Adolescent Brain Development: A Framework for Understanding Unique Vulnerabilities and Opportunities

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Goals of This Presentation

- To address *pragmatic problems* in youth linked to behavioral and emotional development & disorders
- Emphasize brain/behavior/social context *interactions* in the developmental pathway to some disorders
- Highlight research indicating puberty/adolescence:
  - is a sensitive developmental period in the integration of regulatory systems (especially goals + emotions)
  - creates unique vulnerabilities and opportunities for intervention (i.e. another period of plasticity).
Pragmatic Problems: The Health Paradox of Adolescence

- Measures of most abilities indicate adolescence is the healthiest and most resilient period of the lifespan.

- From Childhood to Adolescence:
  - Improvements in strength, speed, reaction time, mental 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.
Sources of Morbidity and Mortality in Adolescence:

- Primary causes 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, health problems related to risky sexual behaviors…
- Increase in risk-taking, sensation-seeking, and erratic (emotionally-influenced) behavior.
Adolescence

Youth are heated by Nature
as drunken men by wine.

--Aristotle

I would that there were no age between ten and twenty three...for there is nothing in between but getting wenches with child, wronging the ancientry, stealing, fighting...

--Shakespeare (The Winter’s Tale; Act III)
Scientific Questions

- What is the empirical evidence that adolescents are “heated by Nature”?
- Are these changes based in biology? In the hormones of puberty?
- Are there specific brain changes that underpin some behavioral and emotional tendencies & problems that emerge in adolescence?
- What are the implications of understanding these questions regarding intervention?
Normal (?) Adolescent Behavior: An Illustrative Anecdote

Amidst the festivities of a grand party a young guy notices a strikingly beautiful 13-year-old girl and is immediately smitten...

He approaches her and begins to flirt boldly...

She tries to rebuff him but is flattered by his attention and finds him quite attractive...
By the time he departs the scene, with a kiss followed by a second kiss, these two have exchanged less than a hundred words—yet, both are swooning with sensations of falling, desperately, in love…

All mental processes—thinking, planning, goals, feelings, and motivations have been suddenly transformed…these brains have been completely gripped by this brief encounter
Longing, obsession, and desire….

In the hours after this meeting, these two cannot stop thinking about each other.

The intensity of desire is so strong that each would happily forego food, sleep, comfort, and all competing pleasures, simply to be in each other’s presence again.
A Second (Clandestine) Rendezvous Ensues …

Passionate feelings now accelerate at a feverish pitch…

Within a few days their deepest wish is to be joined together until the end of time

Each begins to feel as if the entire universe has always meant for them to be together
All priorities have been re-ordered; now value each other above all else...

Both are willing to spurn friends and family, risk dangers, transcend pain and difficulties just to be together....soon begin to feel as if death itself would be preferable to living apart

All this, though they just met four days previously and barely know each other
If seen by a psychiatrist who did *not* understand youthful passions:

- These adolescents could be judged as meeting diagnostic criteria for several major mental disorders and cognitive impairments.

- Without some empathy for the heat and power of young love, this story would not seem believable—it *would sound utterly ridiculous*....

yet...
**Romeo and Juliet (1595): quite a popular and persevering story**

- Basic elements date back to the writings of the Greek novelist Xenophon (4th century A.D)
- Luigi da Porto (1535) named the feuding families Montecchi and Capellati & set the scene in Verona
- French version: Sevin (1542);
- Other Italian versions: poem by Clizia (1553), a novella by Bandello (1554), and a play by Groto (1578).
- An English poem version by Arthur Brooke (1562) was titled *The Tragical History of Romeus and Juliet.*
Shakespeare’s adaptation (1595): became one of the most successful dramas in history

- In contrast to Luigi da Porto’s version where Giulettta was 18 years old and the courtship was slow-paced, developing over several weeks.
- Shakespeare made Juliet 13 and compressed the entire romance into four days.
- Given Shakespeare’s wisdom in human behavior, why a heroine so young in a romantic tragedy?
Choice is even more striking given historical changes in pubertal timing

