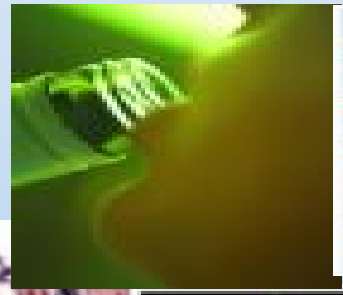
Adolescent Brain Development in Context: Implications for Health, Education, and Social Policy

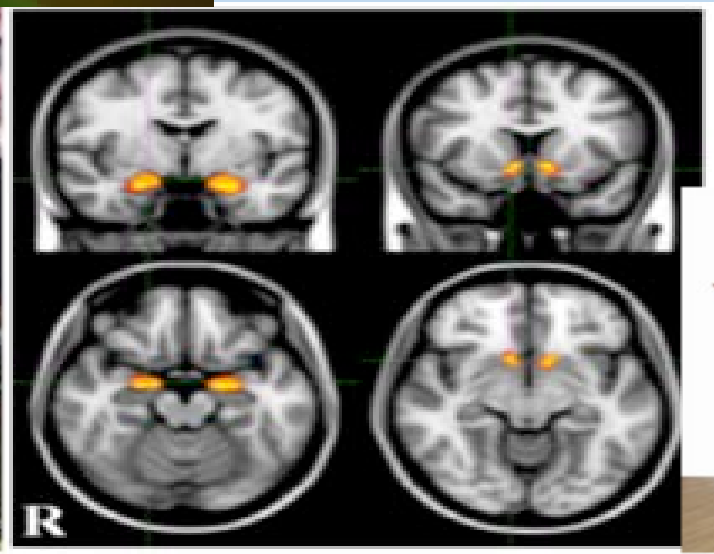
Ron Dahl

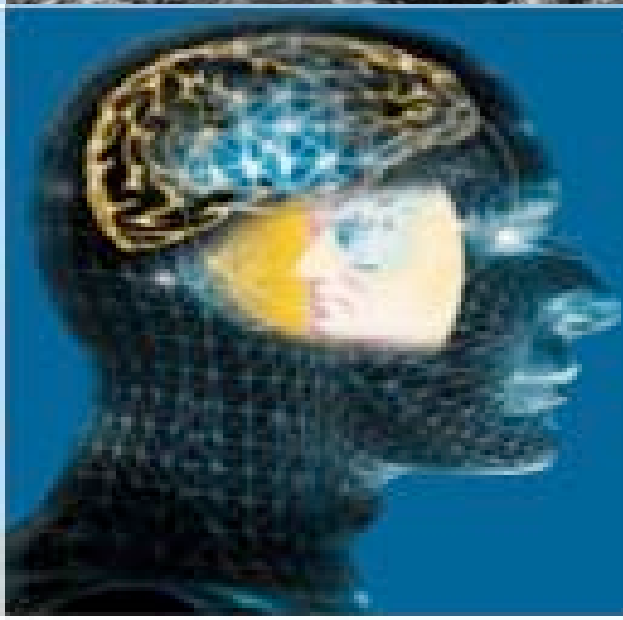
Center on the Developing Adolescent

UC Berkeley

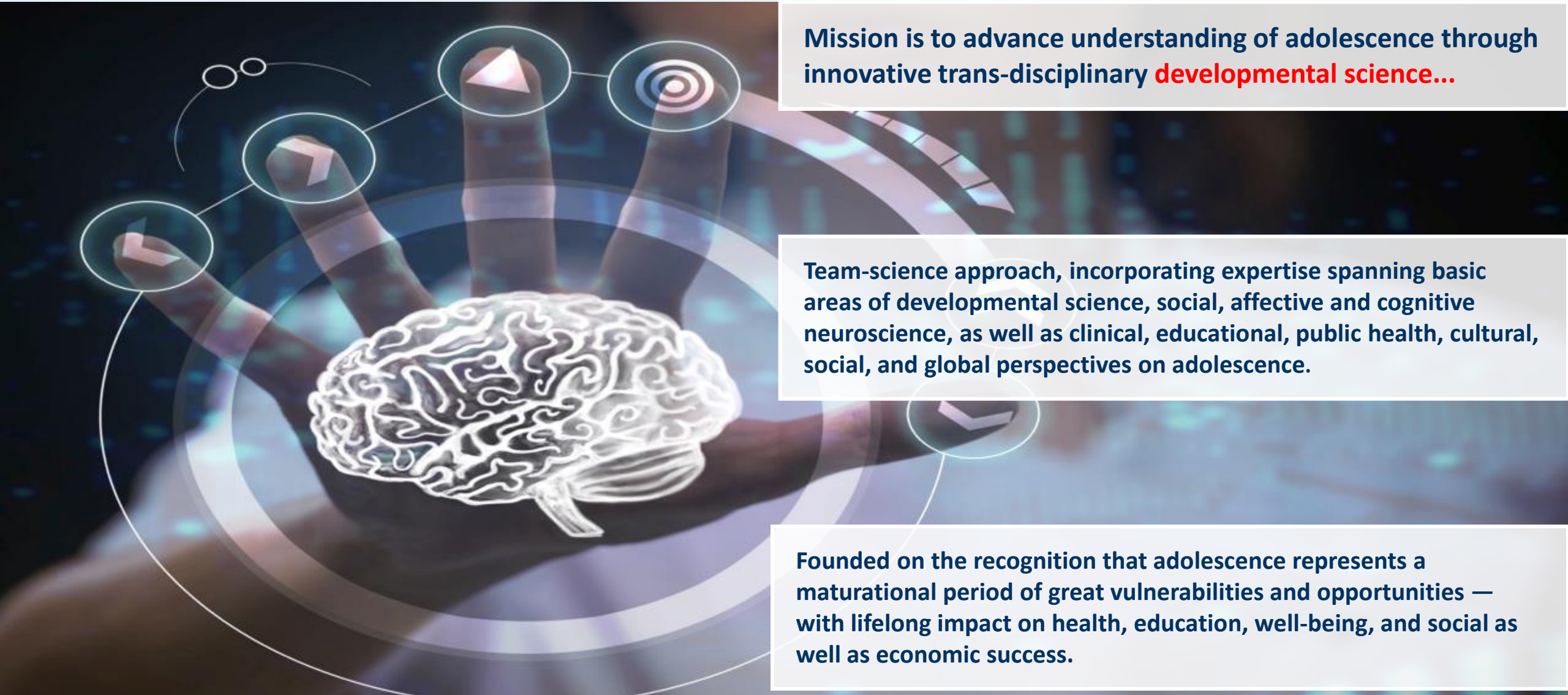


CENTER ON THE DEVELOPING ADOLESCENT

Connecting Emergent Brain Research to Programs and Policy



Mission is to advance understanding of adolescence through innovative trans-disciplinary developmental science...

Team-science approach, incorporating expertise spanning basic areas of developmental science, social, affective and cognitive neuroscience, as well as clinical, educational, public health, cultural, social, and global perspectives on adolescence.

Founded on the recognition that adolescence represents a maturational period of great vulnerabilities and opportunities — with lifelong impact on health, education, well-being, and social as well as economic success.

Developmental Science of Adolescence:

A perfect storm of *interacting* levels of change…

Rapid physical growth; the activation of new drives and motivations;
Sex-specific changes in facial structure, voice, and body characteristics;
Changes in sleep and circadian regulation; metabolic changes;
Wide array of cognitive and emotional changes;
Profound changes in social motivations, social context and social roles

Biological/ Behavioral/ Neurodevelopment/ Peer/ Family/ School/ Culture/ Media….

…and figuring out how to relate to the world, and yourself, as a suddenly and mystifyingly sexual being…

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Profound changes in social motivations, social context and social roles

Biological/ Behavioral/ Neurodevelopment/ Peer/ Family/ School/ Culture/ Media….

Multiple levels of bi-directional interactions; dynamic processes over time that are actively sculpting these developing neural systems …

dark side: the negative spirals…

The Light Side: Adolescence as a Perfect Storm of Opportunities

Learning/Exploration/Acquiring Skills/Habits/Intrinsic Motivations

Identity formation/Attitudes/ Setting Goals & Priorities

Compelling need for transdisciplinary research to

understand unique opportunities for social and emotional learning

Positive Developmental Spirals

Developmental Science of Adolescence

Developmental Science: Understanding Individual Differences as Individual Trajectories

Developmental Pathways to Individual Differences?

(height as simple exemplar of developmental science principles)

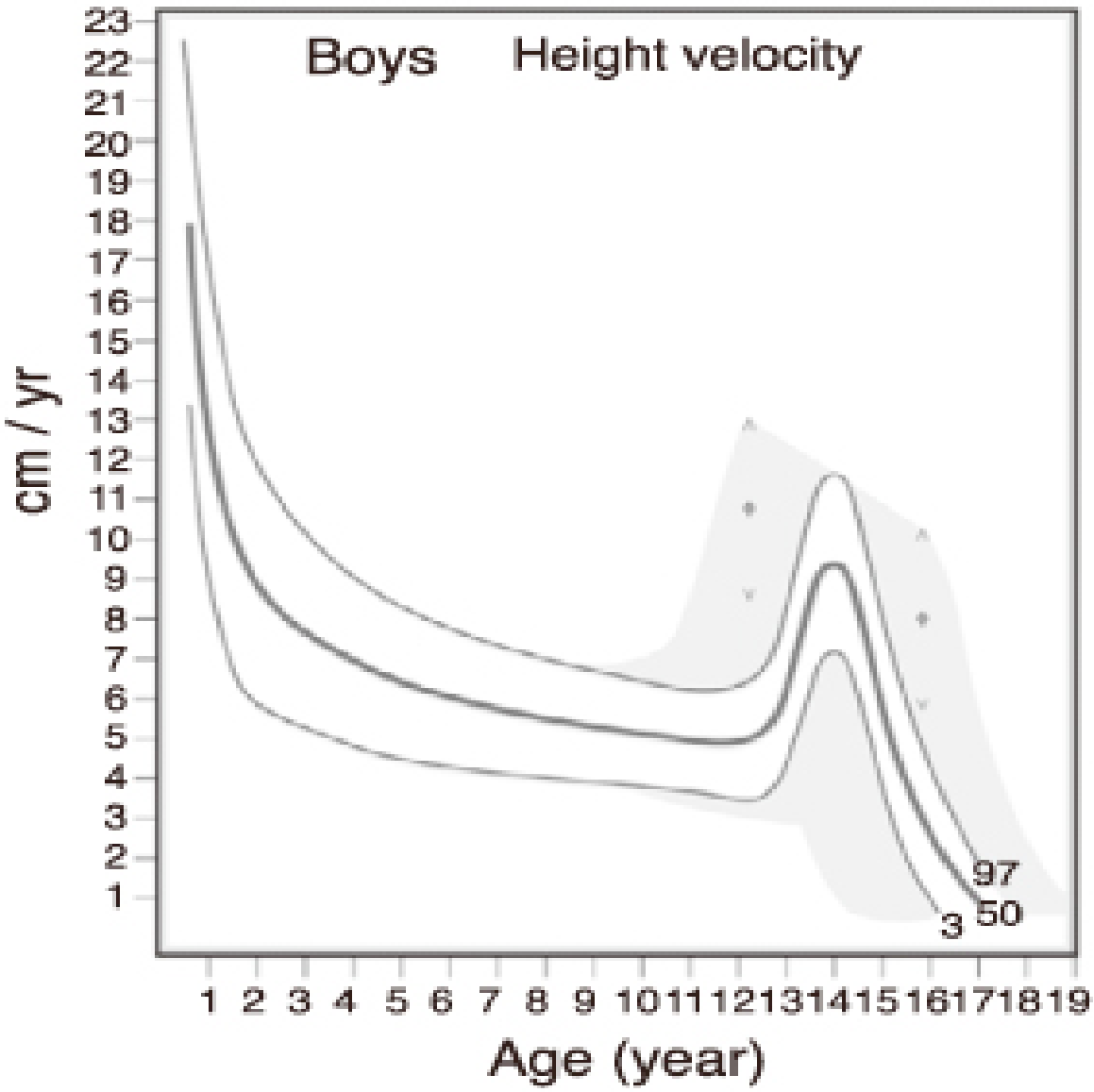
World's tallest man:
Sultan Kosen 8'9"
meets world's shortest man:
Chandra Danoi 1'9"

