



# The Universe of Adolescent Sleep

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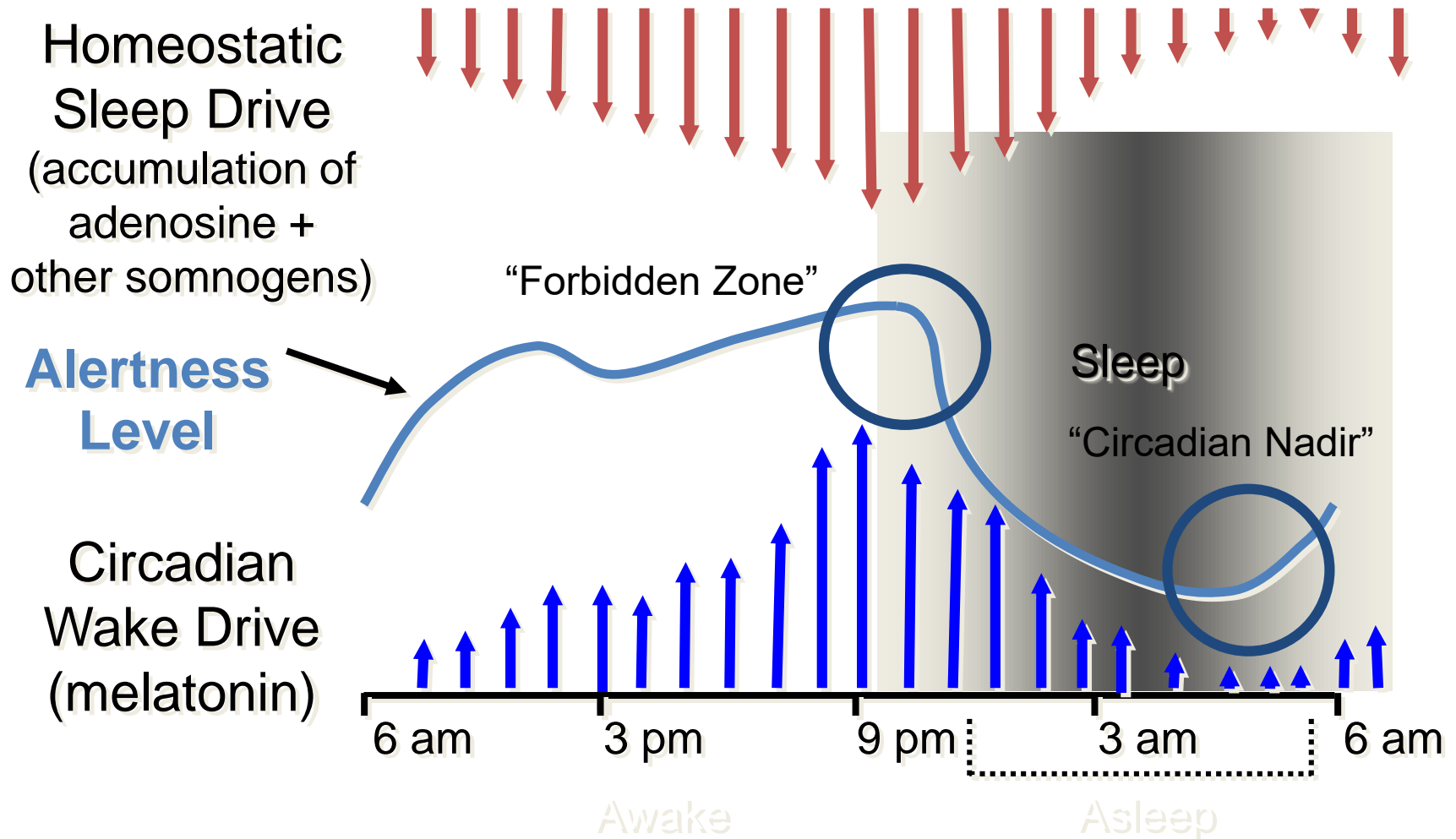
# Objectives

- Describe normal sleep development during adolescence and recommendations for achieving healthy sleep
- Outline the neurocognitive, health and safety consequences of deficient sleep in adolescents and identify prevalence of sleep disorders
- Summarize the data supporting healthy school start times as a public health intervention



First, consider a few basics...

