

Brain and Behavioral Development in Adolescence

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Adolescent Over-the-Counter Drug Product Use
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Overview

- Adolescent Risk-Taking
- A Tale of Two Brain Systems
- The MacArthur Juvenile Capacity Study
- Implications for Policy and Practice

- Commit more crimes (both property crimes and violent crimes)
- Engage in more binge drinking
- Are less likely to practice safe sex
- Attempt suicide more often
- Taxpayers spend hundreds of millions of dollars on educational efforts to reduce risk-taking, most of which are ineffective

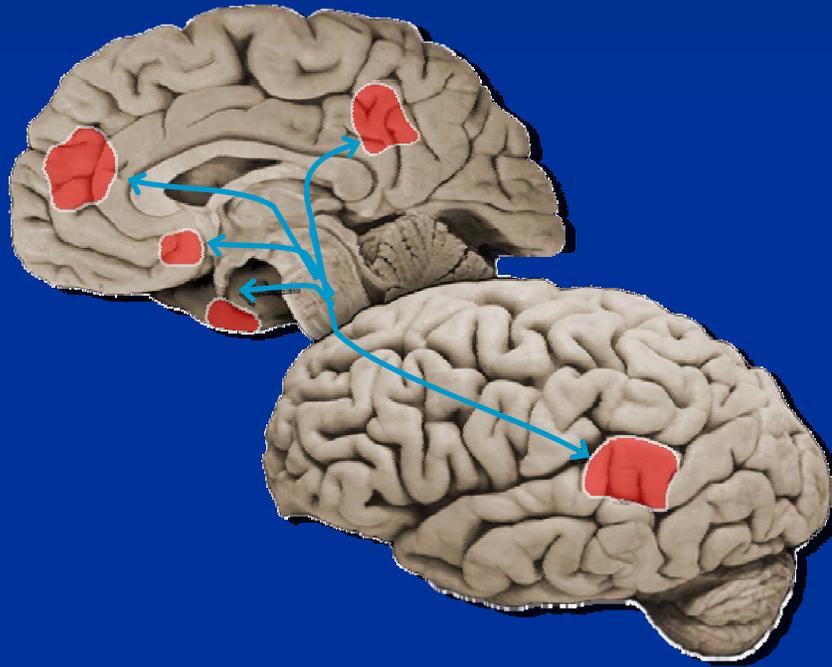
A Tale of Two Systems

Brain Development in Adolescence

- Brain development continues until a later age than previously believed
 - Synaptic pruning
 - Myelination
- Structural (anatomical) change is accompanied by functional change (patterns of activity)
- Some is driven by maturation, some is driven by experience, most is driven by a combination
- Different brain systems mature at different points within the adolescent decade

The Socio-Emotional System

Linked to processing of emotions, social information, reward and punishment



Key Nodes

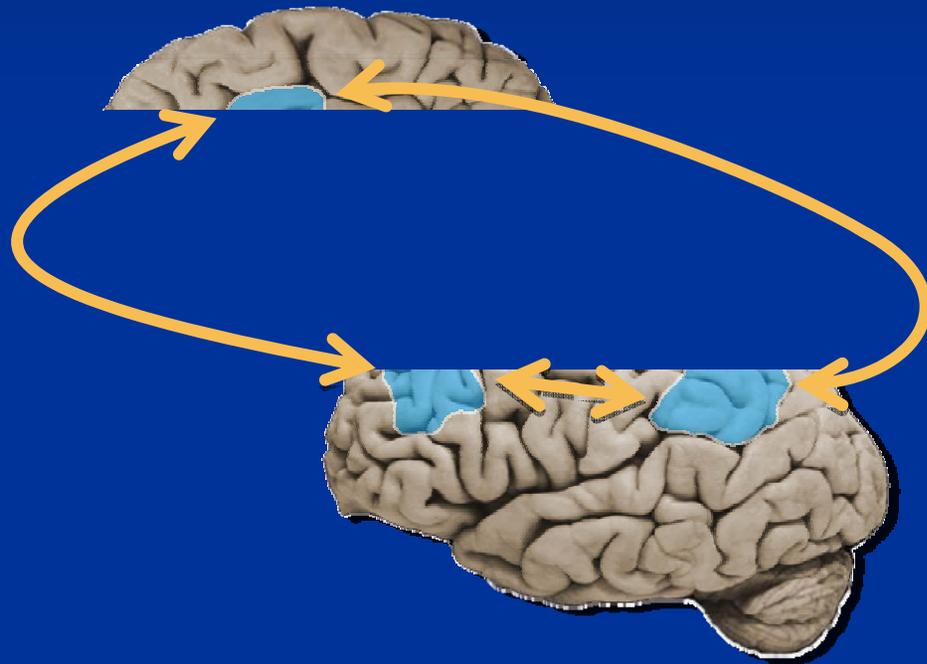
- ◆ Ventral striatum (nucleus accumbens)
- ◆ Ventromedial PFC
- ◆ Orbitofrontal cortex
- ◆ Posterior cingulate cortex
- ◆ Amygdala
- ◆ Superior temporal sulcus