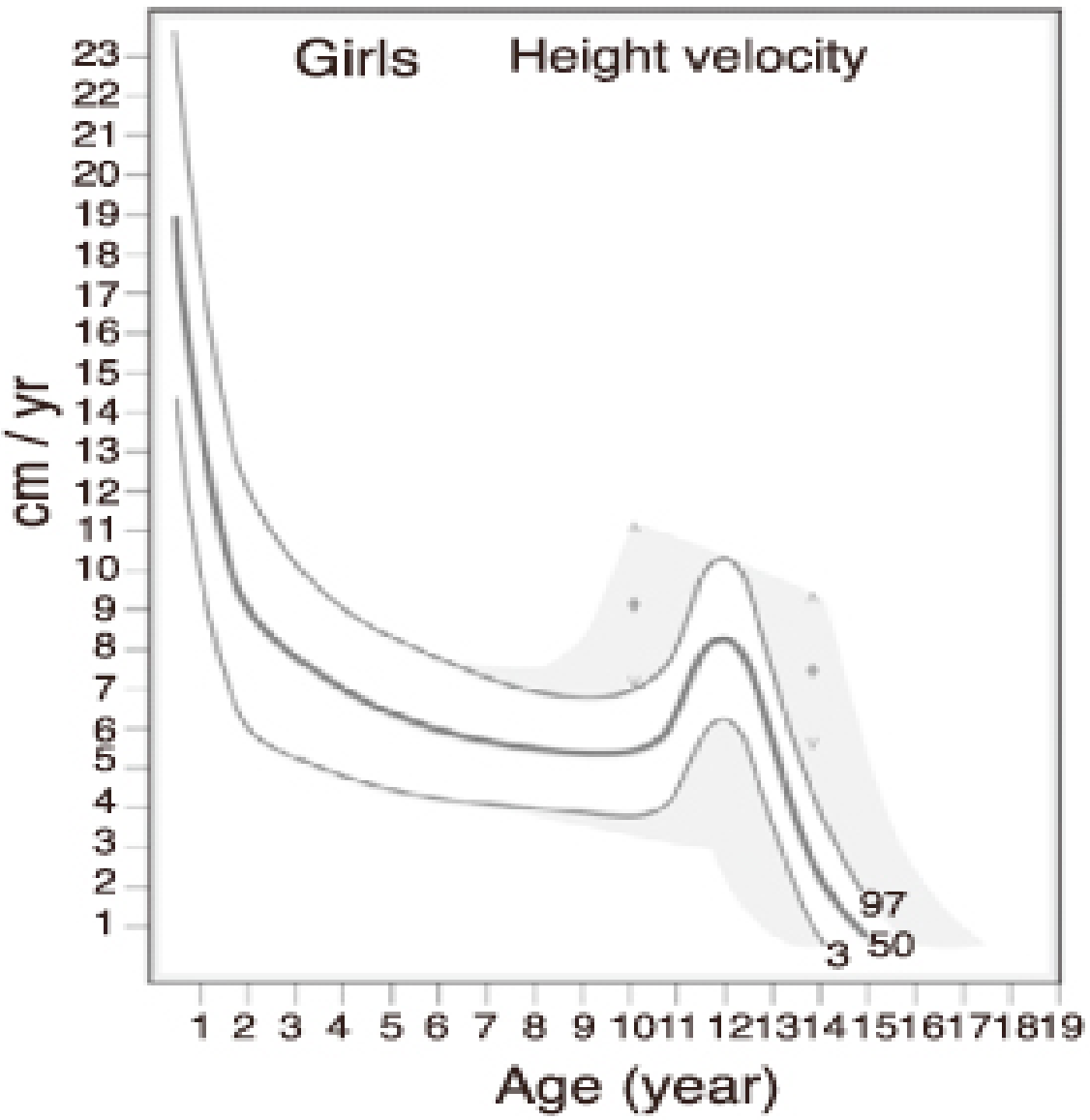
"Even though he is short and I am tall,
we have had similar struggles throughout our lives,"
Kosen said…

Cohort study 348,706 infants with data examining association between birth length and adult height:

Cohort study 348,706 infants with data examining association between birth length and adult height: (R = 8%)

Pubertal Spurt in Growth Velocity





Q1: Does the onset of puberty initiate a ‘learning spurt’ in human development

- Changes in neural systems (especially dopaminergic systems involved in reward processing and learning) during pubertal maturation
- Evidence that puberty is associated with **re-orientation to social and emotional information processing streams** (particularly):
  - Learning about social relationships, social roles, peers, potential romantic partners, social hierarchies, and interest in sexual behavior
  - Learning about the self and exploring one’s place in these social hierarchies, strong desire for acceptance, belonging, admiration and respect
- Creates a window of opportunity (and vulnerability) to learning/social contexts that will impact individual differences across the lifespan….

The Health Paradox of Adolescence

Adolescence is (physically) the healthiest period of the lifespan: prior to adult declines; beyond the frailties of infancy and childhood:

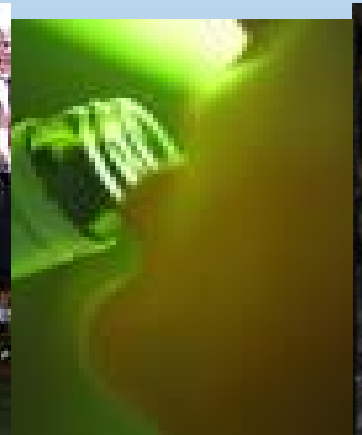
- Improvements in strength, speed, reaction time, reasoning abilities, immune function …
- Increased resistance to cold, heat, hunger, dehydration, and most types of injury …

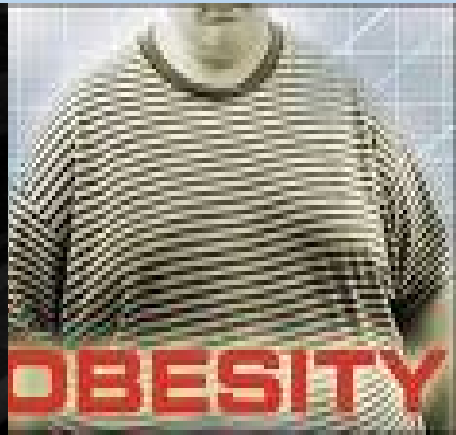
- Yet: overall morbidity and mortality rates *increase* > 200-300% from childhood to late adolescence

Morbidity & Mortality in Adolescence:

- Primary sources of death/disability are related to problems with *control of behavior and emotion*
- Increasing rates of accidents, suicide, homicide, depression, alcohol & substance use, violence, reckless behaviors, eating disorders, STDs, health problems related to risky sexual behaviors… obesity
- Behaviors with long-term health (lifetime) consequences

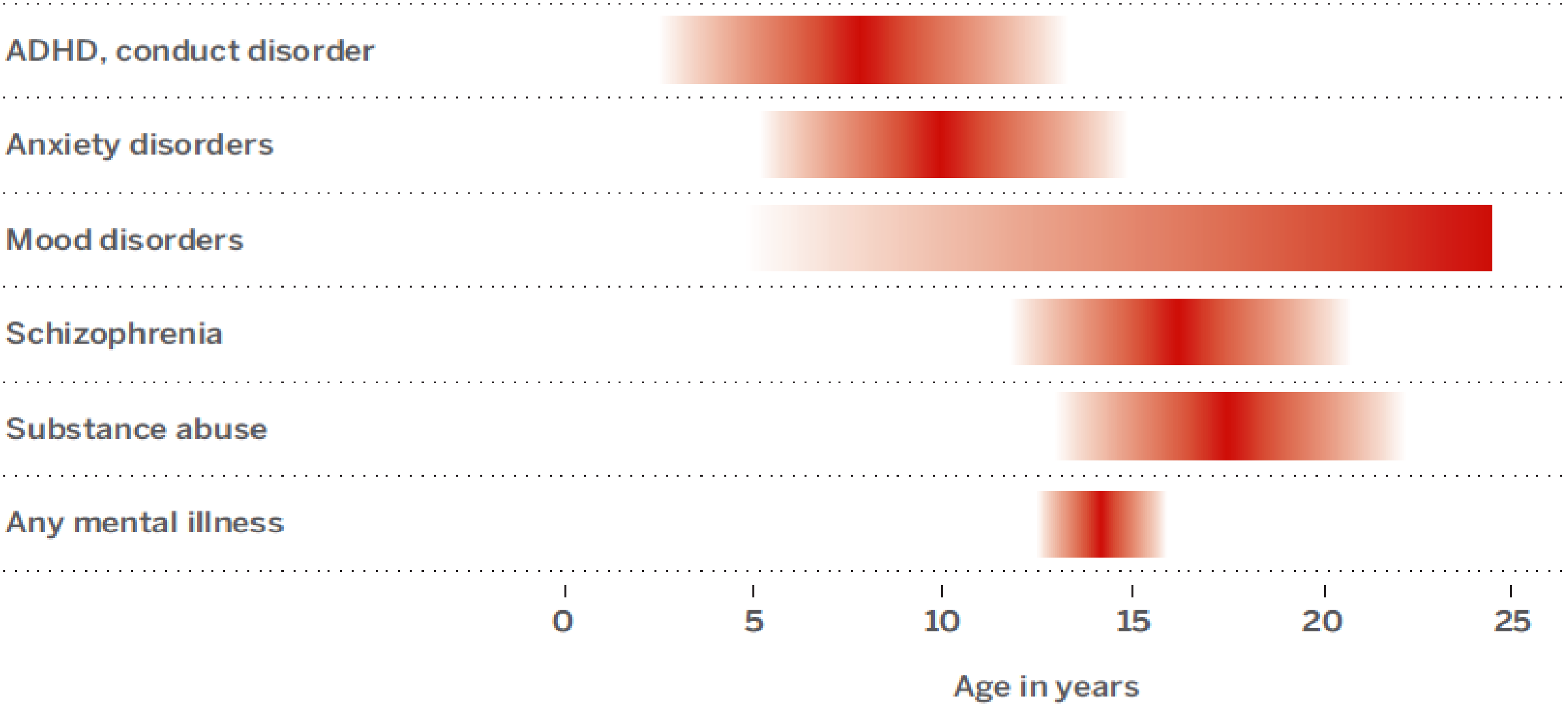






Emergence and peak in mental disorders during adolescence

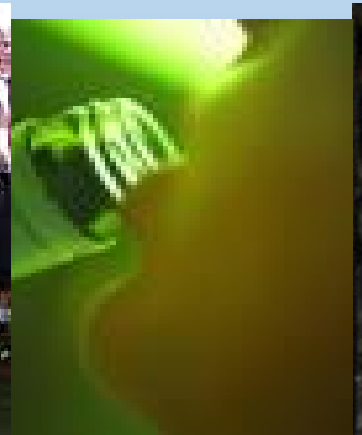
One in five adolescents have a mental illness that will persist into adulthood

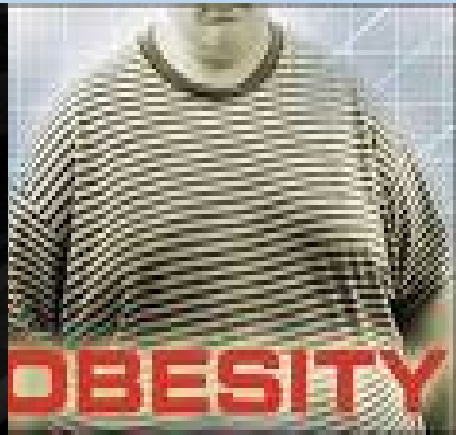


Q2: Where are the best opportunities for basic science advances that can be leveraged to create impact?

