The Nuances of Scoring Pediatric Sleep Studies

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2. I have the following relationships with entities **producing, marketing, re-selling, or distributing** health care goods or services consumed by, or used on, patients.

<table>
<thead>
<tr>
<th>Type of Potential Conflict</th>
<th>Details of Potential Conflict</th>
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<tbody>
<tr>
<td>Grant/Research Support</td>
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<td>Consultant</td>
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<td>Financial support</td>
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<td>Other</td>
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3. The material presented in this lecture has no relationship with any of these potential conflicts, OR

4. This talk presents material that is related to one or more of these potential conflicts, and the following objective references are provided as support for this lecture:

1. 
2.
Objectives

1. Discuss the nuances of scoring a pediatric sleep study
2. Review the pediatric visual and respiratory criteria according to the 2.3/2.4 scoring manual
3. Recognize various examples of sleep stages and respiratory events
Ages Where Pediatric Visual Rules Apply

• Used to stage sleep and wakefulness at children 2 mos post-term or older
  - Pearl: @ 6 month post-term, all wave forms for “adult” stage definition are present
• If < 2 months post-term, see Pediatric Task Force Review paper

Anders Manual

- Established 1971
- Criteria for scoring neonatal/infant PSG’s
- Sleep onset commonly seen in REM, up to 2-3 months post-term
- Important to recognize breathing patterns
- Chin EMG may vary
- Eyes open = wakefulness
- 4 EEG sleep/wake patterns
Ages for Infant Staging

• Infants 0-2 months post-term or 37-48 weeks conceptional age

Terms:

Gestational Age (GA) - weeks infant in uterus
Legal Age - age in weeks since birth
Conceptional Age (CA) - GA + legal age (weeks)
Prematurity - GA < 37 weeks
Full Term - birth at GA of 37-42 weeks

Staging 0-2 Months

- W- Wakefulness
- R- REM sleep
- N- NREM sleep
- T- Transitional sleep
Quiet Sleep
Active Sleep
Infant PSG

Documentation:

- Eyes open?
- Breathing pattern?
- Eye movements?
- Chin tone?
- EEG pattern?
## Infant Staging Summary

Copyright © 2015 by the American Academy of Sleep Medicine. All Rights Reserved. Scoring Manual Version 2.3

<table>
<thead>
<tr>
<th>Stage</th>
<th>Behaviors</th>
<th>Respiration</th>
<th>EEG</th>
<th>EOG</th>
<th>Chin EMG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wake (W)</td>
<td>Calm or active with eyes open, scanning eye movements, crying, feeding, brief eye closure with crying</td>
<td>Irregular, rapid and shallow</td>
<td>LVI or M</td>
<td>Eye blinks, REMs, scanning eye movements, transient eye closure when crying</td>
<td>Present, movement artifact</td>
</tr>
<tr>
<td>NREM (N)</td>
<td>Eyes closed, few movements, periodic sucking, occasional startle, reduced movement compared to W</td>
<td>Regular</td>
<td>TA, HVS, sleep spindles, or M</td>
<td>Eyes closed, not moving</td>
<td>Present, could be lower than Wake</td>
</tr>
<tr>
<td>REM (R)</td>
<td>Eyes closed, small movements</td>
<td>Irregular, some central pauses (may or may not reach criteria for apnea)</td>
<td>LVI or M (rarely HVS)</td>
<td>Eyes closed with REMs</td>
<td>Lowest in record, transient muscle activity may occur</td>
</tr>
</tbody>
</table>
Technical Specifications for Children

• Adult electrode derivations for EEG, EOG and chin EMG are acceptable for recording sleep except distances;

  – Between the chin EMG electrodes often needs to be reduced from 2 cm to 1 cm.

  – From the eyes in EOG electrodes often need to be reduced from 1 cm to 0.5 cm in children and infants with small head size.
• **Sleep spindles** may be seen by age 4-6 weeks post-term and are present in all normal infants by age 2-3 months post-term. At this age, spindles are asynchronous between the hemispheres, but become more synchronous over the first year of life.

• **K complexes** are usually present by age 4-6 months post-term.

• **Slow wave activity** ($\geq 75 \mu V$, 0.5-2 Hz typically in the frontal regions) may first appear by 2 mos of age and is usually present by age 4-5 months post-term.

• **NREM sleep** can be scored as stage N1, N2 or N3 in most infants by age 5-6 months post-term and occasionally in infants as young as 4 mos post-term.
Recognizing NREM vs REM in Infants < 6 months
Non-EEG Correlates

• **R- REM**
  – Irregular respiration
  – Chin EMG atonia
  – Transient muscle activity
  – Rapid eye movements

• **N- NREM**
  – Regular respiration
  – Non or rare vertical eye movements
  – Preserved chin EMG tone
Where Adult Clinicians Get Stuck in Scoring Sleep in Kids:

- Waking rhythms and sleep onset
- Recognizing variant frequencies and amplitudes, slower and bigger
Scoring Stage Wake (child)

Posterior dominant rhythm (PDR):

The dominant reactive EEG rhythm over the occipital regions in relaxed wakefulness with eyes closed which is slower in infants and young children and attenuates with eye opening or attention.

