Developmental Changes to Sleep Biology Affect Adolescent Sleep

Mary A. Carskadon, PhD
EP Bradley Hospital SleepforScience Research Lab
Alpert Medical School of Brown University
The central question

Why do adolescents (once such champion sleepers, so eager to start the day) struggle against going to sleep in the evening and struggle to wake up in the morning?
Adolescent Sleep Biology
Density of neuronal connections, cerebral metabolic rate, and brain wave amplitude decline during adolescence.
The “look” of sleep changes

Brain structure/processes and sleep phenomenology change across adolescence, but how does sleep regulation change developmentally and how does this play out behaviorally?
Sleep regulation—2-process model (Borbély, 1982)

What developmental changes occur to the circadian timing system?
Circadian Regulation Changes: Measures to Assess Process C

• **Phase preference or chronotype**—when do you prefer to be active, sleeping, etc.?

• **Phase**—what time is it in your brain?

• **Period**—what is the internal day length?

• **Phase response to light**—how does phase respond to light?

• **Amplitude** of circadian rhythms
Animals with Adolescent Phase Delay

• Macca mulatta (Rhesus monkeys)
• Octodon degus (degu)
• Rattus norvegicus (laboratory rat)
• Mus musculus (laboratory mouse)
• Psammomys obesus (fat sand rat)
• Homo sapiens (humans)

Hagenauer et al., Devel Neurosci, 2009
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Hagenauer et al., *Devel Neurosci*, 2009
Phase Preference in 6th Graders

Carskadon, Vieira & Acebo *Sleep* 1993

![Graph showing phase preference in 6th graders]

**A. Girls**  \( F(2,263) = 3.12 \ p<.05 \)

**B. Boys**  \( F(1,175) = 3.46 \ p<.10 \)
Chronotype and Adolescence

- Time of weekend midsleep
- 2nd decade = big delay
- “Biological marker for the end of adolescence?”

Ronneberg et al., Current Biol., 2004
Melatonin Phase and Puberty Stage

- Melatonin = ‘hormone of darkness’
- Melatonin = marks the brain’s nighttime, gate for sleep
- Adolescence = later timing of melatonin

Carskadon et al. NYAS, 2004
Greater sensitivity to evening light at puberty onset

Crowley et al., JCEM, 2015
Intrinsic Circadian Period: Adolescents vs. Adults

Carskadon & Acebo *Sleep*, 2005
Salivary Melatonin Amplitude

Crowley et al., *Dev Psychobiol*, 2011
Circadian Rhythms Summary

• Timing (phase) delays during adolescence

• Phase-dependent light sensitivity may change

• Longer intrinsic period in may delay phase

• Reduced amplitude of the circadian clock may dampen the signal for sleep

• Result: late nights are favored (so, too, late mornings)
What developmental changes occur to the sleep-wake homeostasis (sleep pressure) system?
Homeostatic Changes: Measures to Assess Process S

• Slow wave sleep—(NREM 3 + 4; N3) sleep stages
  [Qualitative: deep sleep]

• Slow wave activity (SWA) in sleep
  [Quantitative: slow EEG waves]

• Sleep propensity—speed of falling asleep
  [sleep latency]
An Exemplary Night of sleep...in a well-slept teen.

**CYCLE OF SLEEP IN A NORMAL TEENAGER**

- **Slow Wave Sleep**
- **REM Sleep**

**Time of Night:**
- 23:00 = Lights Out
- 08:00 = Lights On

**NREM:**
1. Wake
2. NREM
   - 2
   - 3
   - 4

**REM:**
- Movement Arousal
- Transient Arousal
Changes of Slow Wave Sleep and EEG Slow Waves (SWA)

Tanner 1 (12.3 years)

Tanner 5 (14.5 years)

Jenni & Carskadon, *Sleep*, 2004
Sleep pressure dissipation does not change in adolescence

Jenni & Carskadon, *Sleep* 2004
Across pubertal development, SWA accumulation rate slows

**Tanner Stages 1/2**

- $t_d = 2.8 \text{ h}$
- $t_i = 8.9 \text{ h}$

**Tanner Stage 5**

- $t_d = 2.7 \text{ h}$
- $t_i = 12.1 \text{ h}$

Jenni, Achermann & Carskadon *Sleep*, 2005
Proposed developmental changes in accumulation of sleep pressure as a function of time since waking depicted for different ages. Sleep pressure accumulates more slowly during the day with increasing age.

Sleep pressure accumulation: sleep propensity

Taylor et al., J Sleep Res, 2005
Summary of Process S Change

• Recovery sleep process does not change across adolescence
  • Need for sleep is stable (?)

• Accumulation of sleep pressure slows
  • Staying awake longer is easier

• Result: late nights are easier to achieve, but the same amount of sleep is needed
Adolescent sleep biology…

The main point is that the bioregulatory factors—sleep/wake homeostasis and circadian biology—both favor a delay in the timing of sleep as adolescence progresses.

The bottom line is: too little sleep for school days and social jet lag due to circadian and homeostatic factors.
Social jet lag in a middle school girl: grade 6, age 12