The Socio-Emotional System

- Undergoes major changes in early adolescence around the time of puberty
- Linked to increase in dopaminergic activity in pathways from limbic system to PFC
- Changes result in
 - Increased attentiveness to rewards
 - Increased sensation-seeking
 - Increased/easier emotional arousal (both positive and negative emotions)
 - Increased attentiveness to social information

The Cognitive Control System

Associated with working memory, logical reasoning, planning, and regulating impulses



Key Nodes

- ◆ Anterior Cingulate Cortex
- ◆ Lateral Prefrontal Cortex
- ◆ Posterior Parietal Cortex

The Cognitive Control System

- Develops gradually from preadolescence on, well into the mid-20s
- Changes result in
 - Better impulse control
 - Better emotion regulation
 - More foresight
 - More planning ahead
 - Better reasoning

Timing is Everything

- The excitation of the socioemotional system occurs early in adolescence, around puberty
- The maturation of the cognitive control system is gradual and not complete until late adolescence or early adulthood
- The “accelerator” is activated before a good braking system is in place
- Result: Starting the engines without a skilled driver behind the wheel

Summary and Some Hypotheses

- Adolescence is a time of a still-maturing cognitive control system and still-maturing connections between socio-emotional and cognitive control systems
- Indicators of tendency toward reward seeking should show most significant development during first half of adolescence
- Indicators of maturation of cognitive control system should show more gradual development over entire adolescent period
- Middle adolescence (ages 14-16) should be an especially vulnerable period (greatest imbalance between easily aroused socio-emotional system and still immature cognitive control system)

MacArthur Juvenile Culpability Study

Principal Investigators

Marie Banich, University of Colorado

Elizabeth Cauffman, University of California, Irvine

Sandra Graham, UCLA

Laurence Steinberg, Temple University

Jennifer Woolard, Georgetown University

MacArthur Juvenile Capacity Study

- Purpose: To examine age differences in capacities affecting judgment and decision-making
- Design: Five data collection sites nationally
 - Philadelphia, D.C., Denver, Los Angeles, Orange County California
 - 935 individuals from ages 10 to 20
 - Computerized performance tests of planning, preference for immediate versus delayed gratification, impulsivity, risk-taking, sensation-seeking, reward sensitivity
 - Standardized questionnaires measuring similar characteristics

Sample Characteristics

■ N=935

■ Age

- 10-11 12.5%
- 12-13 14.7%
- 14-15 13.8%
- 16-17 15.2%
- 18-21 15.9%
- 22-25 14.6%
- 26-30 13.2%

■ Age Groups comparable with respect to:

- Race/ethnicity
- Sex
- Household Education
- IQ

■ Household Education

- < High School 11.9%
- High School Grad 22.8%
- Some College 34.1%
- College Graduate 21.4%
- Post-College 9.7%