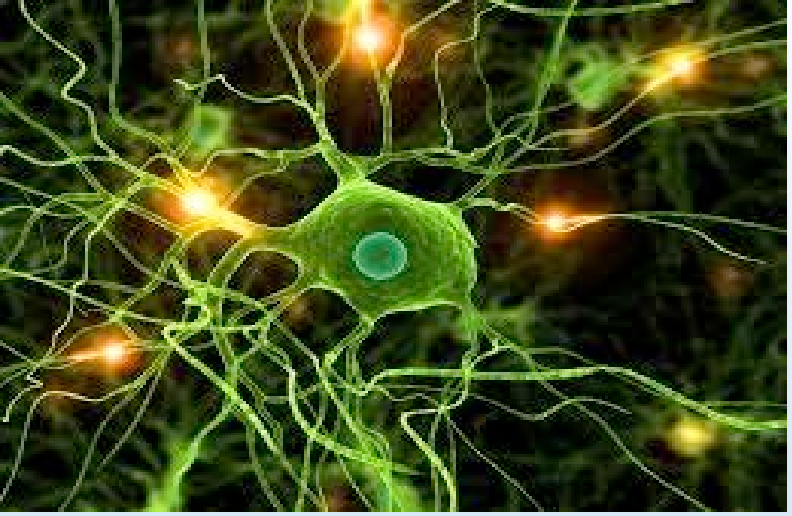
Developmental psychology?
Behavioral endocrinology?
Genetics/epigentics?
Molecular and cellular neuroscience?
Developmental cognitive/affective/social neuroscience?







Developmental Science of Adolescence



Neural Plasticity

- Encompasses a wide range of synaptic and non-synaptic processes that underpin the brain's capacity to instantiate learning.
- A great deal of scientific interest has focused on understanding 'sensitive' or 'critical' periods of development.
- Windows of opportunity for specialized learning

Neural Plasticity

- Hensch lab: pioneering contributions to understanding molecular processes and mechanisms underlying critical periods of brain development
- Can now experimentally manipulate the molecular mechanisms underpinning plasticity
  - by removing the molecular ‘brakes’ to reopen critical developmental learning windows for visual processing in animal models (Yang 2012)
  - in adult humans by pharmacologically reopening critical-periods for learning precise musical pitch (Gervain 2013).
- Developmental science: understanding ***how the balance of plasticity/stability changes across the lifespan***

Neural Plasticity

- Capacity for learning and experience to shape key developing neural systems does **not** end at age 3…
- As some windows of plasticity close, others open.
- Brain development requires ***balance of stability and plasticity.***
- **Onset of puberty (ages 9 -14) represents an important set of shifts in this balance**.
- Not a question of plastic (yes or no); rather ***what kinds of plasticity, what specific windows of opportunity***

Sensitive window of learning: what does the brain ‘expect’ to learn

- The infant brain, for example, ‘expects’ some kinds of visual experiences that are necessary to organize and tune the visual systems
- Similarly, the infant brain ‘expects’ language and social experiences—
  - the particular language an infant hears during this window of opportunity will have life-long impact…
  - as will the quality of social and emotional caretaking…

How do young children learn to (expertly): walk, talk, control their eyes, recognize familiar faces, read emotion in faces…? Practice

- **Toddler learning to walk takes 14,000 steps (46 football fields) and incurs 100 falls per day**. (Adolf et al 2012)
- By 2 months, infants have executed more than 2.5 million eye movements (Johnson et al 2003).
- By 2 years of age: have looked at faces…emotional faces…millions of times
- ***Patterns of neural connection are shaped by:***

patterns of behavior—practice, practice, practice

[Social contexts interacting with 'attractors'

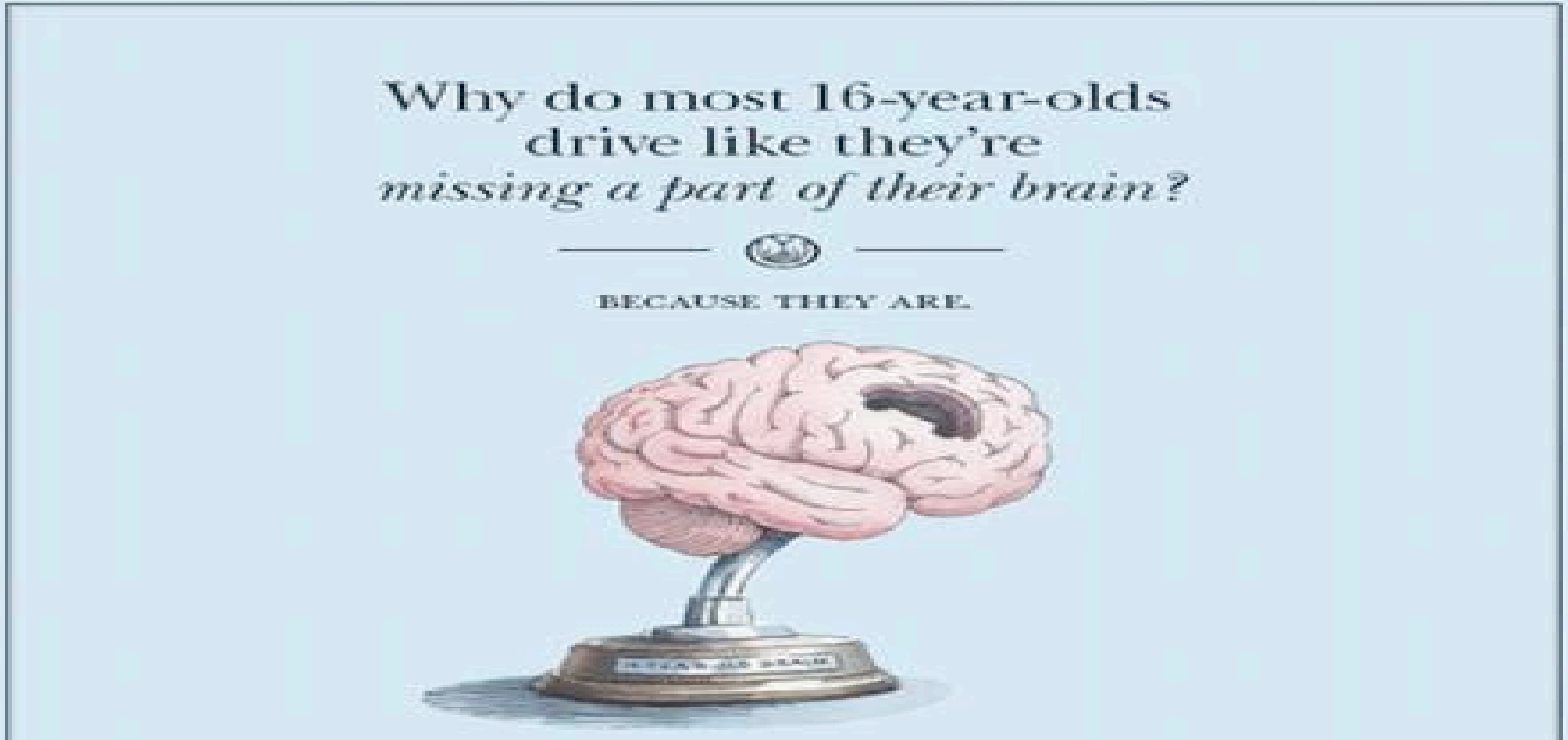
….attractors that activate desirable feelings…]

Q3: How have evolutionary forces shaped *what the adolescent brain 'expects' to learn?*

- How does pubertal maturation impact the sensitivity of neural systems for sensitive and engaged learning?
- What kinds of information processing does the adolescent brain become naturally more attuned to and motivated to engage for rapid learning? What are the 'attractors'?
- What are the **early adolescent corollaries** to an infant's natural attraction to repeatedly *practice*—and eventually master—control of eye movements, speaking words, reading faces, and walking?

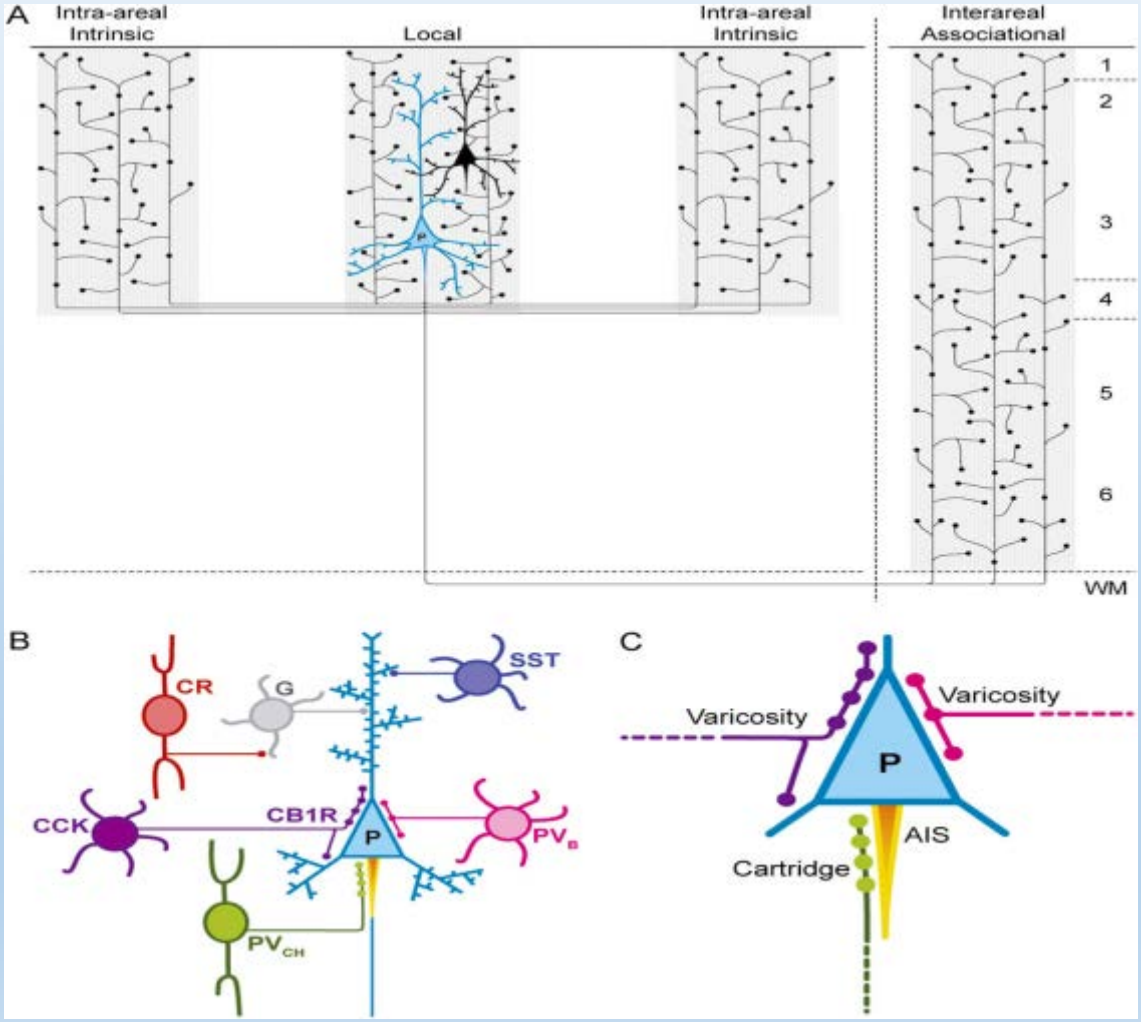
Adolescent Brain Development:

Myth of the ‘broken’ brain or ‘missing’ brain and ‘immature PFC’



Adolescence: protracted, complex, circuitry development with multiple sensitive periods…

David Lewis: even within layer 3 of one subregion of DLPFC:
dramatically different developmental trajectories depending on micro-circuitry, dopamine receptor subtype, etc…



Crone and Dahl 2012

Understanding adolescence as a period of social–affective engagement and goal flexibility

- Meta-analysis of fMRI studies of adolescent brain development
- No consistent support for immature PFC as the basis for 'adolescent' risk behavior or decision-making
- Large variability in findings (increased, decreased, or no differences in PFC activation) **depending on tasks, motivation, and social context**….

