Sleep Assessment

Not Just an Inactive Brain in an Inactive Body

While often conceptualized as an inactive brain in an inactive body, sleep is a multifaceted construct. Accordingly trying to assess sleep only through the lens of total sleep duration provides a limited perspective of this health behavior. To get a more complete picture of sleep it is necessary to understand the different ways in which sleep can be assessed.

Topics: Sleep Health — SATED — Sleep Architecture — Sleep Stage Identification

Sleep Health — A pattern of sleep–wakefulness, adapted to individual, social, and environmental demands, that promotes adequate functioning of physical, mental, and social processes. Characterized by subjective satisfaction with sleep, sustained alertness during waking hours, appropriate timing, and adequate efficiency and duration.

The vast majority of research on sleep as it relates to health has focused upon the negative consequences of poor or restricted sleep rather than the potential benefits of good sleep. As such, the state of the literature is largely more focused on the idea of **sleep deficiency** — a deficit in the quantity or quality of sleep obtained versus the amount needed for optimal health. In many ways this orientation of sleep research reflects pre–1940's era perspectives of health (e.g., good sleep is the avoidance of problematic sleep; health as the absence/avoidance of illness, disease, and debilitating conditions). The idea of framing healthy sleep as only that which is necessary to promote adequate functioning appropriate for individual, social, and environmental demands (aligning with modern perspectives of health), is only starting to become integrated into this area of research. Accordingly, it is important to acknowledge that the present state of the literature provides minimal insights beyond this negative perspective — poor sleep is definitely bad, while good sleep is simply not bad. Nevertheless, evidence has consistently observed that poor sleep is related to greater overall mortality risk, heart disease, diabetes, and hypertension.

Sleep Time Duration [Time in Bed] — The duration of the period from going to bed to getting out of bed.

Sleep Time Duration [Actual Sleep Time] — The total duration of the period in a non–awake state.

The Canadian 24–hour Movement Guidelines recommendations for sleep specifically utilized the recommended sleep time duration from the National Sleep Foundation. These guidelines recommend 9 to 11 hours of sleep for children aged 5 to 13, 8 to 10 hours for children aged 14 to 17, and 7 to 9 hours of sleep for adults. The recommendation for sleep duration in adults similarly aligns with consensus statements by the American Academy of Sleep Medicine and the Sleep Research Society. However, an important point emphasized by the panel that created these guidelines for the National Sleep Foundation is that some individuals may deviate from the recommended times with no adverse (harmful or unfavorable) effects. However, individuals with sleep durations which excessively deviate from these recommended sleep durations may have serious health problems already or may be compromising their health and wellness by intentionally restricting sleep **— if those behaviors are sustained for a long period**. Additionally, another critical clarification is that although sleep time duration recommendations are used as the fundamental guideline behavior; this is simply a reflection of the evidence base surrounding the importance of sleep for health. Population level studies in this area do not typically differentiate between time in bed and actual sleep time. Since actual sleep time is less than the time spent in bed, these studies tend to bias data towards higher sleep duration estimates.

Within research on the relationship between sleep, health, and wellness; there are five key dimensions of sleep known as **SATED** that are particularly relevant: **S**atisfaction with sleep, **A**lertness during waking hours, **T**iming of sleep, sleep **E**fficiency, and sleep **D**uration. The concept of **Satisfaction** with sleep or quality of sleep reflects the subjective assessment of sleep quality that is independent from the quantity of sleep obtained. So an individual who sleeps for a long duration may still report perceiving the sleep to be of low quality. This dimension of sleep has been found to be particularly important for mental health with individuals who chronically report poor quality sleep also exhibiting greater prevalence of anxiety and depression.

Alertness reflects the ability to maintain attentive wakefulness during the day. Although it can seem odd to characterize a dimension of sleep as its absence; an individual will have greater difficulty maintaining attentive wakefulness during the day if poor sleep occurs. This dimension of sleep has been found to be an important factor in risks associated with accidents, poor academic performance, and medication errors.