- Age of menarche has decreased rapidly in US and Europe over past 200 years
- Lack precise data on puberty in 16\textsuperscript{th} century England (& then as now likely a wide range of individual differences in rates of maturation).
- Yet, the \textit{average} 13-year-old girl in Shakespearean England was much less developed than the average 13-year-old girl today.
Shakespeare Was Dramatizing Natural Tensions of Adolescence

- Juliet has a physical appearance capable of launching a Romeo into raging attraction and uncontrollable devotion.
- Evidence of post-pubertal awakening of romantic passions in her own behavior.
- Yet, she has the knowledge, judgment, and emotional *skills* of a 13 year-old child.
Four Centuries Later…

- Knowledge of adolescent development has expanded significantly through science
- These dramatic tensions can now be examined in light of broader understanding of cognitive and emotional development & the role of puberty in brain maturation
- Perhaps an even greater appreciation for the insights of Shakespeare…
Overview of Presentation

- Part 1: *Conceptual model* of adolescence as a key developmental period for brain/behavior/social context interactions (*plasticity*)
- Part 2: Developmental changes in *sleep/arousal regulation* as a specific example to illustrate key features of the model
- Part 3: Focus on *the development of affect regulation* in adolescence within this model
Part 1: What is Adolescence?

- How do we conceptualize and define the adolescent period?
- Anthropologic look at adolescence in traditional societies as a framework for understanding
- Why is it important to consider the underlying biologic and brain system level of changes?
- A few examples of neuroscience studies illustrating key principles
Conceptualizing Adolescence

- Aristotle: “youth are heated by Nature as drunken men by wine”
- Socrates: “inclined to contradict parents and tyrannize their teachers”
- G.S. Hall (1904) a period of heightened “storm and stress”
- 1960s and 1970s: attempts to understand the problems as due to “raging hormones”
Arnett (1999) Review Of “Storm And Stress”

- Many (perhaps most) adolescents navigate this interval with minimal difficulties
- However, empiric evidence for:
  - Increased conflicts with parents (intensity)
  - Mood volatility (and increased negative mood)
  - Increased risk behavior, recklessness, and sensation-seeking
Yet, Many Adolescents Do Struggle; Problems of Enormous Magnitude

- Overall morbidity and mortality rates increase 200-300% between middle childhood and late adolescence/early adulthood
- Onset of problems such as nicotine dependence, alcohol and drug use, poor health habits, etc. that will show up as mortality in adulthood
- Many adult onset problems such as depression can be traced to early episodes in adolescence
Defining Adolescence

- *That awkward period between sexual maturation and the attainment of adult roles and responsibilities.*
- The transition from:
  - “child” status (requires adult monitoring)
  to
  - “adult” status (*self*-responsibility for behavior).
- The developmental interval that encompasses the body and brain changes of puberty.
Adolescence: Component Processes

- Rapid Physical Growth
- Sexual Maturation
- Secondary Sexual Characteristics
- Motivational and Emotional Changes
- Cognitive Development
- Maturation of Judgment, Self-Regulation Skills
- Brain Changes Linked to *Each* Component
- Suite of Changes with *Relative* Synchrony
Puberty

**Hypothalamus**

GnRH → pulses → FH/LSH → gonadarche

(remarks: release of inhibition)

(?)

ACTH

AASH (?)

Other?

**Pituitary**

GRH → GH → growth spurt

[testosterone] → adrenarche

[estrogens]

[adrenal] → secondary sexual characteristics

[androgens]
Puberty and Brain Development

- Some brain changes precede pubertal increase in hormones and body changes.
- Some brain changes appear to be the consequence of pubertal processes (e.g. hormone effects feeding back upon the brain; estrogen receptor beta distributed throughout the brain).
- Some adolescent brain maturation appears to be independent of pubertal processes.
7.2 Age at menarche, 1860–1970.

