THE DEVELOPMENT OF SLEEP IN INFANTS AND CHILDREN
FALL FOCUS, 2018

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OBJECTIVES

• At the completion of this session the attendees will be able to
  • Describe the progression of normal sleep from infancy through the school aged child
  • Summarize the most common age related sleep disturbances/disorders
  • Assess the bi-directionality between behavioral and physiologically sleep related issues
OBJECTIVES FOR PREMIE/NEONATAL AND INFANT SLEEP

• Describe the progression of sleep over the first year of life
• Consider the importance of maturational milestones captured on the EEG
• Define corrected age
SLEEP

• Important neurological marker of maturation
• What is not there is important too!
• Parental, cultural and ecological factors interact bi-directionally
  • Breast vs bottle feeding
  • Negative sleep associations
  • Bed sharing

Redecker, Developmental Aspects of Normal Sleep in Redecker and McEnany 2011)
TERMS TO KNOW-
PREMIE/NEONATE

- Trace Discontinue
- Trace Alternant

### Age Terminology During the Perinatal Period

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Units of Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gestational age</td>
<td>Time elapsed between the first day of the last menstrual period and the day of delivery</td>
<td>Completed weeks</td>
</tr>
<tr>
<td>Chronological age</td>
<td>Time elapsed since birth</td>
<td>Days, weeks, months, years</td>
</tr>
<tr>
<td>Postmenstrual age</td>
<td>Gestational age + chronological age</td>
<td>Weeks</td>
</tr>
<tr>
<td>Corrected age</td>
<td>Chronological age reduced by the number of weeks born before 40 weeks of gestation</td>
<td>Weeks, months</td>
</tr>
</tbody>
</table>

AAP, 2004
Age terminology during the perinatal period.

POSTMENSTRUAL AGE

GESTATIONAL AGE

CHRONOLOGICAL AGE

First Day of Last Menstrual Period

Conception (Implantation/Fertilization)

Birth

Expected Date of Delivery

Corrected Age

Date of Assessment

Committee on Fetus and Newborn Pediatrics
2004;114:1362-1364
CIRCADIAN RHYTHM DEVELOPMENT

- The circadian timing system undergoes major developmental changes within the first months after birth:
  - At age 1 month, the 24-h core body temperature rhythm emerges;
  - At age 2 months, infants begin to sleep more at night than during the day;
  - At age 3 months, endogenous production of the circadian driven hormones melatonin, cortisol starts to cycle in a 24-h rhythm.
SLEEP CONSOLIDATION
NEONATAL EEG

A 5-step process should be performed when analyzing a neonatal EEG. The 5 steps consist of the following:

- Knowledge of the post-menstrual age and topography of the infant's head
- Identification of artifacts in the EEG
- Identification of sleep and wake states
- Feature extraction
- Classification of the record as normal or abnormal and the clinical correlation provided to the clinician

Koser et al
http://emedicine.medscape.com/article/1139599-overview#aw2aab6b4
IMPORTANT TO KNOW

- EEG matures according to time
- Maturational milestones
  - Sleep spindles
  - K-Complex
  - Discontinuous Continuous
- Sleep features
  - REM onset until ~4 months
  - Sleep cycles ~50-60 min
  - REM sleep ~50% TST, gradually decreasing

- Synchrony: this term refers to the simultaneous appearance of morphologically identical waveforms in areas on the same side or opposite sides of the head
- Symmetry: symmetry refers to the occurrence of approximately equal amplitude, frequency, and form of EEG activities over homologous areas on opposite sides of the head.

- 10/20 System VERY important
A. Ages for Which Infant Sleep Staging Rules Apply

1. Infant sleep staging rules should be used to score sleep and wakefulness in infants 0-2 months post-term (37-48 weeks conceptional age). \textsuperscript{N1,N2,N3,N4} RECOMMENDED

\textbf{Note 1.} Conceptional age (CA) is gestational age (GA) at birth plus the number of weeks postpartum. GA is the time elapsed between the first day of the mother's last menstrual period and the day of delivery expressed in completed weeks. If the pregnancy was achieved using assisted reproductive technology, GA is calculated by adding 2 weeks to the CA. Chronological age (or postnatal or legal age) is the time elapsed since birth (can be expressed in days, months, or years).

\textbf{Note 2.} At birth, an infant is classified as one of the following: premature (<37 weeks gestation); full-term (37-42 weeks); or post-term (born after 42 weeks). A neonate is a child during the first 28 days after birth; an infant is a child age 1 to 12 months.\textsuperscript{1}

\textbf{Note 3.} Knowing an infant's CA is crucial for interpreting the normalcy, immaturity or abnormality of an EEG or PSG because the brain and the EEG continue to develop and mature at a similar rate independent of whether the infant is in utero or post-delivery.

