Sleep Theories

Understanding the Biological Drive

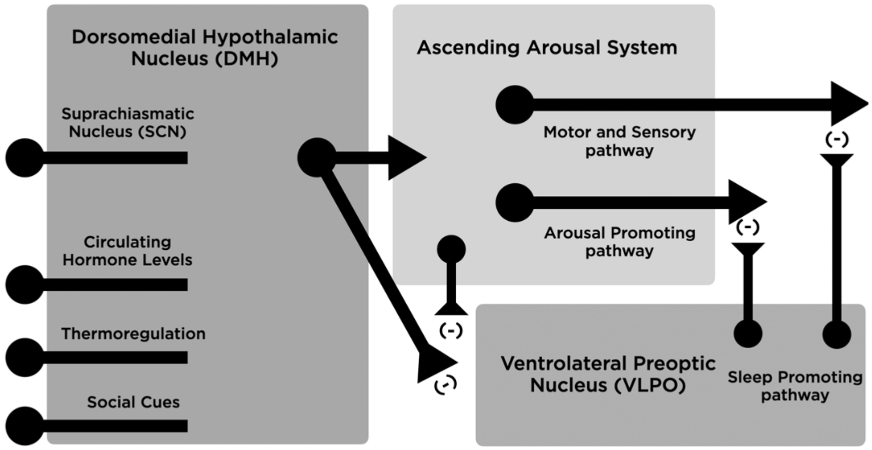
Despite general societal awareness that sleep relates to health, we still have relatively little understanding of why this is. However, some insight is provided by taking into consideration the underlying architecture of sleep and its hypothesized biological purpose. In doing so, the relationship between physical activity and sleep becomes almost an expected outcome.

Topics: Neural Coordination of Sleep and Wakefulness — Protective Field Theory — Energy Conservation Theory — Restorative Theory — Memory Consolidation Theory — Influence of Physical Activity on Sleep — Thermogenic Hypothesis — Light Exposure Hypothesis

Among the fundamental mechanisms that coordinate and govern sleep (and conversely wakefulness), the most well known is the circadian rhythm. Circadian rhythms are highly heritable — about half of the variation in circadian rhythms is attributable to specific genetic factors — and predominately driven by daylight. Although the circadian system plays a critical role, the daily rhythms of sleep and wakefulness are highly influenced and in some cases even over-ridden by neural, behavioral, and environmental factors. At the most basic level, however, the regulation of sleep and wakefulness is the result of the effects of two opposing factors: **circadian phase** and **homeostatic sleep pressure**.

Within the circadian system, the **suprachiasmatic nucleus** (SCN) of the hypothalamus serves as the central pacemaker that generally follows a 24-hour cyclic period and is fundamentally a biological clock. Interestingly, regardless of if an animal is awake during the day (diurnal) or awake at night (nocturnal), the activity of the suprachiasmatic nucleus (SCN) in the animal increases in response to daylight. Although the suprachiasmatic nucleus (SCN) is important, the **critical hub of the circadian system is the dorsomedial hypothalamic nucleus** (DMH) which receives inputs from the suprachiasmatic nucleus (SCN) as well as a number of other systems (receiving information regarding food, temperature, and social cues) to generate a coordinated and adaptable sleep-wake rhythm.

Figure: Wake and Sleep Promoting Pathways.



The primary role of the dorsomedial hypothalamic nucleus (DMH) is in coordinating the generation of a wake-promoting signal through the ascending arousal system. The ascending arousal system follows two primary branches bringing online **the motor and sensory pathway by way of the thalamus** and the **arousal promoting pathway by way of the locus coeruleus, dorsal and median raphe nuclei, and tuberomammillary nucleus**. In contrast to what might be expected, the circadian wake promoting signal is relatively minimal following waking but becomes progressively stronger during the course of the day. The peak of this wake-promoting signal occurs between 7 and 10pm and then rapidly diminishes. When the signal from the dorsomedial hypothalamic nucleus (DMH) diminishes, the **ventrolateral preoptic nucleus** (VLPO) of the hypothalamus becomes active to promote sleep. The ventrolateral preoptic nucleus (VLPO) sends inhibitory signals to the various pathways within the ascending arousal system to create a sleep-promoting signal. Upon onset of sleep, the circadian sleep-promoting signal is relatively minimal but becomes progressively stronger during the course of the sleep; peaking between 4 and 6am before rapidly diminishing.

The interplay between neural circuits within the circadian system is commonly described as a **flip-flop switch** (also known as a rocker switch). This concept borrows from electrical engineering to describe a circuit that minimizes transitional states and therefore has abrupt transitions. Rather than wake-promoting and sleep-promoting pathways having distinct and fully independent systems that could potentially both be active at the same time, they are mutually inhibitory upon the other. When the dorsomedial hypothalamic nucleus (DMH) is activating the wake-promoting pathway, the dorsomedial hypothalamic nucleus (DMH) and the branches of the ascending arousal system serve to inhibit the ventrolateral preoptic nucleus (VLPO) to prevent the sleep-promoting pathway. But conversely, when the ventrolateral preoptic nucleus (VLPO) is activating the sleep-promoting pathway it serves to inhibit the branches of the ascending arousal system to prevent the wake-promoting pathway. This flip-flop circuit explains the relatively abrupt transitions between sleep and wake. The nature of this circuit, however, means that it is also prone to influence from homeostatic sleep pressure.