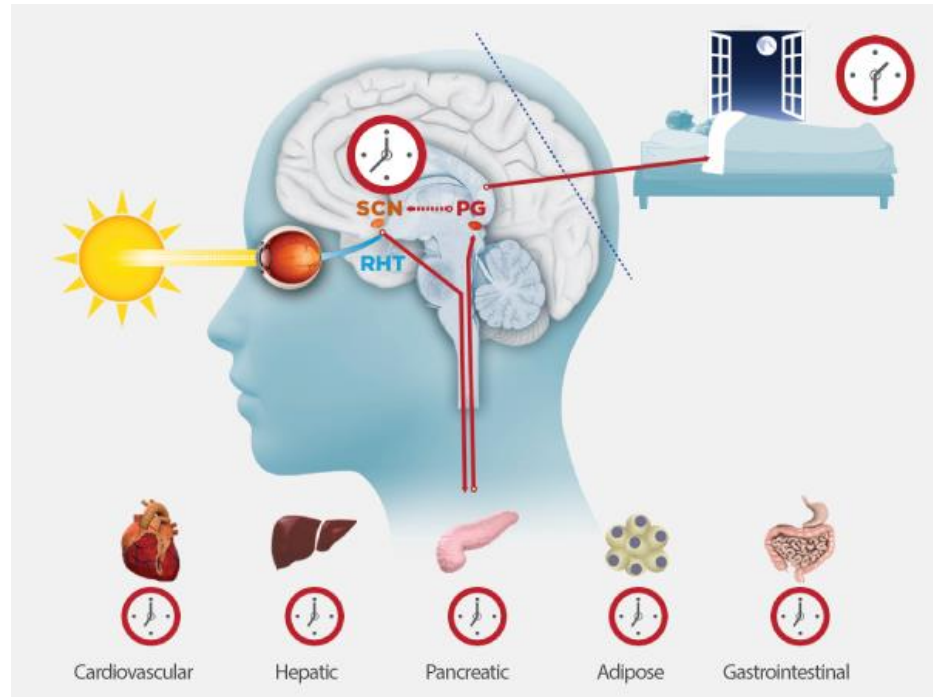
# “Two Process” Model of Sleep Regulation



Now, imagine all of this shifting later by 2 hours...

# Both Sleep Time and Sleep Timing are “Biological Imperatives”

In addition to a “master clock” in the brain, each cell in the body possesses a “circadian oscillator”/ “clock” which must be synchronized with one another and the environment



“Misalignment” between internal circadian clocks and the external light-dark cycle results in profound impairments in physiologic function and health

# What is “Deficient” Sleep?

- A concept that acknowledges that short sleep duration (compared to sleep needs) and circadian misalignment (a mismatch between biological circadian rhythms and environmental demands), while inter-related, may both contribute to behavioral and cognitive impairments and poor health outcomes
- In other words, it's not just **how much** you sleep, but **when** you sleep that's critical

# Adolescent Sleep: The “Perfect Storm”?





# Adolescent Sleep:

## Biological and Circadian Factors

- All adolescents experience a normal shift in circadian rhythms with age and in association with the onset of puberty → “eveningness” chronotype\*
- This results in a biologically-based shift (delay) of up to several hours in both the natural fall sleep *and* morning wake times\*
- Changes in the sleep drive also make it easier for adolescents to stay up later\*

\*Based on objective data from rigorous studies examining biological markers of sleep and puberty in adolescents under controlled conditions in the lab



# Adolescent Sleep:

## Biological and Circadian Factors

- On a practical level, due to these factors as well as the “forbidden zone”, it’s very difficult for the average adolescent to fall asleep much before 11pm on a regular basis\*
  - Teens cannot “make” themselves fall asleep earlier
- 
- In order for high school students in Franklin to obtain the recommended amount of sleep (~9 hours) at the current school start time, they would need to fall asleep by 9:30p

# Adolescent Sleep: Environmental Factors

- Competing priorities for sleep: homework, activities, after-school employment, social networking
- Circadian phase delay may be further exacerbated by evening light exposure (between dusk and bedtime)
  - Suppresses brain release of melatonin
  - Greater sensitivity to evening light at puberty onset
  - Blue light from “screens” (TV, computer, e-readers)
- Consumption caffeine and other stimulants
  - 18-30% of teens use energy drinks
  - Daytime sleepiness major driver
  - Use associated with risky behaviors; gateway drug?



