How Developmental Changes in Sleep Biology May Affect Adolescent Behavior

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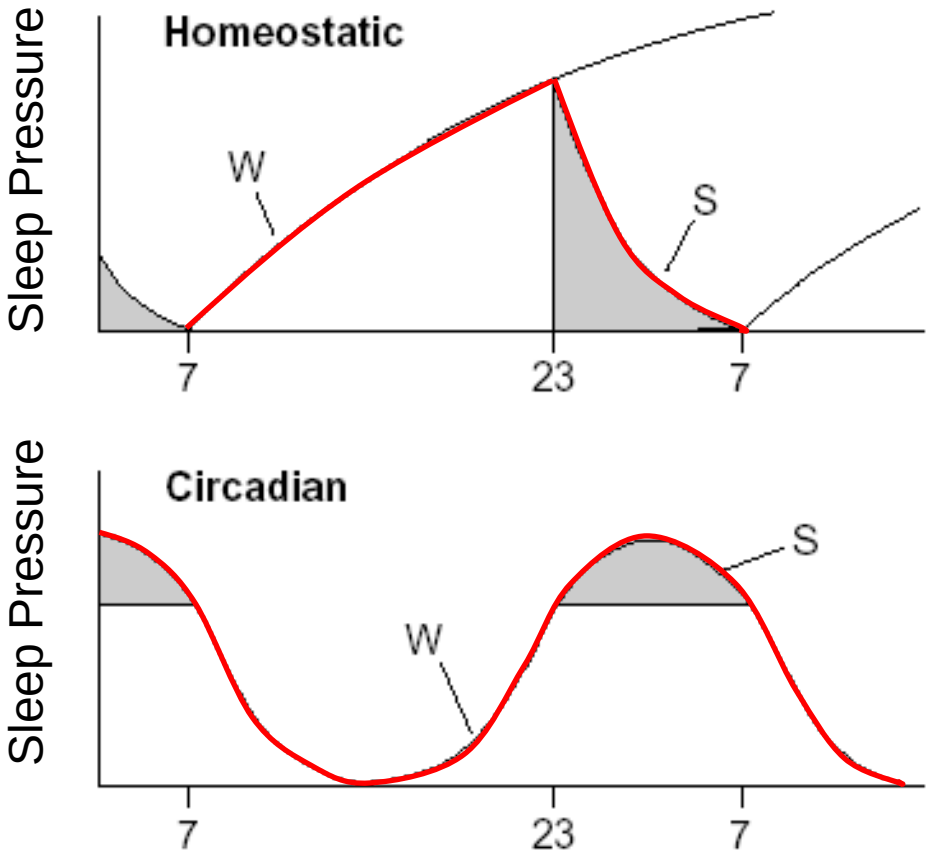
Conflict of Interest

- 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



From: Borbely AA. Human Frontier Science Program, 2000.

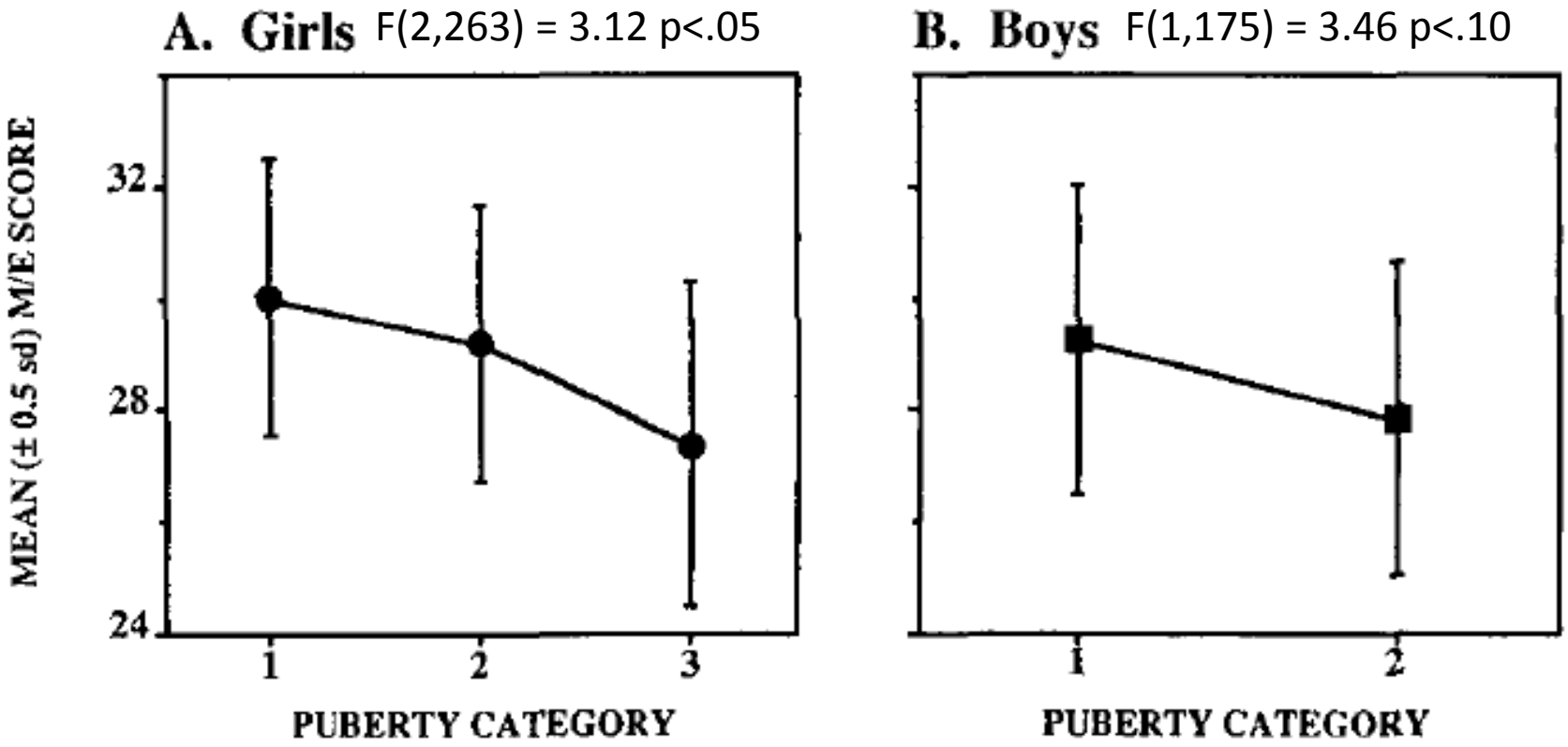
Observed features of the clock during adolescence

Species Manifesting Juvenile Phase Delay

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

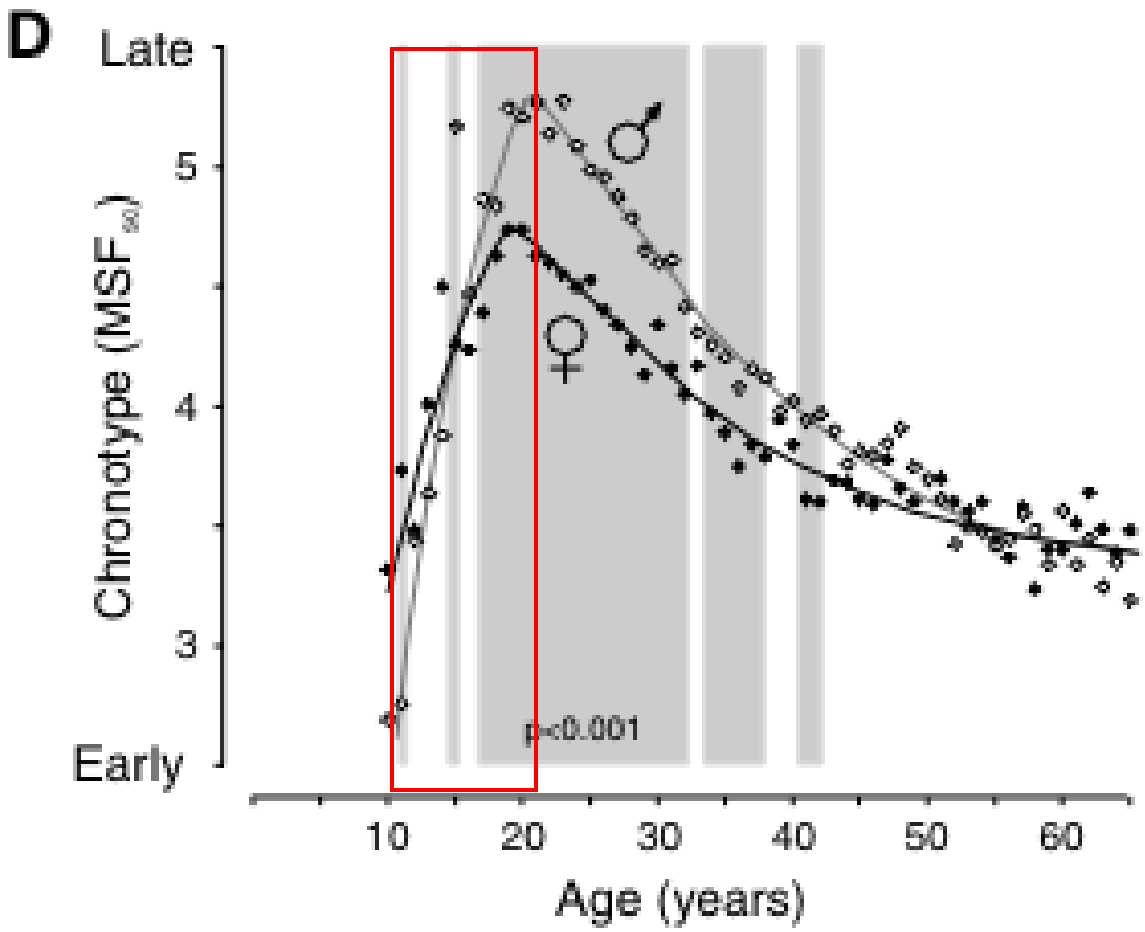
Hagenauer et al., *Devel Neurosci*, 2009