The idea of homeostatic sleep pressure reflects the fundamental basis that humans accumulate a need to sleep during prolonged periods of wakefulness. This is colloquially referred to as **sleep debt** based upon evidence that inadequate sleep can appear to accumulate and increase the drive/pressure to obtain sleep. Although the specific mechanisms that contribute to increasing homeostatic sleep pressure are still unclear, it is generally thought that **accumulation of adenosine** may play a role. Adenosine is a byproduct of cellular metabolism and has been observed to accumulate during prolonged wakefulness. When injected near the ventrolateral preoptic nucleus (VLPO), adenosine causes rodent models to sleep. Conversely, the properties of caffeine cause it to block adenosine from binding to receptors resulting in maintaining a wakeful state. However, there may be multiple other mechanisms (referred to as **somnogens**) and inflammatory factors which accumulate during wakefulness that serve to activate the sleep-promoting pathway (or inhibit the wake-promoting pathway) to induce sleep.

Accordingly, upon entering a waking state there should be very little homeostatic sleep pressure. Therefore, the circadian wake-promoting pathway need only be minimally active to maintain a wakeful state. However, as homeostatic sleep pressure accumulates throughout the day, the activity in the circadian wake-promoting pathway needs to to proportionately increase. At some point, either driven by circadian influences or homeostatic sleep pressure, the flip-flop switch causes the sleep-promoting pathway to actively inhibit the wake-promoting pathway until sleep occurs. Since the homeostatic sleep pressure remains elevated the circadian sleep-promoting pathway need only be minimally active to maintain a sleeping state. However, as that homeostatic sleep pressure dissipates (goes away), the activity in the circadian sleep-promoting pathway needs to to proportionately increase to maintain the sleeping state.

Why do we need to sleep?

Despite the well-established research demonstrating that sleep is essential, such that sleep deprivation/restriction can result in both short and long-term consequences for health and wellbeing; the biological function of why we sleep remains unknown. Nevertheless, several theories of the function of sleep have been proposed. It is important to note that the major theories are not mutually exclusive. Specific aspects of sleep may provide opportunities for each of the underlying mechanisms proposed to play a role.

Protective Field Theory of Sleep — The cyclic pattern of sleep balances the fundamental biological function of sleep with the need for environmental awareness.

Since sleep represents the time when the organism is most vulnerable to predators and environmental risks, there is a biological imperative to minimize this risk. Although the **protective field theory** of sleep is often misunderstood as somehow relating to sleep in general, this theory is actually attempting to explain the biological basis for different sleep stages. During both NREM Sleep stage 3 (N3) and REM sleep, the organism exhibits exceptionally low muscle tone and upon awaking take the longest to return to fully conscious states. As such, the benefit of cycling through sleep stages — specifically separating NREM Sleep stage 3 (N3; slow-wave) and REM sleep with periods of NREM Sleep stage 2 (N2; light) sleep — is to provide an opportunity for greater environmental awareness and the ability to rapidly transition from sleep to fully awake states.

It also explains why time spent in NREM Sleep stage 2 (N2; light) is relatively short during early phases of sleep but grows progressively longer with sleep duration. During early portions of the sleep, the individual is likely relatively safe — otherwise signals integrated into the dorsomedial hypothalamic nucleus (DMH) would be helping to keep the individual awake — but as sleep duration increases the environmental risks may have changed. Therefore, it is biologically advantageous to become more aware of external stimuli as the sleep duration increases. As humans spend nearly half of their total sleep duration in NREM Sleep stage 2 (N2; light), this general degree of environmental awareness present within this sleep stage is biologically advantageous to avoid predation and increase survival. The assumption of this theory then is that light stages of sleep are not a biological necessity but rather exist as a protective field for NREM Sleep stage 3 (N3) and REM sleep which are necessary.

Energy Conservation Theory of Sleep — Sleep enables an opportunity to adopt a low-energy state.

Although there are a number of variants of energy conservation theories attributed to different individuals, the fundamental premise is that times when organisms sleep also tend to be times when it would be biologically advantageous to adopt a low-energy state. Although normal wakeful states represent periods of high energy expenditure, they also tend to represent periods in which there is greater opportunity for energy accumulation. Conversely, sleep behaviors tend to occur during periods when their is reduced opportunity for energy accumulation or when the risks associated with energy accumulation are elevated. For instance, as humans have relatively poor night vision, the ability to successfully acquire food without incurring injury during the night is diminished. Given this situation, it is preferable to enter into the low-energy state of sleep and to conserve energy as much as possible. Similarly, in other organisms, the relative timing of their sleep patterns (diurnal or nocturnal) tends to align with those periods when the food they eat is most abundantly available and the risks of obtaining that food are lower.

Consistent with this theory, organisms with higher metabolic rates also tend to sleep for longer periods than organisms with lower metabolic rates. The benefit of entering into sleep is that metabolic rate during sleep tends to be 5 to 15% lower than during waking states. Although generally applicable to all stages of sleep, energy conservation theories tend to focus upon the idea of energetic trade-offs between sleep stages. Although the brain is highly active during REM sleep, the increased energy consumption is offset by the absence of motor function. During NREM Sleep stage 2 (N2; light sleep), the brain is less active so the body can allow motor function to resume while still maintaining this lower energy state. Although not always explicitly indicated, when discussing human sleep behaviors energy conservation theories will occasionally begin to incorporate aspects of the Protective Field Theory of Sleep into justifications for adopting a less efficient stage during light sleep.

Restorative Theory of Sleep — Sleep enables an opportunity for cellular renewal and regeneration that may not be possible during waking states.