# Sleep and Screens

- We examined whether the self-reported use of light-emitting electronic devices (televisions, computers, and smartphones) in bed before falling asleep modified the impact of the SST changes in HS students<sup>1</sup>
- Before SST changes, adolescents who reported such use had shorter school-night sleep duration
- However, the impact of the SST change on sleep duration was similar between those who did and did not use such devices in bed before falling asleep
- These findings suggest that *this practice does not appear to alter the potential beneficial impacts on sleep of a delay in SST*

# “Weekend Oversleep” and “Social Jet Lag”

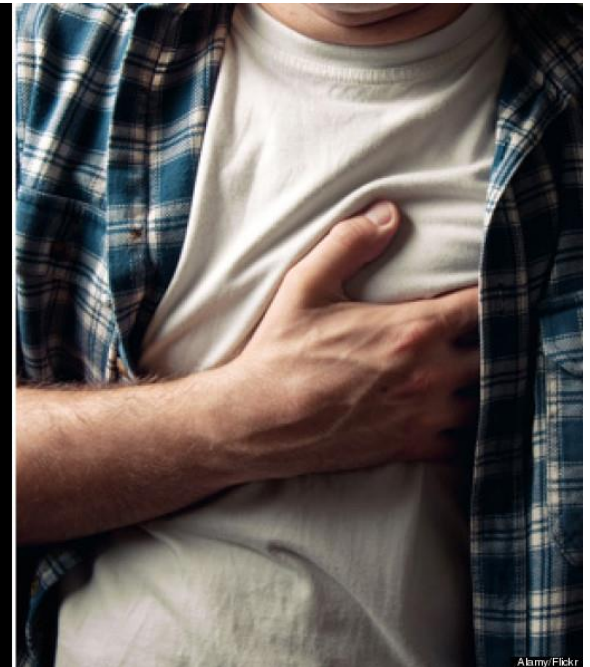
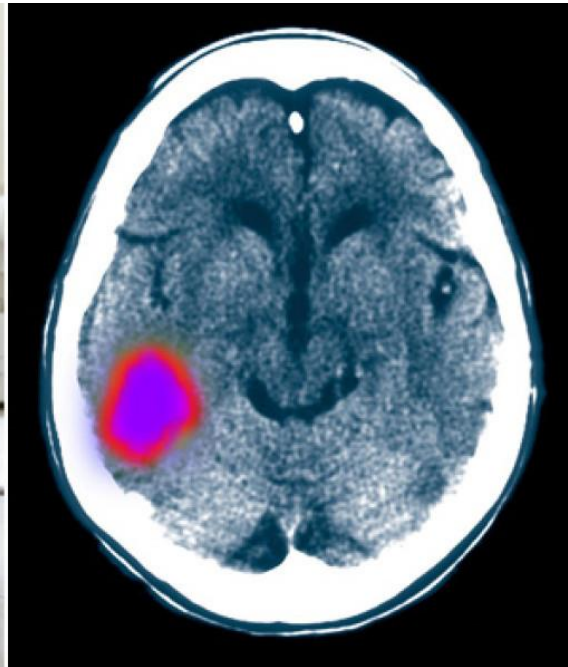
- Weekend oversleep
  - Practice of “making up” sleep
  - Marker of chronic insufficient sleep
  - But does not reverse or compensate for impairments
- Social jet lag
  - Shift in bedtime and wake times on non-school days
  - Leads to “circadian misalignment”
    - Exacerbation circadian phase delay
    - Shift melatonin onset
- Prevents sufficient build-up of sleep drive
  - Difficulty falling asleep Sunday night
- Result: permanent state of “jet lag”
  - Adjustment takes 1 day/time zone crossed
  - Effects persist up to 3 days

# The Bottom Line

- These changes in sleep are in direct conflict with earlier high school start times (before 8:30am)
  - As a result, students are required to wake for the day and function during the “circadian nadir” (the lowest level of alertness during the 24 hour day)
  - Early wake times also selectively rob teens of REM (rapid eye movement) sleep, which is critical for learning (*of new information in particular*) and memory
  - And they are unable to meet sleep needs
    - For optimal health, safety and achievement the average middle and high school student needs 8-10 hours of sleep\*