■ Sex

- Male 49.2%
- Female 50.8%

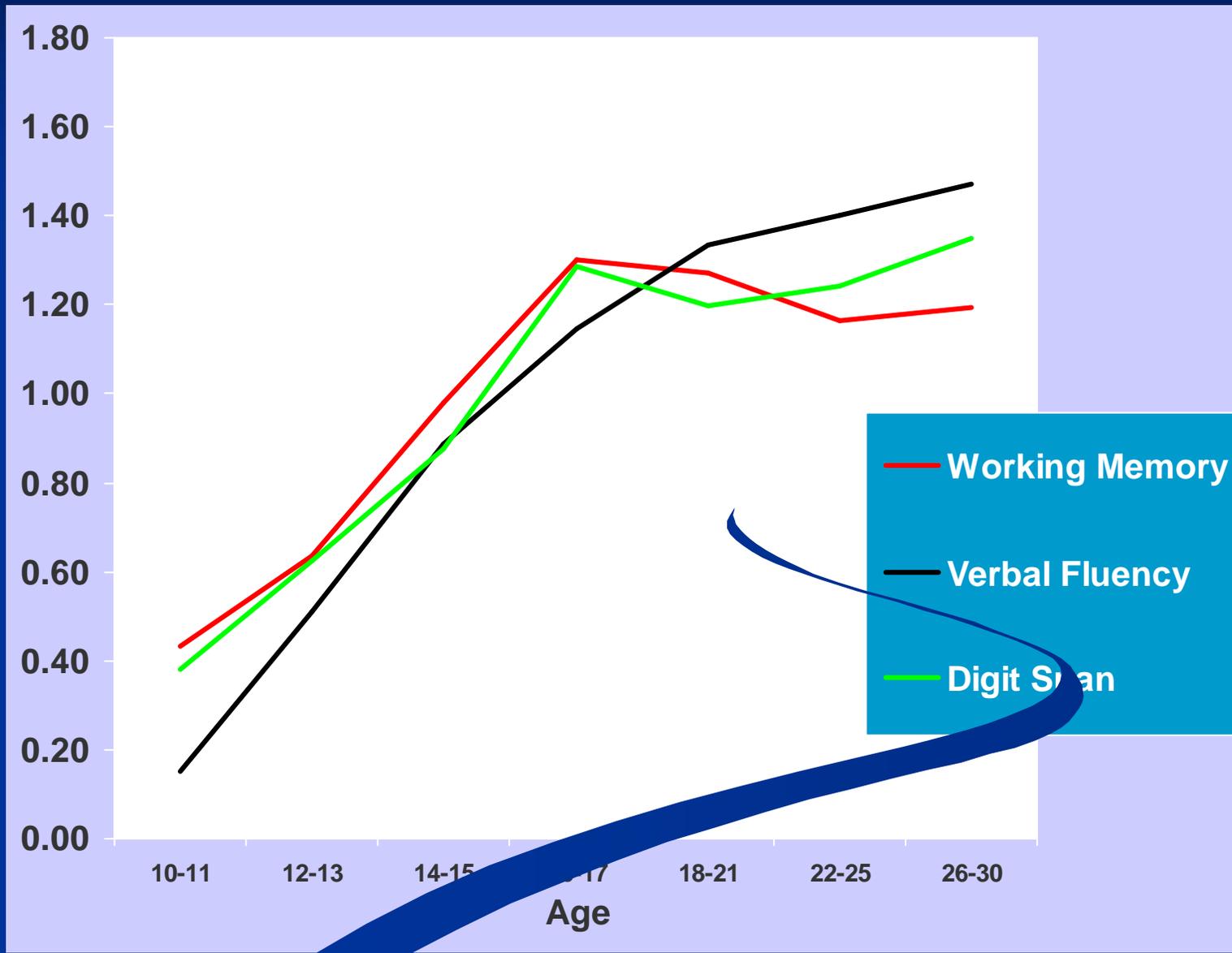
■ Race/Ethnicity

- African-American 29.2%
- Asian-American 15.1%
- Hispanic 21.2%
- White 24.0%
- Other 9.9%

Main Areas Assessed

- Aspects of Basic Intellectual Ability
 - Verbal Fluency
 - Basic Information-Processing Abilities (e.g., memory)
- Outcomes Influenced by the Socio-Emotional System
 - Sensation Seeking
 - Risk Taking
 - Reward Salience
- Outcomes Influenced by the Cognitive Control System
 - Impulse Control
 - Thinking Ahead
 - Resistance to Peer Influence
- Questionnaires and Performance Tasks