\textbf{Note 4.} For premature infants (<37 weeks CA) refer to discussion in the Pediatric and Infant Scoring Task Force review paper.\textsuperscript{2}
A. Ages for Which Pediatric Sleep Staging Rules Apply

1. Pediatric sleep staging rules can be used to score sleep and wakefulness in children 2 months post-term or older.\textsuperscript{1,2}

**Note 1.** For children less than 2 months post-term, refer to IV. Sleep Staging Rules Part 3: Rules for Infants.

**Note 2.** There is no precise upper age boundary for pediatric sleep staging rules; refer to discussion in the Pediatric Task Force review paper.\textsuperscript{1}
C. General Scoring of Sleep Stages

1. The following terminology should be used when scoring sleep in children 2 months post-term or older:
   a. Stage W (Wakefulness)
   b. Stage N1 (NREM 1)
   c. Stage N2 (NREM 2)
   d. Stage N3 (NREM 3)
   e. Stage N (NREM)
   f. Stage R (REM)

Because of the variability of sleep in infants, 4 possible scenarios for scoring NREM sleep are described below:

2. If all epochs of NREM sleep contain no recognizable sleep spindles, K complexes or high-amplitude 0.5-2 Hz slow wave activity, score all epochs of NREM sleep as stage N (NREM).

3. If some epochs of NREM sleep contain sleep spindles or K complexes, score these as stage N2 (NREM 2). If in the remaining NREM epochs, there is no slow wave activity comprising more than 20% of the duration of epochs, score as stage N (NREM).

4. If some epochs of NREM sleep contain greater than 20% slow wave activity, score these as stage N3 (NREM 3). If in the remaining NREM epochs, there are no K complexes or spindles then score as stage N (NREM).

5. If NREM is sufficiently developed that some epochs contain sleep spindles or K complexes and other epochs contain sufficient amounts of slow wave activity, then score NREM sleep in this infant as either stage N1, N2 or N3 as in an older child or adult.
## MATURATIONAL FEATURES

<table>
<thead>
<tr>
<th>Waveform</th>
<th>Age of Initial Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep spindles</td>
<td>6 weeks - 3 months post-term</td>
</tr>
<tr>
<td>K complexes</td>
<td>3-6 months post-term</td>
</tr>
<tr>
<td>Slow wave activity</td>
<td>2-5 months post-term</td>
</tr>
<tr>
<td>Posterior dominant rhythm</td>
<td></td>
</tr>
<tr>
<td>Frequency of 3.5-4.5 Hz</td>
<td>3-4 months post-term</td>
</tr>
<tr>
<td>Frequency of 5-6 Hz</td>
<td>5-6 months post-term</td>
</tr>
<tr>
<td>Frequency of 7.5-9.5 Hz</td>
<td>3 years</td>
</tr>
<tr>
<td>Mean frequency of 9 Hz</td>
<td>9 years</td>
</tr>
<tr>
<td>Mean frequency of 10 Hz</td>
<td>15 years</td>
</tr>
<tr>
<td>Vertex sharp waves</td>
<td>4-6 months post-term</td>
</tr>
<tr>
<td>Hypnagogic hypersynchrony (HH)</td>
<td>3-6 months post-term</td>
</tr>
</tbody>
</table>
IMPORTANCE OF SPINDLES

- Sleep spindles are associated with neurocognitive development in children, especially with memory consolidation.
- There are significant differences between children with obstructive sleep apnea (OSA) and controls.
- Children with mild OSA demonstrate a different pattern of sleep spindle activity (less spindle activity).
- Sleep spindle activity seems to be involved with mechanisms related with neurocognitive consequences in children with OSA.

MORE ABOUT SPINDLES

• Sleep spindles are linked to
  • cognitive abilities, including working memory and problem solving
  • learning efficiency,
  • memory consolidation.