Restorative theories of sleep have also been presented in a number of forms and attributed to different individuals, but the underlying conceptual argument is that sleep provides an opportunity for the body and brain to allocate energetic resources towards restorative function. A key clarification is that these theories do not actually argue that cellular repair can only occur during sleep. Rather, some aspects of cellular repair and renewal may be more efficiently engaged in when the body is not awake and moving. The major evidence in support of this theory of sleep is that hormones released during sleep tend to have predominately anabolic (tissue building) function while catabolic hormones tend to be suppressed. Restorative theories of sleep tend to focus on NREM Sleep stage 3 (N3; slow-wave sleep) as this stage of sleep is considered particularly important for supporting musculoskeletal recovery and growth as well as promoting enhanced immune function. For instance, growth hormones are predominately released during this stage. Within the brain, protein synthesis has been found to be enhanced during slow-wave sleep; and deprivation of slow-wave sleep has been found to impair the growth of new neurons (neurogenesis). During periods of greater growth — such as during adolescence and pregnancy — time spent in slow-wave sleep is increased. In this sense, upon falling asleep the body spends a large portion of time within slow-wave sleep presumably to begin restorative function. The gradual reduction in time spent in slow-wave sleep over the course of the night would then be an expected occurrence reflecting a reduced need for cellular repair and renewal.

REM sleep also appears to be a time when neural repair and regeneration processes occur, and is implicated as a period when oligodendrocytes (brain cells that generate and maintain myelin axonal coatings) are the most active. During REM sleep, astrocytes (glial cells that outnumber neurons 5 to 1 which are involved with regulating blood flow, altering neurotransmitters, and are involved in the maintenance of neurons) work to clear neural metabolic waste and promote flushing of neural tissues by shrinking and expanding. In this sense, the greater brain activity observed during REM sleep may reflect the restorative clearance of metabolic byproducts by microglia and astrocytes. As neuronal environments are improved and neurotransmitters are replaced, resting membrane potentials within neural tissues may be altered resulting in increased brain activity. Since this would presumably also increase the likelihood of unintentional firing of motor patterns, it would also explain why hyperpolarization of spinal motor neurons occurs as it would prevent these motor patterns from eliciting movement. Such a perspective would similarly align with the observation that REM sleep is relatively short during early periods of the sleep, but as microglia and astrocytes are able to clear greater neural waste in the brain, the time spent in REM sleep increases.

Memory Consolidation – Network Integrity Theory of Sleep — Sleep provides a period for the reorganization and strengthening of neural networks critical to support memory and daily function.

Memory consolidation theories and synaptic-neuronal network integrity theories build upon research focusing on the relationship between sleep and cognitive function. Such research has investigated not only the role of sleep deprivation/restriction on memory/cognition but also on how time spent in specific stages of sleep impacts upon the ability to sustain information within long-term memory and maintain high-levels of cognitive performance. The fundamental conclusion is that sleep provides a critical period when neural networks underlying memory and high level cognitive processes reorganize and strengthen. In particular, both the time spent in NREM Sleep stage 3 (N3; slow-wave sleep) and the density of sleep spindles appear to be particularly important for supporting memory consolidation. Whereas time spent in REM sleep appears particularly important for consolidating emotionally charged memories and may promote better removal of irrelevant or unnecessary information from memory. As motor activity can impair or interfere with memory consolidation; during both NREM Sleep stage 3 (N3; slow-wave sleep) and REM sleep, motor outputs are suppressed potentially as a means of avoiding this issue.

Influence of Physical Activity on Sleep

Societally there tends to be a perception that individuals should avoid engaging in physical activity too close to when they go to bed. However, research in this area indicates that the beneficial influence of physical activity remains the same whether it is performed more than eight hours before bedtime, three to eight hours before, or less than three hours before bedtime. The exception being that engaging in physical activity within less than three hours of going to bed reduces the time spent within NREM Sleep stage 1 (N1), appearing to indicate that it may help individuals to fall asleep faster.

Regardless of when the physical activity is engaged in, following even a single bout of physical activity there appears to be an increase in total sleep time, improved sleep efficiency, and a shift towards increasing the amount of time spent within NREM Sleep stage 3 (N3, slow-wave sleep) and decreasing the amount of time in REM sleep. Although no differences in the type of physical activities or the intensity of physical have been observed; for moderate-to-vigorous intensities of physical activity, longer duration of activity (up to around 90 minutes) is associated with greater benefits. Similarly, overwhelming evidence indicates that habitual (chronic) physical activity engagement is associated with enhanced perceptions of sleep quality (satisfaction), increased daytime alertness, faster sleep onset latency, increased duration of sleep, and greater time spent within NREM Sleep stage 3 (N3, slow-wave sleep); generally mirroring the effects of a single bout of physical activity. Further, improvements in sleep associated with regular engagement in physical activity have also been observed within individuals with sleep disorders and has been found to be associated with a reduced need for the use of sleep medications.

The beneficial effects of both acute and chronic physical activity engagement on sleep have been attributed to a number of potential mechanisms. Early research attributed these effects to thermogeneic responses (**Thermogenic Hypothesis**); whereby changes in core body temperature that occurred during activity served as a trigger to promote better sleep outcomes. The underlying concept was that the increase in core body temperature during activity were followed by rapid decreases in core body temperature following the cessation of the activity. This rapid decrease in body temperature serves as a **somnogen** to activate the sleep-promoting pathway to induce sleep more quickly. However, such explanations are a poor fit for observations that even physical activity eight hours prior to going to sleep has beneficial effects; and have come into question given that these effects still occur in context where body temperature does not rise during activity. It may also be that physical activity provides an opportunity for greater exposure to light (**Light Exposure Hypothesis**). As light therapy has been found to promote better sleep outcomes, the engagement in physical activity without outdoor settings during daylight hours or within well-lit gyms may contribute to the beneficial effects of physical activity on sleep. However, such a mechanism would suggest that individuals who choose to engage in physical activity during non-daylight hours or within low-light gym environments may minimize the beneficial influence of the activity engagement as it relates to sleep.