Phase Preference in 6th Graders



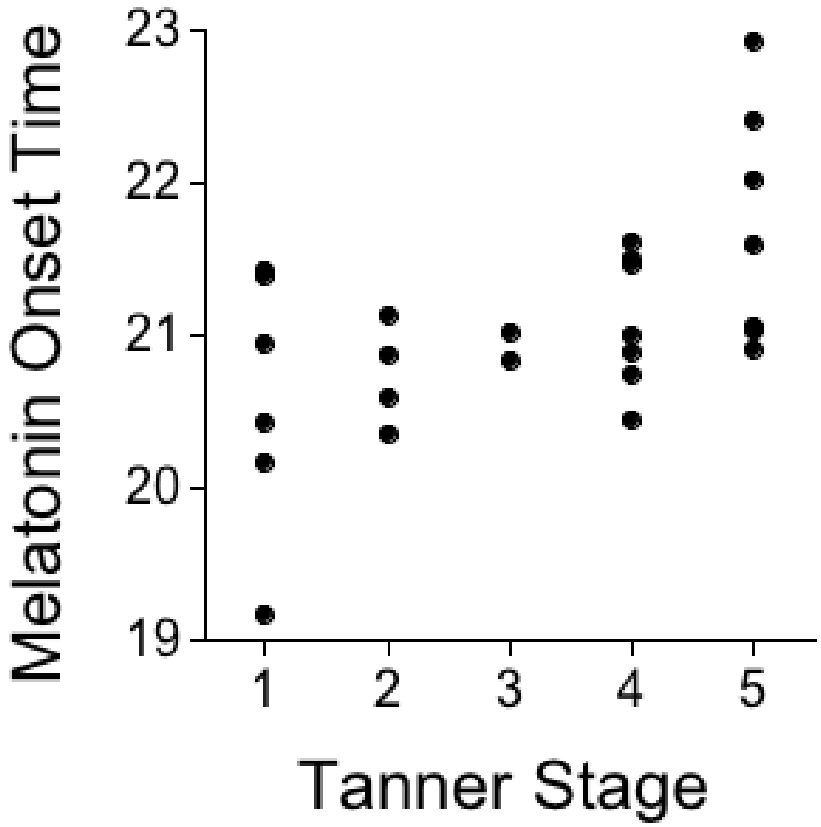
Carskadon, Vieira & Acebo *Sleep* 1993

Chronotype and Adolescence



Roenneberg et al., *Current Biol.*, 2004

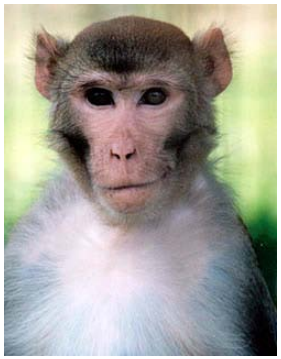
Melatonin Onset (DLMO) Phase and Puberty Stage

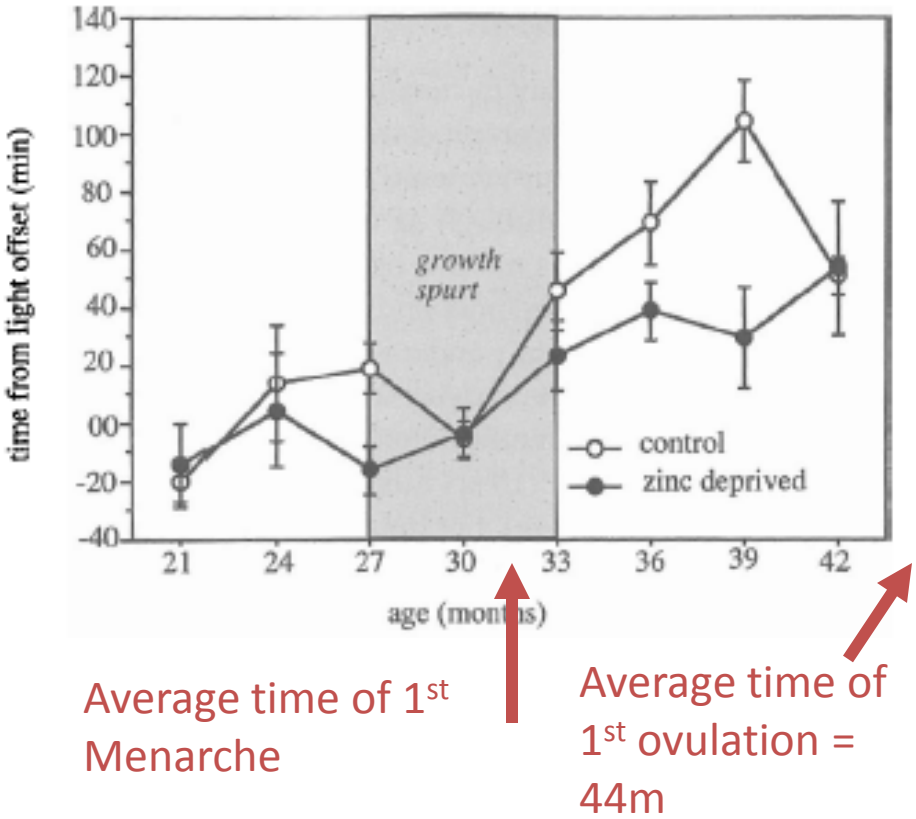


Carskadon et al. *NYAS*, 2004

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.