• Data from a growing number of studies indicate sleep spindle abnormalities in individuals with
  • mental retardation
  • autism spectrum disorder
  • neurodegenerative disease
  • sleep disorders
  • and mental illness

https://www.hindawi.com/journals np/2016/3670951/
C. General Scoring of Sleep Stages

1. The following terminology should be used when scoring sleep in infants 0-2 months post-term (37-48 weeks CA):^1,^2
   a. Stage W (Wakefulness)
   b. Stage N (NREM)
   c. Stage R (REM)
   d. Stage T (Transitional)

2. Score epochs using the following rules: ^RECOMMENDED
   a. Score sleep stages in 30-second, sequential epochs commencing at the start of the study
   b. Assign a stage to each epoch
   c. If two or more stages coexist, assign the stage comprising the greatest portion of the epoch
   d. If two or more PSG characteristics are discordant for stage R or stage N sleep, score the epoch as stage T (Transitional) sleep
   e. Score sleep onset as the first epoch of sleep.^3

3. Sleep and wakefulness in infants 38 to 48 weeks CA are scored based on behavioral observation; regularity or irregularity of respiration; and EEG, EOG, and chin EMG patterns defined in Tables 1-6. ^RECOMMENDED

4. Score sleep based on behavioral characteristics as defined in Table 1. ^RECOMMENDED
## AASM Scoring Rules - Infants

### Table 1. Behavioral characteristics of sleep stages.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Behavioral Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wake</td>
<td>Calm or active with eyes open, scanning eye movements; Brief eye closure can occur with crying</td>
</tr>
<tr>
<td>N</td>
<td>Eyes closed, few movements, sucking can occur</td>
</tr>
<tr>
<td>R</td>
<td>Eyes closed, REM seen under closed eyelids, squirming, sucking, grimacing, small movements of the face or limbs</td>
</tr>
</tbody>
</table>

### Table 2. Respiration characteristics of sleep stages.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Respiration Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wake</td>
<td>Irregular, rapid, and shallow</td>
</tr>
<tr>
<td>N</td>
<td>Regular</td>
</tr>
<tr>
<td>R</td>
<td>Irregular, some central pauses (may or may not meet criteria for apnea)</td>
</tr>
</tbody>
</table>
### Table 3. EEG characteristics of sleep stages.\(^{N7,N8}\)

<table>
<thead>
<tr>
<th>Patterns</th>
<th>EEG Characteristics</th>
<th>Stage(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discontinuous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trace alternant (TA)(^{N9,N10})</td>
<td>This EEG pattern in full-term infants is generally only seen in stage N sleep. It is characterized by at least 3 alternating runs of bilaterally symmetrical synchronous high voltage (50-150 (\mu V)) bursts of 1-3 Hz delta activity lasting 5-6 seconds (range 3-8 seconds) alternating with periods of lower amplitude (25-50 (\mu V)) 4-7 Hz theta activity (range 4-12 seconds).</td>
<td>N</td>
</tr>
</tbody>
</table>
# AASM Scoring Rules - Infant

<table>
<thead>
<tr>
<th>Continuous</th>
<th>Description</th>
<th>Stage(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low voltage irregular (LVI)</td>
<td>Continuous low voltage mixed-frequency activity with delta and predominantly theta activity.</td>
<td>R, Wake</td>
</tr>
<tr>
<td>High voltage slow (HVS)(^{N11})</td>
<td>Continuous synchronous symmetrical predominantly high voltage 1-3 Hz delta activity.</td>
<td>N, rarely R</td>
</tr>
<tr>
<td>Mixed (M)</td>
<td>Both high voltage slow and low voltage polyrhythmic components; these are intermingled with little periodicity. The amplitude is lower than seen in the HVS pattern.</td>
<td>Wake, R, rarely N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waveforms of interest</th>
<th>Description</th>
<th>Stage(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep spindles(^{N12,N13})</td>
<td>12 to 14 Hz, asynchronous, most prominent in midline central (CZ) and central derivations. Occur only in stage N sleep.</td>
<td>N</td>
</tr>
</tbody>
</table>
## AASM Scoring Rules - Infant-Summary

<table>
<thead>
<tr>
<th>Stage</th>
<th>Behavioral</th>
<th>Respiration</th>
<th>EEG</th>
<th>EOG</th>
<th>Chin EMG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wake</td>
<td>Eyes open, crying, feeding</td>
<td>Irregular</td>
<td>LVI or M</td>
<td>REMs, blinks, scanning eye movements</td>
<td>Present</td>
</tr>
<tr>
<td>N</td>
<td>Reduced movement relative to wake (Eyes closed, periodic sucking, occasional startle)</td>
<td>Regular</td>
<td>TA, HVS, sleep spindles, or M</td>
<td>Eyes closed with no EMs</td>
<td>Present or low</td>
</tr>
<tr>
<td>R</td>
<td>Eyes closed Small movements</td>
<td>Irregular</td>
<td>LVI or M (rarely HVS)</td>
<td>REMs or Eyes closed with no EMs&lt;sup&gt;16&lt;/sup&gt;</td>
<td>Low, TMA may occur</td>
</tr>
</tbody>
</table>

LVI = low voltage irregular, M = mixed, TA = trace alternant, HVS = high voltage slow, REMs = rapid eye movements.
Tracé discontinu (TD). An infant of 24 weeks' gestational age at age 4 weeks with an intraventricular hemorrhage and left shoulder twitching. Periods of alternating high-voltage mixed frequencies and periods of voltage suppression are normal findings before 28-30 weeks' postconceptional age.