Sleep **Timing** reflects the placement of sleep within the 24–day — the timing of going to bed/waking up, and the midpoint of sleep time. Across a number of investigations, later sleep timing and variability in sleep timing have been associated with adverse cardiometabolic health outcomes and greater risk of obesity; and is a critical issue in the context of shift workers and those with variable scheduling practices. Sleep continuity or **Efficiency** reflects the ease of falling and returning to sleep as well as the ability to sleep throughout the night without waking up. This dimension of sleep has been found to be particularly important in the regulation of perceptions of stress and emotional reactivity. The concept of sleep **Duration** represents a major dimension that is commonly assessed within population–level investigations but it has been argued that it may be the least relevant for health and wellness outside of circumstances associated with severe sleep restriction/deprivation. However, individuals who exhibit deviant patterns of sleep duration exhibit greater risk of mortality from all causes.

Sleep — A reversible behavioral state of perceptual disengagement from and unresponsiveness to the environment.

However, a more refined understanding of the relationship between sleep and health may be provided by assessing more specific components of sleep. The concept of sleep is based on both physiological and behavioral changes that occur during this state. Although sleep is often conceptualized as an inactive brain in an inactive body, there is a characteristic pattern to sleep whereby both the brain and body cycle through periods of greater activity. This pattern is referred to as **Sleep Architecture** and characterizes the stages of sleep into wakefulness (stage W), multiple stages of non–rapid eye movement sleep (NREM), and rapid eye movement sleep (REM).

The **wakefulness sleep stage** (stage W) reflects the transition from fully alert wakefulness to drowsiness. If your father is sitting on the couch watching TV and starts to 'nod off', this is the sleep stage you are observing. If we were to put electrodes on his scalp to measure his brain activity using electroencephalography (EEG), we would be able to observe the hallmark of this sleep stage: the presence of a **posterior dominant rhythm** (also known as alpha rhythm or alpha bursts) within EEG activity that occurs when the eyes close. This pattern of activity reflects EEG activity within the 8 to 13 hertz frequency range that is relatively small over frontal brain regions and grows progressively larger over occipital (towards the back of the head) regions. When the eyes are open this posterior dominant rhythm dissipates (goes away). Another facet of the wakefulness sleep stage is **reactivity** to external stimuli. In response to noises or other stimuli (such as changing what is playing on the TV), your father will still exhibit alterations in brain activity and reactive eye movements indicating general awareness of the external stimuli. Finally, during this stage the individual may exhibit **hypnic jerks** — irregular spontaneous or reactive movements of all or part of the body that can sometimes be accompanied by a sense of falling.

Non–rapid eye movement (NREM) sleep encompasses a number of separate stages of sleep that are characterized by progressive decreases in responsiveness to external stimuli. Historically, the characterization of this aspect of sleep subdivided it into 4 distinct stages; however, the American Academy of Sleep Medicine (AASM) now classifies NREM sleep into 3 stages (N1, N2, N3) predominantly on the basis of EEG activity. The **NREM Sleep stage 1 (N1)** reflects the period in which an individual moves from drowsiness to **light sleep**, representing the first point at which an individual would be considered to be asleep. However, an individual can still be easily woken from this sleep stage and if they are, may not feel like they were asleep. So even though your father had officially fallen asleep while watching the TV; if you were to wake him, he would likely feel like he was just letting his eyes close for a bit and was not actually sleeping.

The hallmark characteristic of this sleep stage is the presence of **theta waves** reflecting EEG activity within the 4 to 7 hertz frequency range as well as **vertex sharp waves** (which look somewhat like a sail boat) that are most prominent over central (the middle) regions. During this stage there is usually a reduction in muscle tone as muscles relax, slow eye movements, as well as initial reductions in body temperature, blood pressure, cardiac and ventilatory rate. The time it takes to transition from a state of wakefulness to this sleep stage is referred to as **sleep onset latency**. Individuals who take more than 60 minutes to transition from wakefulness to NREM Sleep stage 1 (N1) are considered to have poor sleep onset latency (trouble falling asleep). Whereas

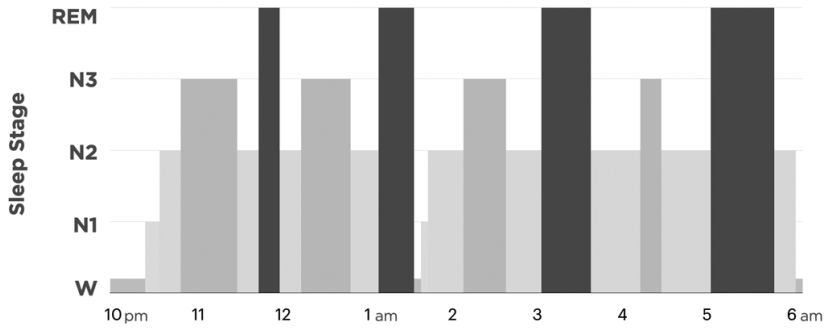
an individual who takes 15 to 30 minutes to transition to this stage is considered to have good sleep onset latency.