Herman-Giddens et al 1997 Study of 17,000 Girls in US Pediatric Practices With Complete PE: Percentage with Breast/Pubic Hair Development at Tanner 2 or above

![Bar chart showing percentage of girls with breast/pubic hair development at Tanner 2 or above at 7 and 8 years of age, separated by Euro-American and African-American race.]
Adolescence: An Anthropological Perspective

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.
Adolescence in traditional societies: interval between child and adult status

- End of childhood usually marked by puberty (ritual)
- Onset of adult status in traditional societies?
  - marriage
  - work roles (e.g. hunting)
  - owning property
  - becoming a parent
  - independence (absence of monitoring)
- Interval between puberty & marriage as an index
Puberty, Marriage, and Adult Roles in Traditional Human Societies
(Schlegel and Barry’s Anthropologic Study of 186 societies)

- Among girls, marriage occurred within two years of the onset of puberty in 63% of the societies studied.
- Among boys the ability to take a wife could require a specific level of achievement (such as making a first kill on a hunt or developing a specific set of skills that increased economic opportunities to provide for a family).
- Yet, even for males in these traditional circumstances 64% were married within four years of puberty.
Puberty, Marriage, and Adult Roles in Contemporary Society (United States)

- Average age of menarche is now age 12; average age of first marriage for females is 26.

- This pattern reflects recent changes:
  - In 1970 timing of first marriage in the U.S:
    - age 21 for women
    - age 23 for men
  - By the 2000 census this had changed:
    - age 26 for women
    - Age 27 for men.
Puberty, Marriage, and Adult Roles in Contemporary Society (Japan)

- Average age of menarche has decreased four years over the past century
  - In Japan (1875) menarche at 16.5 years
  - In 1975 average age of menarche: 12.2 years

- Average age at first marriage in Japan is now
  - 26 years of age in women
  - 28.4 years of age in men
Puberty, Marriage, and Adult Roles in Contemporary Society

- Not simply changing attitudes about marriage.
- Many adult social roles—starting careers, owning a home, choosing to become parents—are now occurring a decade or more after puberty.
- These changes have advantages (especially academic and economic opportunities).
- These changes have costs (and create vulnerabilities).
- Adolescence has expanded from a 2-4 year interval in traditional societies to an 8-15 year interval in contemporary society.
Historical Changes in Adolescence: Implications Regarding the Brain

- The dramatic *expansion* of the adolescent interval raises critical questions about brain development.
- Relevance of considering different components of adolescent development.
- Evidence that some brain changes are linked closely to puberty while other aspects of maturation are dependent on age/experience.
Puberty and Brain Development

- Some brain changes *precede* pubertal increase in hormones and body changes
- Some brain changes appear to be the *consequence* of some pubertal processes
- Some adolescent brain maturation appears to be *independent* of pubertal processes
- Potential for creating internal dis-synchrony
Puberty versus Adolescence: Empirical Investigations

- In most adolescent studies: age, level of pubertal development, and social experience are correlated & difficult to disentangle (exception: endocrine disorder)

- Requires studies designed to examine these issues:
  - youth of the same age & social experience (e.g. all 13 year olds in the same grade) but varying in level of pubertal maturation
Sensation-Seeking in Subjects 11-13 Years of Age; 
*No significant age correlation* (Martin et al 2002)
Puberty and Motivation/Emotion

- Strongest links to pubertal changes per-se are in the domains of romantic motivation, sexual interest, emotional intensity, sleep/arousal regulation, appetite, and affective disorders [Pine to discuss more]
- A general increase in risk-taking, novelty-seeking, sensation-seeking (reward-seeking).
- Animal studies also show increase in novelty-taking (risk-taking?) in the peri-adolescent period (Spear 2000). [Kelley to discuss more]
Puberty and “Igniting Passions” in the Developing Brain

- Profound changes in romantic interest, motivation
- Intensification of many types of goal-directed behavior, including intense motivation for long-term and abstract goals (particularly related to social-status)
- Relatively understudied aspect of adolescent development (emotion and motivational changes)
Adult Status: Requires developing self-control of behavior & emotions:

- appropriately inhibit or modify behaviors to avoid negative future consequences
- initiate, persist, sequence steps toward goals
- navigate complex social situations despite strong affect
- Skills in the self-regulation of affect and complex behavior to serve long-term goals
- Involves neurobehavioral systems in PFC -- among the last regions of the brain to achieve full functional maturation
What Happens to Cognitive Development when Puberty is Early?