Despite such attributions, the general perspective is that the beneficial relationship of physical activity for sleep may actually be the result of aligning with two hypothesized fundamental reasons why we sleep: energy conservation and body restoration. In the context of the energy conservation theory of sleep, the increased energy expenditure that occurs during physical activity requires an adaptive response to attempt to minimize total daily energy expenditure. So long as the physical activity is not excessive in duration (which might indicate a threat to survival); the energy expended during physical activity can be potentially offset through sleep. Therefore, enabling the organism to enter sleep faster and spend more time within the most energy efficient stage of sleep is a reactive response ultimately in service of maintaining low energy expenditure. In the context of the restorative theory of sleep, physical activity places substantial stress upon physiological systems which then requires reparative processes to be engaged. So as the individual engages in more prolonged physical activity, metabolic byproducts are created and accumulate alongside inflammatory cytokines. There is also potential for the activity to induce skeletal muscle and tissue damage. The presence of these various metabolic and inflammatory markers may serve as **somnogens** to activate the sleep-promoting pathway to induce sleep more quickly. As a result of the activity, greater time must be spent within NREM Sleep stage 3 (N3; slow-wave sleep) to repair and regenerate the body.

Finally, although it is commonly accepted that poor sleep contributes to impaired physical performance; the actual evidence indicates that poor sleep may not actually directly impact performance. Rather poor sleep contributes to a greater awareness of physical exertion and cognitive impairments associated with vigilance (being aware of potential dangers), sustaining attention, and emotional regulation. While these may impair physical performance in some circumstances, the larger issue is that each of these elements increase the relative risk of incurring an injury. Thus, it should come as no surprise that poor sleep is associated with a greater risk of incurring an exercise-related injury.

Additional Resources:

Saper, C. B., Scammell, T. E., & Lu, J. (2005). Hypothalamic regulation of sleep and circadian rhythms. Nature, 437(7063), 1257-1263. https://doi.org/10.1038/nature04284

Why do we

Sleep?

Circadian Phase

Highly heritable with about 50% of the variation attributed to genetic factors.

Predominately driven by daylight.

Homeostatic Sleep Pressure

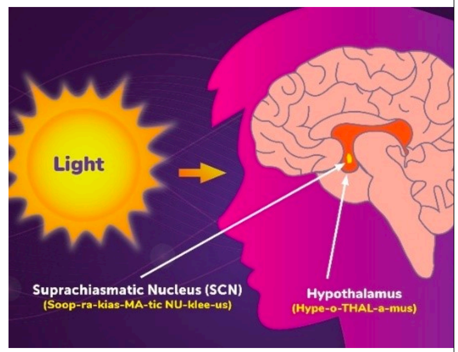
Drive to Sleep

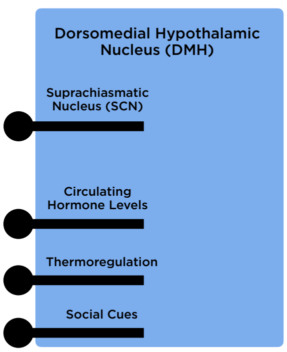
Daily rhythms of sleep and wakefulness are highly influenced and in some cases even over-ridden by neural, behavioral, and environmental factors.

Suprachiasmatic Nucleus (SCN)

Serves as the central pacemaker that generally follows a 24-hour cyclic period.

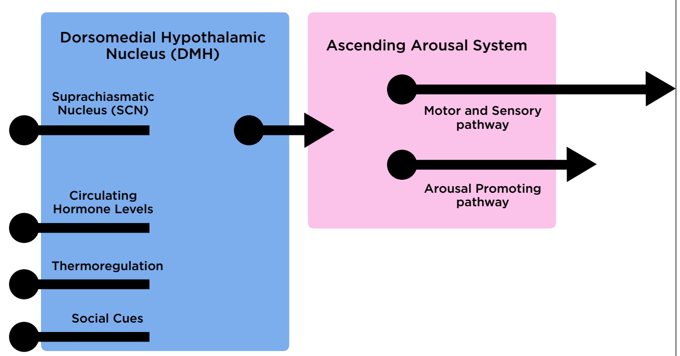
Activity increases in response to daylight.





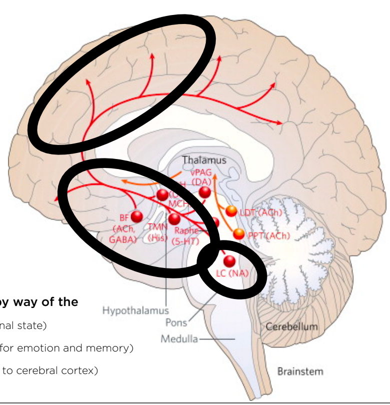
Serves as the critical hub of the circadian system.