  (See Special section on adolescent brain development in DCN Feb 2016)

Adolescent Brain Development

Adolescent brains:

- **very well adapted for the tasks and challenges of adolescence**
- unique *opportunities* for social, emotional, & motivational learning
- learning about the complex social world they must navigate – including the hierarchies, social rules for gaining acceptance and status, and the mystifying discovery of a sexual self….

-- Neural systems learning to calibrate complex social and emotional 'valuing' systems – fast automatic systems that use 'feelings' as fast signals

Social Emotional Learning (about self and others)

We search on our journeys, for a self to be,

for other selves to love and work to do.

— Frederick Buechner

I've learned that people will forget what you said,
people will forget what you did,
but people will never forget how you made them feel.
—Maya Angelou

Adolescent Brain Development

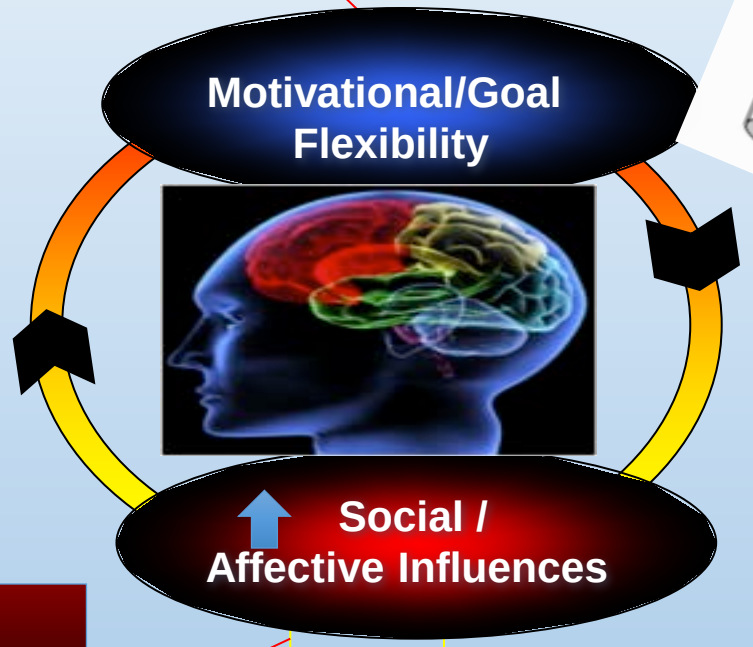
Crone & Dahl 2012

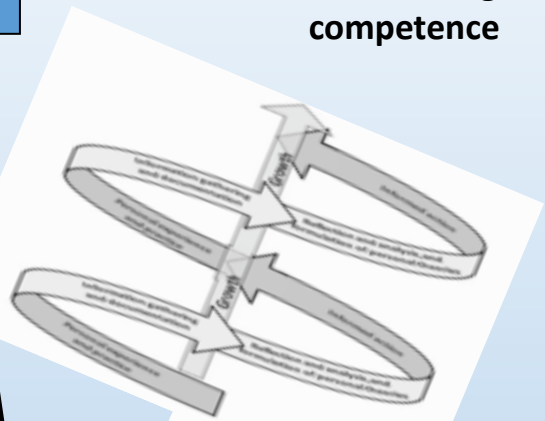
Frontal-Cortical Engagement (variable)

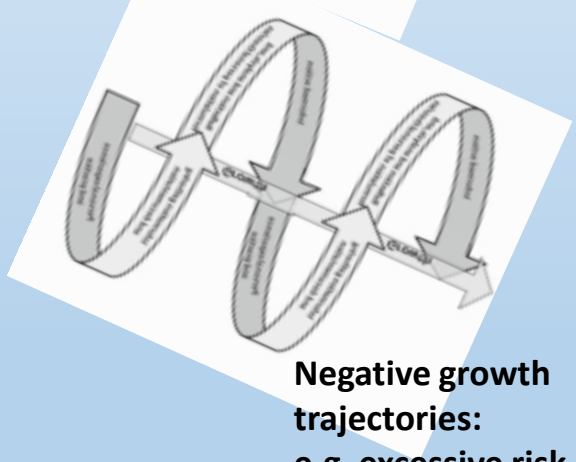
Cognitive control system

DLPFC
Parietal cortex

Positive growth trajectories:
e.g. adaptive exploration, mature long-term goals, social competence







Onset of puberty

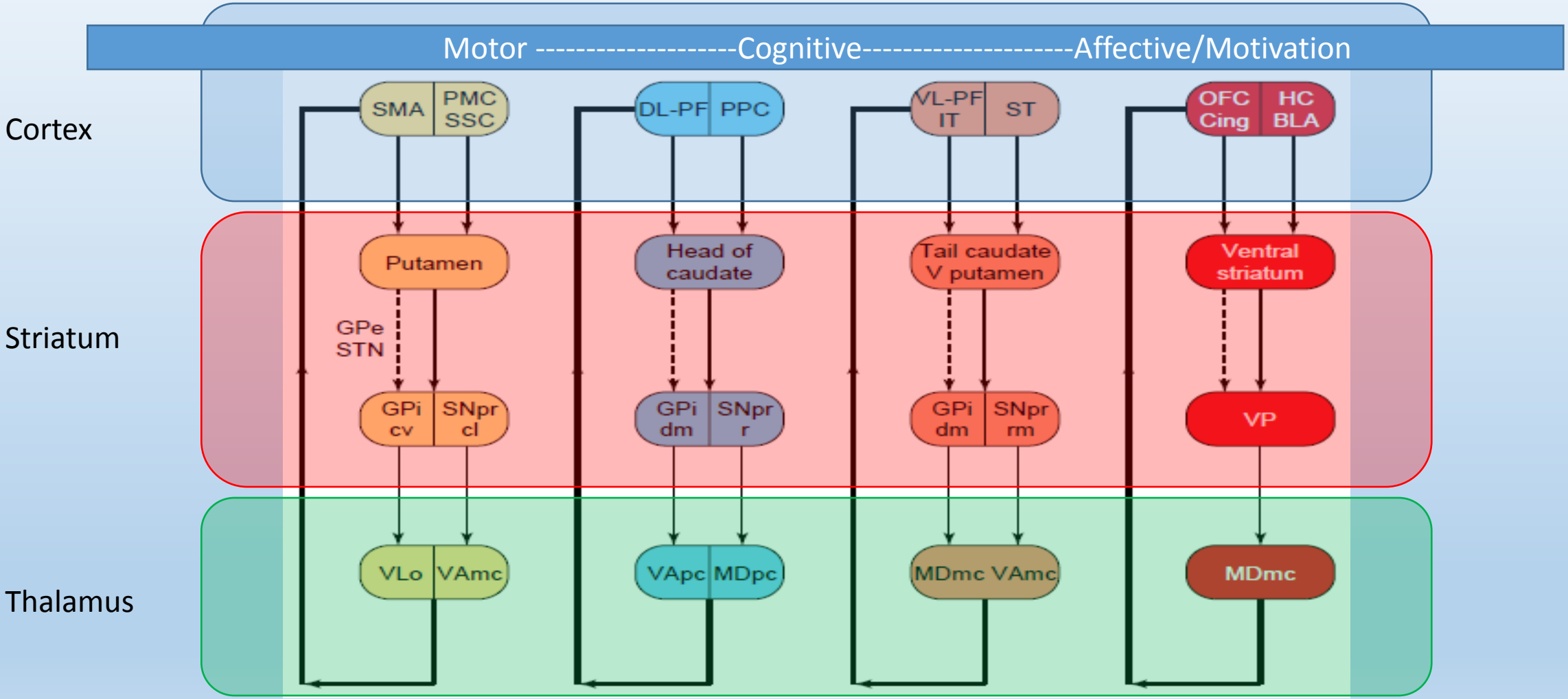
Limbic Engagement:
↑Affective salience of social cues & context

Subcortical structures
Ventral striatum
Amygdala

Negative growth trajectories:
e.g. excessive risk-taking, substance use, depression, social withdrawal