NREM Sleep stage 2 (N2) reflects the second phase of **light sleep**. The hallmark characteristic of this sleep stage is the presence of **sleep spindles** which are bursts of EEG activity within the 11 to 16 hertz frequency range that present maximally over frontal and central regions. These sleep spindles are thought to reflect periods in which sensory inputs are 'disconnected' in the brain to optimize the process of long–term memory consolidation. A second hallmark characteristic of NREM Sleep stage 2 (N2) is the presence of **K–complexes** which are single positive and then negative deflections in the EEG activity that present maximally over frontal regions. These K–complexes can occur either spontaneously or in response to an external stimulus in the environment — indicating that individuals retain some degree of environmental awareness during this sleep stage.

NREM Sleep stage 3 (N3) combines the original 3rd and 4th stages of sleep and reflects a period of sleep known as **deep sleep** or **slow wave sleep**. If awakened during this sleep stage, the individual may experience grogginess (weariness, fatigue, dazed). The hallmark characteristic of this sleep stage is the presence of long, slow EEG activity known as **delta waves** within the 0.5 to 2 hertz frequency range that presents maximally over frontal regions. However, sleep spindles and K complexes may still occur during this sleep stage. During this stage movement of the eyes and body are not typically seen and body temperature, blood pressure, cardiac and ventilatory rate all fall to their lowest levels.

Consistent with its name, **rapid eye movement sleep** (REM) is characterized by rapid eye movements that occur despite the eyes being in a closed state. Rapid eye movement sleep is considered the deepest stage of sleep, however the activity of the brain returns to nearly the same levels as those observed while awake as this stage is the period in which most dreams occur. During this stage of sleep, hyperpolarization of spinal motor neurons contributes to muscle immobility referred to as **atonia** and the abolishment of spinal reflexes. However, minor brief, jerky twitches of the body can still occur. During rapid eye movement, sleep brown adipose tissue becomes more active within tissues near the spinal cord contributing to increases in body temperature, and blood pressure, cardiac and ventilatory rate all increase to near the same levels observed during wakeful states.

Figure: Exemplar Hypnogram.



The transition between stages of sleep is often visualized using a **hypnogram** to depict the time spent within each stage of sleep. During sleep, individuals follow a typical sleep architecture pattern. The prototypical pattern is W to N1 to N2 to N3 then back to N2 before going into REM sleep. However, following the first sleep cycle this is often shortened to cycle from N2 to N3 then back to N2 before going into REM sleep. In humans, this sleep architecture pattern usually lasts around 90 to 100 minutes for each cycle and four to five sleep cycles are completed. But interestingly, the amount of time spent within each sleep stage varies by sleep cycle. Individuals will usually only spend five to ten minutes in NREM Sleep stage 1 (N1) and may not return to this stage for the remainder of the sleep. The time spent in NREM Sleep stage 2 (N2) and REM sleep is relatively minimal during initial sleep cycles and progressively increases during the duration of the sleep, such that the final REM stage can last almost an hour in some cases. In contrast, during the initial sleep cycles there is greater time spent in NREM Sleep stage 3 (N3), but with successive cycles the time spent in this stage decreases and may even be absent.

Exemplar Sleep Cycle Pattern

	W	N1	N2	N3	N2	REM
First Cycle	25	10	15	40	15	15
Second Cycle			15	35	20	25
Third Cycle	1	2	25	30	25	35
Fourth Cycle			35	15	35	45
Fifth Cycle			40			

Minutes in each stage.