- Most measures of cognitive development correlate with age and experience (not sexual maturation)
  - Planning, Logic, and Reasoning ability
  - Inhibitory control
  - Problem-solving; understanding consequences
- Data consistent with a model that *these* aspects of brain maturation are time-dependent (or experience-dependent) processes and relatively *independent* of pubertal timing
- These continue to develop *long after puberty is over*
Brain Development in Healthy Children and Adolescents: Longitudinal and Cross-Sectional Data (243 Scans from 145 Subjects) [Giedd et al]
Brain Development by Anatomic Region (145 Children & Adolescents age 4-22 years of age who underwent 243 MRI Scans) [Giedd et al]

Peak
Cerebellum vs. Other Peaks:
* <.002, ** <.0001
Hypothesis: Starting the engines without a skilled driver

- Earlier timing of puberty results in several years with a sexually-mature body and sexually-activated brain circuits ("igniting passions")
- Yet with *relatively immature neurobehavioral systems necessary for self-control and affect regulation*
- Predict: increased risk for disorders of self-control; difficulties navigating complex social-emotional situations
Adolescence: Risk for behavioral and emotional disorders

- Successful navigation of pubertal transition:
  - increased cognitive (self-) control over emotions and behavior
  - *in accordance with abstract principles*
  - consideration of long-term consequences
  - complex social rules
  - use of strategies, planning, and goals
  - requires cognitive-emotional integration
Cognitive-Emotional Integration (cont’d)

- Affect regulation in complex & highly-arousing social situations
- Decision-making/behavioral choice under conditions of strong emotion (“hot” vs. “cold” cognitive processes)
- Navigating behavior in ambiguous settings w/ strongly conflicting feelings
Adolescence, Social Roles, and External Constraints

- In many ways adolescence represents the interval between the beginning of sexual maturation and the attainment of adult roles and responsibilities in society.
- The transition from parental control to self-control is usually framed in social context.
- Many young adolescents are faced with enormous amounts of freedom in which to navigate complex decision-making.
Brain systems underpinning higher levels of cognitive-emotional integration

Establishing new links between more complex ways of thinking and new emotional experiences

Opportunities for early intervention/prevention in identified high-risk samples

“Igniting passions” can be sculpted by experience
Part 2: Sleepless in Adolescence: Puberty, Arousal, & the Brain

Sleep is not only a biological necessity but also a physiologic drive. In today’s fast-paced world, though, sleep is often the first thing to go.....

Adolescence is the time of greatest vulnerability from the standpoint of sleep....

--William C. Dement
Sleep/Arousal Regulation as an Example to Illustrate Key Principles

- Some developmental changes in sleep regulation are biologic & linked to puberty
- Some changes in sleep regulation linked to social influences, habits, and patterns
- Interactions between these domains can lead to a negative spiral of consequences
- Small shift in motivation (tendency to stay up later) can lead to dramatic changes in behavior
The Mystery of Sleep

- Sleep is ubiquitous across species
- Sleep is necessary for life (survival without sleep is parallel to living without food)
- Actual function/purpose of sleep is a complete mystery
- Sleep appears particularly important during early development (reason unknown)
Sleep Vs. Rest

- Sleep is an active process with many brain regions showing increased activity.
- The continuity, patterning, and timing of sleep is essential to the restorative process.
- Behaviorally, sleep requires a decrease in awareness/responsiveness.
- Relative “disconnection” between neurobehavioral systems linked while awake.
Sleep: Evolutionary Biology

- Since systems of vigilance, processing, and responding are disconnected from each other -- sleep is restricted to SAFE places

- Most species:
  - physical niches (burrows/ nests)
  - temporal niches (times of minimal predation)
  - behavioral patterns
Sleep au naturel?
Human Sleep: Evolutionary Biology

