An Introduction to Sleep Staging and the Diagnosis of Sleep Disorders

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The Talk

1. Polysomnography - The Basics
2. Sleep Staging and Scoring of Events: AASM Criteria
3. Sleep Related Breathing Disorders
4. Parasomnias
5. Sleep Related Movement Disorders
Polysomnography – The Basics

AASM Criteria Version 2.1 (2014)
Polysomnography

- EOG - Electrooculogram
- EEG - Electroencephalogram
- EMG - Electromyogram
- EKG - Electrocardiogram
- Tracheal noise
- Nasal and oral airflow
- Thoracic and Abdominal Respiratory Effort
- Pulse oximetry
Electrooculography picks up the inherent voltage of the eye. The cornea has a positive voltage output, while the retina has a negative polarity.
Electroencephalography in the Overnight Sleep Study

Differential Amplifier

C3 - A2
O1 - A2

Electroencephalography

G1
G2
Relaxed Jaw

Differential Amplifier

Open mouth or Clenched Teeth

G1

G2

Differential Amplifier

Open mouth or Clenched Teeth
Thermocouple Sensors

- Combination of two dissimilar metals
- Voltage changes are seen with exhalation and inhalation
Parameters for Staging Human Sleep

EOG leads - left eye and right eye

EEG leads - one central EEG lead and one occipital EEG lead (minimum)

EMG - one submental EMG channel
Sleep Staging and Scoring of Events

AASM Criteria Version 2.1 (2014)
Sleep Stages: AASM classification (2014)

N stages: Non-REM
- N1 sleep stage
- N2 sleep stage
- N3 sleep stage

• R: Rapid Eye Movement

- Fast
- Slow
Stage Wake - W

- More than 50% of the 30s Epoch contains either:
  - Alpha rhythm (posterior dominant rhythm): Trains of sinusoidal 8–13 Hz activity recorded over the occipital region with eye closure, attenuating with eye opening.
  - Eye blinks: Conjugate vertical eye movements at a frequency of 0.5–2 Hz present in wakefulness with the eyes open or closed.
  - Reading eye movements: Trains of conjugate eye movements consisting of a slow phase followed by a rapid phase in the opposite direction as the individual reads.
Alpha Activity

- Alpha EEG: 8-13 cps
- Alpha: occipital region
- Alpha: crescendo-decrescendo appearance

Central lead EEG tracing (zoomed to 4 times larger than normal)
Stage Wake Eyes Closed vs. Eyes Open
Sleep Stage - N1

- Relatively low voltage, mixed frequency EEG (2-7 Hz)
- High amplitude up to 200uV
- Approximately 5-10% of Sleep period
- Can respond to external stimuli
- Dominantly theta waves 4-7 Hz
- If represents >10% of TST then could be a sign of fragmented Sleep with frequent EEG arousals/WK stage
- An epoch is scored as stage N1 if the majority of the epoch meets the criteria for stage N1 (EEG showing LAMF EEG activity) in the absence of evidence for another sleep stage.
Sleep Stage - N1

- **Slow eye movements (SEM):** Conjugate, reasonably regular, sinusoidal eye movements with an initial deflection usually lasting >500 msec
- **Low-amplitude, mixed-frequency (LAMF) EEG activity:** Low-amplitude, predominantly 4–7 Hz activity.
- **Vertex sharp waves (V waves):** Sharply contoured waves with duration <0.5 seconds maximal over the central region and distinguishable from the background activity.
- **Sleep onset:** The start of the first epoch scored as any stage other than stage W. (In most individuals this will usually be the first epoch of stage N1.)
Theta Activity

• A frequency of 4-7 Hz
• Produced in the central vertex region
• No amplitude criteria for Theta
• The most common sleep frequency
Sleep Stage: N2

EEG characterized by
- Sleep spindles
- K-Complexes
- Delta waves present 0-20%

Approximately 15-25 % of Sleep period

K-Complexes: EEG waveforms having a well delineated sharp negative wave followed by a slower positive component
Sleep Stage N2

Scored in accordance with the following definitions:

• **K complex**: A well-delineated, negative, sharp wave immediately followed by a positive component standing out from the background EEG, with total duration ≥0.5 seconds, usually maximal in amplitude when recorded using frontal derivations. For an arousal to be associated with a K complex, the arousal must either be concurrent with the K complex or commence no more than 1 second after termination of the K complex.