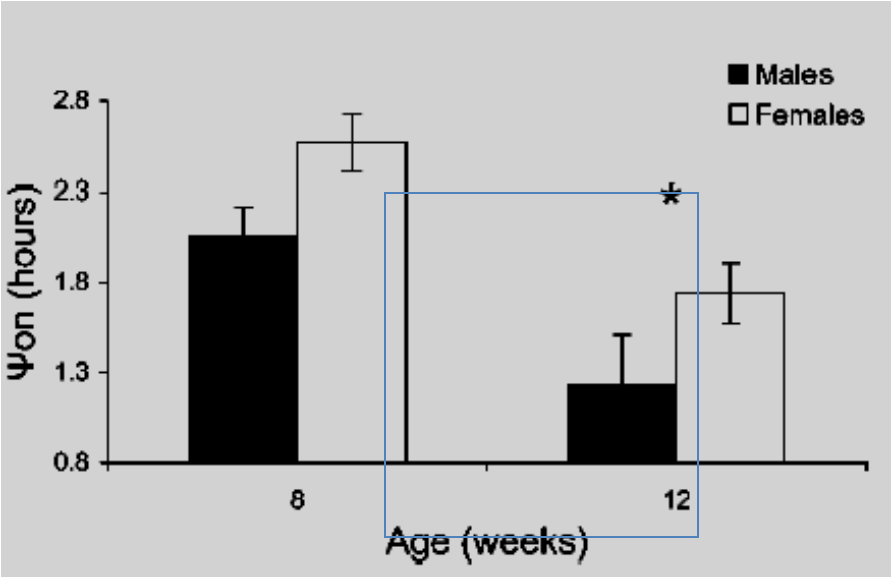




Golub et al., In: *Adolescent development…*, 2002

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

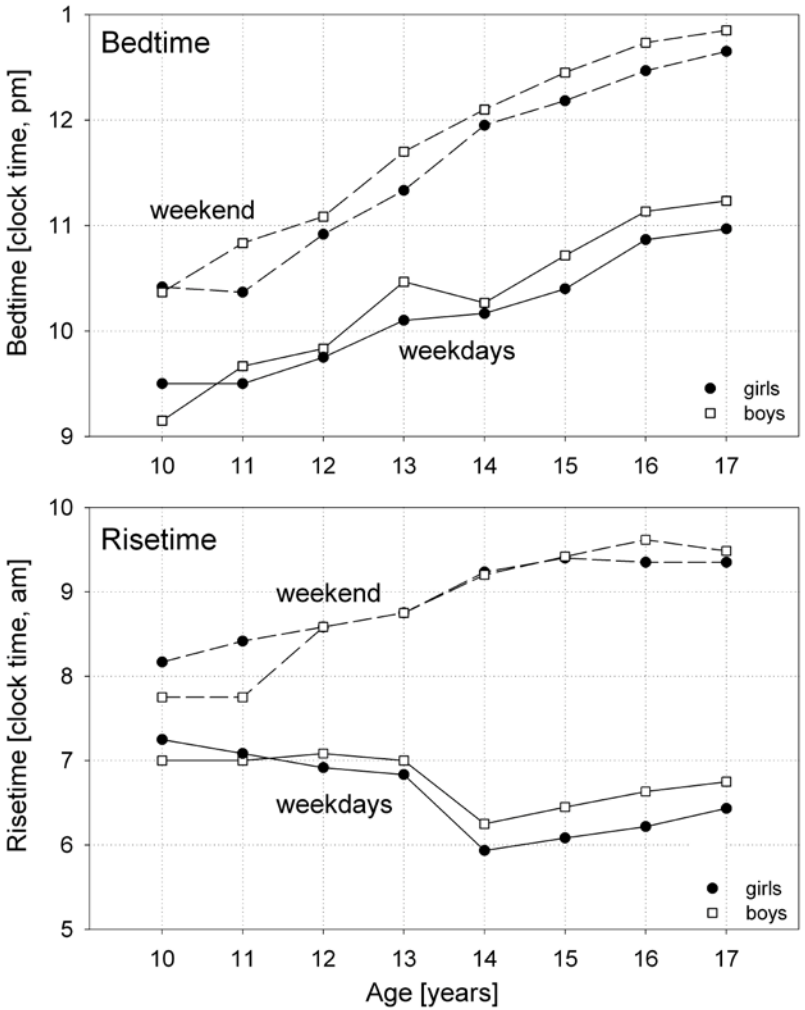
What might underlie/support/influence a phase delay?

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

Adolescent Self-Report

Bedtime

Risetime



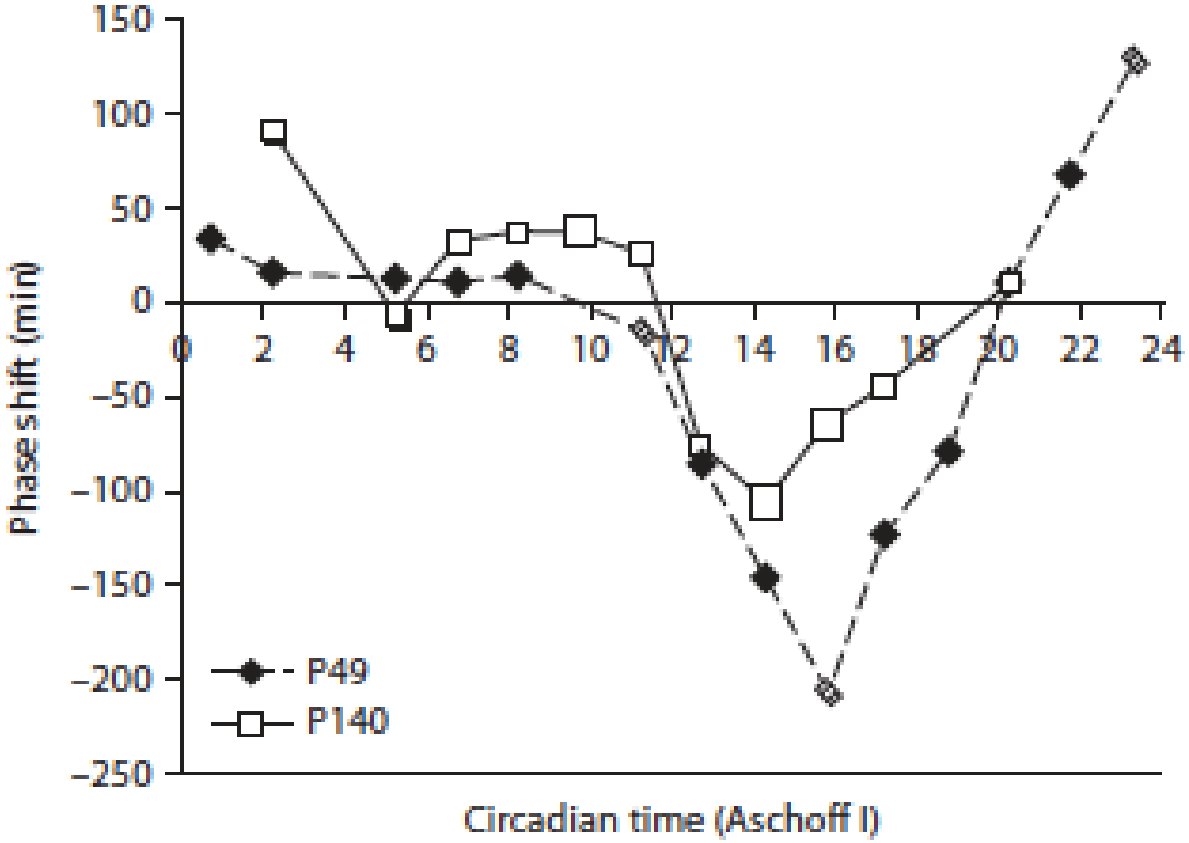
Sleep Research Society

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

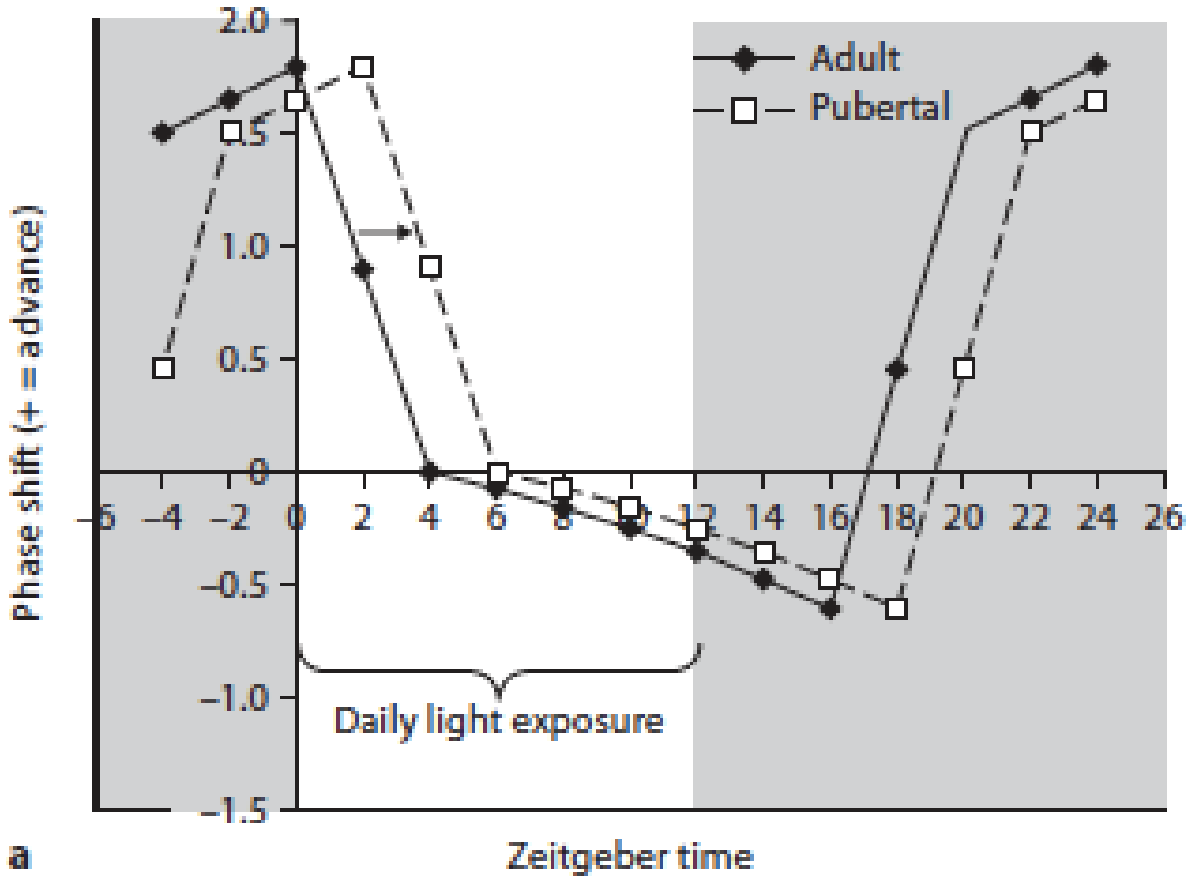


Hagenauer et al., *Devel Neurosci*, 2001; after Weinert & Kompaeurova, *Zoology*, 1998

What might underlie phase delay?