- Stage 4 sleep: completely unresponsive
- REM sleep: loss of muscle tone (unable to sleep in trees or cliff ledges)
- Human ancestral environment: filled with huge, nocturnal-hunting carnivores
- NO evidence of physically safe sleep sites
Human Sleep: Evolutionary Psychology

- Safety as a SOCIAL construct
- In most social primates an alone primate is a dead primate
- Vigilance and stress/threat systems are wired accordingly
- Power of social belonging/rejection influencing human sleep patterns
- DEVELOPMENTAL CHANGES
Sleep and The Developing Brain

- Average 2 year old child has spent
  - about 9,500 hours sleeping (about 13 months)
  - About 8,000 hours in all waking activities combined (about 11 months)
- From age 2-5 years about equal amounts of time spent waking and sleeping
- Sleep is the primary activity of the brain during early development
Sleep: Learning and Memory

- Increasing evidence that sleep is fundamental to consolidation of learning (including procedural learning as well as explicit memory)
- Most of the neuroscience work in this area has been done in adult humans and animals
- Some compelling hints that these processes are even more crucial during development
Pubertal Influences on Sleep and Arousal Regulation

- Evidence that the need for sleep actually increases at puberty
- Greater daytime sleepiness (increased need for sleep) even if obtaining as much night sleep as prepubertal children
- Also a pubertal shift in circadian (biologic clock) to preferring later bedtimes and rise-times (adolescent “owl” tendencies vs. child “lark” tendencies)
Historical Changes in Environment

- In a social context > 100 years ago when it became dark there were limited options for stimulating activity:
  - Motivation to stay up later usually *balanced* by motivation (need) for more sleep
  - Limited options for multi-day “sleeping-in”
- Context of modern life alters this balance: access to light, stimulation, arousal at night
Factors contributing to LATE bedtimes/sleep onset times:

- Biologic tendency for sleep delay +
- Social influences toward sleep delay +
- Greater freedom to self-select bedtimes +
- Access to light and stimulating activities +
- Stress/anxiety/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 11:15 pm in high school seniors, the average wake-up time on school days is 6:15 am.
- 10% of high school students must get up before 5:30 am to catch buses.
- 15% of high school students report averaging 6 or less hours of sleep per night on school days.
Circadian (Biological Clock) Factors

- During summers, vacations, and weekends, adolescent sleep/wake schedules are phase delayed (e.g. 3 am - noon)
- Circadian advance requires slow, steady changes (students often partially-adapted to school schedules)
- Delayed circadian phase contributes to difficulty falling asleep, difficulty waking
Contributing Factors/vicious Cycle

- “Catch-up” sleep on weekends pushes circadian system to further delay
- Use of stimulants (caffeine and nicotine) can contribute to DFA (difficulty falling asleep)
- Full time students working greater than 20 hours/week with significant sleep symptoms
- Stress and conflict contribute to emotional arousal and further DFA
What are the Consequences of Insufficient Sleep in Adolescents?

- Missed school
- Sleepiness (including micro-sleeps)
- Negative synergy with alcohol
- Tiredness (decreased motivation)
- Irritability and low-frustration tolerance
- Difficulties with self-control of attention, emotion, and behavior
Consequences of Insufficient Sleep in Adolescents (behavior & emotion)

- Difficulties with focused attention
- Irritability, Emotional lability
- Affect regulation & Cognitive Emotional Integration
- Direct effects on learning, memory consolidation
A Spiral of Negative Effects?