Receives inputs from the suprachiasmatic nucleus (SCN) as well as a number of other systems (receiving information regarding food, temperature, and social cues) to generate a coordinated and adaptable sleep-wake rhythm

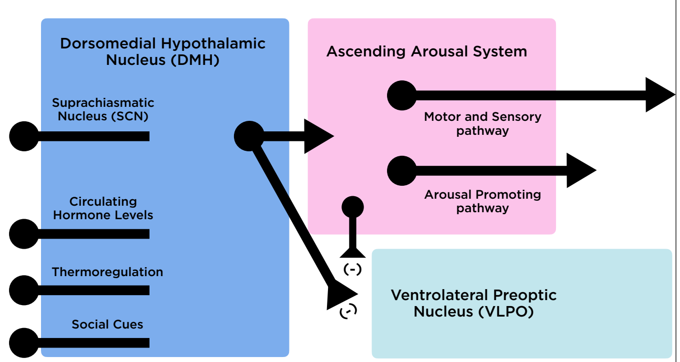


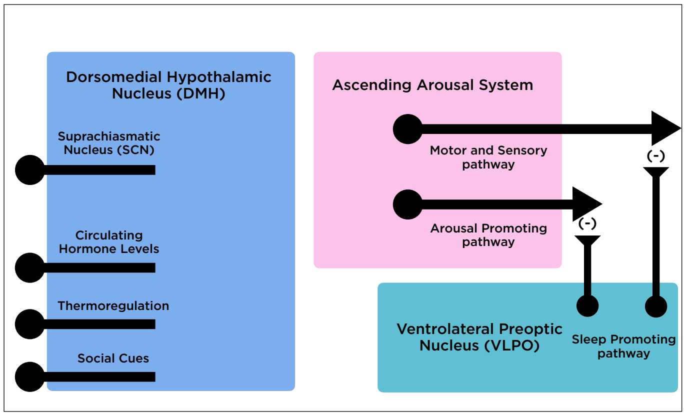
Ascending Arousal System

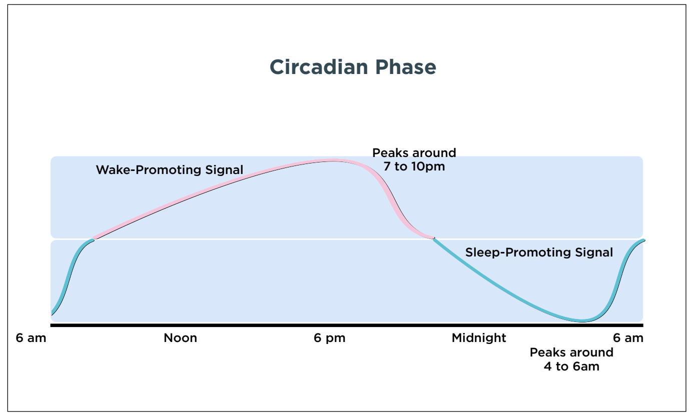
Motor and Sensory pathway by way of the Thalamus
(relay regarding movement and sensory function)



Arousal Promoting pathway by way of the
Locus Coeruleus (attentional state)
Dorsal and Median Raphe Nuclei (relay for emotion and memory)
Tuberomammillary Nucleus (relay to cerebral cortex)

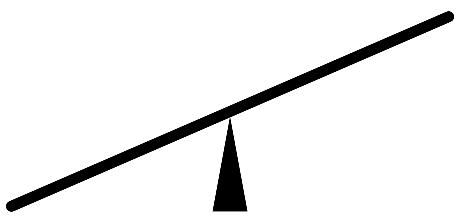






Flip-Flop (Rocker) Switch

The Wake-Promoting Pathway and the Sleep-Promoting Pathway are mutually inhibitory. When one is active, the other is suppressed.



Homeostatic Sleep Pressure

Reflects the fundamental basis that humans accumulate a need to sleep during prolonged periods of wakefulness.

Sleep Debt - inadequate sleep can appear to accumulate and increase the drive/pressure to obtain sleep.

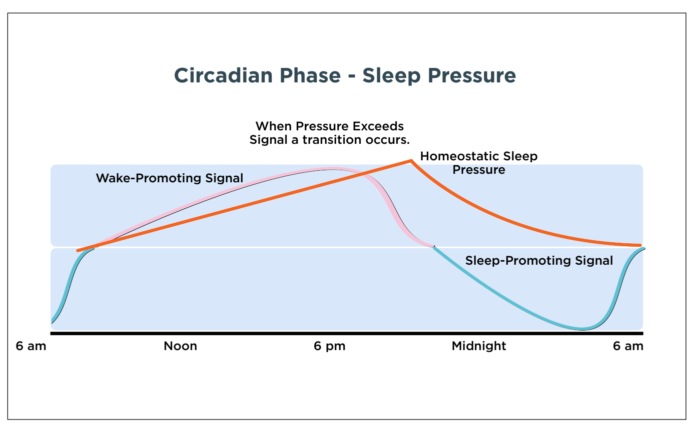
- The specific mechanisms that contribute to increasing homeostatic sleep pressure are still unclear.
- It is generally thought that accumulation of Adenosine may play a role.
  - Adenosine is a byproduct of cellular metabolism and has been observed to accumulate during prolonged wakefulness.
  - When injected near the ventrolateral preoptic nucleus (VLPO), adenosine causes rodent models to sleep.
  - Caffeine blocks adenosine from binding to receptors resulting in maintaining a wakeful state.

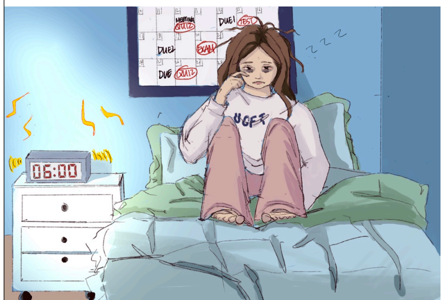
Homeostatic Sleep Pressure

Reflects the fundamental basis that humans accumulate a need to sleep during prolonged periods of wakefulness.