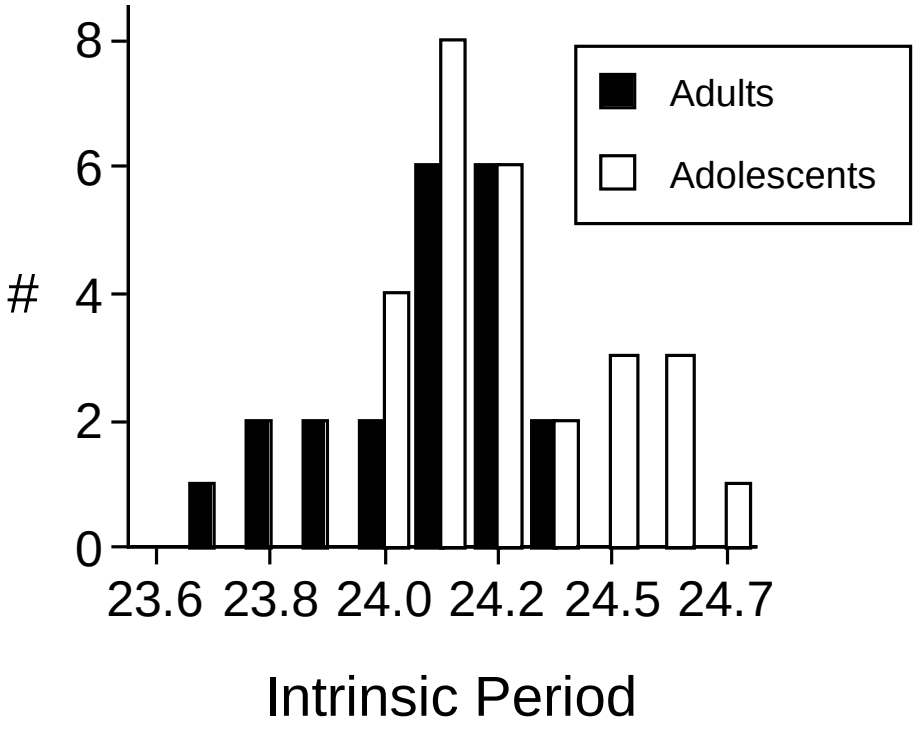
- Changes in light exposure
  - Staying up later // more late light
  - Waking up later // less morning light
- Change in phase-dependent sensitivity to light exposure
- Longer intrinsic circadian period (i.e., longer internal day length)

Longer Period = Later Phase



Hagenauer et al., *Devel Neurosci*, 2009

Intrinsic Circadian Period: Adolescents vs. Adults

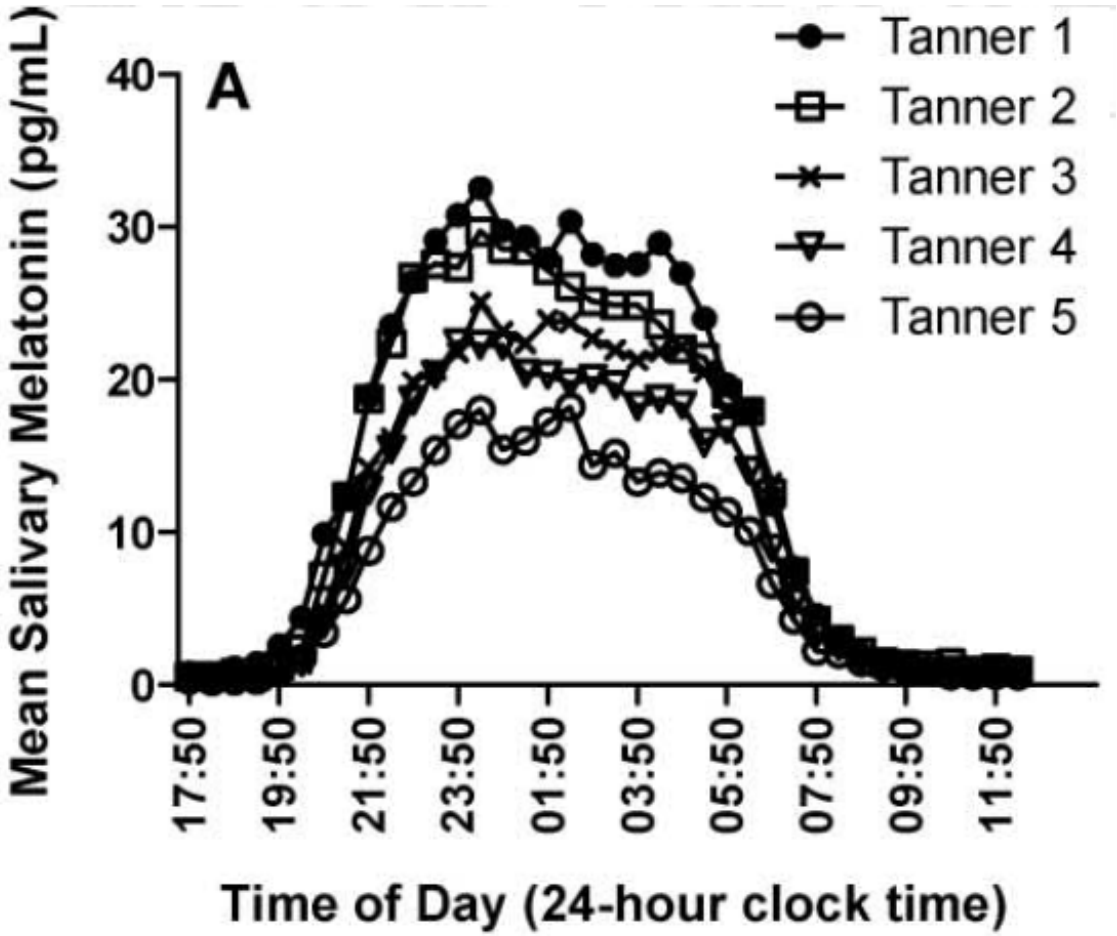


Carskadon & Acebo *Sleep,* 2005

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

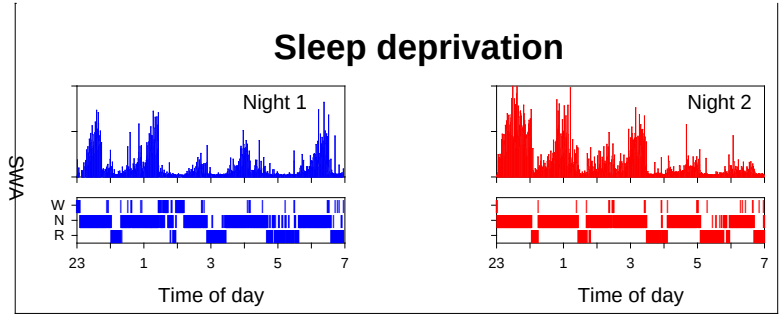
- Phase is delayed during adolescent development
  - Phase preference (chronotype) is later
  - Melatonin phase is later
- Phase-dependent light sensitivity may change
- Intrinsic period in adolescents may affect phase
- Reduced amplitude of the circadian clock may dampen the signal for sleep

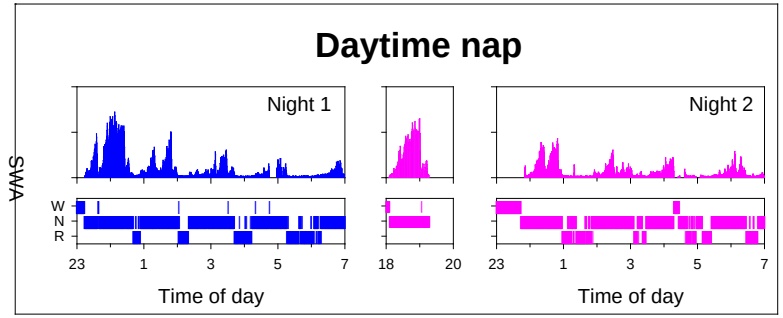
- Result: late nights are favored (so, too, late mornings)

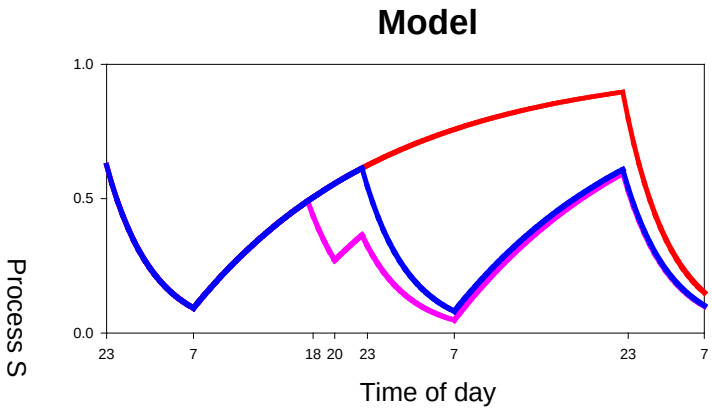
Features of Adolescent Sleep-Wake Homeostasis (Human)