Koszer et al http://emedicine.medscape.com/article/1139599-overview#aw2aab6b4
TRACÉ ALTERNANT

Tracé alternant (TA). Un nourrisson de 42 semaines d'âge gestationnel naît par césarienne, avec des scores d'Apgar de 4/4/4 et d'épisodes de fréquentes mouvements de bras et de jambes. TA se produit avec des respirations régulières, une EMG à faible voltage et des mouvements d'œil minimaux. Les périodes d'atténuation de voltage peuvent survenir périodiquement pendant le sommeil calme.
QUIET SLEEP

Fig. 8. An EEG segment of a 41-week 1-day-old female that documents high-voltage slow quiet sleep. Regular respirations and the absence of rapid eye movements are noted.

Scher, M (2008) Ontogeny of EEG-sleep from neonatal through infancy periods
Fig. 7. An EEG segment of a 40-week 2-day-old female, depicting mixed frequency active sleep, characterized by continuous EEG, body movements, rapid eye movements (arrowhead), and irregular respirations and heart rate. Note the onset of a spontaneous arousal coincident with a temporary flattening of the EEG background.

Scher, M (2008) Ontogeny of EEG-sleep from neonatal through infancy periods
## SUMMARY OF SLEEP RELATED CHANGES

### Table 1. State-related Polygraphic Changes in the Neonate

<table>
<thead>
<tr>
<th>Physiological Measure</th>
<th>Awake/Sleep State</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Awake</td>
<td>Active Sleep</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quiet Sleep</td>
</tr>
<tr>
<td>EMG (chin)</td>
<td>Phasic and tonic</td>
<td>Phasic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tonic</td>
</tr>
<tr>
<td>Respiration</td>
<td>Irregular</td>
<td>Irregular</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regular</td>
</tr>
<tr>
<td>Eye movements</td>
<td>Random or pursuits</td>
<td>Rapid eye movements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Absent</td>
</tr>
<tr>
<td>Body movements</td>
<td>Facial, limbs, and body</td>
<td>Sucking and irregular limb movements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>
DEVELOPMENTAL FACTORS
NEWBORNS-6 MONTHS

• Sleep
  • NB Require 16-18 hours/day; polyphasic, ~equal between night and day; expectation that child awakens
  • ~6 Months 14-16 hours/day; sleep fairly consolidated into night; fewer daytime naps
  • More sensitive to light/dark cues

• Development
  • Primarily met by caregiver

• Communication
  • Crying

• Increased mobility

Vriend, et al., 2011; Johnson and Mindel, 2011
0-2 MONTHS

Mixed

HVS

Trace Alternant

Low Voltage
Irregular
ASYNCHRONOUS SPINDLES
DOCUMENTATION: VERY IMPORTANT

• Pay particular attention to:
  • the presence and type of eye movements,
  • facial movements
  • respiration (regular or irregular),
  • sucking, crying, grimacing
  • Suck-swallow incoordination
UPDATED SUID AND SIDS INFO

• SUID
  • any sudden and unexpected infant death, whether explained or unexplained

• SIDS
  • Sudden Infant Death Syndrome
  • SIDS is the leading cause of death among infants aged 1–12 months, and is the third leading cause overall of infant mortality in the United States

• Deaths still occurring ~ 3500/year
Breakdown of Sudden Unexpected Infant Death by Cause, 2015

- Sudden infant death syndrome: 43%
- Unknown cause: 32%
- Accidental suffocation and strangulation in bed: 25%
SUDDEN UNEXPECTED INFANT DEATH

The graph shows the trend of deaths per 100,000 live births due to different causes from 1990 to 2015. The combined SUID rate has seen a significant decrease over the years. The sudden infant death syndrome has also decreased, but at a slower rate compared to combined SUID. The unknown cause has shown a slight decrease, while accidental suffocation and strangulation in bed has remained relatively stable.
SAFE SLEEP/SAFE BABIES

• Place the baby to sleep on his back for every sleep
• Place the baby to sleep on a firm sleep surface
• Keep soft objects, loose bedding, or any objects that could increase the risk of entrapment, suffocation, or strangulation out of the crib.
• Place your baby to sleep in the same room where parents sleep but not the same bed.
• Breastfeed as much and for as long as possible.
• Schedule and go to all well-child visits.
• Keep the baby away from smokers and places where people smoke
SAFE SLEEP/SAFE BABIES