• **Sleep spindle**: A train of distinct sinusoidal waves with frequency 11–16 Hz (most commonly 12–14 Hz) with a duration ≥0.5 seconds, usually maximal in amplitude in the central derivations.

• Begin scoring stage N2 (in absence of criteria for N3) if EITHER OR BOTH of the following occur during the first half of that epoch or the last half of the previous epoch:
  a. One or more K complexes unassociated with arousals
  b. One or more sleep spindles
Sleep Spindles

- Sleep Spindle - 12-14 cps
- Central - vertex region
- > .5 to 2-3 seconds in duration
- .5 second spindles - 6-7 cycles
- Indicative of stage 2 sleep
K Complexes

- Sharp, slow waves, with a negative, then positive deflection
- No amplitude criteria
- Duration must be at least .5 seconds
- Predominantly central-vertex in origin
- Indicative of stage N2
- They may occur with or without arousals
Sleep Stage N3

- Relatively high amplitude, low frequency EEGs < 2 Hz
- Also known as slow wave sleep (SWS) or Delta sleep
- Delta waves present > 20%
- Approximately 40-50% of Sleep period
- Predominant during the first third of night
- Growth hormone released
Delta Activity

- Sleep Delta activity - frequency of .5-2 cps
- Clinical EEG - frequency of ≥ .5-4 cps
- Seen predominantly in the frontal region
- Delta Activity - amplitude of ≥ 75mn

Delta EEG Activity (zoomed in 4 times larger than normal)
Sleep Stage - R

- Characterised by rapid eye movements
- Saw-toothed EEG waves
- Relatively mixed amplitude and frequencies
- Considered to be “paradoxical”: The brain is active but the body is paralyzed
- Lowest muscle tone during sleep: atonia
- Alpha activity may present: 1-2 Hz
Sleep Stage - R

1. Score in accordance with the following definitions:
   - **Rapid eye movements (REM):** Conjugate, irregular, sharply peaked eye movements with an initial deflection usually lasting <500 msec.
   - **Low chin EMG tone:** Baseline EMG activity in the chin derivation no higher than in any other sleep stage and usually at the lowest level of the entire recording.
   - **Sawtooth waves:** Trains of sharply contoured or triangular, often serrated, 2–6 Hz waves maximal in amplitude over the central head regions and often, but not always, preceding a burst of rapid eye movements.
   - **Transient muscle activity:** Short irregular bursts of EMG activity usually with duration <0.25 seconds superimposed on low EMG tone. The activity may be seen in the chin or anterior tibial EMG derivations, as well as in EEG or EOG deviations, the latter indicating activity of cranial nerve innervated muscles (facial muscles and scalp). The activity is maximal in association with rapid eye movements.

2. Score stage R sleep in epochs with ALL of the following phenomena (definite stage R):
   a. Low-amplitude, mixed-frequency (LAMF) EEG activity without K complexes or sleep spindles
   b. Low chin EMG tone for the majority of the epoch and concurrent with REMs
   c. REMs at any position within the epoch
REM Sleep (Stage R)

Three Components:
- EEG activation,
- Muscle atonia, and,
- Episodic bursts of rapid eye movements.

Tonic and Phasic types of REM sleep are distinguished usually for research purposes. The most commonly used marker of REM sleep phasic activity in human beings are:
- bursts of rapid eye movements;
- muscle twitches and,
- cardio-respiratory irregularities often accompany the REM bursts.

The mental activity of human REM sleep is associated with dreaming, based on vivid dream recall reported after approximately 80% of arousals from this state of sleep.

Inhibition of spinal motor neurons by brainstem mechanisms mediates suppression of postural motor tonus in REM sleep.

A highly activated brain in a “paralysed” body
Arousals

• Score arousal during sleep stages N1, N2, N3, or R if there is an abrupt shift of EEG frequency including alpha, theta and/or frequencies greater than 16 Hz (but not spindles) that lasts at least 3 seconds, with at least 10 seconds of stable sleep preceding the change.

• Scoring of arousal during REM requires a concurrent increase in submental EMG lasting at least 1 second.
Scoring Respiratory Events

1. Obstructive Apnoea
2. Central Apnoea
3. Mixed Apnoea
4. Hypopnoeas
Blood oxygen levels reduce to < 3% of baseline value.
Scoring Apneas: AASM Criteria

1. Score a respiratory event as an apnea when BOTH of the following criteria are met:
   a. There is a drop in the peak signal excursion by ≥90% of pre-event baseline using an oronasal thermal sensor (diagnostic study),
   b. The duration of the ≥90% drop in sensor signal is ≥10 seconds.