Sleep Homeostasis Model

(Borbély 1981)

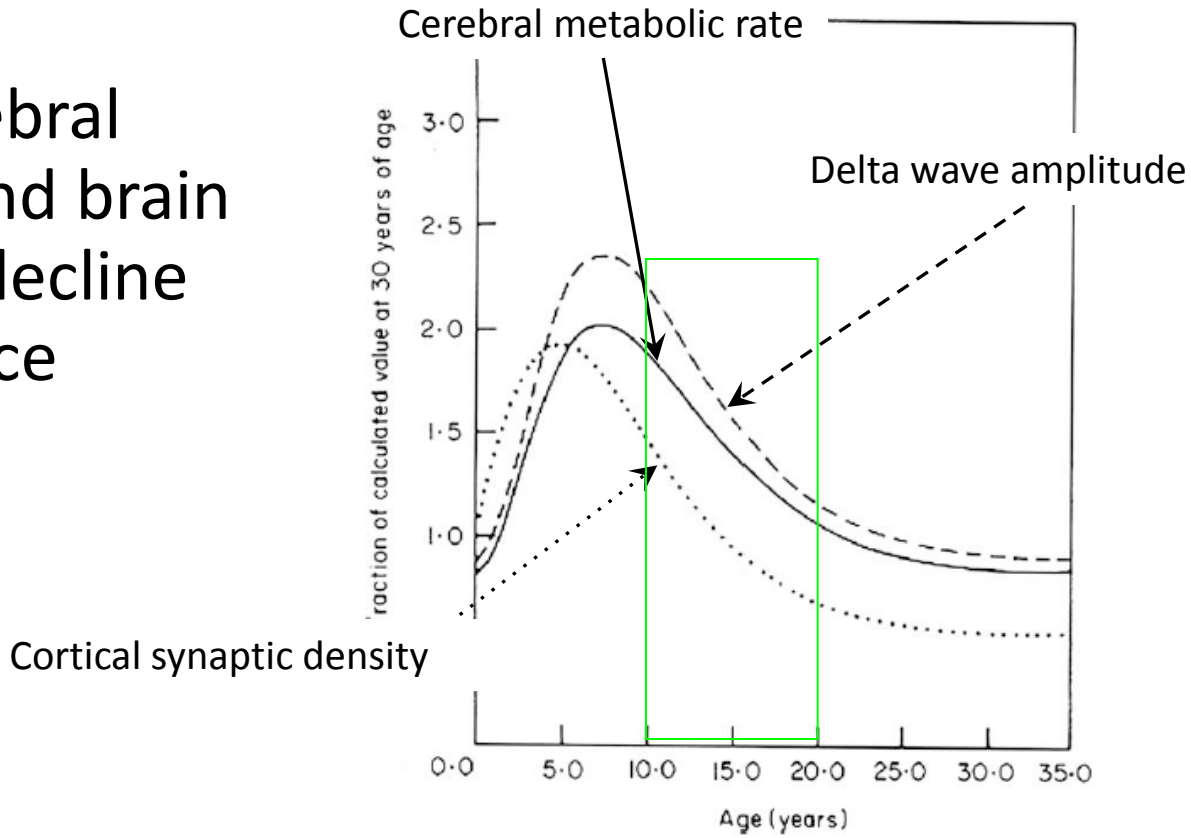






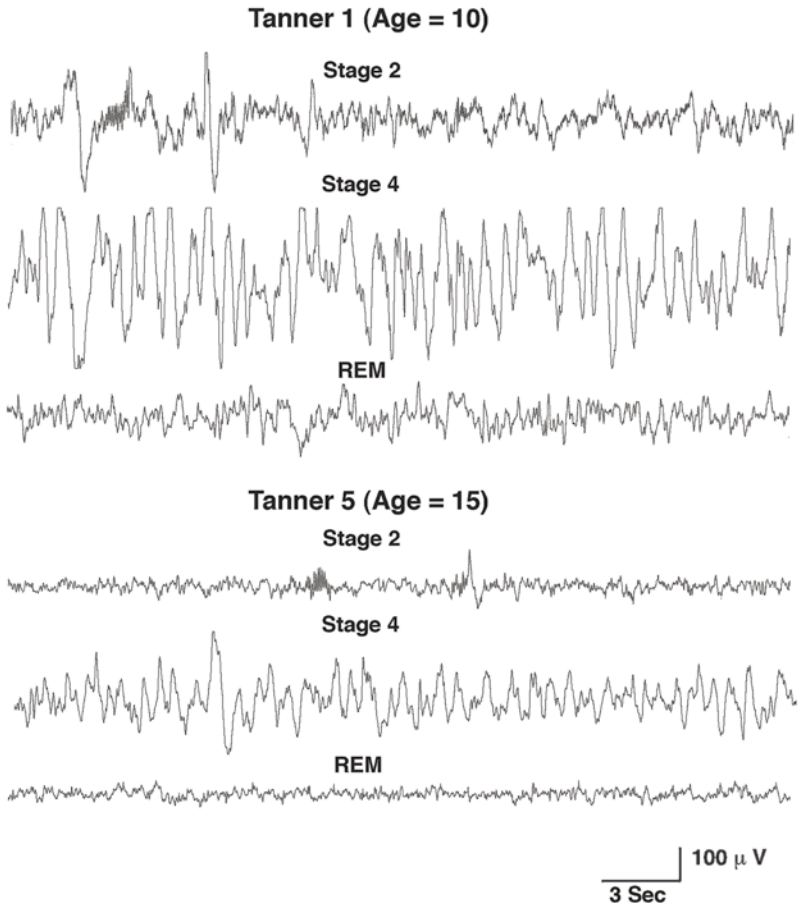
Adolescent Brain Changes

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



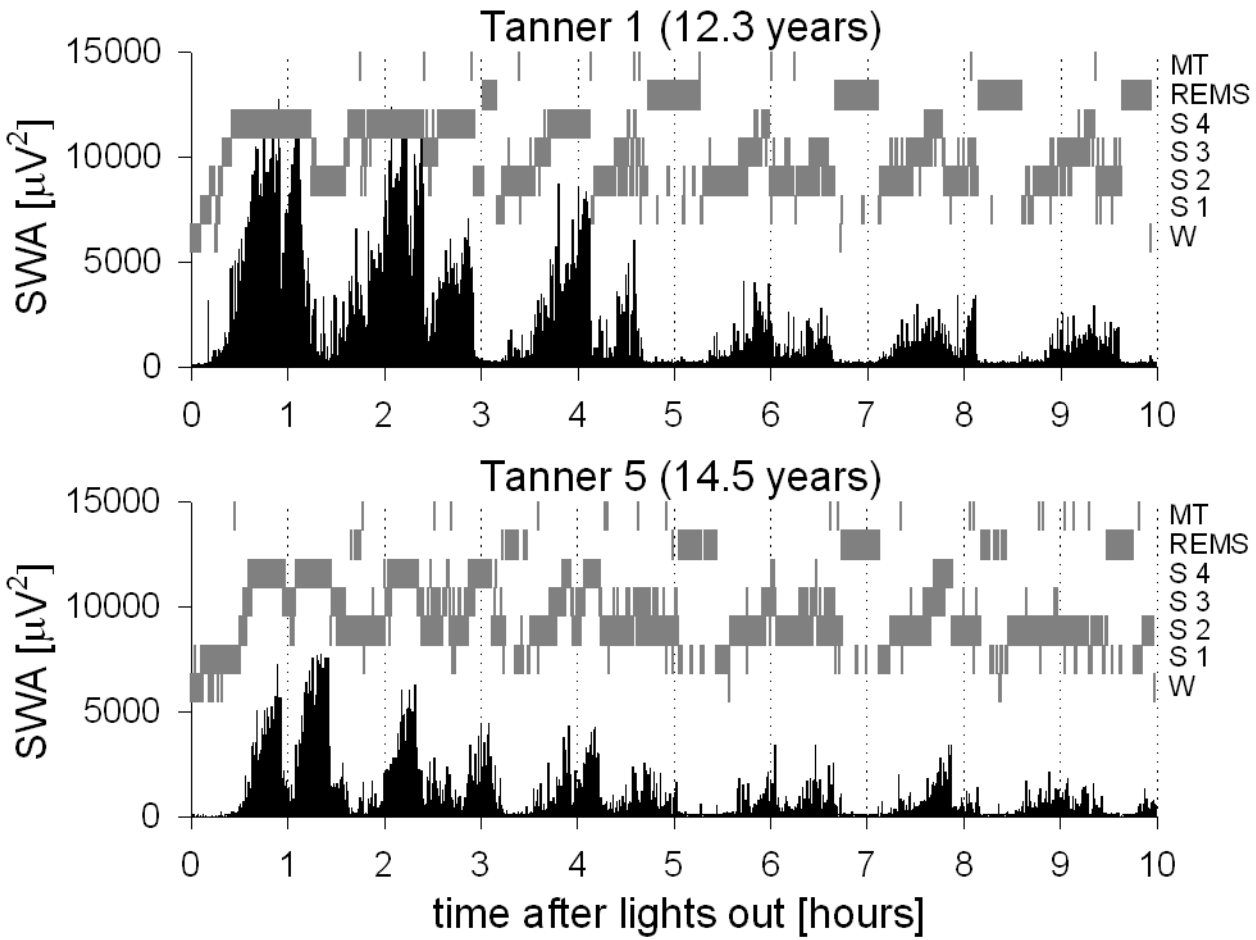
Feinberg et al., *J Theor Biol.*,1990

The “look” of sleep changes



Tarokh & Carskadon, *Encyclopedia of Neuroscience, 2009*