Time/Development

CORTICAL STRIATAL THALAMIC LOOPS

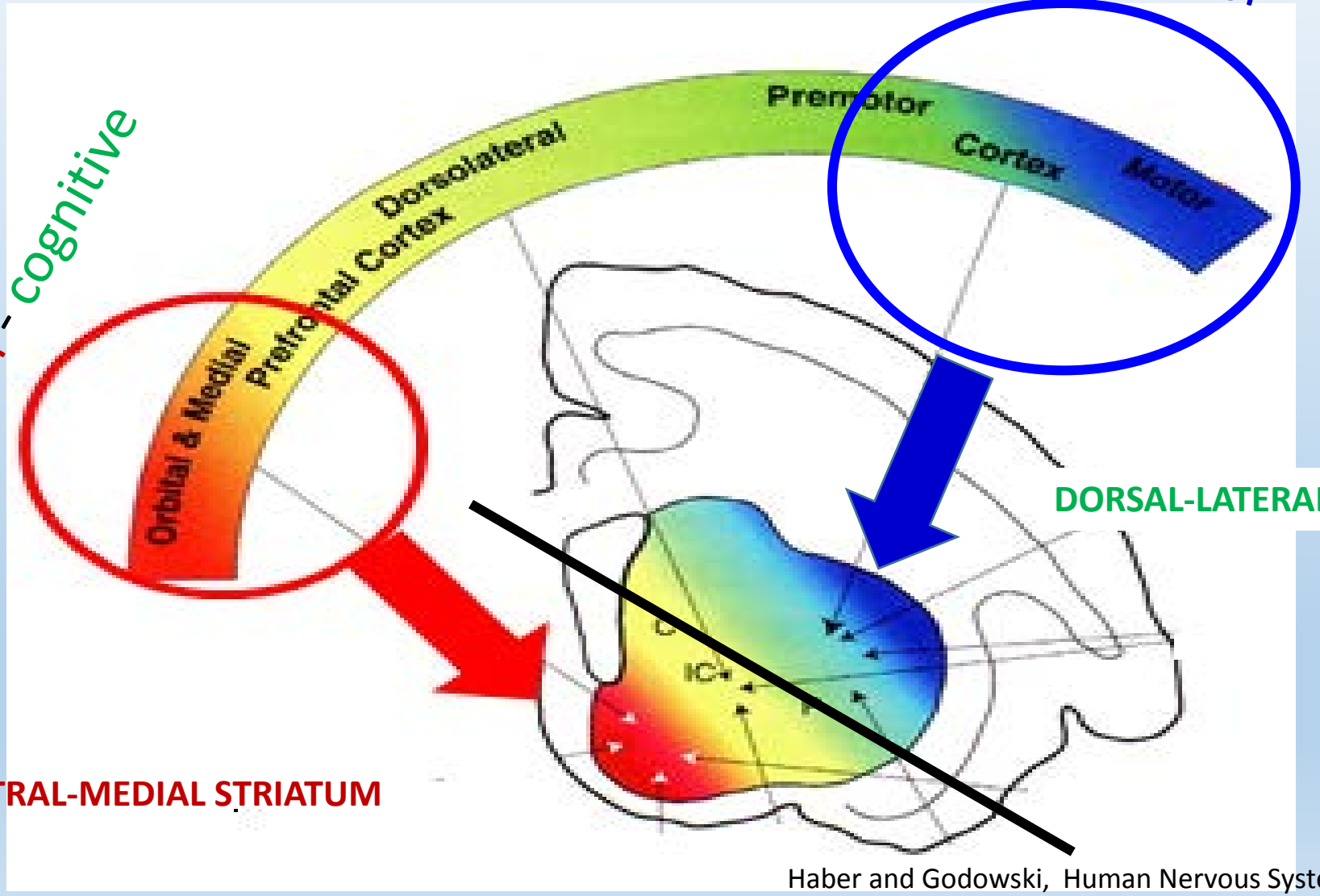


Lawrence et al., 1998, TINS; Alexander Delong, Strick 1986

STRIATUM

Cognitive - motor

Emotional - cognitive



DORSAL-LATERAL STRIATUM

VENTRAL-MEDIAL STRIATUM

Haber and Godowski, Human Nervous System, 2002

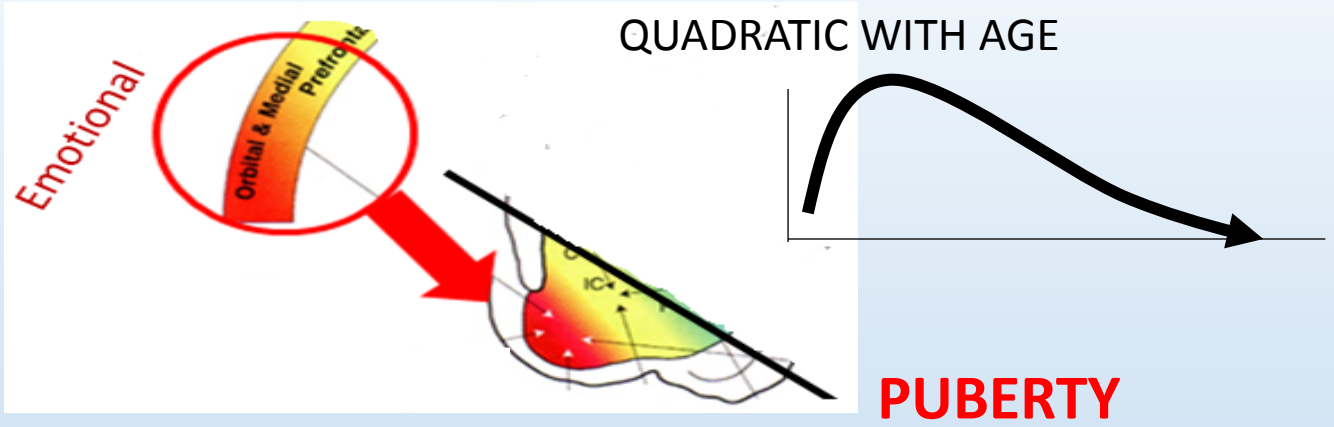
Emotion

Motivation

Cognition

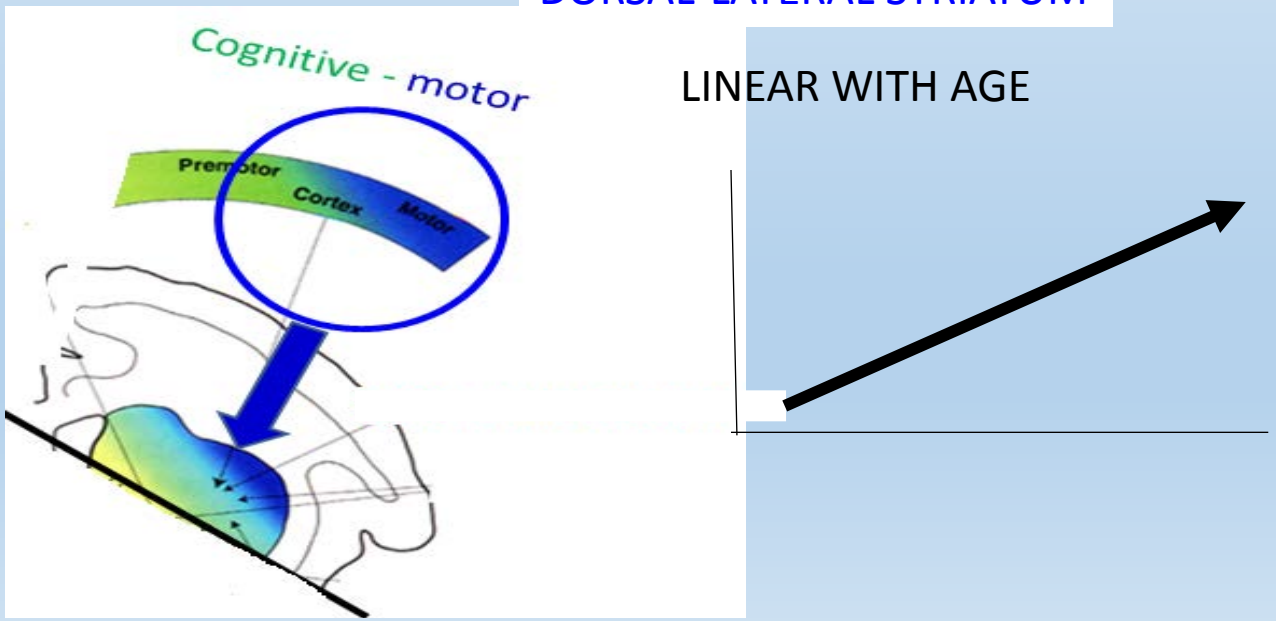
Motor

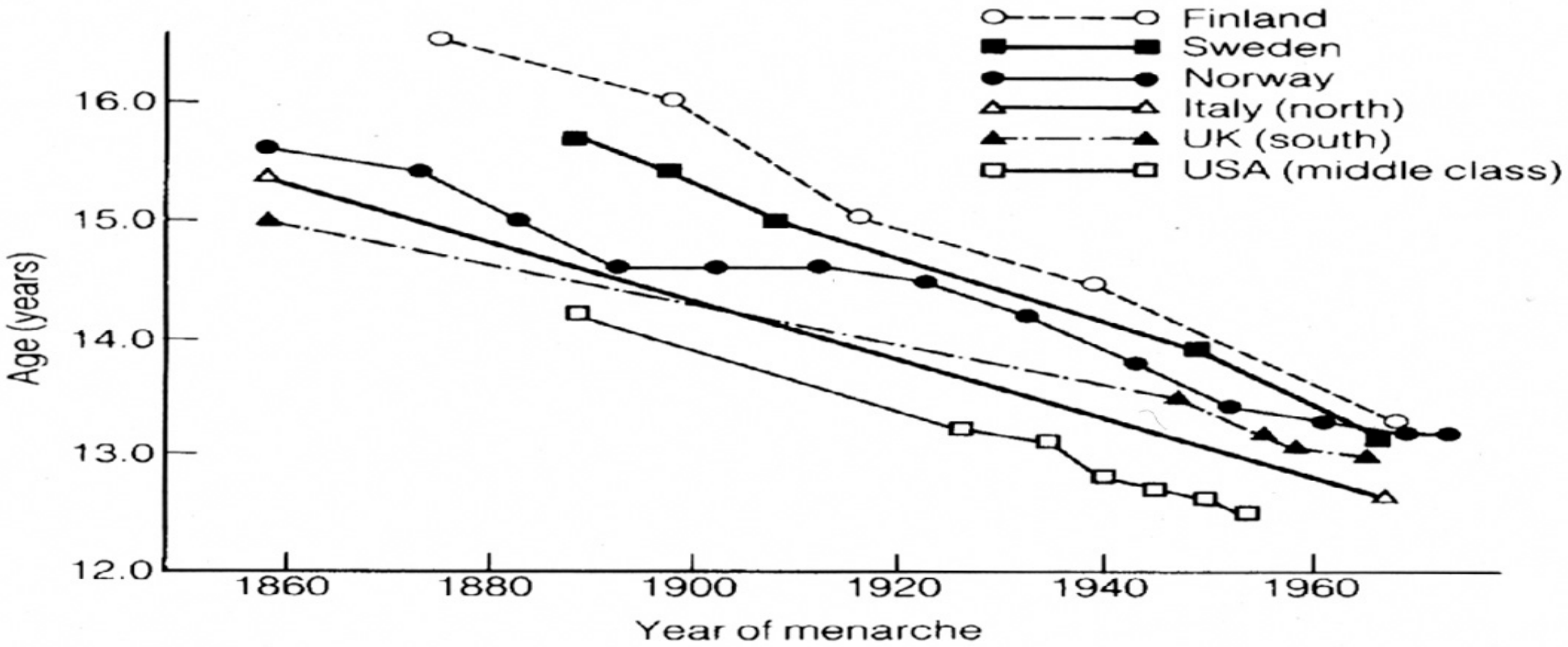
VENTRAL-MEDIAL STRIATUM



PUBERTY

DORSAL-LATERAL STRIATUM





7.2 Age at menarche, 1860–1970.
Sources of data and method of plotting detailed in J.M. Tanner, *Foetus into Man*, 2nd edn, Castlemead Publications, 1989.

The past 150 years have witnessed a quiet revolution in human development that still sweeps across the globe today: children nearly everywhere are growing faster, reaching reproductive and physical maturity at earlier ages, and achieving larger adult sizes than perhaps ever in human history.

--Carol M Worthman, Ph.D.

Adolescent Brain Development

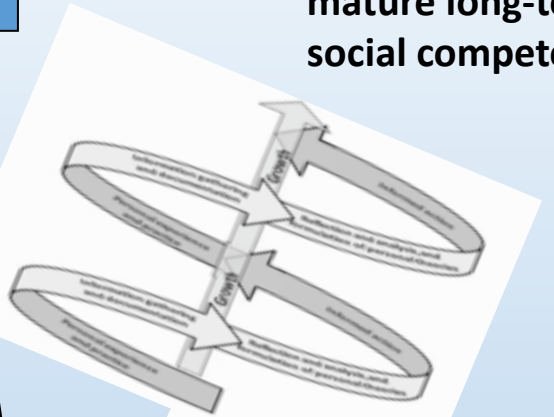
Crone & Dahl 2012

Frontal-Cortical Engagement (variable)

Cognitive control system

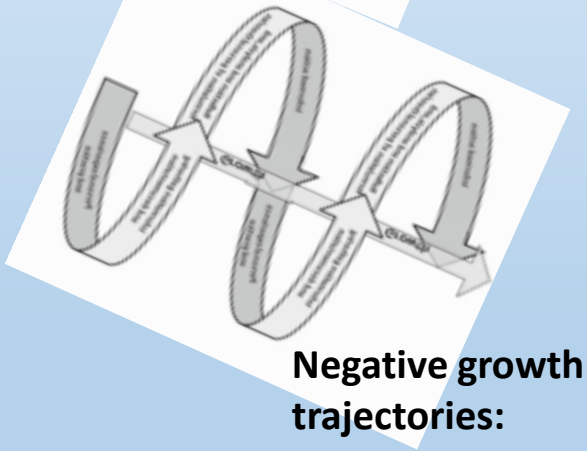
DLPFC
Parietal cortex

Positive growth trajectories:
e.g. adaptive exploration, mature long-term goals, social competence