Frequency is:

- 3.5-4.5 Hz when first seen in infants 3-4 months post-term
- 5-6 Hz by 5-6 months
- 7.5 to 9.5 Hz by 3 years of age and amplitude is usually >50 μV
## Posterior Dominant Rhythm (PDR) in Children

<table>
<thead>
<tr>
<th>Age</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-4 months post-term</td>
<td>3.5-4.5 Hz</td>
</tr>
<tr>
<td>5-6 months</td>
<td>5-6 Hz</td>
</tr>
<tr>
<td>By 3 years</td>
<td>7.5 to 9.5 Hz</td>
</tr>
</tbody>
</table>

Amplitude is usually > 50 μV in children
## Posterior Dominant Rhythm (PDR) in Children

<table>
<thead>
<tr>
<th>Age</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 3-4 mos</td>
<td>Slow, irregular occipital changes</td>
</tr>
<tr>
<td>By 3-4 mos post-term</td>
<td>75% have irregular 50-100 $\mu$V occipital activity</td>
</tr>
<tr>
<td>By 5-6 mos</td>
<td>Some have 50-110 $\mu$V, 5-6 Hz</td>
</tr>
<tr>
<td>By 12 mos</td>
<td>70% have 50-110 $\mu$V, 5-6 Hz</td>
</tr>
<tr>
<td>By 3 yrs, normal post term</td>
<td>82% mean &gt; 8 Hz (range 7.5-9.5 Hz)</td>
</tr>
<tr>
<td>By 9 yrs</td>
<td>65% mean &gt; 9 Hz</td>
</tr>
<tr>
<td>By 15 yrs</td>
<td>65% have mean &gt;10 Hz</td>
</tr>
</tbody>
</table>

Average amplitude average 50-60 $\mu$V; 9% >100 $\mu$V (6-9 yr old); rarely < 30 $\mu$V
**Scoring W**

- **Alpha rhythm**: Trains of sinusoidal, 8-13 Hz activity recorded over the occipital region present with eye closure and which is reactive (attenuates with eye opening).

- **Eye blinks**: Conjugate vertical eye movements at a frequency of 0.5-2 Hz present in wakefulness with 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 child reads or visually scans the environment.

- **Rapid eye movements (REM)**: Conjugate, irregular, sharply peaked eye movements with an initial deflection usually lasting <500 msec. While rapid eye movements are characteristic of stage R sleep, they may also be seen in wakefulness with eyes open when subjects visually scan the environment.
Sleep Stages

Stage W (Wakefulness)

• Stage N1 (NREM 1)
• Stage N2 (NREM 2)
• Stage N3 (NREM 3)

• Stage N (NREM)
• Stage R (REM)
Stage W
AASM Scoring Manual Version 2.4

• Score epochs as stage W when more than 50% of the epoch contains EITHER or BOTH:

a. Age-appropriate posterior dominant rhythm over the occipital region (individuals generating alpha rhythm with eye closure)
b. Other findings consistent with stage W (all individuals)
   - Eye blinks (0.5-2 Hz)
   - Rapid eye movements associated with normal or high chin muscle tone
   - Reading eye movements
Wake
Stage N1
AASM Scoring Manual Version 2.3

In individuals who generate a posterior dominant rhythm, score stage N1 if the PDR is attenuated or replaced by low amplitude, mixed-frequency activity for more than 50% of the epoch in individuals who do not generate a posterior dominant rhythm, score stage N1 commencing with the earliest of ANY of the following:

- Activity in the range of 4-7 Hz with slowing of background frequencies by ≥1-2 Hz from those of stage W
- Slow eye movements
- Vertex sharp waves
- Hypnagogic hypersynchrony
- Diffuse or occipital-predominant, high-amplitude, rhythmic 3-5 Hz activity
N1 Sleep, 8 yr old
N1 Sleep, 8 yr old
Stage N2

_Same as adult rules_

• Sleep spindles are usually seen in infants by 2-3 months post-term

• K complexes are usually present 5-6 months post-term
N2 Sleep
Stage N2
Stage N3

*Same as the adult rules:*

- Slow wave activity in pediatric populations are often of high amplitude (100-400 µV), 0.5-2.0 Hz activity

- Maximal over the frontal regions

- First appears as early as 2 months, more often 3-4.5 months post-term
N3 Sleep
N3 Sleep
As the low frequency filter is increased, the slow wave activity disappears.
REM Sleep
Stage R and CA
Scoring Cardiac Events