Slow Wave Sleep & Slow Wave Activity

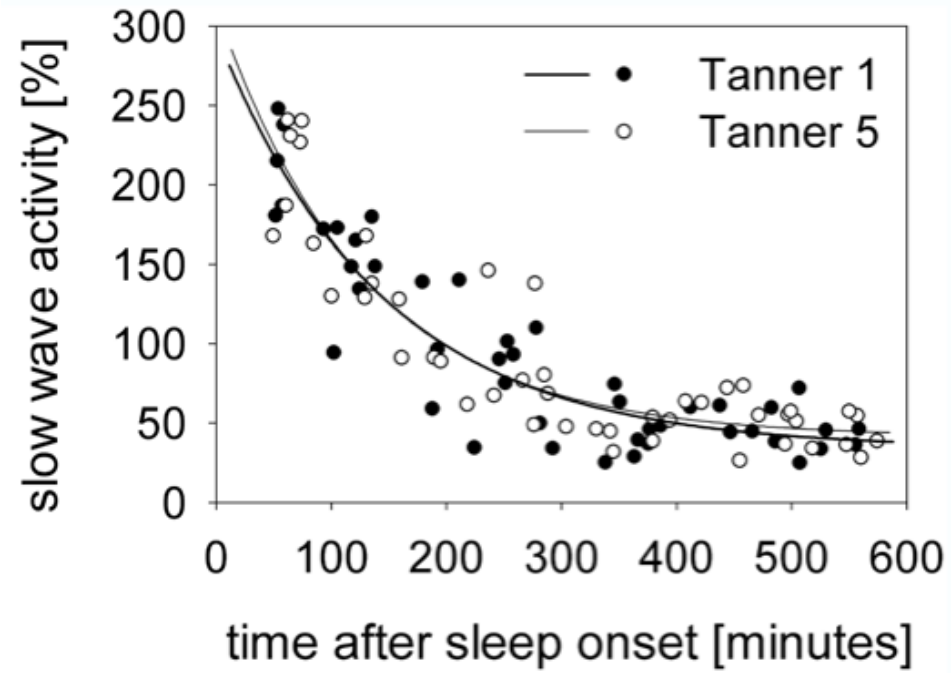


Jenni & Carskadon *Sleep*, 2004

Sleep phenomenology changes; does sleep regulation?

Sleep pressure dissipation does not change in adolescence

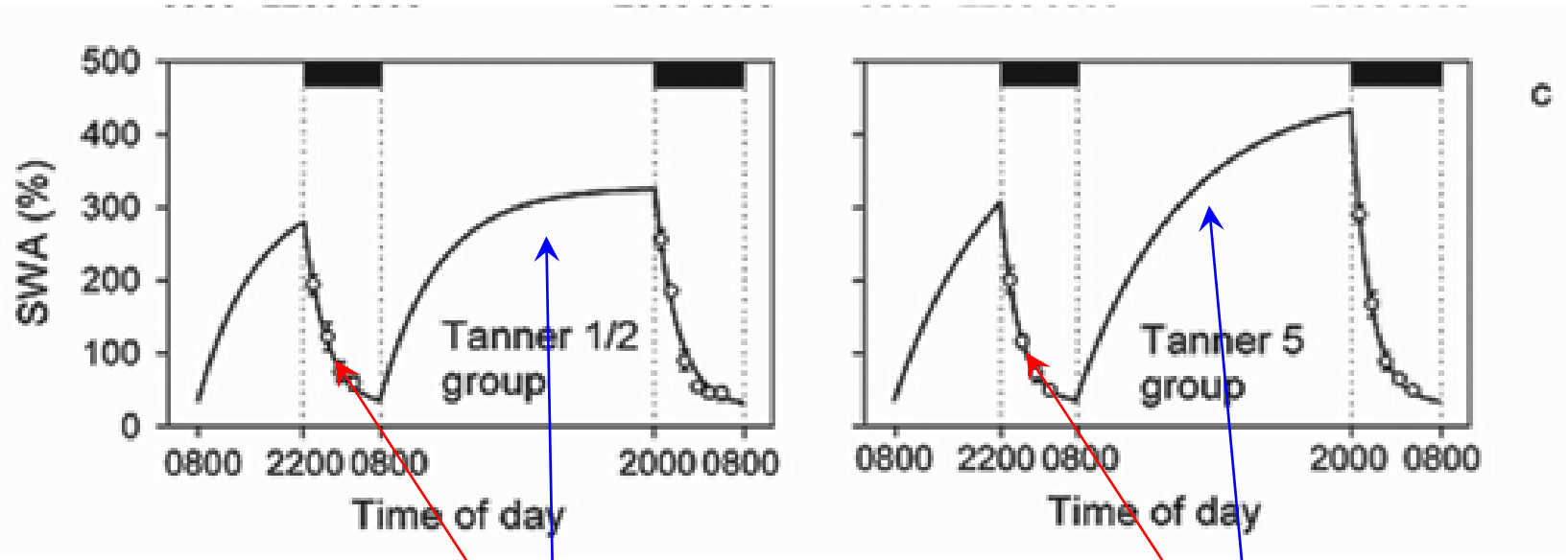
- SWA dissipation is unchanged across pubertal development