Motivational/Goal Flexibility

Social / Affective Influences



Onset of puberty

Limbic Engagement:
↑Affective salience of social cues & context

Subcortical structures
Ventral striatum
Amygdala

Negative growth trajectories:
e.g. excessive risk-taking, substance use, depression, social withdrawal

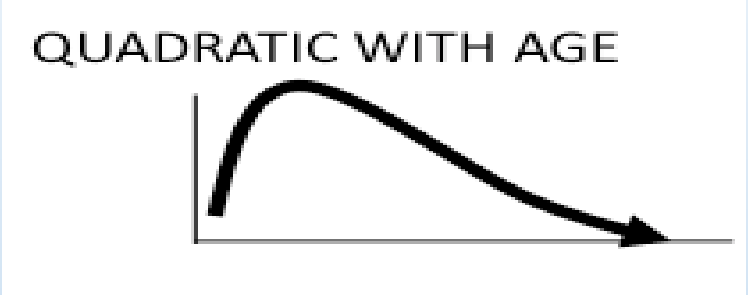
Time/Development

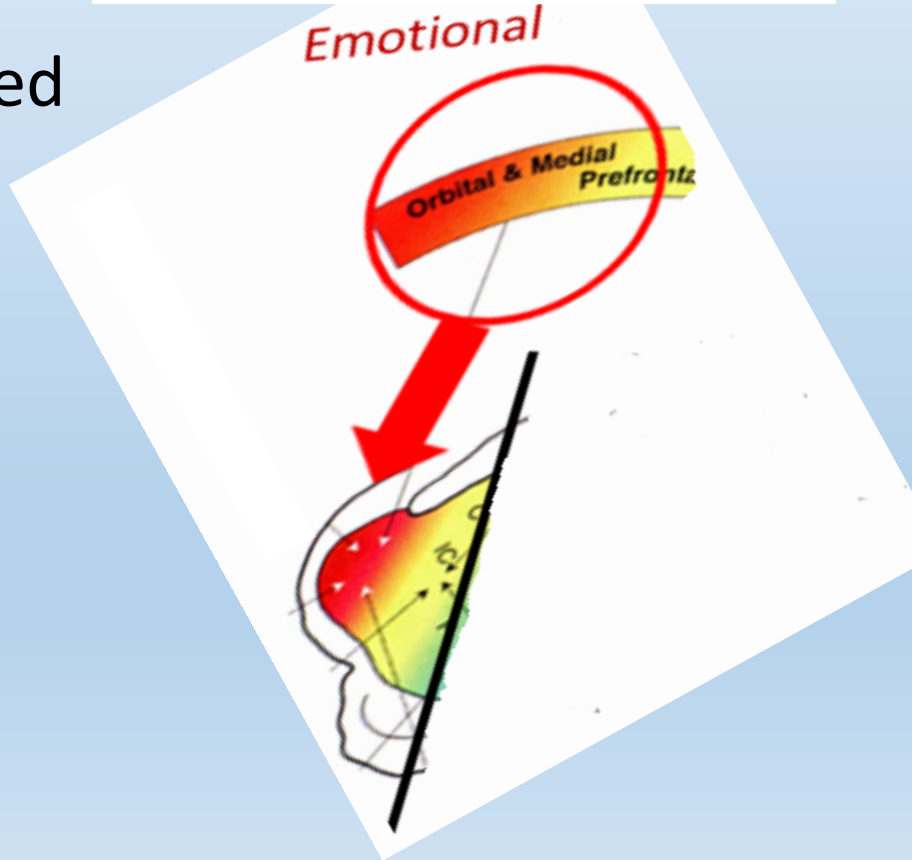
Human Puberty: *Igniting Passions* in the Developing Brain

- Profound changes in romantic interest, motivation, emotional intensity
- Increase in sensation-seeking
- Developing passions for specific types of goal-directed behavior (particularly goals related to social-status)

A period of natural motivational learning?

The affective (feeling-based) aspect of wanting, liking, desiring *particular kinds of goals and priorities….*





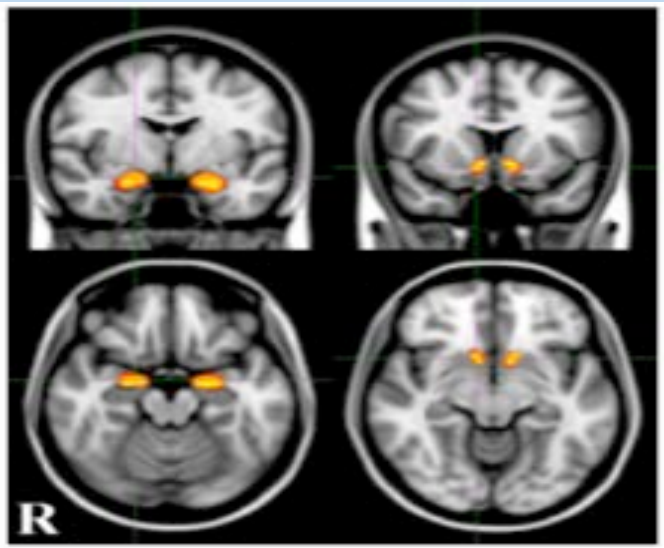
Early adolescence as a maturational period for adjusting motivations and early identity (self-relevant emotions)

- ***The intensity of romantic and sexual feelings in early adolescence***
- ***The motivational salience of romance and sex***
- ***The impact of early experiences on self relevant emotions, cognitions, and the emergence of an individual identity…?***
- ***Finding a path to acceptance, belonging, respect, autonomy…***
- ***The interactions across other adolescent domains (risk taking, novelty seeking, increased fear and emotional reactivity)?***
- ***High-intensity motivational learning… ?***

Slicing into the complexity
of interacting levels of change…

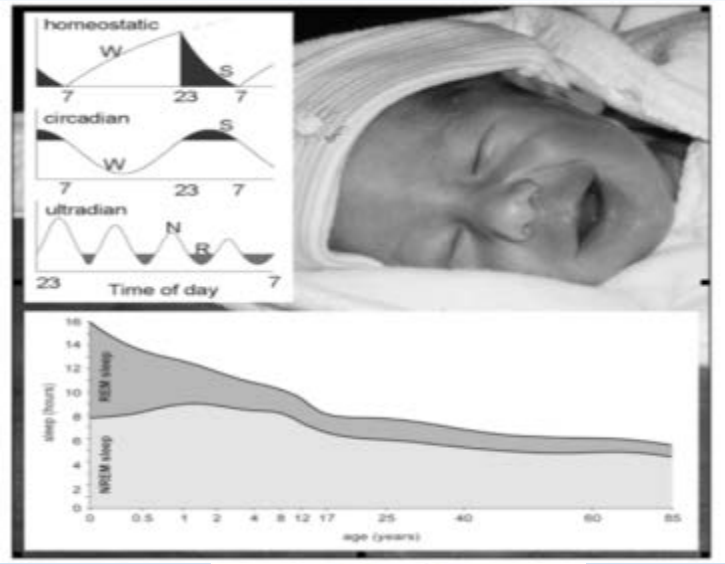
Puberty-specific changes in sensation-seeking, status-seeking, and value-based decision making.

Sleep and Circadian Regulation to Illustrate the model

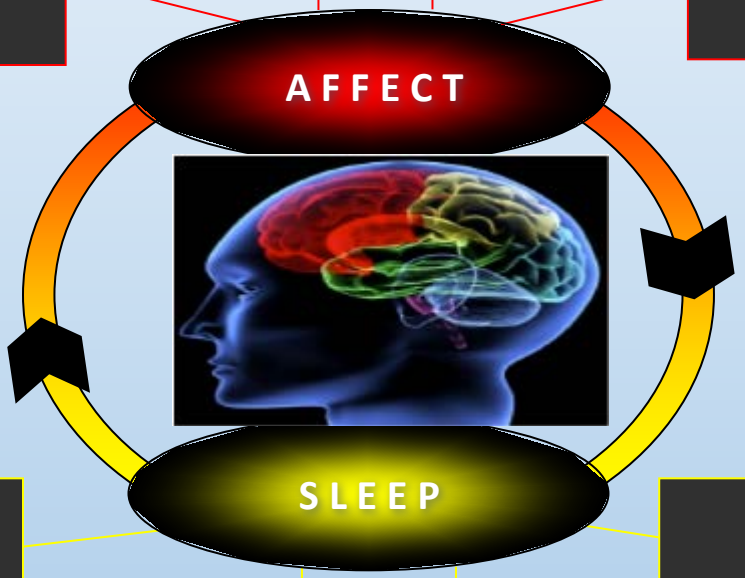


Developmental Science of Sleep

- Compelling scientific mysteries
- Enormously practical/ clinical
- Trans-disciplinary: pediatrics, psychiatry, psychology, neuroscience…
- Policy impact
- Sleep/arousal; learning and brain plasticity
- Relevance to a broad range of behavioral and emotional problems



Sleep, Learning, Affect Regulation, & Brain Development



emotion

motivation

arousal

flexibility, skills, regulation

Developmental Trajectory
Brain/Behavior/Social Context
INTERACTIONS

Cognitive Processes, Learning & Brain Plasticity

circadian
(timing/variability)

continuity and patterning
(amount/structure)

type
(REM/NREM)

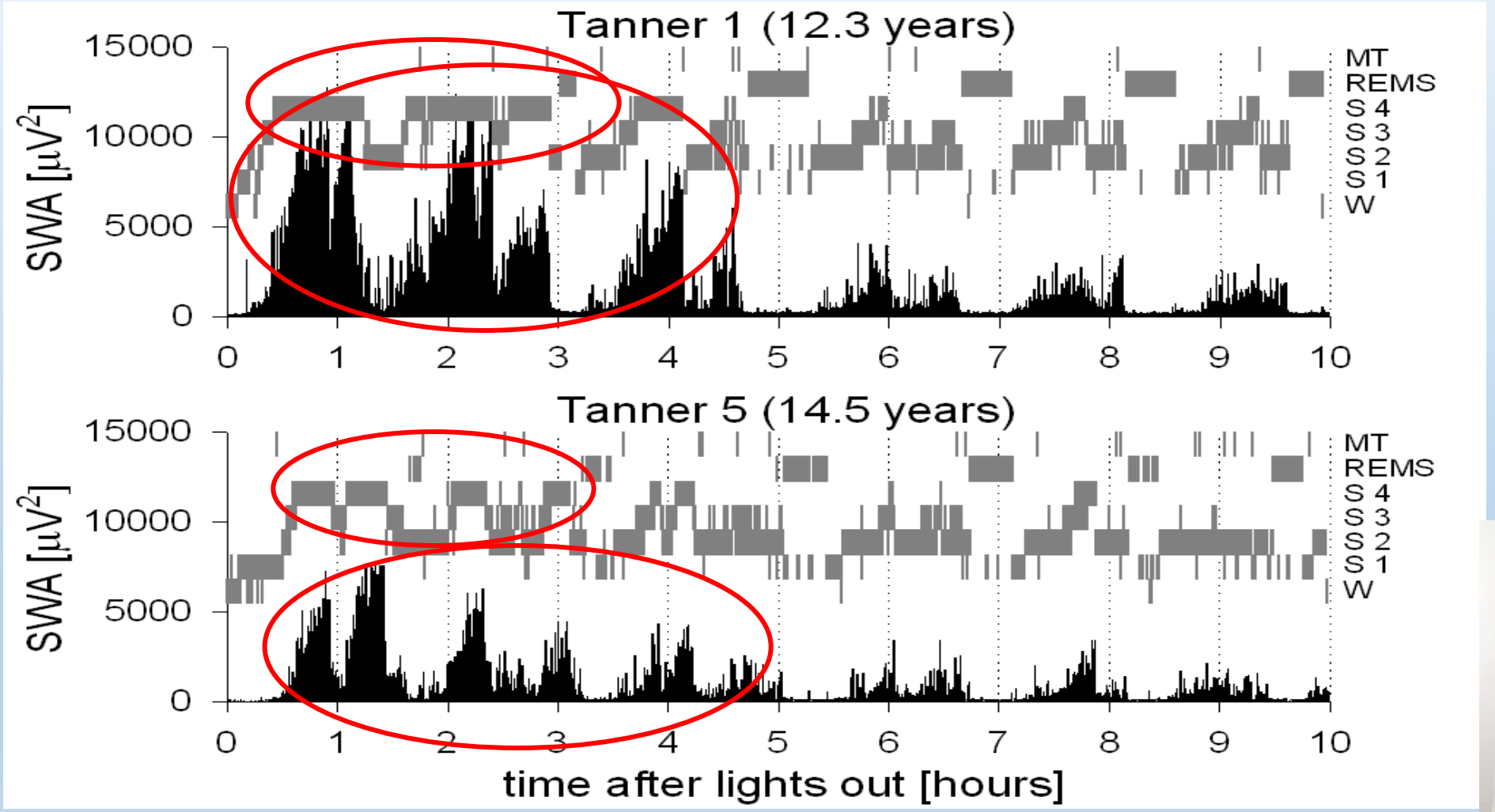
depth/disruption
(initiate/maintain)

Clinical and Policy: Early intervention and Prevention

Sleep in Adolescence: Pubertal Changes?