\*AASM recommendations, 2016

# Effects of Deficient Sleep on Health, Safety and Performance



# Neuroprotective Role of Sleep

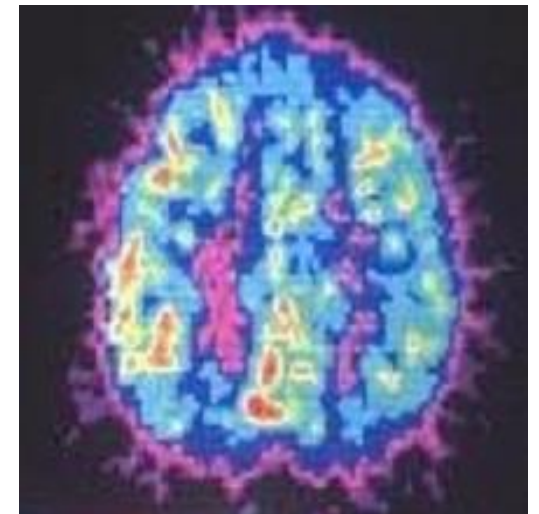
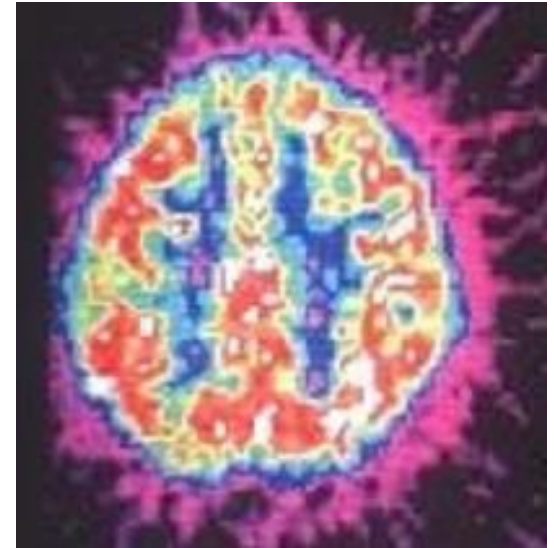
- Sleep deprivation/prolonged wakefulness affects neuronal functions
  - Neuronal “plasticity”: ability of the brain to change structure/function in response to the environment
  - Gene activation/expression
  - Neurogenesis
  - Brain cell protection/repair from stress
  - Highest susceptibility during critical developmental periods
- Recent research has found evidence of a “glymphatic system” which eliminates toxins in the brain during sleep and allows the brain to have a “clean slate” from which to work





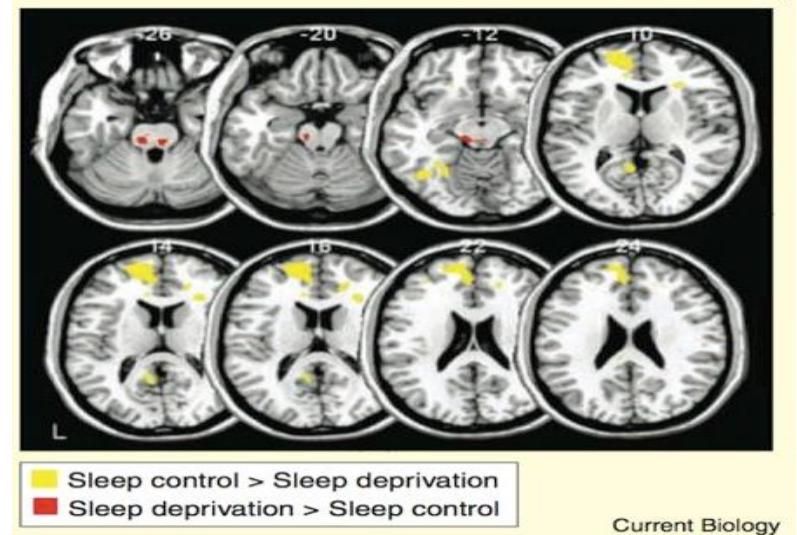
# Sleep and Behavioral Self-Regulation

- Experimental sleep restriction has selective effects on the prefrontal cortex (PFC) and “executive functions”
  - Flexibility
  - Planning
  - Problem-solving
  - Decision-making
  - Divergent thinking
  - Cognitive set shifting
  - Judgment, motivation
  - Monitoring, modifying and inhibiting behavior
  - Modulation of emotions
- Rapid development in adolescence



# Sleep and Emotional Regulation

- Sleep impacts response to positive and negative stimuli:
  - Increased response of the “emotional brain” (limbic system/striatum)
  - Weaker PFC connectivity
  - Heightened emotional response with less regulatory control