Jenni & Carskadon, *Sleep* 2004

Across pubertal development, SWA *accumulation* rate changes

Tanner Stages 1/2 | Tanner Stage 5

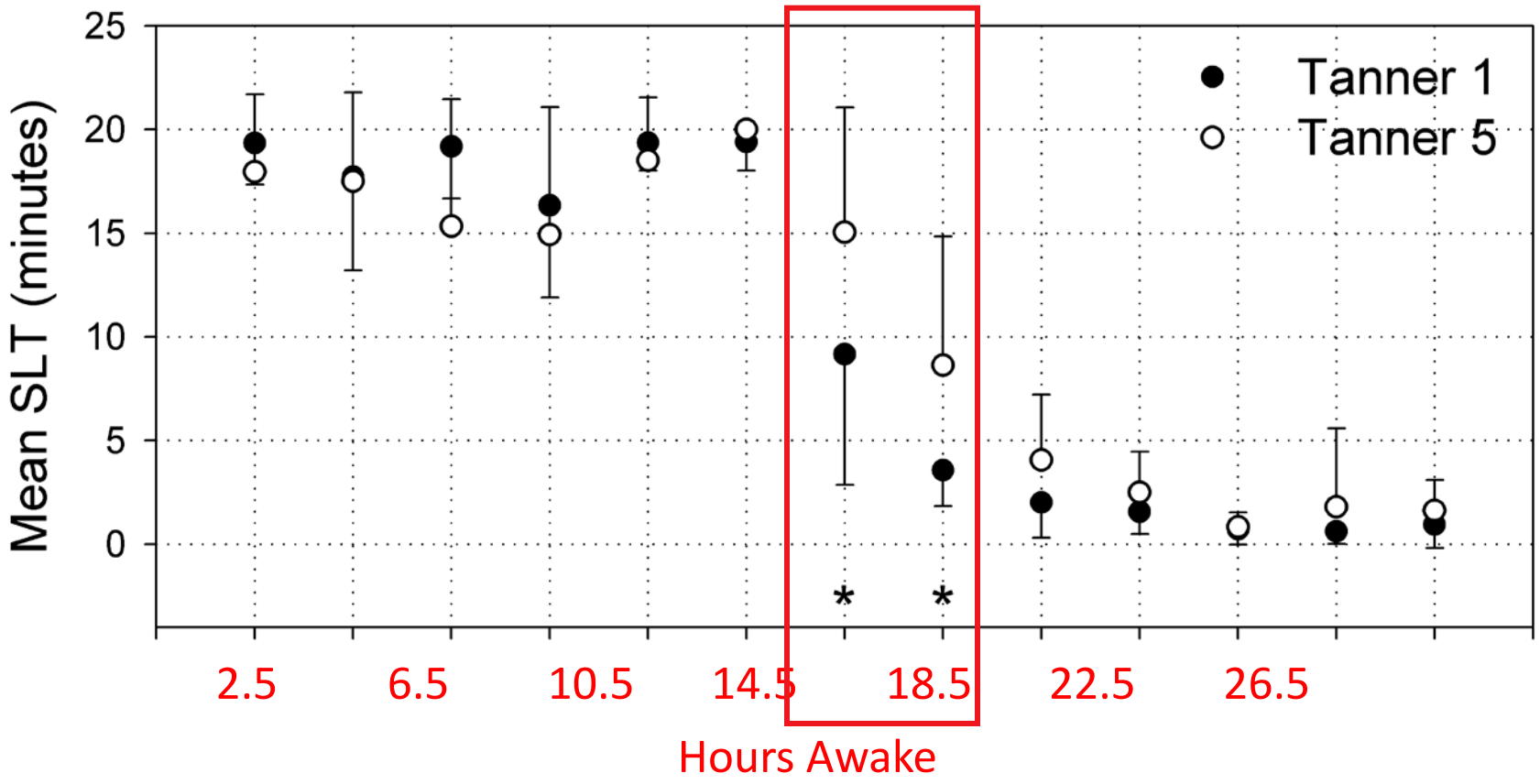


t_d = 2.8 h | Decay Time Constant | t_d = 2.7 h

t_i = 8.9 h | Rise Time Constant | t_i = 12.1 h

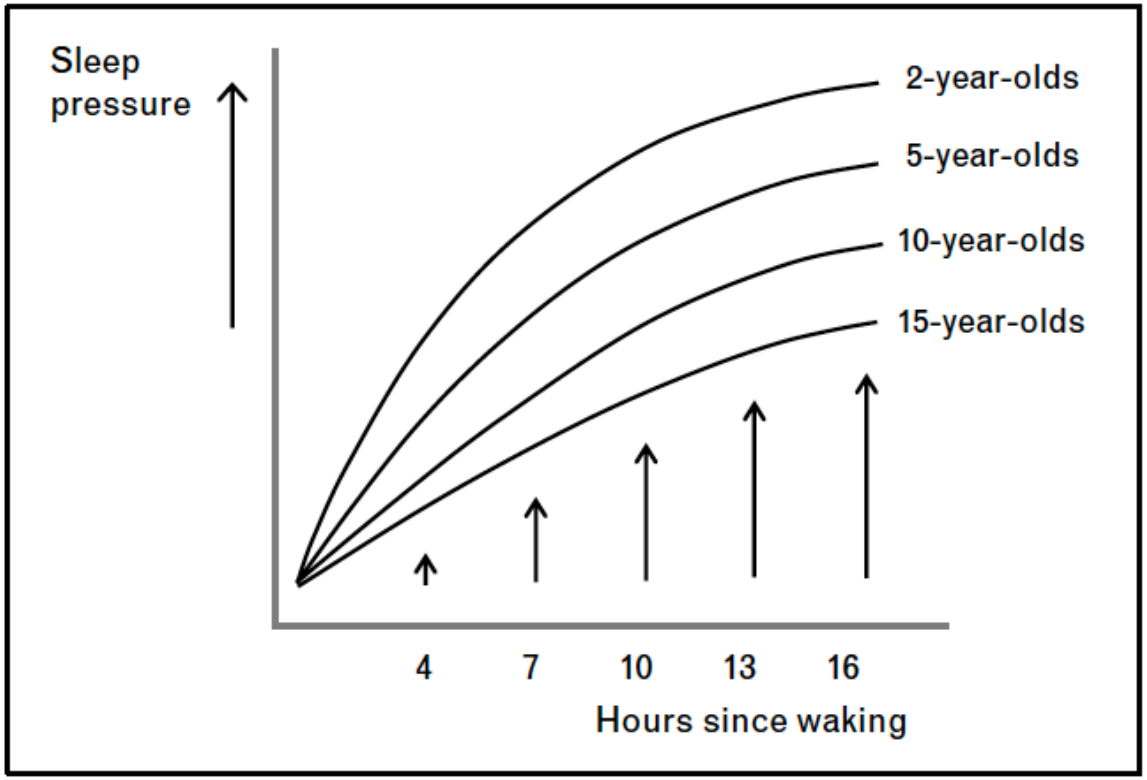
Jenni, Achermann & Carskadon *Sleep*, 2005

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.

