How Developmental Changes in Sleep Biology May Affect Adolescent Behavior

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Conflict of Interest

• none
Two-Process Model of Sleep Regulation (Borbély, 1982)

- Sleep propensity increases as waking accumulates and dissipates with sleep
- Sleep propensity oscillates with a daily (circadian) variation

Observed features of the clock during adolescence
Species Manifesting Juvenile Phase Delay

• Homo sapiens (humans)
• Macca mulatta (Rhesus monkeys)
• Octodon degus (degu) [some ?]
• Rattus norvegicus (laboratory rat)
• Mus musculus (laboratory mouse)
• Psammomomys obesus (fat sand rat)

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

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

B. Boys  \( F(1,175) = 3.46 \ p<.10 \)

Carskadon, Vieira & Acebo *Sleep* 1993
Chronotype and Adolescence

Roenneberg et al., *Current Biol.*, 2004
Melatonin Onset (DLMO) Phase and Puberty Stage

Carskadon et al. NYAS, 2004
Activity offset delays in pubertal Macaques

- Puberty: phase delay in the daily offset of activity
- If puberty is inhibited by zinc deprivation, the phase delay does not occur.

Golub et al., In: *Adolescent development...*, 2002
Pubertal Phase Delay in Degus

- Activity onset delays at puberty in both males and females

First preputial and vaginal openings develop at about 8-14 weeks

Hummer et al., 2007
What might underlie/support/influence a phase delay?

• Changes in light exposure
  – Staying up later // more late light
  – Waking up later // less morning light
Adolescent Self-Report

Bedtime

Risetime

Jenni & Carskadon, SRS BSG, 2005
What might underlie phase delay?

• Changes in light exposure
  – Staying up later // more late light
  – Waking up later // less morning light

• Change in phase-dependent sensitivity to light exposure
Exaggerated phase delay to light in pubertal female mice

What might underlie phase delay?

• Changes in light exposure
  – Staying up later // more late light
  – Waking up later // less morning light

• Change in phase-dependent sensitivity to light exposure

• Longer intrinsic circadian period (i.e., longer internal day length)
Longer Period = Later Phase

Hagenauer et al., *Devel Neurosci*, 2009
Intrinsic Circadian Period: Adolescents vs. Adults

Carskadon & Acebo *Sleep*, 2005
What might underlie phase delay?

• Changes in light exposure
  – Staying up later // more late light
  – Waking up later // less morning light
• Change in phase-dependent sensitivity to light exposure
• Longer intrinsic circadian period (i.e., longer internal day length)
• Diminished amplitude of the circadian rhythm
Salivary Melatonin Amplitude

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

• Phase is delayed during adolescent development
  – Phase preference (chronotype) is later
  – Melatonin phase is later
• Phase-dependent light sensitivity may change
• Intrinsic period in adolescents may affect phase
• Reduced amplitude of the circadian clock may dampen the signal for sleep

• Result: late nights are favored (so, too, late mornings)
Features of Adolescent Sleep-Wake Homeostasis (Human)
Sleep Homeostasis Model (Borbély 1981)
Adolescent Brain Changes

Density of neuronal connections, cerebral metabolic rate, and brain wave amplitude decline during adolescence

Feinberg et al., *J Theor Biol.*, 1990
The “look” of sleep changes

Tanner 1 (Age = 10)
Stage 2
Stage 4
REM

Tanner 5 (Age = 15)
Stage 2
Stage 4
REM

Slow Wave Sleep & Slow Wave Activity

Tanner 1 (12.3 years)

Tanner 5 (14.5 years)

Jenni & Carskadon *Sleep*, 2004
Sleep phenomenology changes; does sleep regulation?
Sleep pressure dissipation does not change in adolescence

- SWA dissipation is unchanged across pubertal development

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

Tanner Stages 1/2

Tanner Stage 5

$td = 2.8 \text{ h}$  $ti = 8.9 \text{ h}$  Decay Time Constant  Rise Time Constant

$td = 2.7 \text{ h}$  $ti = 12.1 \text{ h}$

Jenni, Achermann & Carskadon *Sleep*, 2005
Sleep tendency & extended wakefulness

Taylor et al., J Sleep Res, 2005
Model of Process S in Development

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.

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 Behavior

- Bedtime becomes later
- Rise time becomes earlier (school dependent)
- Total amount of sleep is reduced
- Chronic insufficient sleep has its strongest effects on sleepiness in the morning, especially if waking at an adverse circadian phase
- Evening alertness is bolstered by the clock-dependent alerting signal
When Sleep Biology and Social Systems Interact: School Start Time
MSLT in high school students

- 10th grade
- Start time = 0720
- No schedule manipulation
- Sleeping about 7 hours a night

Carskadon et al. *Sleep*, 1998
REM sleep tendency also affected

Carskadon et al. *Sleep*, 1998
Consequences of Clock/Homeostasis/Lifestyle Interaction

- Variable sleep timing
- Chronic insufficient sleep
- Deficits in mood, learning, impulse control, etc.
- Excessive sleepiness & possible caffeine use?
Caffeinated Beverage Daily

NSF Sleep in America Poll, 2006
Evening caffeinated beverages disturb sleep?

Greater sleepiness and more caffeine use?
A sampling of gaps...

- What affect do caffeinated energy drinks have on nighttime sleep?
- Do caffeinated energy drinks affect circadian rhythms?
- What is the impact of caffeinated energy drinks on alertness, performance, attention, and learning acquisition in the daytime?
- Do these beverages affect sleep-dependent learning?
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