- Some developmental changes in sleep regulation appear to be linked to puberty :
  - Increased Sleepiness
  - Circadian/sleep changes

Changes of Slow Wave Sleep and Slow Wave Activity (SWA)

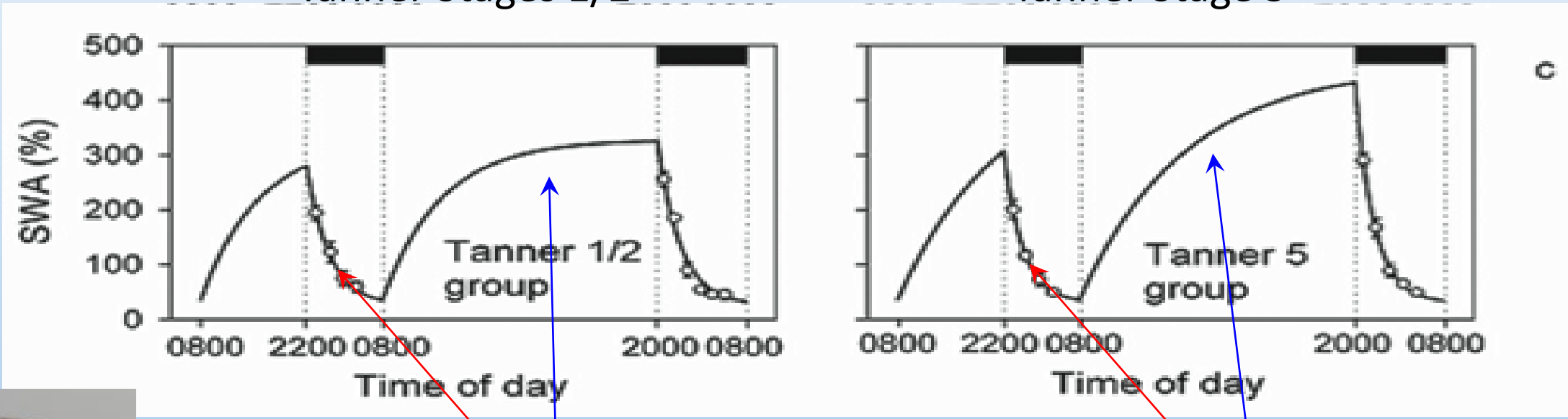


Jenni & Carskadon, *Sleep,* 2004

Across pubertal development, SWA accumulation rate changes

Tanner Stages 1/2

Tanner Stage 5



t_d = 2.8 h

t_i = 8.9 h

Decay Time Constant

Rise Time Constant

t_d = 2.7 h

t_i = 12.1 h

Jenni, Achermann & Carskadon *Sleep*, 2005

What developmental changes occur to the circadian timing system at puberty?

Species showing Adolescent Phase Delay (directly linked to gonadal hormonal changes)

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

Hagenauer et al., *Devel Neurosci*, 2009

Karatsoreos et. al 2011 Androgens modulate structure and function of the suprachiasmatic brain clock. Endocrinology 152:1970–1978

SCN: Suprachiasmatic Nucleus

- Androgens: Influence oscillator coupling
- In Humans: pubertal changes in sensitivity to light (and social cues)?
- Light and social cues as biological signals…(jet-lag)…

Puberty:
Circadian Rhythms Summary

- Phase delays during adolescence
  - DLMO (Melatonin) onset is later
- Phase-dependent light sensitivity may change
- Interactions with dopamine and reward-learning? Social cues?

- Behavioral Result: tendency to prefer sleeping later (nights and late mornings…)

Sleep: Pubertal Changes in Sleep Regulation?

- Some developmental changes in sleep regulation appear to be linked to puberty :
  - Increased Sleepiness
  - Circadian/sleep preferences shift

- Consider these biological changes in sleep tendencies, in earlier periods of human history…

Social factors in contemporary society contribute to LATE bedtimes/sleep onset times:

- Peers and social activities
- Greater freedom to self-select bedtimes
- Access to light and stimulating activities
- Stress/anxiety or excitement $\Rightarrow$ difficulty falling asleep
- Major circadian shift on weekends/vacation
- Work, Sports, Homework, Projects, meds...

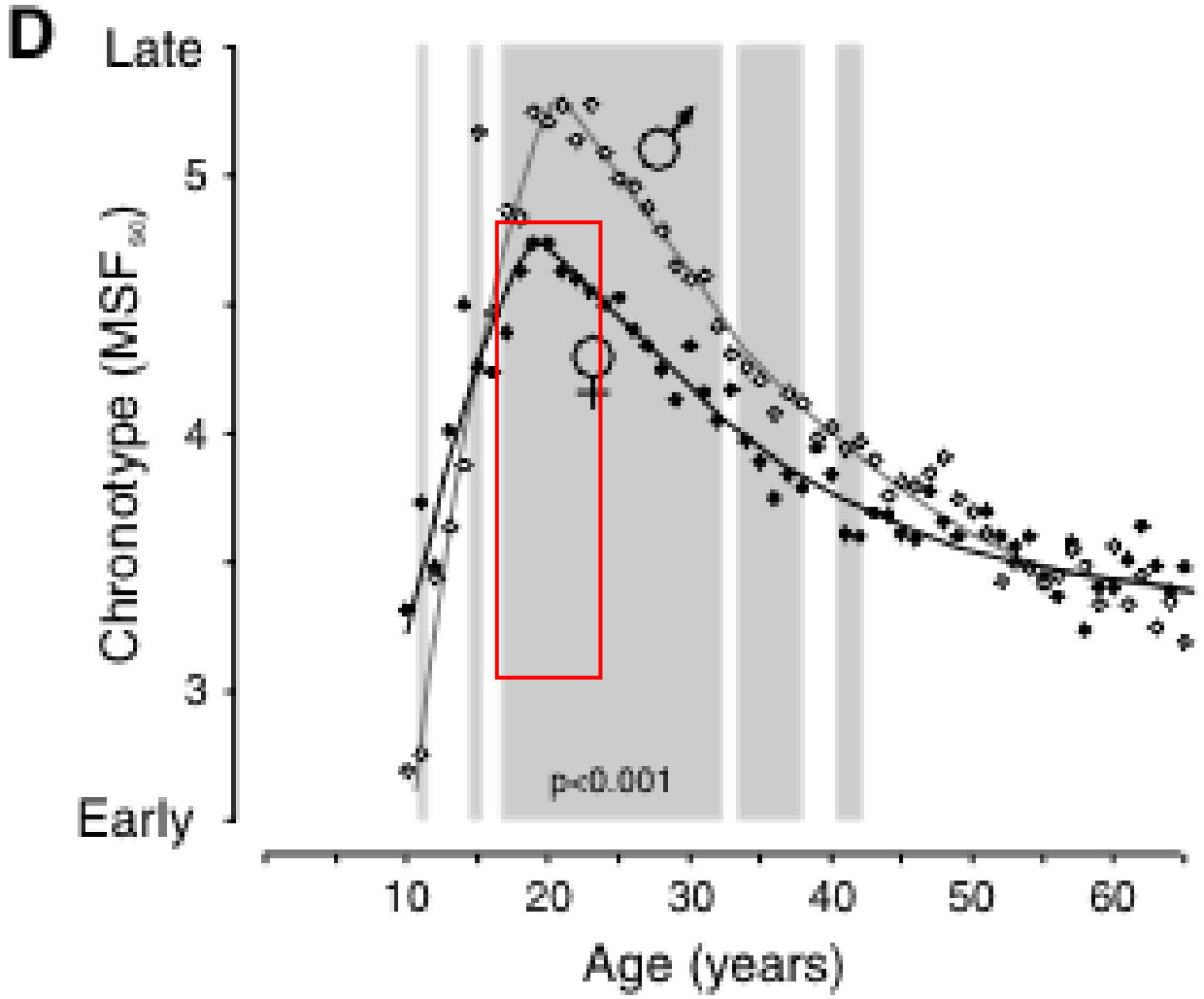
The School-Sleep Squeeze

- Despite *average* school night bedtimes of 11:30 pm in high school seniors, the average wake-up time on school days is 6:15 am.
- Greater than 10% of US high school students must get up before 5:30 am to catch buses
- More than 15 % of high school students report averaging 6 or less hours in bed on school days (need 8 or more)

Contributing Factors/Vicious Cycle

- “Catch-up” sleep on week-ends pushes circadian system to further delay
- Use of stimulants (caffeine and nicotine) can contribute to Difficulty Falling Asleep
- Blue spectra light (TV, computer, personal device screens) > red-orange light
- Stress and conflict contribute to emotional arousal and further Difficulty Falling Asleep

Sleep Timing In Contemporary Societies: Social Jet-lag in Adolescence



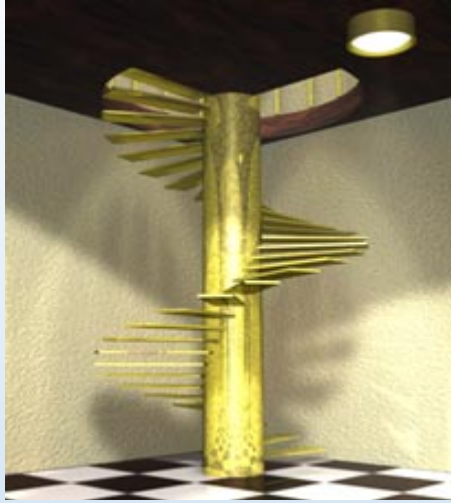
- Shift in time of mid-sleep on “free” days
- Delay begins at puberty and is marked across the 2nd decade
- Is the inflection a “biological marker for the end of adolesence?”

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

In sum:


Late Bedtime
Less Sleep
Tired During School Week
Weekend Sleep-in
Teen World

A Small Set of Biological Changes at Puberty Can Lead to a Spiral of Negative Effects



- Late night/erratic schedules ⇒

  Sleep Deprivation

  ⇒ erodes mood and motivation

  ⇒ greater stress and affective problems

  ⇒ interferes further w sleep/arousal regulation

  ⇒ greater difficulty falling asleep

- Social context that amplifies the

biologic change ⇒ a torrential spiral?

What are the consequences?

- If 30-40% of U.S. adolescents are typically getting less than optimal sleep and experiening chronic social jet-lag,

  what are the costs and consequences?