*Helm et al 2007*

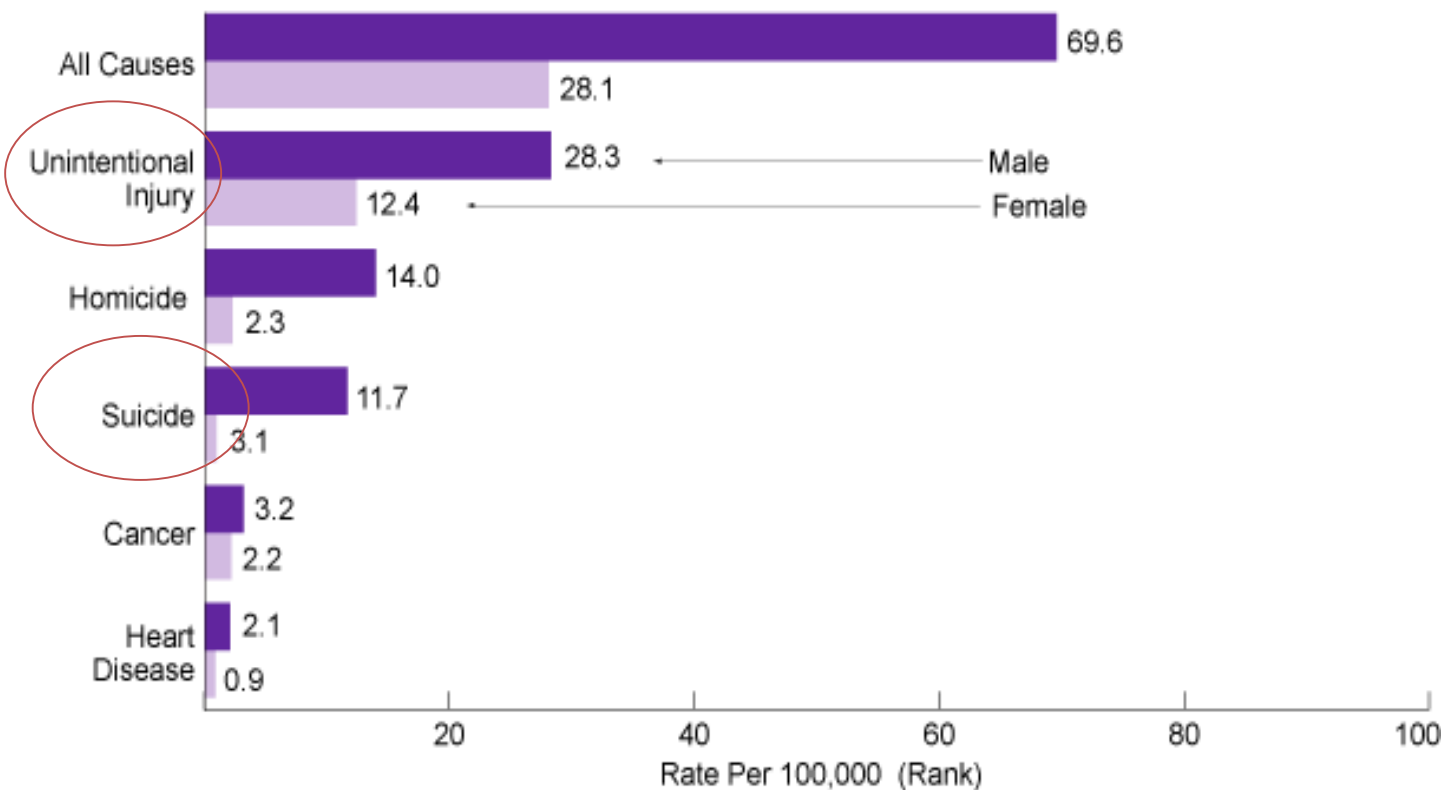
# Sleep and Risk Taking Behaviors

- Selective areas of the brain (striatum) are important for reward-related function
  - Positive emotions
  - Motivation
  - Response to reward
- These undergo structural/functional changes in adolescence
- Studies suggest insufficient sleep linked to changes in reward-related decision making
  - Perceive less negative  
take greater risks

*O'Brien & Mindell 2005; Giedd 2009;  
Holm et al 2009*



## Mortality Rates Among Adolescents Aged 15–19 Years, by Selected Leading Cause and Sex, 2010



Source: Centers for Disease Control and Prevention, National Center for Health Statistics. Compressed Mortality File 1999-2010. CDC WONDER Online Database, compiled from Compressed Mortality File 1999-2010 Series 20 No. 20, 2012. Retrieved from: <http://wonder.cdc.gov/ucd-icd10.html>. Accessed: November 15, 2012.