- Late night/erratic schedules ⇒ Sleep Deprivation
  - ⇒ erodes mood and motivation
  - ⇒ greater stress and affective problems
  - ⇒ interferes further with sleep/arousal regulation
  - ⇒ greater DFA

- The Balance of Sleep/Arousal Regulation
  - tilted HEAVILY toward chronic arousal
Summary principles of sleep/arousal changes at puberty

- Relatively small changes in tendency to want to stay up later (motivational shift that has a basis in neurobehavioral systems)
- Can, in some social situations, result in a huge spiral of effects impacting every aspect of an adolescents life.
- Brain/behavior/social-context Interactions are key to understanding this problem

- How do children learn to control emotions and motivations in order to achieve long term goals?
- How are these skills challenged at puberty when the intensity of some emotions and motivations undergo natural shifts (like the change in sleep)?
- How do emotions/motivations influence the cognitive aspects of decision-making (and vice-versa)?
The *Regulation of Affect*

Thompson: “extrinsic and intrinsic processes responsible for monitoring, evaluating, and modifying emotional reactions, especially their intensive and temporal features, *to accomplish one’s goals.*”

- What is being regulated?
  - The expression of emotion
  - The experience of emotion
  - Arousal levels
- Includes explicit (conscious) and implicit processes (procedural learning and skill development)
The *Regulation of Affect*

- Modifying affect *in accordance with goals, rules, or learned strategies*
- What is being regulated?
  - Attention
  - The expression of emotion
  - The experience of emotion
  - Arousal levels
  - BEHAVIOR
- Includes explicit (conscious) and implicit processes (procedural learning and skill development)
The Development of Affect Regulation

- Early strategies in childhood:
  - Distraction and control of attention
  - Self-soothing
  - Signaling for parent/adult
  - ? Modifying affective experience/calibrating action-tendencies

- Later emergence of self-regulatory skills and cognitive strategies
Affect Regulation/Dysregulation: Conceptual Issues

- Concept of *emotion regulation* increasingly popular among researchers and clinicians trying to understand developmental psychopathology

- Yet:
  - relative lack of specificity in models regarding *how* affect regulation is altered
  - limited evidence of specific changes in affect regulation
Affect Dysregulation: Emotional Disorders in Adolescence

- Rates of Depression increase sharply during adolescence
- Gender difference in depression emerges in adolescence (females 2X as likely to have MDD)
- Increase risk for MDD and panic disorder in adolescent females appears to be linked to puberty more strongly than age
Neurobehavioral Systems Framework to Affective Processes

- Emotional salience for two reasons: possible *reward* or possible *threat* (punishment)
- Recognizing and preparing to *approach* rewards
  - seeking vs getting rewards; anticipations
- Recognizing and preparing to *escape* threats
  - Threat, anxiety, fear, pain
- Social context
“What you want to be holding is a halberd. What you’ve got there is an adjustable cheese slicer.”
Adolescent Decision-making: Another source of paradox

- In many measurable aspects of decision-making, adolescents are approaching adult levels of competence by 15 years of age.
- Yet, in real life situations, adolescents show extremely high rates of “poor” decision-making.
- What is the reason that:
  - Driving age is 16; voting and most “adult” decisions at age 18; drinking alcohol at 21; renting a car from commercial agency at 25.
  - Standing trial as an adult for murder at age 14.
Examples of Development of Decision-making & Behavioral Control that Emerge Gradually Across Adolescence

- Damasio “gambling” task that relies upon intuitive or “gut-feeling” learning about what is rewarding and punishing
  - Learning to avoid the “bad” decks of cards
  - Increasing selection of “good” decks without needing conscious awareness they are good.
- Voluntary Control of eye-movements
Development of Advantageous Decision-making (Crone et al 2003)

![Graph showing the development of advantageous decision-making over 10 trial blocks for 18-25 year olds. The graph compares advantageous and disadvantageous choices with a trend line indicating an increase in advantageous choices over time.]
Development of Advantageous Decision-making (Crone et al 2003)

[Graph showing the development of advantageous decision-making in 13-15 year-olds with data points for advantageous and disadvantageous outcomes across trial blocks.]
Development of Advantageous Decision-making (Crone et al 2003)

![Graph showing the development of advantageous decision-making over 10-12 years. The graph plots choices against trial block for both advantageous and disadvantageous gains.](image)
Development of Advantageous Decision-making (Crone et al 2003)