The gold–standard approach for assessing sleep stages is through the use of **polysomnography** (PSG) which assesses EEG activity, blood oxygenation, heart rate, ventilatory rate, as well as leg and eye movements. This approach enables characterizing the specific attributes associate with each sleep stage that align with the criteria set forth by the American Academy of Sleep Medicine. However, the nature of this measurement approach means that sleep assessments

must typically be done within specially equipped sleep laboratories that have staff appropriately trained in setting the person up and monitoring them while they sleep. More recent advances in technology have enabled the ability to bring many of these measures into home–based environments and even consumer–grade products exist which can incorporate EEG–based approaches into devices that could be self–applied for regular home–based monitoring of these aspects of sleep.

Absent the use of EEG, approaches for assessing sleep stages such as those used by Fitbit and Apple watches rely upon integrating heart rate and accelerometry measures to try to differentiate what stage of sleep an individual may be in. Although these devices all claim to use proprietary algorithms for differentiating sleep stages, the fundamental approach used by all is relatively straightforward. Recall that in **light sleep** — NREM Sleep stage 1 (N1) and NREM Sleep stage 2 (N2) — there are reductions in heart rate but still the potential for the body to move. So if you are sleeping in this stage we should see some amount of movement (typically below that of normal day to day activity) but heart rate should be relatively low. In **deep sleep** (NREM Sleep stage 3; slow–wave sleep) heart rate is typically suppressed as is movement of the body. So if you are in this stage we should see exceptionally low movement as well as low heart rate. Within **REM** sleep, heart rate becomes elevated to similar levels as waking but movement of the body is suppressed. So if there is exceptionally little movement but an increase in heart rate this would indicate being in REM sleep. By combining measurement of movement using accelerometry and heart rate it is possible to segment sleep stages into **wakefulness** (when there is both normal heart rate and movement is diminished relative to daily activity but more present than in deep sleep and REM sleep), **light sleep** (combining NREM Sleep stage 1 and stage 2), **deep sleep** (NREM Sleep stage 3; slow–wave sleep), and **REM sleep**.

Additional Resources:

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., … & Hillard, P. J. A. (2015). National Sleep Foundation's sleep time duration recommendations: Methodology and results summary. Sleep Health, 1(1), 40-43. http://dx.doi.org/10.1016/j.sleh.2014.12.010

Hirshkowitz, M. (2004). Normal human sleep: An overview. Medical Clinics, 88(3), 551-565. http://dx.doi.org/10.1016/j.mcna.2004.01.001

Sleep Health

A pattern of sleep-wakefulness, adapted to individual, social, and environmental demands, that promotes adequate functioning of physical, mental, and social processes.

Sleep Deficiency

A deficit in the quantity or quality of sleep obtained versus the amount needed for optimal health.

Poor sleep is definitely bad.

Good sleep is simply not bad.

Poor sleep is related to greater overall mortality risk, heart disease, diabetes, and hypertension

Recommended

Sleep Time Duration

- The Canadian 24–hour Movement Guidelines recommendations for sleep specifically utilized the recommended sleep time duration from the National Sleep Foundation.
  - 9 to 11 hours of sleep for children aged 5 to 13
  - 8 to 10 hours for children aged 14 to 17
  - 7 to 9 hours of sleep for adults
- The recommendation for sleep duration in adults similarly aligns with consensus statements by the American Academy of Sleep Medicine and the Sleep Research Society.

Recommended

Sleep Time Duration

Some individuals may deviate from the recommended times with no adverse effects.

- Individuals with sleep durations which excessively deviate from these recommended sleep durations:
  - May have serious health problems already.
  - May be compromising their health and wellbeing by intentionally restricting sleep if those behaviors are sustained for a long period.

Recommended

Sleep Time Duration

Sleep Time Duration is the recommendation because that is the measure used in many large-scale studies.

- Population level studies in this area do not typically differentiate between time in bed and actual sleep time.
  - Actual sleep time is less than the time spent in bed, these studies tend to bias data towards higher sleep duration estimates.

Beyond

Sleep Time Duration

- **Satisfaction with sleep**
  - The subjective assessment of sleep **quality** that is independent from the **quantity** of sleep obtained.
  - Particularly important for mental health with individuals who chronically report poor quality sleep also exhibiting greater prevalence of anxiety and depression.