- no changes except for definition of sinus rates:

- bradycardia for age 6 years and older is defined as a sustained HR <40 bpm

- in children under age 6 years, sinus bradycardia can be defined as 2 SD below the mean heart rate during sleep

- sinus tachycardia in children is defined as 2 SD above the mean heart rate during sleep
Scoring Arousals & Movements

• same as adult rules
Respiratory Monitoring in Children
Criteria for respiratory events during sleep for infants and children can be used for children <18 years, but an individual sleep specialist can choose to score children ≥13 years using adult criteria.
Respiratory Monitoring in Children

- apnea: oro-nasal thermal airflow sensor
- hypopnea: Nasal pressure transducer for airflow
- acceptable sensors for detection of respiratory effort: - esophageal manometry, or calibrated or uncalibrated inductance plethysmography (RIP)
- ** hypoventilation detection: transcutaneous ($T_C$) or end-tidal ($E_T$)CO$_2$
# Airflow Sensors Used In Pediatric Polysomnography

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Methodology</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermistor</td>
<td>Detects changes in temperature</td>
<td>Measures oral as well as nasal flow</td>
<td>Provides a qualitative rather than quantitative assessment of airflow</td>
<td>AASM recommends use for detection of apnea</td>
</tr>
<tr>
<td>Nasal pressure</td>
<td>Detects changes in nasal pressure</td>
<td>Provides a semi-quantitative assessment of airflow</td>
<td>Poor signal in mouth-breathing patients. Frequently obstructed by secretions etc.</td>
<td>AASM recommends use for detection of hypopnea</td>
</tr>
<tr>
<td>End-tidal CO2</td>
<td>Measures PCO$_2$</td>
<td>Provides a quantitative assessment of the PCO$_2$.</td>
<td>Poor signal in mouth-breathing patients. Frequently obstructed by secretions etc. May be over-sensitive in detecting airflow.</td>
<td>Use as a quantitative measure of PCO$_2$ rather than a primary measure of airflow.</td>
</tr>
<tr>
<td>Respiratory inductance plethysmography sum signal</td>
<td>Derives tidal volume from changes in inductance of coils</td>
<td>Tolerated well as no sensors on face.</td>
<td>Difficult to maintain calibrated. Cannot distinguish between obstructive apnea and paradoxing from other causes, e.g., in a young child or child with neuromuscular disease.</td>
<td>Useful for assessing respiratory effort in addition to airflow.</td>
</tr>
<tr>
<td>Pneumotachometer</td>
<td>Measurement of airflow by measuring pressure differences across a known resistance</td>
<td>Quantitative assessment of airflow</td>
<td>Requires a snug-fitting face mask</td>
<td>Use in CPAP studies</td>
</tr>
</tbody>
</table>
Monitoring Carbon Dioxide in Children

• end-tidal PCO₂ often malfunctions or provides falsely low values.

• it is crucial to obtain a plateau in the end-tidal waveform for the signal to be considered valid.
  – in infants, with faster respiratory rates, the end-tidal does not plateau.

• transcutaneous PCO₂ monitoring provides only a semi-quantitative index of trends in alveolar ventilation, and varies unpredictably from the PaCO₂
### Respiratory Events: “2 missed breaths”

<table>
<thead>
<tr>
<th></th>
<th>resp rate</th>
<th>2 breaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult</td>
<td>12/min</td>
<td>10 secs</td>
</tr>
<tr>
<td>Child</td>
<td>20/min</td>
<td>6 secs</td>
</tr>
<tr>
<td>Infant</td>
<td>40/min</td>
<td>3 secs</td>
</tr>
</tbody>
</table>
Score a respiratory event as an apnea when ALL 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), PAP device flow (titration study), or an alternative apnea sensor (diagnostic study).

b. The duration of the ≥90% drop in sensor signal lasts at least the minimum duration as specified by obstructive, mixed, or central apnea duration criteria.

c. The event meets respiratory effort criteria for obstructive, central or mixed apnea.
• Score an apnea as obstructive if it meets apnea criteria for at least the duration of 2 breaths during baseline breathing AND is associated with the presence of respiratory effort throughout the entire period of absent airflow
All events 8 yr old, severe OSA

120 second epoch: Events only need to be 2 skipped breaths.
Score an apnea as central if it meets apnea criteria, is associated with absent inspiratory effort throughout the entire duration of the event AND at least one of the following is met:

a. The event lasts ≥20 seconds.

b. The event lasts at least the duration of two breaths during baseline breathing and is associated with an arousal or a ≥3% arterial oxygen desaturation.