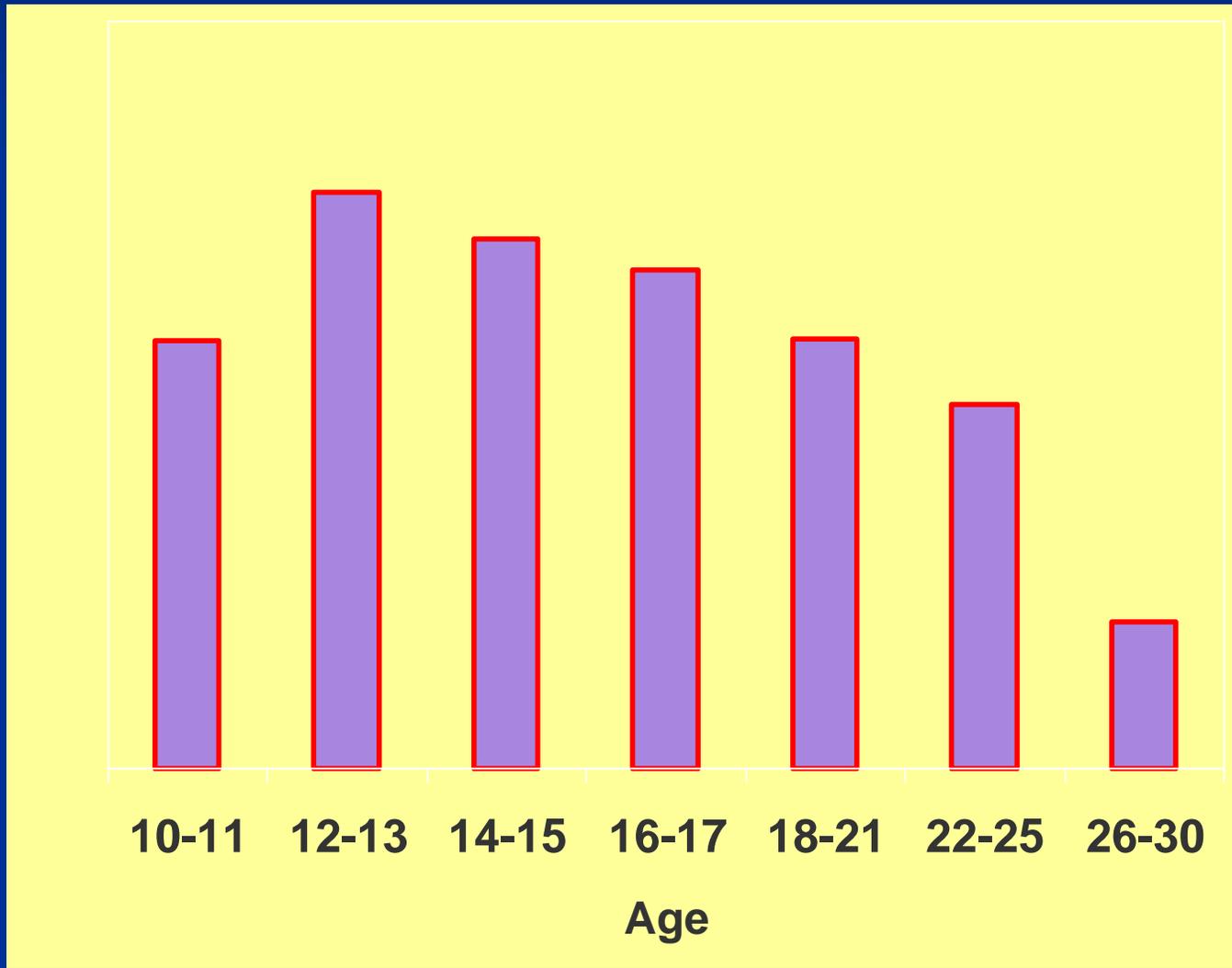
Basic Intellectual Functioning Matures by Age 16



