Adolescent Sleep Patterns and Behavioral Health Risks

Mary A Carskadon, PhD
Chronobiology and Sleep Laboratory of EP Bradley Hospital
Department of Psychiatry and Human Behavior
Alpert Medical School of Brown University
Director, Center for Sleep and Circadian Rhythms in Child and Adolescent Mental Health

No conflicts of interest
The central observation

Adolescents—once such champion sleepers, so eager to start the day—begin to struggle against going to sleep in the evening and struggle to wake up in the morning.

Cincinnati Enquirer, 10/11/99
The central observation is not new...

Terman and Hocking (1913) summed up this prominent developmental progression in adolescent sleep: “It may be that adolescence tends to change the individual from the vesperal to the matinal type of sleeper.”

A mother’s perspective in 2022...

“My [13-y-o] son’s sleep is a phase-shifted nightmare. That, too, seemed to happen overnight. I spent his early childhood wishing I could sleep past 5:30 on a Saturday morning, and now I spend most of Saturday trying to get him out of bed by dinner.”
Adolescent sleep timing is challenging.

Overview

- Biology
  - Circadian timing system
  - Sleep/wake homeostasis
- Behavior
  - Psychosocial factors
- Behavioral health outcomes
Two-Process Model of Sleep Regulation
(Borbély, 1982)

- **Process S:** Sleep pressure rises with wake and falls with sleep
- **Process C:** Sleep pressure oscillates daily (circadian)

Let’s begin with a look at circadian timing.

How have we measured the Circadian Timing System?

- Phase preference or chronotype—when do you prefer to be active, sleeping, etc?
- Phase—what intrinsic marker can we use?
- Period—what is the internal day length?
- Phase response to light—how does phase change with timed light input?
- Amplitude of circadian rhythms
Changes to the circadian timing system during adolescence

Chronotype and Adolescence

- Middle of sleep on “free” nights
- Till Roenneberg identified this pattern as a “Biological marker for the end of adolescence”

Roenneberg et al., Current Biol., 2004
Species With Juvenile Phase Delay in Sleep/Wake Behavior

- Homo sapiens (humans)
- Macca mulatta (Rhesus monkeys)
- Octodon degus (degu) [some ?]
- Rattus norvegicus (laboratory rat)
- Mus musculus (laboratory mouse)
- Psammomys obesus (fat sand rat)
- Callithrix jacchus (common marmoset)

Hagenauer et al., *Devel Neurosci*, 2009

The behavioral pattern is clear: The timing of sleeping and waking moves later across adolescence.
A few outputs of the circadian timing system


Melatonin onset opens the window for sleep each night

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Melatonin Phase and Puberty Stage (Humans)

Carskadon et al. NYAS, 2004

Melatonin Onset Time

Tanner Stage

Melatonin Offset Time

Tanner Stage

Carskadon et al. NYAS, 2004
What may underlie/support phase delay?

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

Response to light is phase dependent

- Evening light pushes phase later (delay)
- Morning light pulls phase earlier (advance)
Adolescent Actigraphy—Longitudinal Timing of Sleep on Weekdays

Onset

Offset

Crowley et al., PLOS ONE, 2014

Adolescent Actigraphy—Longitudinal Timing of Sleep on Weekends

Onset

Offset

Crowley et al., PLOS ONE, 2014
What else may underlie/support phase delay?

Exaggerated phase delay to light in pubertal female mice

Hagenauer et al., Devel Neurosci, 2001; after Weinert & Kompaeurova, Zoology, 1998
What else may underlie/support phase delay?

- Lengthening of intrinsic circadian period (i.e., longer internal day length)

Intrinsic Circadian Period: Adolescents vs. Adults

Carskadon & Acebo Sleep, 2005
What else may underlie/support phase delay?

- Diminished amplitude of the circadian rhythm

Salivary Melatonin Amplitude

Crowley et al., Dev Psychobiol, 2011
Circadian timing seems to play a role

- Timing (phase) delays across adolescence
- Phase preference (chronotype) is later
- Melatonin phase is later
- 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?
How have we measured the Sleep Homeostatic System?

- Slow wave (NREM stages 3+4) sleep [qualitative: deep sleep]
- Slow-wave activity (SWA) in sleep [quantitative: slow EEG waves]
- Sleep propensity (speed of falling asleep)

The “look” of sleep changes

Tarokh & Carskadon, Encyclopedia of Neuroscience, 2009
Slow wave sleep (SWS) stages and EEG Slow Waves (SWA)

What about the processes of SWA dissipation and accumulation?

Tanner Stages 1/2  

Tanner Stage 5

$\tau_d = 2.8 \text{ h}$  
$\tau_i = 8.9 \text{ h}$  
Decay Time Constant  
Rise Time Constant

$\tau_d = 2.7 \text{ h}$  
$\tau_i = 12.1 \text{ h}$
Sleep homeostasis also plays a role

- 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 seems to be needed

Taylor et al., J Sleep Res, 2005
What about the psychosocial landscape?

