and Cardiopulmonary Coupling (CPC)

- **Stable sleep, High Frequency Coupling (HFC)**
  - Driven by *parasympathetic activity* (rest & digest) and large scale synchrony in cortical networks.
  - Dominated by integrated activity centered around individual respiratory cycles.
  - Heart rate slows down and speeds up in synchrony with respiration.
  - Sleep electrical brain waves are dominated by “slow” activity.

- **Unstable sleep, Low Frequency Coupling (LFC)**
  - Driven by a different set of integrated network behavior with dominance of the *sympathetic nervous system* (fight & flight).
  - Dominated by low frequency cycling of respirations and low heart rate variability.
The Sleep Spectrogram
(Stable sleep – Unstable sleep – REM/Wake)
Deep Sleep

- Deep sleep (a.k.a. Delta waves, Slow Wave Sleep, Stable Sleep (High Frequency Coupling)).
  - The most vital stage of sleep; the first stage that the brain attempts to recover from sleep deprivation.
  - During deep sleep both brain and body activity drop to their lowest point during the sleep cycle and blood is redirected from the brain to muscles.
  - During deep sleep learning and memory consolidation happens, the brain restores the energy expended during waking hours. Deep sleep is also important for immune function and hormone secretion.
REM Sleep (a.k.a. Dream Sleep) is associated with:

- Processing emotions
- Retaining memories
- Relieving stress

The brain is more active in REM sleep, than during awake and lack of REM results in:

- Slower cognitive and social processing
- Problems with memory
- Difficulty concentrating
### Delta Waves and CPC correlation

- **Sleep Heart Health Study I (SHHS I)**
  - PSG database of 5840 subjects were analyzed
  - 3150 studies of individuals with AHI<5 events per hours of sleep.
  - Exclusion criteria ECG signal drop out, AF, Ventricular bigeminy, demand ventricular or biventricular pacing. (33)

- **Conclusion**
  - Delta waves (slow-wave EEG) correlates with ECG-derived CPC-HFC, supporting a link between cortical EEG activity and brain stem-related cardiorespiratory functions $r \ 0.40+/0.18$, $p=0.001$.
  - HFC is a biomarker of “stable sleep” and correlates with non-Cyclic Alternating Pattern, blood pressure dipping, strong respiratory sinus arrhythmia, breath to breath stability of tidal volumes and stable arousal threshold.
Delta waves and CPC correlation
References

3. Van Dongen HPA, Belenky G. Individual differences in vulnerability to sleep loss in the work environment Ind Heealth. 2009;47:518-526
7. Van Dongen, Maislin, Mulington and Dinges 2003
References


22. Johnson et al. (2004). Modulation the homeostatic process to predict performance during chronic sleep restriction. Aviation, Space and Environmental Medicine, 75(3 Suppl): A141-6

References