2. Score an apnea as **obstructive** if it meets apnea criteria and is associated with continued or increased inspiratory effort throughout the entire period of absent airflow.

3. Score an apnea as **central** if it meets apnea criteria and is associated with absent inspiratory effort throughout the entire period of absent airflow.

4. Score an apnea as **mixed** if it meets apnea criteria and is associated with absent inspiratory effort in the initial portion of the event, followed by resumption of inspiratory effort in the second portion of the event.
Common Rules

• All respiratory events need to be at least 10 seconds long
• All events need to have at least a 3% $\text{SaO}_2$ desaturation
• EEG arousals will occur with most respiratory events
Obstructive Apnoea

- No airflow for $\geq 10$ seconds
- Increasing respiratory effort. Usually seen as paradoxical.
- $\text{SaO}_2$ desaturation $<3\%$ (may be adjusted)
Obstructive Apnoeas
Central Apnea

- Absence of airflow at the nose and mouth for $\geq 10$ seconds
- A complete absence of respiratory effort as measured by:
  - Thoracic Expansion
  - Abdominal Expansion
  - Intercostal / Diaphragmatic EMG
- $\text{SaO}_2$ drop of $\geq 3\%$
Central Apnoea
Mixed Apnea

- A complete absence of nasal and oral airflow
- A total absence of respiratory effort at the beginning of the event, followed by a gradual increase in effort which eventually breaks the apnea
- An oxygen desaturation of $\geq 3\%$
Mixed Apnea

- May have a short central component or a large one
- As with all events, mixed apneas may be longer in REM
- May be created by hyperventilation following an obstructive apnea
Hypopnea

- Reduction in airflow of more than 30% of baseline value
- $\text{SaO}_2$ desaturation of $\geq 3\%$
- Usually is a steadily increasing effort signal
- (Arousal)
Airflow reduction

Inhale

Exhale

> effort with paradox

Paradox ends

SAO2 desaturation
Scoring Hypopnoea (AASM, 2014)

1. Score a respiratory event as a hypopnea if ALL of the following criteria are met: RECOMMENDED
   a. The peak signal excursions drop by ≥30% of pre-event baseline using nasal pressure
   b. The duration of the ≥30% drop in signal excursion is ≥10 seconds.
   c. There is a ≥3% oxygen desaturation from pre-event baseline OR the event is associated with an arousal.

2. Score a respiratory event as a hypopnea if ALL of the following criteria are met: ACCEPTABLE
   a. The peak signal excursions drop by ≥30% of pre-event baseline using nasal pressure
   b. The duration of the ≥30% drop in signal excursion is ≥10 seconds.
   c. There is a ≥4% oxygen desaturation from pre-event baseline.

2. If electing to score OBSTRUCTIVE HYPONEAS, score a hypopnea as obstructive if ANY of the following criteria are met:
   a. There is snoring during the event.
   b. There is increased inspiratory flattening of the nasal pressure or PAP device flow signal compared to baseline breathing.
   c. There is an associated thoracoabdominal paradox that occurs during the event but not during pre-event breathing.
Hypopnoea with Arousal
Hypopnoea without Arousal
Obstructive Hypopnoea
RERAs

Score a respiratory event as a respiratory effort-related arousal (RERA) if there is a sequence of breaths lasting ≥10 seconds characterized by:

a. Increasing respiratory effort or by flattening of the inspiratory portion of the nasal pressure (diagnostic study) waveform leading to arousal from sleep

b. The sequence of breaths does not meet criteria for an apnea or hypopnea.
ICSD-3 Categories

• Insomnia
• Sleep Related Breathing Disorders
• Central Disorders of Hypersomnolence
• Circadian Rhythm Sleep-Wake Disorders
• Parasomnias
• Sleep Related Movement Disorders
Sleep Related Breathing Disorders

• OSA
• CSA
• Sleep Related Hypoventilation Disorders
• Sleep Related Hypoxemia Disorder
• Isolated Symptoms and Normal Variants
OSA

Diagnostic Criteria: (A and B) or C satisfy the criteria

A. The presence of one or more of the following:

1. The patient complains of sleepiness, nonrestorative sleep, fatigue, or insomnia symptoms.
2. The patient wakes with breath holding, gasping, or choking.
3. The bed partner or other observer reports habitual snoring, breathing interruptions, or both during the patient’s sleep.
4. The patient has been diagnosed with hypertension, a mood disorder, cognitive dysfunction, coronary artery disease, stroke, congestive heart failure, atrial fibrillation, or type 2 diabetes mellitus.