# Depression Symptoms and Risky Behaviors

- In a sample of HS students (N>10,000), 38% overall with insufficient sleep
  - $\leq 6$  hours; 19% 8<sup>th</sup> graders/42% 10<sup>th</sup> graders/56% 12<sup>th</sup> graders
- 10% overall with optimal sleep
  - $\geq 9$  hours; 19% 8<sup>th</sup> graders/6% 10<sup>th</sup> graders/3% 12<sup>th</sup> graders
- 40% of teens getting 6 or less hours of sleep report depression symptoms (sadness, hopelessness)
- Almost 3 times as many students getting less than 6 hours of sleep report alcohol use in the past 30 days compared to those getting 9+ hours

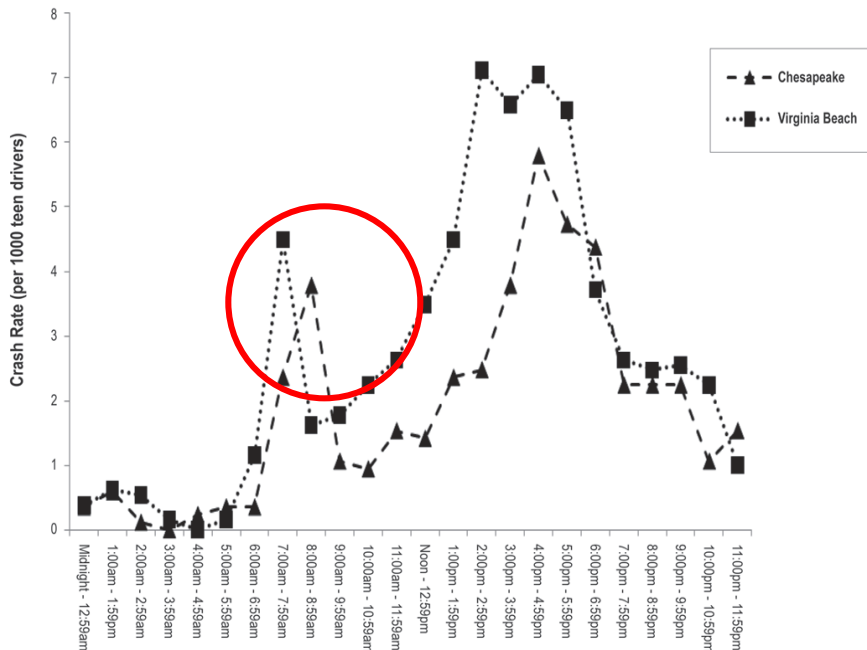
# Safety Issues: Drowsy Driving and MVAs

- Two-thirds of accidental injury fatalities in adolescents are related to road crashes (CDC 2012)
- AAA study (2015) found that 16.3% of 16-18 year olds reported driving while “so tired you had a hard time keeping your eyes open” at least once in the past 30 days<sup>1</sup>
- 48% of adolescent drivers reported drowsy driving; every hour less sleep on school-nights compared to a sleep duration of  $\geq 8$  hrs was associated with an increased risk of drowsy driving<sup>2</sup>