Sleep Debt - inadequate sleep can appear to accumulate and increase the drive/pressure to obtain sleep.

- However, there may be multiple other mechanisms (referred to as **somnogens**) and **inflammatory factors** which accumulate during wakefulness that serve to:
  - Activate the sleep-promoting pathway
  - Or inhibit the wake-promoting pathway





We know that sleep is essential.

Sleep deprivation/restriction can result in both short and long-term consequences for health and wellbeing.

Protective Field Theory of Sleep

The cyclic pattern of sleep balances the fundamental biological function of sleep with the need for environmental awareness.

Why do we

Need Sleep?

Separating NREM Sleep stage 3 and REM sleep with periods of NREM Sleep stage 2 sleep provides an greater environmental awareness and the ability to rapidly transition from sleep to fully awake states.

- The Protective Field Theory of Sleep explains the biological basis for different sleep stages.
  - During both NREM Sleep stage 3 (N3) and REM sleep, the organism exhibits exceptionally low muscle tone and upon awaking take the longest to return to fully conscious states.
  - During NREM Sleep stage 2 (N2, light sleep) the organism has greater environmental awareness and can return to fully conscious states more rapidly.

Why do we

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Separating NREM Sleep stage 3 and REM sleep with periods of NREM Sleep stage 2 sleep provides an greater environmental awareness and the ability to rapidly transition from sleep to fully awake states.

- The Protective Field Theory of Sleep also explains why time spent in NREM Sleep stage 2 (N2; light) is relatively short during early phases of sleep but grows progressively longer with sleep duration.
  - During early portions of the sleep, the individual is likely relatively safe.
  - As sleep duration increases the environmental risks may have changed. Therefore, it is biologically advantageous to become more aware of external stimuli as the sleep duration increases.

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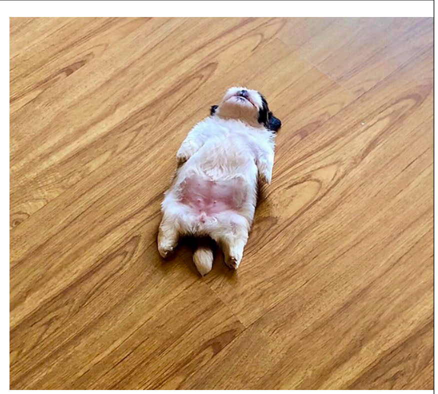
Separating NREM Sleep stage 3 and REM sleep with periods of NREM Sleep stage 2 sleep provides an greater environmental awareness and the ability to rapidly transition from sleep to fully awake states.

- As humans spend nearly half of their total sleep duration in NREM Sleep stage 2 (N2; light), this general degree of environmental awareness present within this sleep stage is biologically advantageous to avoid predation and increase survival.
- The assumption of this theory then is that light stages of sleep are not a biological necessity but rather exist as a protective field for NREM Sleep stage 3 (N3) and REM sleep which are necessary.
  - This theory does not actually explain why they are necessary though.

Energy Conservation Theory of Sleep

Sleep enables an opportunity to adopt a low-energy state.



Why do we

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Times when organisms sleep also tend to be times when it would be biologically advantageous to adopt a low-energy state.

Energy conservation theories of sleep have been put forth in a wide number of forms.

- Although normal wakeful states represent periods of high energy expenditure, they also tend to represent periods in which there is greater opportunity for energy accumulation.
- Sleep behaviors tend to occur during periods when their is reduced opportunity for energy accumulation or when the risks associated with energy accumulation are elevated.
  - Explains diurnal vs nocturnal activity patterns.

Why do we

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Times when organisms sleep also tend to be times when it would be biologically advantageous to adopt a low-energy state.

Energy conservation theories of sleep have been put forth in a wide number of forms.

- Organisms with higher metabolic rates also tend to sleep for longer periods than organisms with lower metabolic rates.
- The benefit of entering into sleep is that metabolic rate during sleep tends to be 5 to 15% lower than during waking states.
  - Largest benefit for NREM Sleep stage 3 (N3).

Why do we

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Times when organisms sleep also tend to be times when it would be biologically advantageous to adopt a low-energy state.

Energy conservation theories of sleep have been put forth in a wide number of forms.

- Energy conservation theories tend to focus upon the idea of energetic trade-offs between sleep stages.
  - Although the brain is highly active during REM sleep, the increased energy consumption is offset by the absence of motor function.
  - During NREM Sleep stage 2 (N2; light sleep), the brain is less active so the body can allow motor function to resume while still maintaining this lower energy state.
    - Will occasionally begin to incorporate aspects of the Protective Field Theory of Sleep into justifications for adopting a less efficient stage during light sleep.

Restorative Theory of Sleep

Sleep enables an opportunity for cellular renewal and regeneration that may not be possible during waking states.

Why do we

Need Sleep?

Sleep provides an opportunity for the body and brain to allocate energetic resources towards restorative function.

Restorative theories of sleep have been put forth in a wide number of forms.

- These theories do not actually argue that cellular repair can only occur during sleep.
  - Rather, some aspects of cellular repair and renewal may be more efficiently engaged in when the body is not awake and moving.
    - The major evidence in support of this theory of sleep is that hormones released during sleep tend to have predominately anabolic (tissue building) function while catabolic hormones tend to be suppressed.