Psychosocial Context of Adolescents

- Exertion/establishment of autonomy
- Employment
- Sports
- Substances
- Homework
- Vaping?
- ‘Screen time’ at night
- Social networking at night
- Romance
- ...and much much more...
- School schedule
**Screen Time**

**Photoreceptors in the Retina**

- Cones
- Rods
- Intrinsically photosensitive retinal ganglion cells [ipRGCs]

Reppert & Weaver Nature, 2002

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*Fig. 1. A graphical representation of the potential impact of electronic media on sleep.*

Cain & Gradisar, Sleep Med, 2010
Melanopsin Action Spectrum

- Action spectra for melatonin suppression peak at ~460 nm
- and do not match known rod and cone photoreceptors

\[ \lambda_{\text{max}} = 446-477 \text{ nm} \]
\[ \lambda_{\text{max}} = 459 \text{ nm} \]

Brainard et al. J Neurosci 2001  
Thapan et al. J Physiol 2001

But it’s not just the blue light!
Is there a role for exogenous melatonin? Chronobiotic vs. Hypnotic

(Adapted from Sack et al., 2000. NEJM. 343(15):1070-1077)

Melatonin receptors in the SCN

<table>
<thead>
<tr>
<th>Sleep-promoting</th>
<th>Phase-shifting</th>
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</thead>
<tbody>
<tr>
<td>MT&lt;sub&gt;1&lt;/sub&gt; agonism</td>
<td>MT&lt;sub&gt;2&lt;/sub&gt; agonism</td>
</tr>
<tr>
<td>Attenuates SCN alerting signal</td>
<td>Synchronizes circadian clock</td>
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</tbody>
</table>
Sleep-promoting effect is limited

School Start Time

- School Starts early in the US
  - Middle school (grades 6-8)
    - ~50% before 8:00 am
    - <25% after 8:30 am
  - High school (grades 9-12)
    - 2005 US: >50% start before 8:00 am
    - 2005 Kansas: 2/3 start before 8:00 am; 99% start at 8:30 am or earlier

- Student transportation (cost of busing)
- Issues of seasonal safety for young children in the dark
- Participation of students in after school activities, especially outdoor winter athletics
School transition study

- Longitudinal study
- 9th grade SST = 8:25
- 10th grade SST = 7:20

- Follow for one week with activity monitoring
- Sleep in lab on Friday night with testing on Saturday using Multiple Sleep Latency Test of sleepiness

MSLT and DLSMO Results In Grade 10

![Graphs showing MSLT and DLSMO results]
Too little sleep

Waking at the ‘wrong’ time

Sleepy in the classroom, especially in the morning

In the US, school start time reform is now seen as a major public health concern.

Adolescent Development & Sleep: The Perfect Storm

PRE-ADOLESCENCE

Screen Time, Social Networking

ADOLESCENCE

Bedtime Autonomy

Academic Pressure

Screen Time, Social Networking

SOCIETAL PRESSURE → EARLY RISE

Sport, School Day Time, etc.

LATE TO BED, EARLY TO RISE ⇒ LONG DAYS, SHORT SLEEP

WEEKEND SLEEP DELAY

EARLY SCHOOL START TIME

The Perfect Storm...
Consequences of too little sleep

Impaired Learning

Too little sleep impairs information acquisition
That is, ability to process input

Too little sleep impairs information retrieval
That is, ability to access learned information

Too little sleep may impair consolidation, stabilization, strengthening of information that happens during sleep!
Figure. Adjusted Association Between Sleep Duration and Risk-Taking Behaviors

<table>
<thead>
<tr>
<th>Risk-Taking Behavior</th>
<th>Prevalence, % (No./Total No.) (N = 67,615)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mood and self-harm</td>
<td>34.3 (23,106/67,419)</td>
</tr>
<tr>
<td>Felt sad or hopeless</td>
<td>28.5 (19,150/67,274)</td>
</tr>
<tr>
<td>Seriously considered suicide</td>
<td>15.9 (10,670/67,235)</td>
</tr>
<tr>
<td>Made plan about how to attempt suicide</td>
<td>12.6 (8,459/66,942)</td>
</tr>
<tr>
<td>Attempted suicide</td>
<td>7.4 (4,524/61,435)</td>
</tr>
<tr>
<td>Attempted suicide and required treatment</td>
<td>2.3 (1,367/60,462)</td>
</tr>
</tbody>
</table>

Data from YBRS, 2007-2015
Weaver et al., JAMA Pediatrics, 10/01/18
Self Critical Rumination and Delayed Sleep Timing

Summary: Insufficient Sleep in Susceptible Teens

- Excessive sleepiness
- Impaired learning
- Impaired behavior regulation, risk taking
- Substance use (including caffeine)
- Auto crashes
- Poor mood, depression, suicidality
- Appetite and metabolic changes; possible association with weight gain, obesity, diabetes risk
For adolescents—

sleep is NOT a waste of time

P.S. It’s not a waste of time for grown ups, either!

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