Beyond
Sleep Time Duration

- **Alertness**
  - The ability to maintain attentive wakefulness during the day.
  - An individual will have greater difficulty maintaining attentive wakefulness during the day if poor sleep occurs.
  - Particularly important for:
    - Risks associated with accidents
    - Poor academic performance
    - Medication errors

Beyond
Sleep Time Duration

- **Timing**
  - The placement of sleep within the 24.
    - The timing of going to bed/waking up, and the midpoint of sleep time.
  - Later sleep timing and variability in sleep timing have been associated with adverse cardiometabolic health outcomes and greater risk of obesity; and is a critical issue in the context of shift workers and those with variable scheduling practices.
    - Underlies the recommendation for consistent sleep times.

Beyond
Sleep Time Duration

- **Sleep continuity or Efficiency**
  - The ease of falling and returning to sleep as well as the ability to sleep throughout the night without waking up.
  - Particularly important in the regulation of perceptions of stress and emotional reactivity.

Beyond
Sleep Time Duration

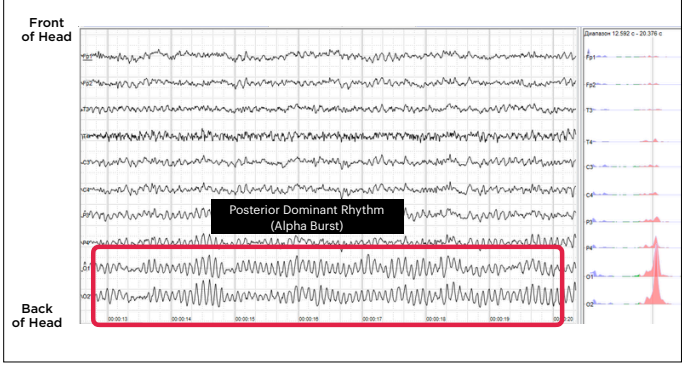
- **Duration**
  - A major dimension that is commonly assessed within population-level investigations.
    - Generally viewed as the least relevant for health/wellbeing.
    - Unless in the context of severe sleep restriction/deprivation.
  - Individuals who exhibit deviant patterns of sleep duration exhibit greater risk of mortality from all causes.

Sleep
Architecture

Wakefulness (W)

Transition from fully alert wakefulness to drowsiness.

- Hallmark Characteristic:
  - Posterior dominant rhythm (also known as alpha rhythm or alpha bursts).
    - EEG activity within the 8 to 13 hertz frequency range
    - Smaller over frontal brain regions and grows progressively larger over occipital regions.
    - Rhythm dissipates when eyes open.



Sleep
Architecture

Wakefulness (W)

Transition from fully alert wakefulness to drowsiness.

- Hallmark Characteristic:
  - Reactivity to external stimuli
    - In response to noises or other stimuli, will exhibit altered brain activity and reactive eye movements.
    - Generally aware of environment.

Sleep
Architecture

Wakefulness (W)

Transition from fully alert wakefulness to drowsiness.

- Hallmark Characteristic:
  - Hypnic Jerks - irregular spontaneous or reactive movements of all or part of the body.
    - Sometimes comes with a sense of falling.
    - About 70% of the population exhibit hypnic jerks.

Sleep
Architecture

Historically subdivided it into 4 distinct stages.

The American Academy of Sleep Medicine (AASM) now classifies NREM sleep into 3 stages predominantly on the basis of EEG activity.

Non-rapid Eye Movement Sleep (NREM)

Sleep
Architecture

NREM Sleep stage 1 (N1)

Reflects the period in which an individual moves from drowsiness to light sleep.

Represents the first point at which an individual would be considered to be asleep.

- Throughout stages of NREM sleep there is progressive decreases in the responsiveness to external stimuli.
- An individual can be easily woken up from N1 sleep and will generally feel like they were not asleep.
  - "Just closing my eyes for a bit"

Sleep
Architecture

NREM Sleep stage 1 (N1)

Reflects the period in which an individual moves from drowsiness to light sleep.

Represents the first point at which an individual would be considered to be asleep.