Jenni & LeBourgeois *Curr Op Psychiatry, 2006*

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

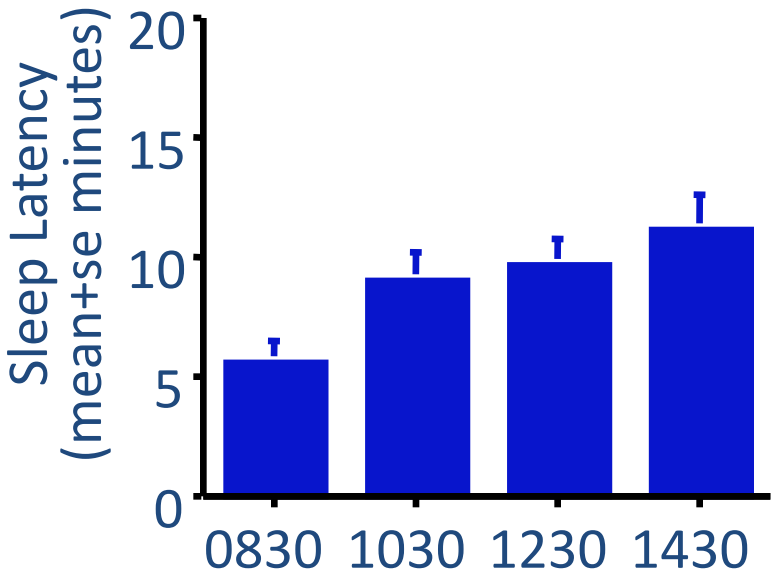
Adolescent Sleep Behavior

- 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

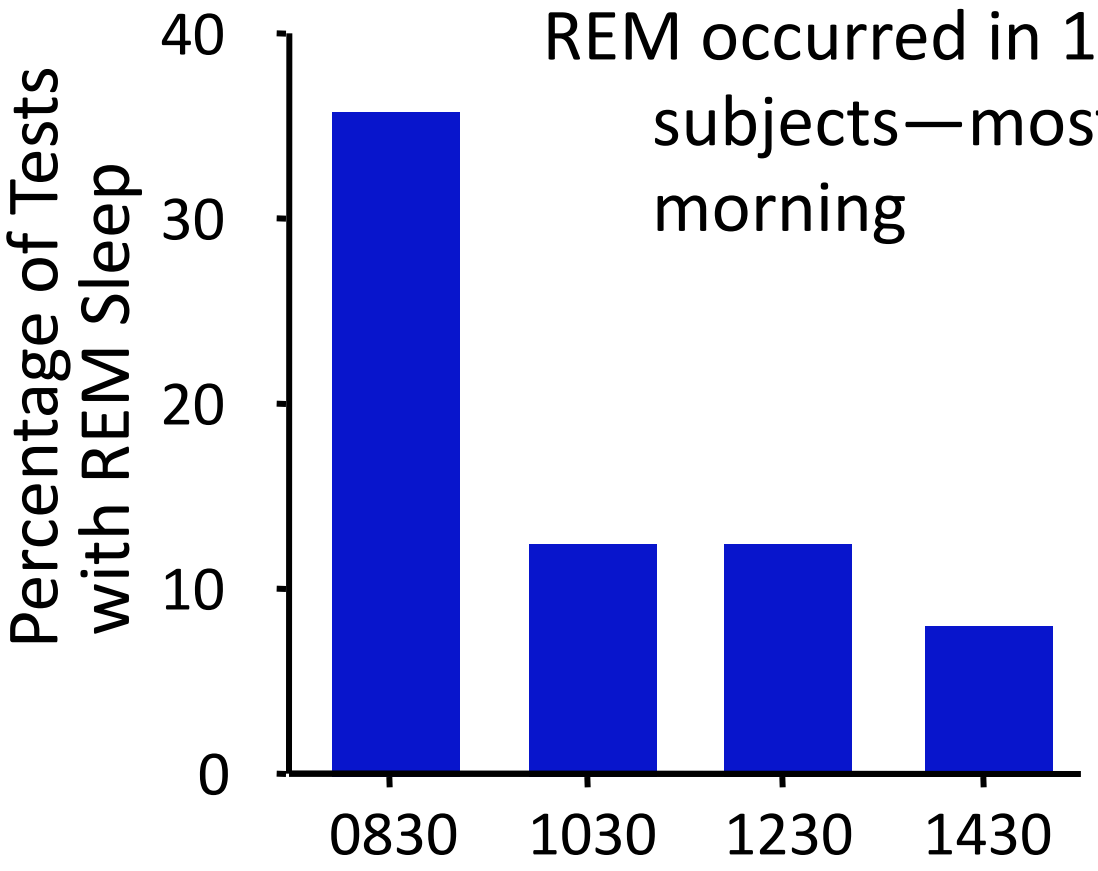
MSLT in high school students

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



Carskadon et al. *Sleep*, 1998

REM sleep tendency also affected



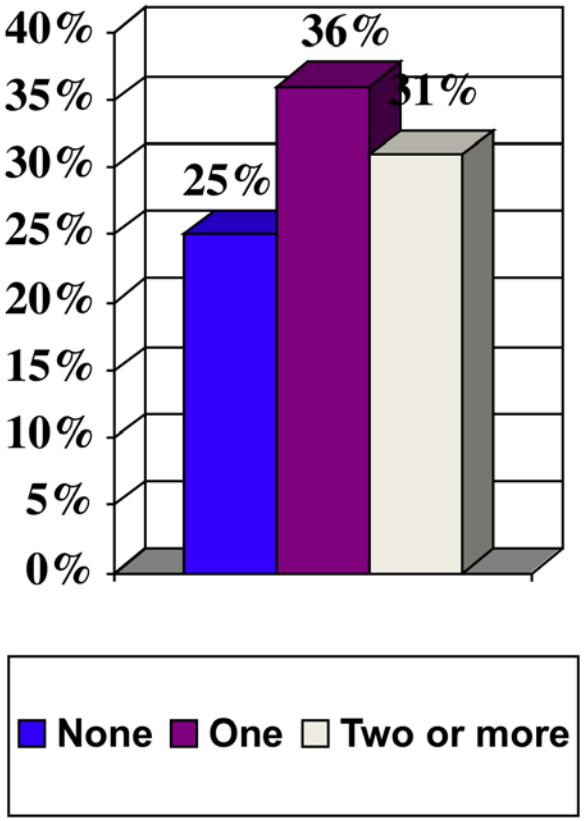
REM occurred in 12 of 25 subjects—most in the morning

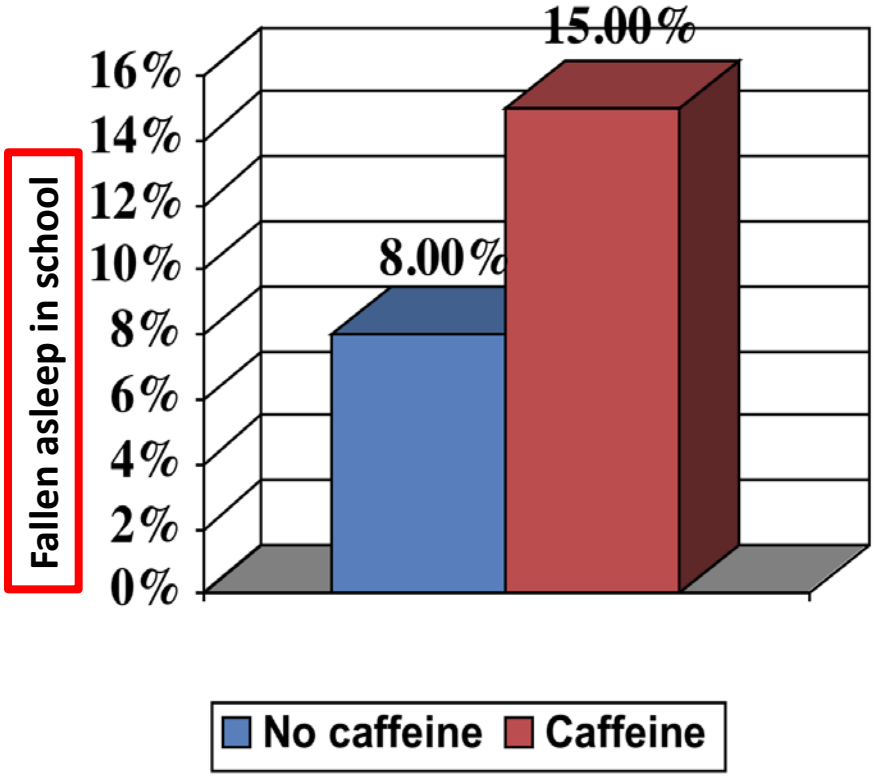
Carskadon et al. *Sleep*, 1998

Consequences of Clock/Homeostasis/Lifestyle Interaction

- Variable sleep timing
  - Social Jet Lag (á la Roenneberg, *Curr Biol,* 2012)
- Chronic insufficient sleep
- Deficits in mood, learning, impulse control, etc.
- Excessive sleepiness & possible caffeine use?

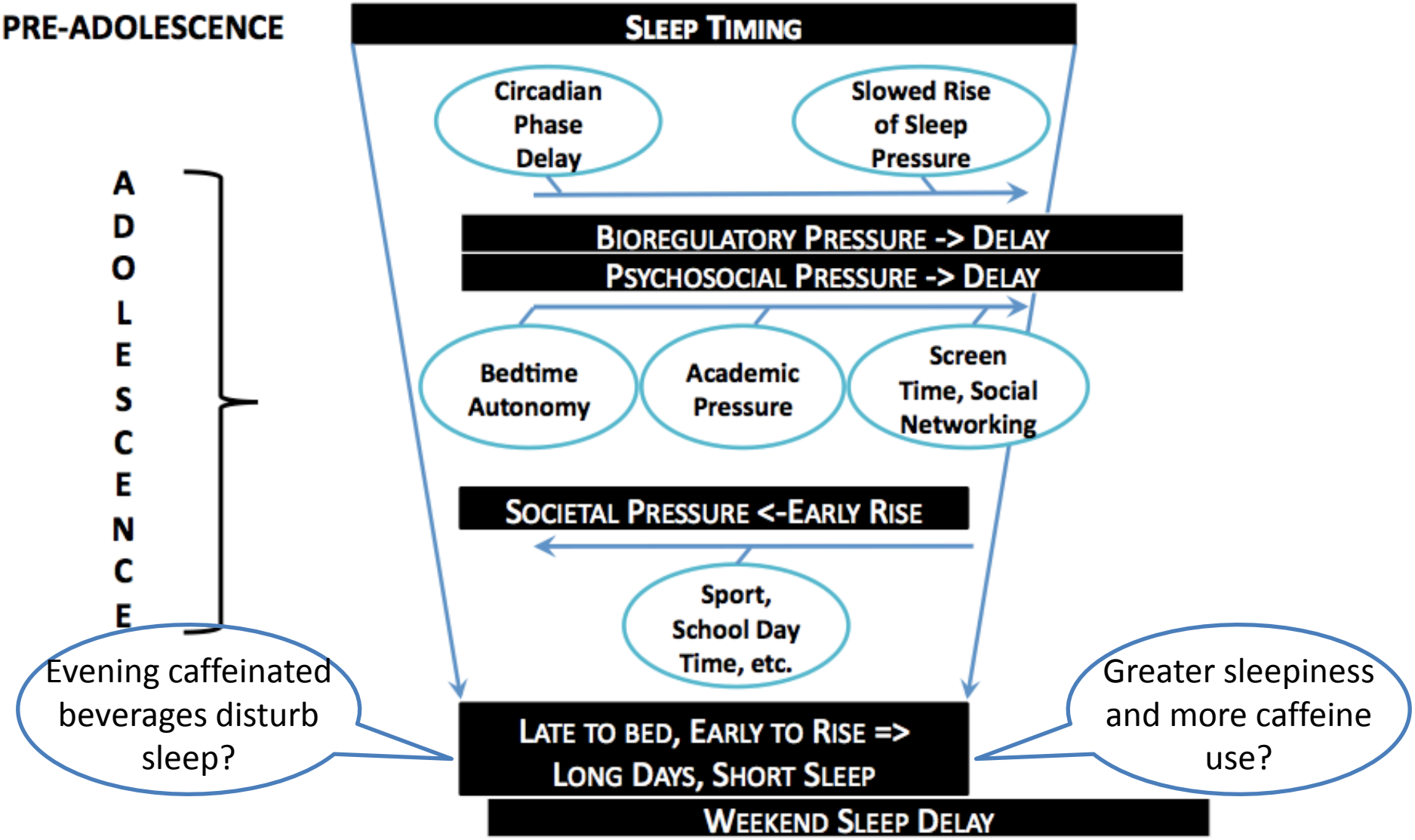
Caffeinated Beverage Daily





NSF *Sleep in America Poll*, 2006

Adolescent Development & Sleep: The Perfect Storm



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Carskadon, *Pediatr Clin North Am*, 2011

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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