6-9 years

TRIAL BLOCK

choices

GAIN

disadvantageous

advantageous

10,0
9,0
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
0,0
1
2
3
4
5
6
7
8
9
10
Development of Eye-movement Control as Example to Illustrate Key Principles [Work of Bea Luna et al; U of Pittsburgh]

- Measure speed, accuracy, and precision of eye-movement control, including the ability to voluntarily override reflexive patterns
- Learning how to control *behavior*
- Advantage of well-mapped brain circuitry
- Tasks easily adapted to brain imagining (fMRI) studies
- Some aspects develop very early; others late
Central Fixation (1.5-2.5s)

Saccade to Peripheral Target (1.5s)

Visually Guided Saccades

- Non-visible Target Locations
- Illuminated Targets
- Correct Gaze Location

Laboratory of Neurocognitive Development (Luna et. al.)
Antisaccades: Look away from illuminated target

Central Fixation

Saccade away from Peripheral Target

Feedback

• Illuminated Targets
↓ Correct Gaze Location

Laboratory of Neurocognitive Development (Luna et. al.)
Developmental Changes In Eye Movement Control

- Visually Guided Saccades (VGS)
  - Young adolescents (age 11-15) perform as well as adults

- Memory Guided Saccades (MGS)
  - Young adolescents perform as well as adults

- Antisaccades (AS)
  - Adolescents do not perform at adult levels until after 15 years of age
Response Suppression Failures

% of Trials

Age Groups (In Years)

Laboratory of Neurocognitive Development (Luna et. al.)
Antisaccade Trial

- 8 - 4 0 4 8

Fixation

36 sec.

Antisaccades

VGS

- 8 - 4 0 4 8

Fixation

36 sec.

Tasks Repeated for 7.5 cycles

Luna et al. (2001) Neuroimage
Frontal Eye Fields, Intraparietal Sulcus, and Superior Colliculus, activated more in adults: Antisaccades vs. VGS

Luna et al. (2001) Neuroimage
Lateral Cerebellum and Dentate Nucleus activated more in adults: Antisaccades vs. VGS

8-13 yrs. 14-17 yrs. 18-30 yrs.

Lateral Cerebellum and Dentate Nucleus

Luna et al. (2001) Neuroimage
Adults employ the SC and FEF, which are areas known to provide preparatory activity needed to successfully suppress saccades.

Adults employ the lateral cerebellum, which may provide assistance in integrating function with prefrontal cortex or in adjusting timing elements of the antisaccade task.
**DLPFC and Basal Ganglia activated more in adolescents: Antisaccades vs. VGS**

8-13 yrs. 14-17 yrs. 18-30 yrs.

DLPFC

Luna et al. (2001) *Neuroimage*
Conclusions: Child & Adolescent Eye Movement Control

- Adolescents demonstrated increased function of DLPFC indicating that compared to adults, teens may experience this as a more difficult task.

- Children demonstrated increased function in posterior parietal cortex known to subserve visual spatial processing

Luna et al. (2001) Neuroimage
Functional integration of widely-distributed circuits lays the groundwork for enhanced voluntary control of behavior during adolescent cognitive development. This may occur through strengthening of circuit-level brain organization (i.e. faster connections across a set of neural systems).

Luna et al. (2001) Neuroimage
“Hot” Cognition: Thinking Under Conditions of High Arousal and Emotion

- Steinberg et al compared performance on computer simulation of risky driving scenario (running yellow lights)
- Adolescents and Adults were similar when tested alone
- When tested in the company of friends adults showed no change but adolescents increased risk
Summary

- Adolescent Affect Regulation/Dysregulation and emotional influences on decision-making represents a crucial and exciting area of investigation.

- Need better integration of clinical, developmental, and cognitive/affective neuroscience focused on adolescents: to understand brain/behavior/social context interactions.

- Understanding mechanisms and developmental pathways to disorders can inform clinical and social policies regarding the vulnerabilities and opportunities in early adolescence.
We search, on our journeys, for a self to be, for other selves to love, and for work to do...

We find by losing. We hold on by letting go.

--Frederick Buechner