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Sleep provides an opportunity for the body and brain to allocate energetic resources towards restorative function.

Restorative theories of sleep have been put forth in a wide number of forms.

- Restorative theories of sleep tend to focus on NREM Sleep stage 3 (N3; slow-wave sleep).
  - This stage of sleep is considered particularly important for supporting musculoskeletal recovery and growth as well as promoting enhanced immune function.
    - Growth hormones are predominately released during this stage.
    - Within the brain, protein synthesis has been found to be enhanced during this stage.
    - Deprivation of slow-wave sleep has been found to impair the growth of new neurons (neurogenesis).

Why do we
Need Sleep?

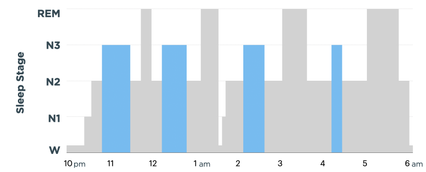
Sleep provides an opportunity for the body and brain to allocate energetic resources towards restorative function.

Restorative theories of sleep have been put forth in a wide number of forms.

- During periods of greater growth — such as during adolescence and pregnancy — time spent in slow-wave sleep is increased.

Upon falling asleep the body spends a large portion of time within slow-wave sleep presumably to begin restorative function.

The gradual reduction in time spent in slow-wave sleep over the course of the night would then be an expected occurrence reflecting a reduced need for cellular repair and renewal.

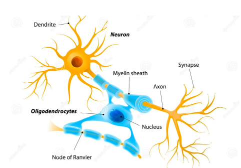


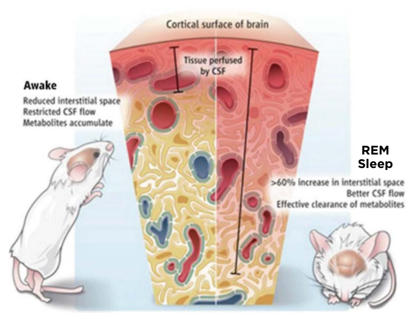
Why do we
Need Sleep?

Sleep provides an opportunity for the body and brain to allocate energetic resources towards restorative function.

Restorative theories of sleep have been put forth in a wide number of forms.

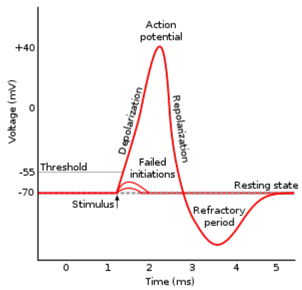
- REM sleep also appears to be a time when neural repair and regeneration processes occur
  - Oligodendrocytes (brain cells that generate and maintain myelin axonal coatings) are the most active during REM sleep.





During REM sleep, astrocytes work to clear neural metabolic waste and promote flushing of neural tissues by shrinking and expanding.

Astrocytes - glial cells that outnumber neurons 5 to 1 which are involved with regulating blood flow, altering neurotransmitters, and are involved in the maintenance of neurons.

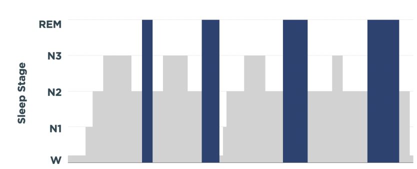


Greater brain activity observed during REM sleep may reflect the restorative clearance of metabolic byproducts by microglia and astrocytes.

As neuronal environments are improved and neurotransmitters are replaced, resting membrane potentials within neural tissues may be altered resulting in increased brain activity.

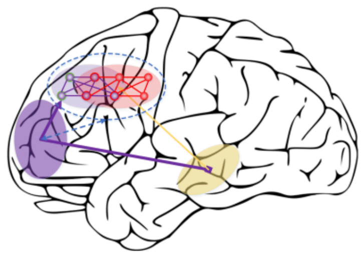
Greater brain activity observed during REM sleep may reflect the restorative clearance of metabolic byproducts by microglia and astrocytes.

REM sleep is relatively short during early periods of the sleep, but as microglia and astrocytes are able to clear greater neural waste in the brain, the time spent in REM sleep increases.



Memory Consolidation / Network Integrity Theory of Sleep

Sleep provides a period for the reorganization and strengthening of neural networks critical to support memory and daily function.



Why do we
Need Sleep?

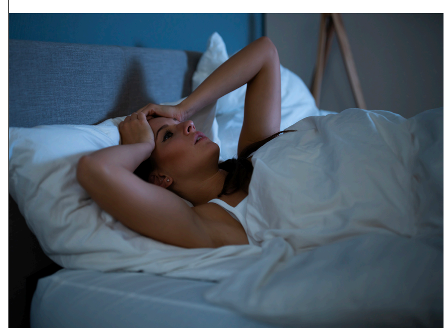
Sleep provides a critical period when neural networks underlying memory and high level cognitive processes reorganize and strengthen.

- Memory consolidation theories and synaptic-neuronal network integrity theories build upon research focusing on the relationship between sleep and cognitive function.
  - Role of sleep deprivation/restriction on memory/cognition.
  - How time spent in specific stages of sleep impacts upon the ability to sustain information within long-term memory and maintain high-levels of cognitive performance.

Why do we
Need Sleep?

Sleep provides a critical period when neural networks underlying memory and high level cognitive processes reorganize and strengthen.

- Both the time spent in NREM Sleep stage 3 (N3; slow-wave sleep) and the density of sleep spindles appear to be particularly important for supporting memory consolidation.
- Time spent in REM sleep appears particularly important for consolidating emotionally charged memories and may promote better removal of irrelevant or unnecessary information from memory.