B. Polysomnography (PSG) or OCST1 demonstrates:

Five or more predominantly obstructive respiratory events (obstructive and mixed apneas, hypopneas, or respiratory effort related arousals [RERAs])3 per hour of sleep during a PSG or per hour of monitoring (OCST).

• OR

C. PSG or OCST1 demonstrates:

Fifteen or more predominantly obstructive respiratory events (apneas, hypopneas, or RERAs)3 per hour of sleep during a PSG or per hour of monitoring (OCST).
CSA Syndromes

- Central Sleep Apnea with Cheyne-Stokes Breathing
- Central Apnea Due to a Medical Disorder without Cheyne-Stokes Breathing
- Central Sleep Apnea Due to High Altitude Periodic Breathing
- Central Sleep Apnea Due to a Medication or Substance
- Primary Central Sleep Apnea
- Primary Central Sleep Apnea of Infancy
- Primary Central Sleep Apnea of Prematurity
- Treatment-Emergent Central Sleep Apnea
Central Disorders of Hypersomnia

- Narcolepsy Type 1 (NC)
- Narcolepsy Type 2 (N)
- Idiopathic Hypersomnia
- Kleine-Levin Syndrome
- Hypersomnia Due to a Medical Disorder
- Hypersomnia Due to a Medication or Substance
- Hypersomnia Associated with a Psychiatric Disorder
- Insufficient Sleep Syndrome
NREM Parasomnias

Disorders of Arousal (From NREM Sleep)
• Confusional Arousals – (NOT in DSM-5)
• Sleepwalking
• Sleep Terrors
• Sleep Related Eating Disorder (Sleep Related Sexual Behaviour – IN DSM-5)
Sudden Arousal from N3
A. Recurrent episodes of incomplete awakening from sleep, occurring during the first third of the major sleep episode, accompanied by

1. **Sleepwalking**: Repeated episodes of rising from bed during sleep and walking about. While sleepwalking, the individual has a blank, staring face, is relatively unresponsive to the efforts of others to communicate with him or her, and can be awakened only with great difficulty.

2. **Sleep Terrors**: Recurrent episodes of abrupt terror arousals from sleep, usually beginning with a panicky scream. There is intense fear and signs of autonomic arousal, such as mydriasis, tachycardia, rapid breathing, and sweating, during each episode. There is relative unresponsiveness to efforts of others to comfort the individual during these episodes.
DSM-5

- **B.** No or little (e.g., only a single visual scene) dream imagery is recalled
- **C.** Amnesia for the episodes is present
- **D.** The episodes cause clinically significant distress or impairment in social, occupational, or other important areas of functioning
- **E.** The disturbance is not attributable to the physiological effects of a substance (e.g. a drug of abuse, a medication)
- **F.** Coexisting mental and medical disorders do not explain the episodes of sleepwalking or sleep terrors

- 307.46 (F51.3): **Sleepwalking type**
  - Specify if:
    - With sleep-related eating
    - With sleep-related sexual behavior (sexsomnia)
- 307.46 (F51.4) **Sleep terror type**
REM-Related Parasomnias

• REM Sleep Behavior Disorder
• Recurrent Isolated Sleep Paralysis
• Nightmare Disorder
Loss of REM Atonia (RBD)

Scoring PSG Features of REM Sleep Behavior Disorder (RBD)

1. Sustained muscle activity (tonic activity) in REM sleep: An epoch of REM sleep with at least 50% of the duration of the epoch having a chin EMG amplitude greater than the minimum amplitude demonstrated in NREM sleep.

2. Excessive transient muscle activity (phasic activity) in REM sleep: In a 30-second epoch of REM sleep divided into 10 sequential 3-second mini-epochs, at least 5 (50%) of the mini-epochs contain bursts of transient muscle activity. In RBD, excessive transient muscle activity bursts are 0.1–5.0 seconds in duration and at least 4 times as high in amplitude as the background EMG activity.