Outcomes Influenced by the Socio-Emotional System

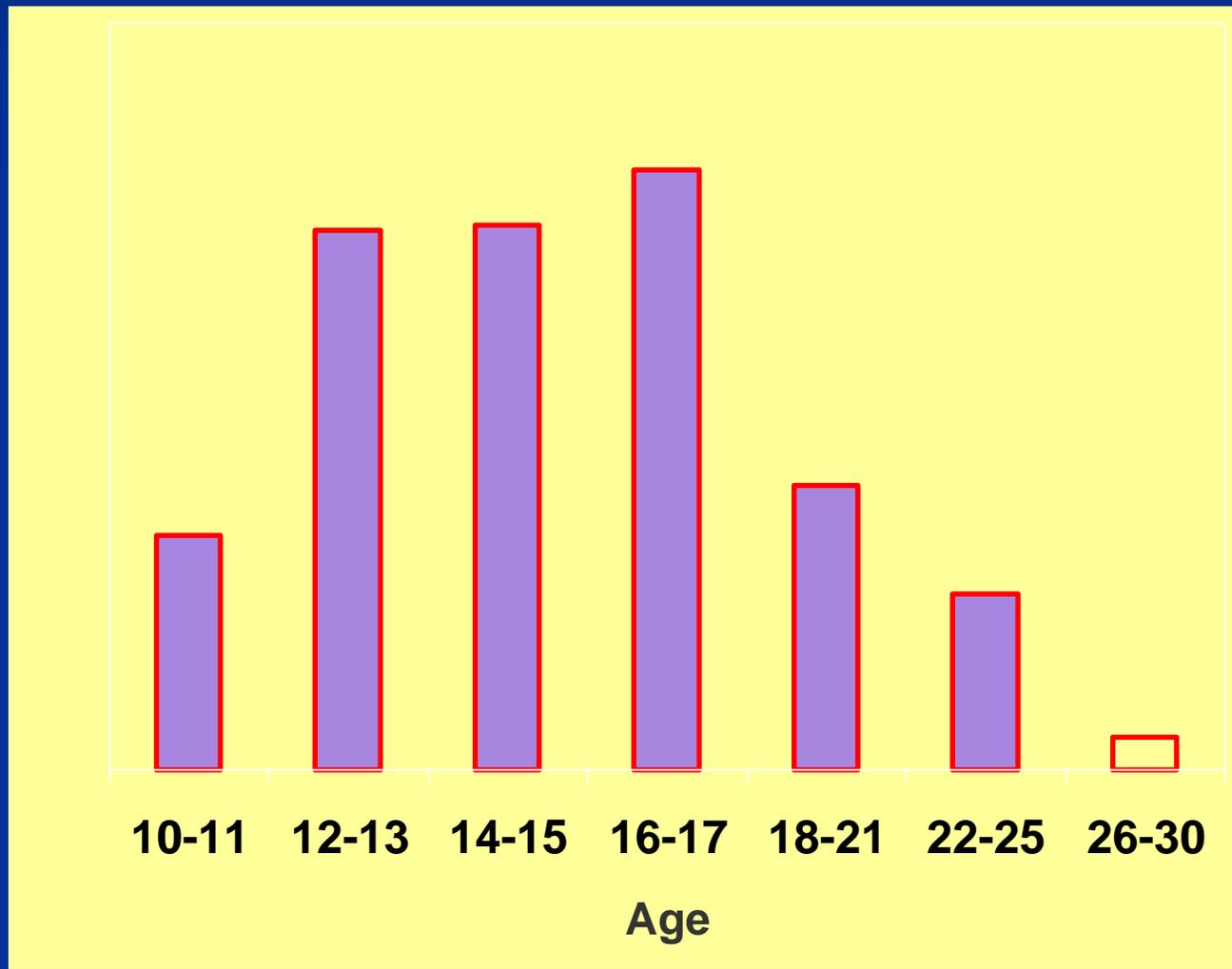
Sensation-Seeking Increases, Then Declines With Age

e.g., “I sometimes like to do things that are a little frightening.”