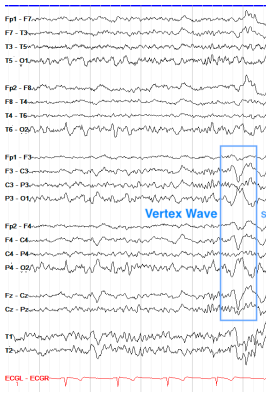
- Hallmark Characteristic:
  - Theta Waves.
    - EEG activity within the 4 to 7 hertz frequency range.
  - Vertex Sharp Waves
    - Most prominent over over central regions.

Theta Waves

EEG activity within the 4 to 7 hertz frequency range

Vertex Sharp Waves

Looks like a single Theta Wave (sailboat shape)



Sleep
Architecture

NREM Sleep stage 1 (N1)

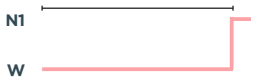
Reflects the period in which an individual moves from drowsiness to light sleep.

Represents the first point at which an individual would be considered to be asleep.

- Hallmark Characteristic:
  - Reduction in muscle tone.
  - Slow eye movements.
  - Reductions in:
    - Body temperature
    - Blood Pressure
    - Heart Rate
    - Ventilatory Rate

Sleep Onset Latency

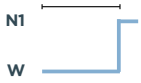
The time it takes to transition from Wakefulness to NREM Sleep Stage 1 (N1).



Poor Sleep Onset Latency

(> 60 minutes)

"Trouble Falling Asleep"



Good Sleep Onset Latency

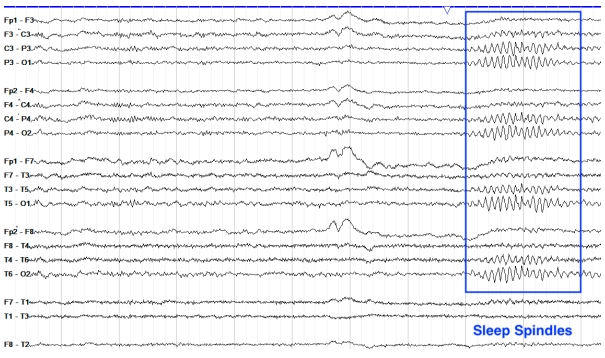
(15 to 30 minutes)

Sleep
Architecture

NREM Sleep stage 2 (N2)

Second phase of light sleep.

- Hallmark Characteristic:
  - Sleep Spindles
    - EEG activity within the 11 to 16 hertz frequency range.
    - Maximal over frontal and central regions.
    - Reflect periods in which sensory inputs are 'disconnected' in the brain to optimize the process of long-memory consolidation.

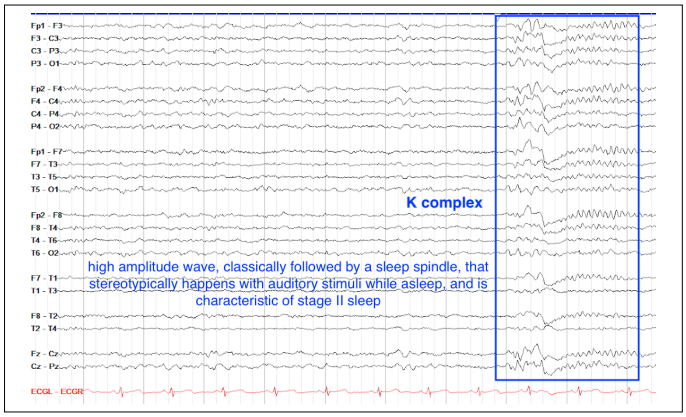


Sleep
Architecture

NREM Sleep stage 2 (N2)

Second phase of light sleep.

- Hallmark Characteristic:
  - K Complexes
    - Single positive and then negative deflections in the EEG.
    - Maximal over frontal regions.
    - Can occur spontaneously or in response to an external stimulus in the environment.
      - Indicate that individuals retain some degree of environmental awareness during this sleep stage.