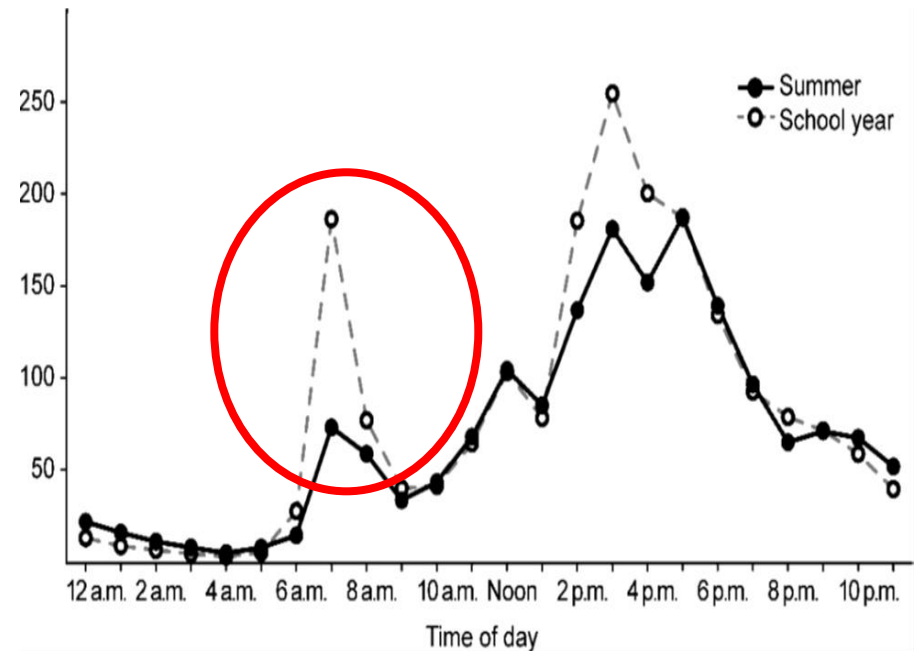
*1 Tefft 2016 2Whitaker, Owens 2018*

# Safety Issues: Drowsy Driving

## Time of Day Teen Crash Rates



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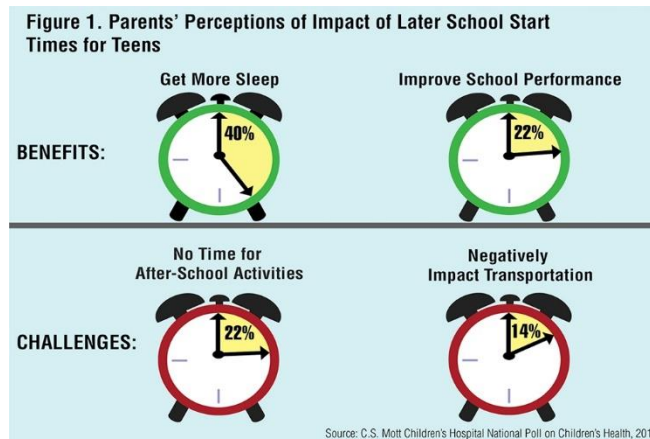
# Safety Issues: Risk Behaviors

- Survey of >50,000 US high school students: injury risk behaviors significantly more frequent in students sleeping < 7 vs 9hrs<sup>1</sup>
  - Infrequent bicycle helmet use
  - Infrequent seatbelt use
  - Texting while driving
  - Rode with drinking driver
  - Drinking and driving (increased 8 vs 9 hrs)

<sup>1</sup>CDC MMWR 4/8/16



# What is the Role of School Start Times?



# AAP Recommendation: Delay School Start Time until 8:30 am or Later\*

American Academy  
of Pediatrics



DEDICATED TO THE HEALTH OF ALL CHILDREN™

## Let Them Sleep: AAP Recommends Delaying Start Times of Middle and High Schools to Combat Teen Sleep Deprivation

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8/25/2014

For Release: August 25, 2014

\*Also endorsed by AMA, CDC, APA, AACAP, AASM, ATS, NASN, NASW, NEA, National PTA

# Longitudinal Analyses of Student Self-Reported Data in US Schools That Changed to Later School Start Times<sup>1</sup>

- Significant changes ( $p < 0.05$ ):
  - Later rise time
  - Later bed times
  - Earlier bed times
  - Longer sleep durations
  - Less weekend catch-up sleep
  - Decline in Epworth scores and less daytime sleepiness
  - Greater sleep satisfaction
  - Less depressed mood
  - More time doing homework

<sup>1</sup>*Wheaton A et al, 2016* [...](#)

# Outcomes: Sleep

- Bedtimes remain similar or shift slightly later, which is offset by morning wake time delay
- Students obtain significantly more sleep
  - More morning sleep
  - The later the start time, the greater the sleep amounts
- Students report less daytime sleepiness (falling asleep in class, doing homework)
- $\geq 8:30$ am the sleep and circadian “sweet spot”?

*\*Wheaton 2016*

## Outcomes: Sleep

School Start Time	7:30-7:35 AM	8:00-8:05 AM	8:20 AM	8:35 AM	8:55 AM
Percent of Students with $\geq 8$ hours on sleep/night	34*-44%	42-50%	50%	57-60%	66%

\*Franklin High School students

*Wahlstrom 2014*

# Outcomes: School Performance

- Increased attendance rates
- Decline in absenteeism rates
- Decline in tardiness rates
- Decreased drop-out rates
- Increased graduation rates
- 1<sup>st</sup> period grades improved
- Increase in GPA\*
- Higher standardized test scores\*