Preference for Risk Increases, Then Declines With Age

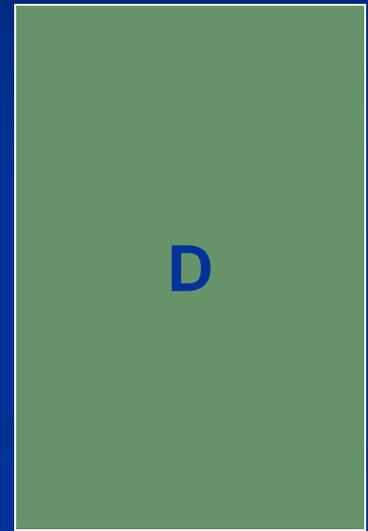
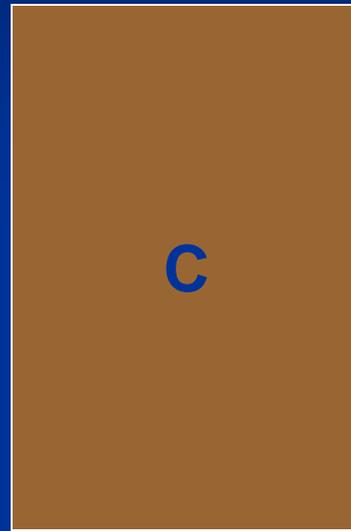
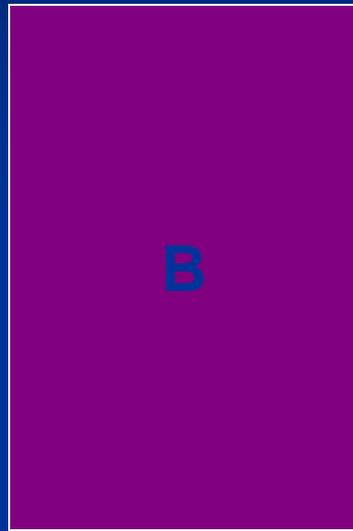
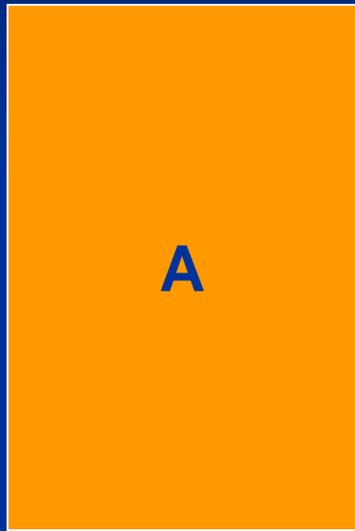
e.g., “How would you compare the benefits
(or pleasures) of having unprotected sex with the risks?”



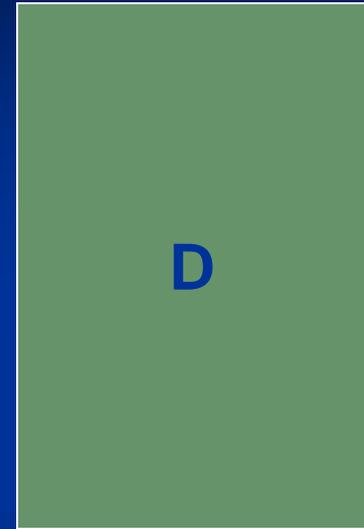
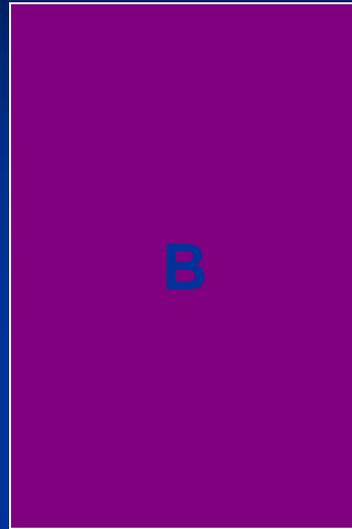
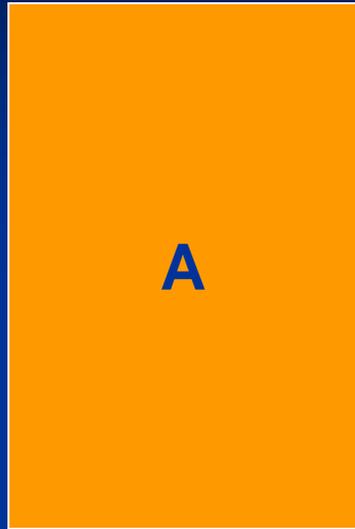
Iowa Gambling Task