c. The event lasts at least the duration of two breaths during baseline breathing and is associated with a decrease in heart rate to less than 50 beats per minute for at least 5 seconds or less than 60 beats per minute for 15 seconds (infants under 1 year of age only).
Central Apnea
Centrals in REM, 18 month old
Score an apnea as mixed if it meets apnea criteria for at least the duration of 2 breaths during baseline breathing AND is associated with absent respiratory effort during one portion of the event AND the presence of inspiratory effort in another portion, regardless of which portion comes first.
Mixed Apnea
Pediatric Hypopnea Rules - NEW

- score a respiratory event as hypopnea if it meets ALL of the following criteria:

  - event is associated with a ≥30% fall in the amplitude of the nasal pressure or alternative signal compared to the pre-event baseline excursion
  
  - fall in the nasal pressure signal amplitude must last for 2 missed breaths

  - event is associated with an arousal, awakening, or ≥3% desaturation
Hypopnea
Hypopneas and Central Apnea
Optional: Central Hypopneas

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If electing to score central hypopneas, score a hypopnea as central if **NONE** 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 occurs during the event but not during pre-event breathing.
Central Hypopnea
Optional:
Respiratory Effort Related Arousals
AASM Scoring Manual Version 2.3

Score a respiratory event as a RERA if:

- Sequence of breaths lasting ≥2 breaths
- Increasing respiratory effort, flattening of the inspiratory portion of the nasal pressure (diagnostic study) or PAP device flow (titration study) waveform, snoring, or an elevation in the end-tidal PCO2
- Leads to arousal from sleep
- Sequence of breaths does not meet criteria for an apnea or hypopnea
Figure 11

RERAs/UARS: multiple arousals in 2-m epoch; this did not fulfill the 30% or 50% drop criteria 2-m epoch
Hypoventilation
AASM Scoring Manual Version 2.3

- Score as hypoventilation during sleep when >25% of the total sleep time as measured by either the arterial PCO2 or surrogate is spent with a PCO2 >50 mmHg
Obstructive Hypoventilation
Periodic Breathing
AASM Scoring Manual Version 2.3

• Score a respiratory event as periodic breathing if there are ≥3 episodes of central pauses in respiration (absent airflow and inspiratory effort) lasting >3 seconds separated by ≤20 seconds of normal breathing.
Periodic Breathing
## Normative Sleep Architecture Values for Children Ages 1-18 yr

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Usual Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep Efficiency (%)</td>
<td>89%, highly variable</td>
</tr>
<tr>
<td>Sleep Latency (min)</td>
<td>23, highly variable</td>
</tr>
<tr>
<td>REM Latency</td>
<td>87-155 (&lt;10 yr), 136-156 (&gt;10 yr)</td>
</tr>
<tr>
<td>Arousal index (N/hr)</td>
<td>9-16</td>
</tr>
<tr>
<td>Stage N1 (% TST)</td>
<td>4-5</td>
</tr>
<tr>
<td>Stage N2 (% TST)</td>
<td>44-56</td>
</tr>
<tr>
<td>Stage N3 (% TST)</td>
<td>29-32 (&lt;10 yr), 20 (&gt;10 yr)</td>
</tr>
<tr>
<td>Stage R (% TST)</td>
<td>17-21 (↑ in young children)</td>
</tr>
</tbody>
</table>

Summary

Infant scoring:
- Sleep onset REM until 2-3 months post-term
- Regularity or irregularity of respiration
- Chin EMG often unreliable
- Eyes open is best to determine Wakefulness

Pediatric scoring rules are similar to adults except:
- Technical adjustments for age
- Sinus heart rates vary with age
- Duration of respiratory events
- Monitoring CO2
<table>
<thead>
<tr>
<th>Respiratory Event</th>
<th>Child</th>
<th>Adult</th>
</tr>
</thead>
</table>
| Obstructive             | 2 missed breath duration  
                          No corroboration required                                           | 10 sec duration  
                          No corroboration required                                           |
| Central                 | 2 missed breath duration*  
                          Assoc: 3% desat, arousal, or HR <50 for 5 sec**  
                          If 20 sec duration, no corroboration needed  
                          Include CA's from PB in CAI                                         | 10 sec duration  |
| Hypopnea                | 2 missed breaths duration  
                          ≥ 30% ↓ NP or back-up  
                          Assoc: 3% desat, arousal, or HR <50 for 5 sec*  
                          | 10 sec duration  
                          ≥ 30% ↓ NP + 4% desat or  
                          ≥ 30% ↓ NP + 3% or arousal                                           |
| Hypoventilation         | ≥ 25% TST with CO₂ >50 mmHg  
                          EtCO₂ or tcCO₂ or arterial  
                          **Recommended**                                                       | ↑ CO₂ >55 mmHg for ≥ 10 min  
                          ↑ CO₂ ≥ 10 mmHg from wake supine to sleep w/ values >50 mmHg for >10 min  
                          Optional                                                            |

*“How To” not specified, consider censor @ 5 s; **if age < 1 yr, use <60 bpm for 15 sec
References

Thank you!