3. The polysomnographic characteristics of RBD are characterized by EITHER or BOTH of the following features:
   a. Sustained muscle activity in REM sleep in the chin EMG
   b. Excessive transient muscle activity during REM in the chin or limb EMG
Loss of REM Atonia
Loss of REM Atonia
Rem Sleep Behavior Disorder (RBD)

ICSD-3 Diagnostic Criteria

Criteria A-D must be met

A. Repeated episodes of sleep related vocalization and/or complex motor behaviors.
B. These behaviors are documented by polysomnography to occur during REM sleep or, based on clinical history of dream enactment, are presumed to occur during REM sleep.
C. Polysomnographic recording demonstrates REM sleep without atonia (RWA)
D. The disturbance is not better explained by another sleep disorder, mental disorder, medication, or substance use.

Notes

1. This criterion can be fulfilled by observation of repetitive episodes during a single night of video polysomnography.
2. The observed vocalizations or behaviors often correlate with simultaneously occurring dream mentation, leading to the frequent report of “acting out one's dreams.”
3. Upon awakening, the individual is typically awake, alert, coherent, and oriented.
4. Medications may unmask latent RBD with preexisting RWA, according to current expert opinion. Therefore, medication-induced RBD can be diagnosed as RBD, using clinical judgment, pending future longitudinal studies.
Other Parasomnias

• Exploding Head Syndrome
• Sleep Related Hallucinations
• Sleep Enuresis
• Parasomnia Due to a Medical Disorder
• Parasomnia Due to a Medication or Substance
• Parasomnia, Unspecified
Sleep Related Movement Disorders

• Restless Legs Syndrome
• Periodic Limb Movement Disorder
• Sleep Related Leg Cramps
• Sleep Related Bruxism
• Sleep Related Rhythmic Movement Disorder
• Benign Sleep Myoclonus of Infancy
• Propriospinal Myoclonus at Sleep Onset
• Sleep Related Movement Disorder Due to a Medical Disorder
• Sleep Related Movement Disorder Due to a Medication or Substance
• Sleep Related Movement Disorder, Unspecified
PLMS

Scoring Periodic Limb Movements in Sleep (PLMS)

1. The following define a significant leg movement (LM) event:
   a. The minimum duration of a LM event is 0.5 seconds.
   b. The maximum duration of a LM event is 10 seconds.
   c. The minimum amplitude of a LM event is an 8 μV increase in EMG voltage above resting EMG.
   d. The timing of the onset of a LM event is defined as the point at which there is an 8 μV increase in EMG voltage above resting EMG.
   e. The timing of the ending of a LM event is defined as the start of a period lasting at least 0.5 seconds during which the EMG does not exceed 2 μV above resting EMG.
PLMS

2. The following define a PLM series:

   a. The minimum number of consecutive LM events needed to define a PLM series is 4 LMs.

   b. The minimum period length between LMs (defined as the time between onsets of consecutive LMs) to include them as part of a PLM series is 5 seconds.

   c. The maximum period length between LMs (defined as the time between onsets of consecutive LMs) to include them as part of a PLM series is 90 sec.

   d. Leg movements on 2 different legs separated by less than 5 seconds between movement onsets are counted as a single leg movement.
PLMS & Arousals

• An arousal and a limb movement that occur in a PLM series should be considered associated with each other if they occur simultaneously or when there is <0.5 seconds between the end of one event and the onset of the other event regardless of which is first.

• When periodic limb movements occur with an interval of less than 10 seconds and each is associated with a 3 second arousal, only the first arousal should be scored though both limb movements may be scored. In this scenario, the arousal index and PLM index with arousal, but not the Periodic Limb Movement Index, would be influenced by not scoring the second “arousal.”
Chin EMG may decrease prior to jerk. Jerks may last from .5 to 5 seconds.

Significant only when accompanied by EEG arousal.
PLMS
Bruxism

The following define bruxism:

a. Bruxism may consist of brief (phasic) or sustained (tonic) elevations of chin EMG activity that are at least twice the amplitude of background EMG.

b. Brief elevations of chin EMG activity are scored as bruxism if they are 0.25–2 seconds in duration and if at least 3 such elevations occur in a regular sequence.

c. Sustained elevations of chin EMG activity are scored as bruxism if the duration is more than 2 seconds.

d. A period of at least 3 seconds of stable background chin EMG must occur before a new episode of bruxism can be scored.

e. Bruxism can be scored reliably by audio in combination with polysomnography by a minimum of 2 audible tooth grinding episodes/night of polysomnography in the absence of epilepsy.
Bruxism