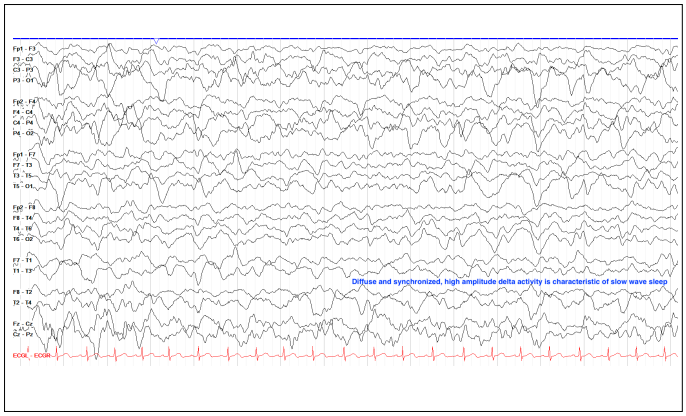
Sleep
Architecture

NREM Sleep stage 3 (N3)

Deep Sleep
Slow Wave Sleep

Combines the original 3rd and 4th stages of NREM sleep.

- If awakened during this sleep stage, the individual may experience grogginess (weariness, fatigue, dazed).
- Hallmark Characteristic:
  - Delta Waves (slow waves)
    - EEG activity within the 0.5 to 2 hertz frequency range.
    - Maximal over frontal regions.
    - Sleep spindles and K complexes may still occur during this sleep stage.



Sleep
Architecture

NREM Sleep stage 3 (N3)

Deep Sleep
Slow Wave Sleep

Combines the original 3rd and 4th stages of NREM sleep.

- Hallmark Characteristic:
  - Exceptionally low levels of movement.
  - Further reductions in:
    - Body temperature
    - Blood Pressure
    - Heart Rate
    - Ventilatory Rate

Sleep
Architecture

Rapid Eye Movement Sleep (REM)

Primary stage where Dreams occur.

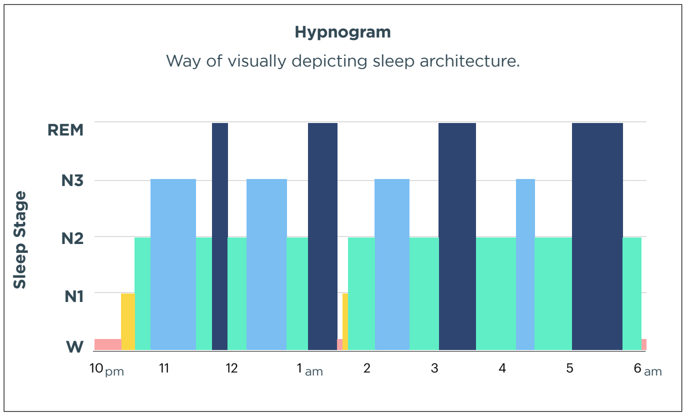
- Hallmark Characteristic:
  - Brain activity returns to nearly the same levels as observed while awake.
  - Atonia
    - Hyperpolarization of spinal motor neurons contributes to muscle immobility.
    - Abolishment of spinal reflexes.
  - Minor brief, jerky twitches of the body can still occur.

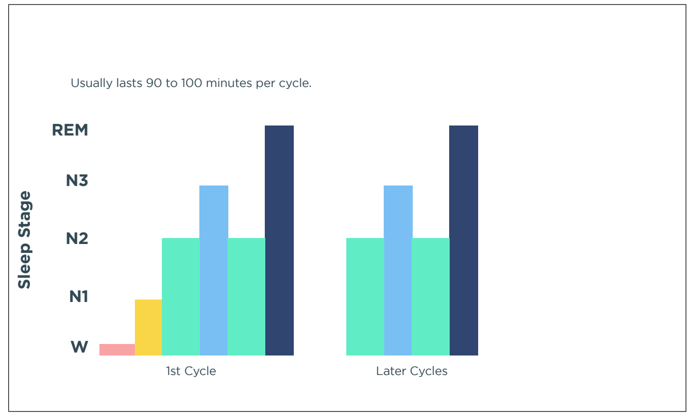
Sleep
Architecture

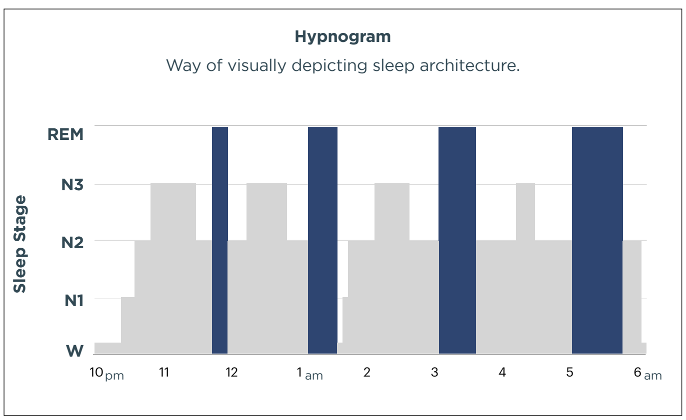
Rapid Eye Movement Sleep (REM)

Primary stage where Dreams occur.