*Wahlstrom 2014; Wheaton 2016; McKeever 2017; Edwards 2012*



# Outcomes: Health & Safety

- Delayed SST are associated with improvements in:
  - Mood (fewer report feeling unhappy, depressed)
  - Health (decreased health center visits)
  - Safety
    - Kentucky: 7:30 to 8:40a start time; teens involved in car crashes down by 16% (vs 9% increase in the rest of the state)<sup>1</sup>
    - Virginia: Adolescent crash rates VA Beach (7:20a) vs Chesapeake (8:40a) 40% higher and peak 1 hour earlier; similar results follow up study<sup>2,3</sup>
    - CDC study (2014): Reduction crash rates in 16-18yo by as much as 65-70% (Minnesota, Colorado, Wyoming)<sup>4</sup>

*Danner and Phillips 2008; 2Vorona et al 2011; 3Vorona et al 2014; 4Wahlstrom 2014*

# School Start Time Change and Motor Vehicle Crashes in High School Students

- Aim: To study the impact of a 50 min delay in high school start times (7:20am to 8:10am) on driving safety in one of the largest school districts in the US
- Analyzed difference in DMV data base car crash rates in 16-18 yo drivers during the 2 years prior to and after the FC start time change compared to the rest of the state
- There was a significant decrease in crash rates in FC and a slight increase (not significant) change in the rest of VA
  - Amounting to approximately 126 fewer crashes
  - Distraction-related crashes declined

# Economic Benefits<sup>1</sup>

- Recent macroeconomic modeling of US state-wide change from current SST to 8:30am vs status quo suggested that benefits of later start times far out-weigh immediate costs (\$150 per student/yr  $\pm$  \$110,000 for infrastructure); includes grades 6-12
  - Based on projected student lifetime earnings: increase HS graduation rates, university attendance PLUS reduction in adolescent car crashes
  - During the 15 year period examined by the study, the average annual gain to the U.S. economy would about \$9.3 billion/yr\*
  - Some states would “break even” after just 2 years
- This study suggests that delaying school start times to 8:30am is a cost-effective, population-level strategy which could have a significant impact on public health and the U.S. economy

*\*Approximate annual revenue of Major League Baseball (US) or almost 3x the worth of Real Madrid soccer team*

<sup>1</sup>Hafner, M, Stepanek M and Troxel W. Later school start times in the U.S.: An economic analysis. Santa Monica, CA: RAND Corporation, 2017. [https://www.rand.org/pubs/research\\_reports/RR2109.html](https://www.rand.org/pubs/research_reports/RR2109.html).

# California Senate Bill 348

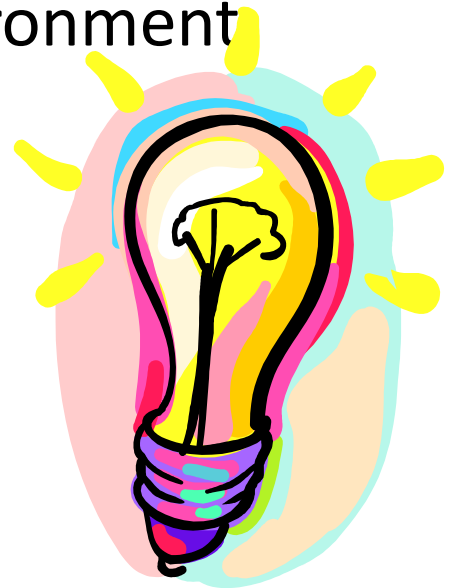
- **10/13/20: California School Start Time Bill becomes law**
  - Public high school will begin no earlier than 8:30 am and middle schools no earlier than 8am
  - State-wide implementation by academic year 2022-23
- “California becomes first state in the country to push back school start times” *LA Times*
- “High schools in California will have mandated start times aimed at helping sleepy teens” *CBS News*
- “California Tells Schools to Start Later, Giving Teenagers More Sleep” *NYT*
- “Students need more sleep. Good for California for giving them a later school start” *Editorial Board Washington Post*

# What Can Schools Do?

- Set healthy school start times
- Include sleep as part of student health education, biology classes
- Help students manage their schedules so that they have time for adequate sleep
- Decrease homework burden
- Buffer early start times by setting limits on evening activities at school as well as early morning/ late evening athletic practices.
- Work with employers to decrease adolescents' work hours
- Include drowsy driving in driver ed

# What Can Parents Do?

- Know the signs of deficient sleep in teens
- Enforce appropriate sleep schedules
- Set limits on after-school activities and jobs
- Keep track of caffeine use
- Monitor drowsy driving: “No ZZZs? No keys!”
- Provide a “sleep-friendly” home environment
- Be a good sleep role model
- Make sleep a priority!





Thank you!  
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