- Do not let the baby get too hot.
- Offer a pacifier at nap time and bedtime.
- Do not use home cardiorespiratory monitors to help reduce the risk of SIDS.
- Do not use products that claim to reduce the risk of SIDS
SUMMARY

• Infant sleep patterns develop over the course of the first year in a step-wise fashion.
• Documentation is crucial during sleep studies.
• SIDS is a leading cause of infant mortality.
• Sleep onset and night-time awakenings are common.
OLDER INFANTS/TODDLERS

• 6-12 months/12-24 months
• TST slightly decreased ~13 hours per day
• 6-9 months, most are sleeping through the night
  • Night waking's are still common (50% waking at least once/week)
  • Night time bottles
• Naps continue, but are shorter
• Development
  • Develops attachment to caregiver---separation anxiety
  • May have learned to fall asleep with caregiver
• Communication
  • Increased mobility and verbalization
• ~20-30% develop BIC SOA

Vriend, et al., 2011; Johnson and Mindel, 2011
EARLY CHILDHOOD

• 2-6 Years
• Transition from crib to bed
• Sleep duration decreases
• Daytime napping decreases/eliminated (<10% 6 year old nap)
• 25-50% have sleep problems
• Increased mobility and language
• Development
  • Initiative and independence
  • Rewards/punishment

Vriend, et al., 2011; Johnson and Mindel, 2011
MIDDLE CHILDHOOD

- 6-12 years
- Should be sleeping 9-10 hours per night
  - Highly energetic; EDS should be warning sign
  - Napping rare
  - Night Owl vs Lark emerge
- ~37% have a parent reported bedtime problem
- Development
  - Peer relationships more important
  - More technology usage
  - Possible increased social anxiety
  - Increasing social and school obligations

Vriend, et al., 2011; Johnson and Mindel, 2011
ADOLESCENCE

- 12-18 years
- ~ 2 hour bedtime delay
  - Social factors
    - Electronics; work; friends and school activities
  - Biological
- Typically have insufficient sleep during the week; make up for this on weekend
- Increased use of caffeine or energy drinks
- Development
  - Decreased parental influence
  - Moodiness and conflicts-- autonomy

Vriend, et al., 2011; Johnson and Mindel, 2011
Between 15% and 30% of 2- to 5-year-old children experience regular difficulties falling asleep (i.e., bedtime problems) or sleeping through the night (i.e., night waking). 

Turnbull, Reid, and Morton, 2013; SLEEP
SLEEP PROBLEMS-YEAR ONE

• 10-30% of children have a sleep problem
• Behavioral Insomnia
  • Sleep onset
  • Night waking
• Colic
SLEEP PROBLEMS: EARLY CHILDHOOD

• Earlier and regular bedtimes (rituals) associated with longer sleep duration
• May have frequent nighttime waking's
  • Temperament; inability to self-soothe
• Exhibit Signs of sleep related breathing problems
Sleep Disorders

Figure 1: A simple model of neighborhood and sociobehavioral determinants of sleep problems in children and adolescents.
AUTISM AND SLEEP

• 1 in 68 children are on the autism spectrum
• Occurs in all racial, ethnic and social economic status
• 4.5 times more common among boys (CDC, retrieved March 5, 2017)
• 53% of children (2–5 years of age) with ASD have a sleep problem

Take Home Point
Sleep development may be different in ASD

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4770638/
AUTISM AND SLEEP: A HELPFUL RESOURCE

Strategies to Improve Sleep in Children with Autism Spectrum Disorders: A Parent’s Guide

Many children with ASD have difficulty with sleep. This can be stressful for children and their families. This informational booklet is designed to provide parents with strategies to improve sleep in their child affected by autism spectrum disorders (ASD). The suggestions in this tool kit are based on both research and clinical experience of sleep experts.

Download the Sleep Tool Kit (Parent Booklet) here!

https://www.autismspeaks.org/science/resources-programs/autism-treatment-network/tools-you-can-use/sleep-tool-kit
SUMMARY

• First 2 -3 months-EEG maturation
• Post 2 months, basically scoring the same as adults
• SUID is declining, important to know the safe sleep rules
• Sleep problems occur throughout childhood
• Many factors impact the sleep of children
• Autism spectrum is a growing problem and should be taken into consideration when assessing childhood sleep
Contact Info
Robyn.woidtke@gmail.com

Thank you