- Hallmark Characteristic:
  - Increased body temperature
    - Increased activity of Brown Adipose Tissue near spinal cord.
  - Increases to near that of waking state:
    - Blood Pressure
    - Heart Rate
    - Ventilatory Rate


Hypnogram
Way of visually depicting sleep architecture.
Sleep Stage
REM
N3
N2
N1
W
10 pm
11
12
1 am
2
3
4
5
6 am


Usually lasts 90 to 100 minutes per cycle.
Sleep Stage
REM
N3
N2
N1
W
1st Cycle
Later Cycles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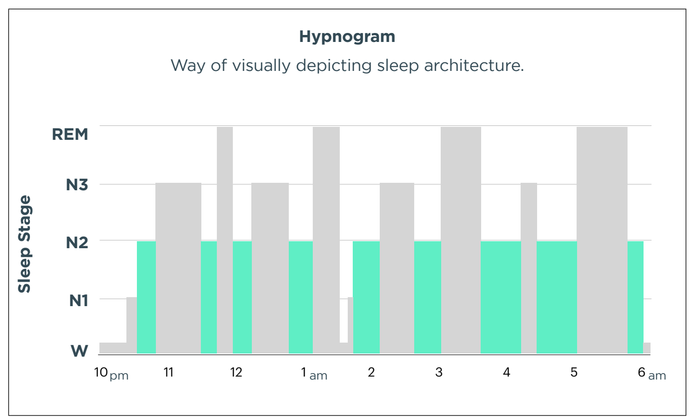
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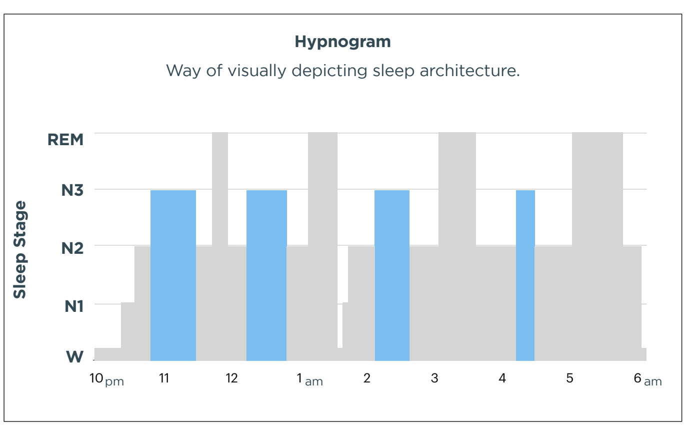
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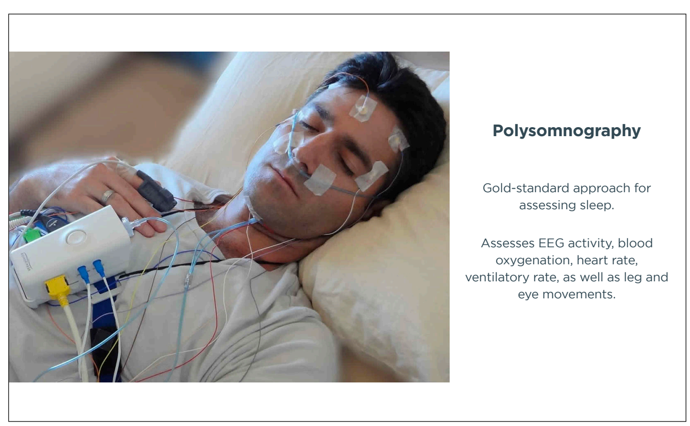
Polysomnography
Gold-standard approach for assessing sleep.
Assesses EEG activity, blood oxygenation, heart rate, ventilatory rate, as well as leg and eye movements.