Societally there is a perception that individuals should avoid engaging in physical activity too close to when they go to bed.

Influence of Physical Activity on
Sleep

- Research in this area indicates that the beneficial influence of physical activity remains the same whether it is performed:
  - More than 8 hours before bedtime
  - 3 to 8 hours before bedtime
  - Less than 3 hours before bedtime.
- The exception being that engaging in physical activity within less than three hours of going to bed reduces the time spent within NREM Sleep stage 1 (N1).
  - It may help individuals to fall asleep faster.

Influence of Physical Activity on
Sleep

- Following even a single bout of physical activity there appears to be:
  - An increase in total sleep time
  - Improved sleep efficiency
  - Increased time spent within NREM Sleep stage 3 (N3, slow-wave sleep)
  - Decreased time spent in REM sleep
- No differences in the type of physical activities or the intensity of physical have been observed
  - For moderate-to-vigorous intensities of physical activity, longer duration of activity (up to around 90 minutes) is associated with greater benefits.

Influence of Physical Activity on

Sleep

- Habitual (chronic) physical activity engagement is associated with:
  - Enhanced perceptions of sleep quality (satisfaction)
  - Increased daytime alertness
  - Faster sleep onset latency
  - Increased duration of sleep
  - Greater time spent within NREM Sleep stage 3 (N3, slow-wave sleep)
- Improvements in sleep have also been observed within individuals with sleep disorders and has been found to be associated with a reduced need for the use of sleep medications.

Why does

Physical Activity Benefit Sleep

Thermogenic Hypothesis

Changes in core body temperature that occurred during activity served as a trigger to promote better sleep outcomes.

- Early research attributed these effects to thermogeneic responses.
- The underlying concept was that the increase in core body temperature during activity were followed by rapid decreases in core body temperature following the cessation of the activity.
  - This rapid decrease in body temperature serves as a **somnogen** to activate the sleep-promoting pathway to induce sleep more quickly.

Why does

Physical Activity Benefit Sleep

Thermogenic Hypothesis

Changes in core body temperature that occurred during activity served as a trigger to promote better sleep outcomes.

- Such an explanation is a poor fit for experimental data.
  - Beneficial influence of physical activity remains the same whether it is performed:
    - More than 8 hours before bedtime
    - 3 to 8 hours before bedtime
    - Less than 3 hours before bedtime.
  - These effects still occur in context where body temperature does not rise during activity.

Why does

Physical Activity Benefit Sleep

Light Exposure Hypothesis

Physical activity provides an opportunity for greater exposure to light which promotes better sleep outcomes.

- Based upon evidence that light therapy has been found to promote better sleep outcomes.
- The engagement in physical activity without outdoor settings during daylight hours or within well-lit gyms may contribute to the beneficial effects of physical activity on sleep.

Why does

Physical Activity Benefit Sleep

Light Exposure Hypothesis

Physical activity provides an opportunity for greater exposure to light which promotes better sleep outcomes.

- Based upon this hypothesis, individuals who choose to engage in physical activity during non-daylight hours or within low-light gym environments may minimize the beneficial influence of the activity engagement as it relates to sleep.
  - No evidence to support this.

Why does

Physical Activity Benefit Sleep

Energy Conservation Theory of Sleep

The increased energy expenditure that occurs during physical activity requires an adaptive response to attempt to minimize total daily energy expenditure.

Why does

Physical Activity Benefit Sleep

Energy Conservation Theory of Sleep

The increased energy expenditure that occurs during physical activity requires an adaptive response to attempt to minimize total daily energy expenditure.

- As long as the physical activity is not excessive in duration (which might indicate a threat to survival).
- The energy expended during physical activity can be potentially offset through sleep.
- Enabling the organism to enter sleep faster and spend more time within the most energy efficient stage of sleep is a reactive response ultimately in service of maintaining low energy expenditure.
  - Explains why longer duration would promote better sleep.

Why does

Physical Activity Benefit Sleep

Restorative Theory of Sleep

Physical activity places substantial stress upon physiological systems which then requires reparative processes to be engaged.

- As the individual engages in more prolonged physical activity, metabolic byproducts are created and accumulate alongside inflammatory cytokines.
- There is also potential for the activity to induce skeletal muscle and tissue damage.
  - Activity may not always induce damage, but the physiological response is the same as when damage occurs.

Why does

Physical Activity Benefit Sleep

Restorative Theory of Sleep

Physical activity places substantial stress upon physiological systems which then requires reparative processes to be engaged.

- The presence of these various metabolic and inflammatory markers may serve as somnogens to activate the sleep-promoting pathway to induce sleep more quickly.
  - Fall asleep quicker and stay asleep longer.
- As a result of the activity, greater time must be spent within NREM Sleep stage 3 (N3; slow-wave sleep) to repair and regenerate the body.

Does Poor Sleep Impair

Physical Performance

- While it is commonly accepted that poor sleep contributes to impaired physical performance; the actual evidence indicates that poor sleep may not actually directly impact performance.
- Poor sleep contributes to:
  - A greater awareness of physical exertion
  - Cognitive impairments associated with vigilance (being aware of potential dangers), sustaining attention, and emotional regulation.

Does Poor Sleep Impair

Physical Performance

- While these may impair physical performance in some circumstances, the larger issue is that each of these elements increase the relative risk of incurring an injury.
- Evidence consistently indicates that poor sleep is associated with a greater risk of incurring an exercise-related injury.