Consequences of Insufficient Sleep in Adolescents

- Sleepiness (lapses)
- Tiredness, motivation
- Difficulties with focused attention
- Irritability, reactive aggression
- Decreased mood, depression?
- Negative synergy with alcohol effects
- Direct effects on learning, memory consolidation
- Increase use of caffeine, stimulants
- Risk for obesity, metabolic syndrome
- Affect regulation?

Youth are heavily over-represented in late-night accidents

Sleep Disturbance Preceding Completed Suicide in Adolescents

Tina R. Goldstein, Jeffrey A. Bridge, and David A. Brent

J Consult Clin Psychol. 2008 Feb; 76(1): 84.

- Sleep disturbances were assessed in 140 adolescent suicide victims with a psychological autopsy protocol and in 131 controls with a similar semistructured psychiatric interview

- Findings support a significant and temporal relationship between sleep problems and completed suicide in adolescents

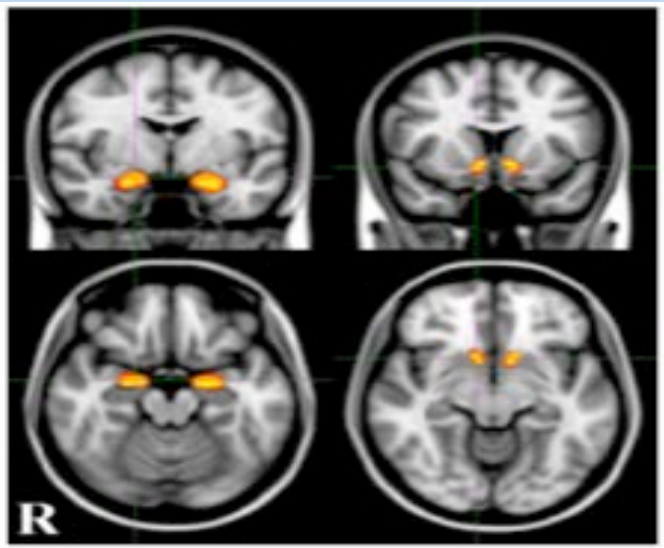
J Clin Psychiatry. 2012 Sep;73(9)
Meta-analysis of sleep disturbance and suicidal thoughts and behaviors.
Pigeon WR, Pinquart M, Conner K.

- Sleep disturbance was significantly associated with an increased relative risk for suicidal ideation, suicide attempt, and suicide ranging from 1.95 (95% CI, 1.4-2.7) to a relative risk of 2.9 (95% CI, 2.5-3.5)
- Depression did not moderate the association between sleep and suicide variables.

Slicing into the complexity:
of interacting levels of change…

Puberty-specific changes in sensation-seeking,
status-seeking, and value-based decision making,

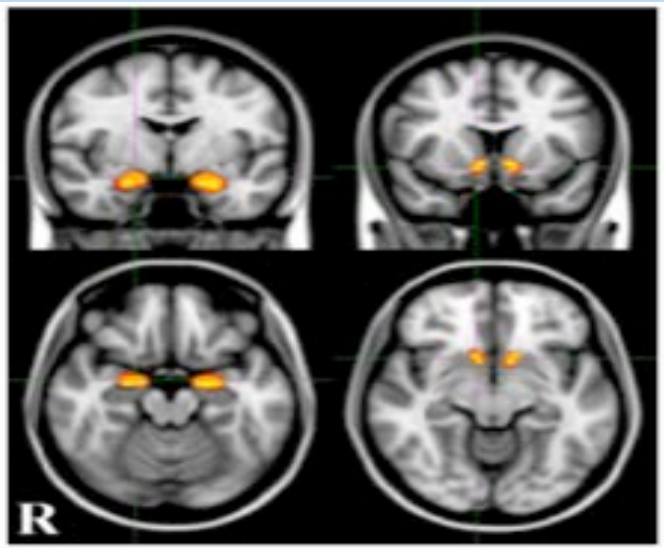
Developmental Science of Sleep and Circadian Regulation
EARLY INTERVENTION/PRVENTION?



Slicing into the complexity
of interacting levels of change…

Puberty-specific changes in sensation-seeking, status-seeking, and value-based decision making.

Motivational Learning
(acquired individual differences in heartfelt goals and priorities)



Q4: Might the pubertal *learning spurt* be specialized for learning about love…

- Not simply romantic and sexual love
- Learning to fall in love with a particular kind of activity or goal…learned ***heartfelt goals***….
- More about ***acquired feelings of motivations***…which creative automatic action-tendencies
- Individual differences in our passions….

  A passion for ideas and ideals. Passion for beauty. Passion to create music, art, and literature; passion to succeed in a particular sport, business, science, politics, or religion... Or failure to feel passion for anything at all…

The capacity for sudden transformational changes in motivation in adolescence…

Falling in love:

can be literal…exchange 100 words and two kisses…

also as a metaphor:

Falling in love with literature, dance, music, a particular religion or philosophy, the idealistic ambition to make the world a better place, with math, science, social justice…

Capacity to hijack motives for addiction (alcohol, drugs, smoking, thrill-seeking…)

Withdrawal and disconnection from any passion (apathy, boredom, depression)

Developmental Science of Motivation?

Early adolescence as a maturational period for adjusting motivations

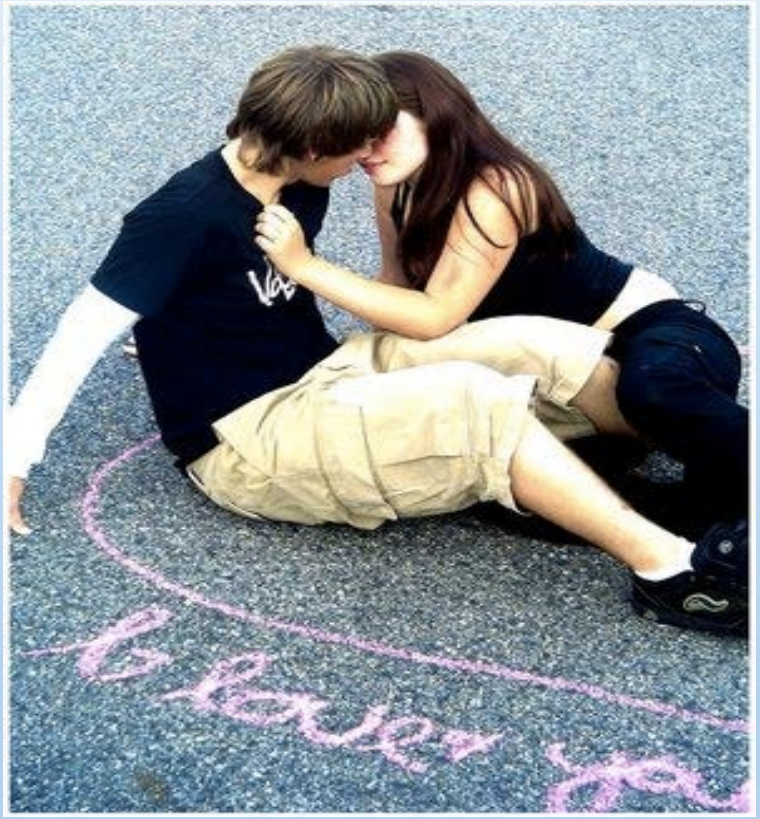
- Specific targets, engagement and intensity
- What are ***the conditions and learning processes*** that erode motives….?
- What are the conditions and processes that activate strong feelings of motivation….toward particular kinds of goals and activities…
- In ways that create ***positive spirals?***

Transdisciplinary developmental science approach to understanding adolescent romantic and sexual behavior: a promising frontier…

Goal of adolescent sexual development

Support normal, healthy sexual development

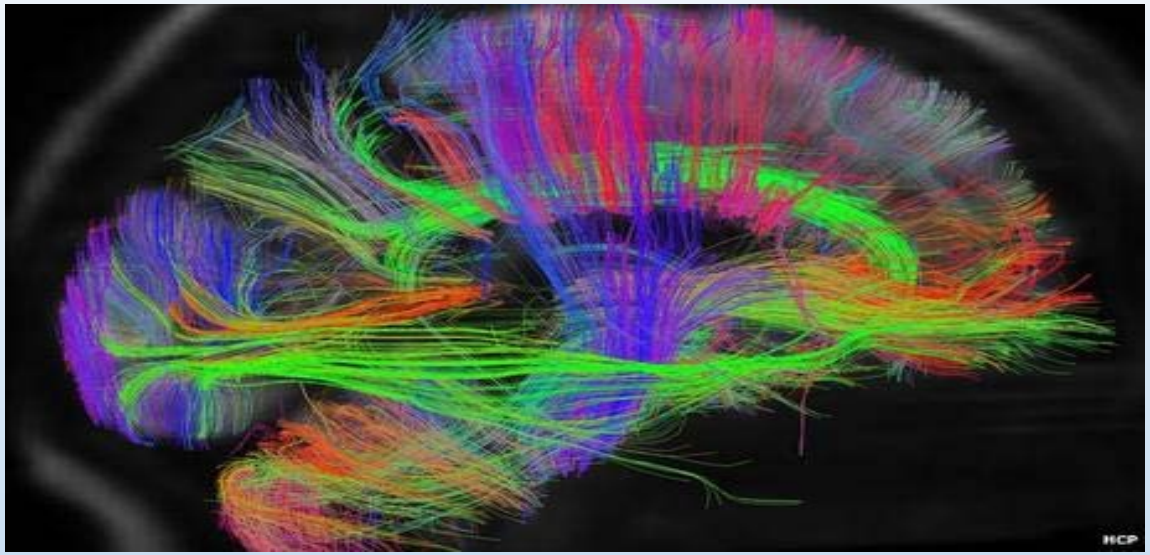
- Sexual socialization
- Development of healthy sexual attitudes and behaviors
- Positive experiences in scaffolded environment



Diminish negative trajectories

- Unwanted or unintended sexual activity
- Poor sexual health outcomes (STI's, unwanted pregnancy)

What can developmental science add?



- Emotional weighting & experience
  - Gamification
- Crafting effective messages
  - Communication Neuroscience
  - Behavioral willingness vs. behavioral intention

?

- Identifying key developmental windows
- Understanding effects of social context
  - Parents
  - Peers
  - Stress

Summary

- Adolescence appears to be a key developmental window of motivational learning—a time of development when the brain expects to adjust the targets and intensity of motivational feelings.
- The ***particular social and mastery experiences during this maturational window shape (and strengthen***) the patterns of connections related to heartfelt goals.
- *Compelling developmental social neuroscience questions* about mechanisms and processes.
- ***Compelling developmental science*** questions relevant to health, education – in the broadest sense – about positive impact during this interval.
- Incredible opportunities for pioneering work by trans-disciplinary teams – a very exciting time!

A Perfect Storm of Opportunities

Learning/Exploration/Acquiring Skills/Habits/Intrinsic Motivations/Values/Attitudes/
Setting Goals & Priorities/Profound Social Changes…

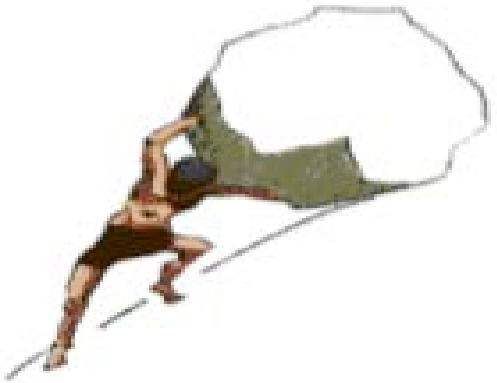
Growth Mindset….

Positive Developmental Spirals

Health, Education, Social, and Economic Outcomes

Window of Opportunity for Social, Emotional, & Motivational Learning

(acquired individual differences in heartfelt goals and priorities)



Thank you

CENTER ON THE DEVELOPING ADOLESCENT