- Subject presented with four decks of cards, face down
- Each card contains information about winning and losing (money, points, candy, etc.)
- Each trial requires choice between passing and playing
- Subject told that two decks are “good” and two are “bad”
- Goal: Maximize winnings by choosing from correct decks
- Outcome: Change over blocks in patterns of card pulling

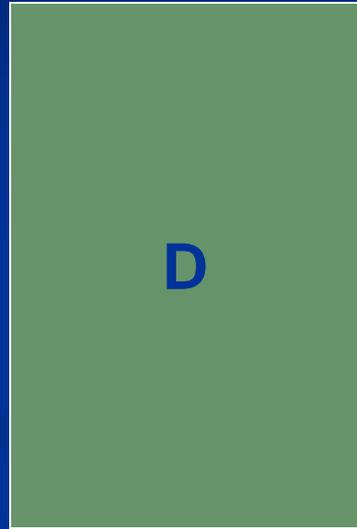
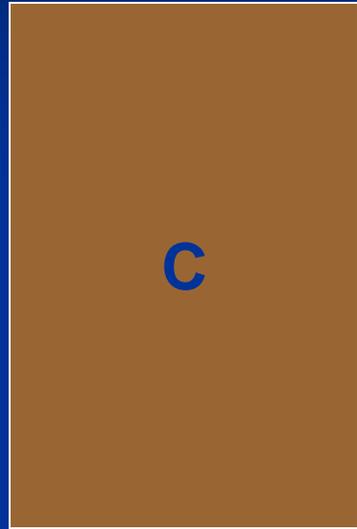
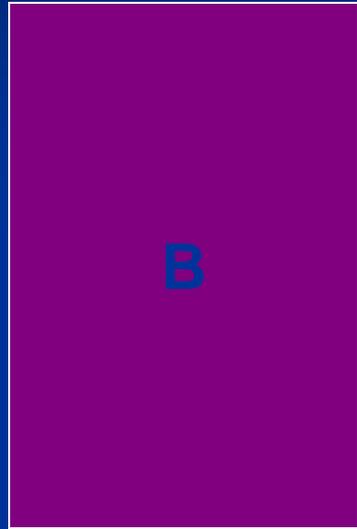
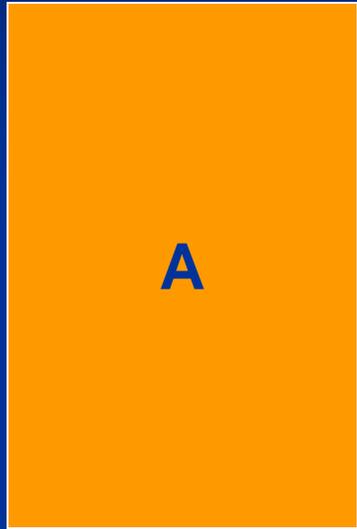
Iowa Gambling Task



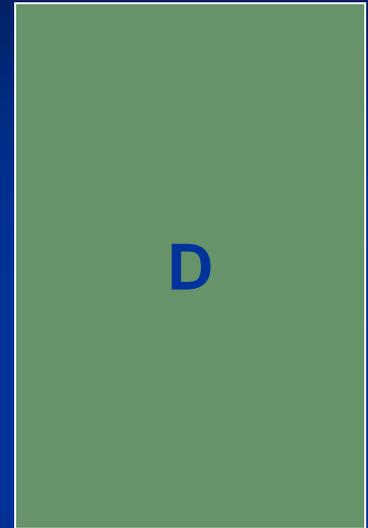
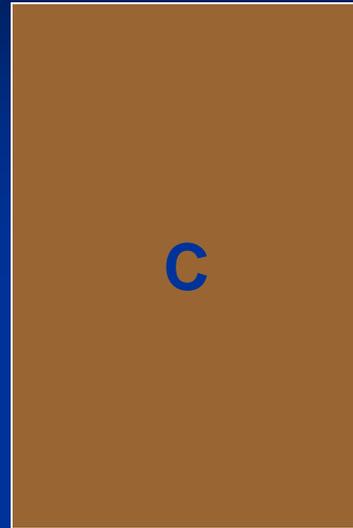
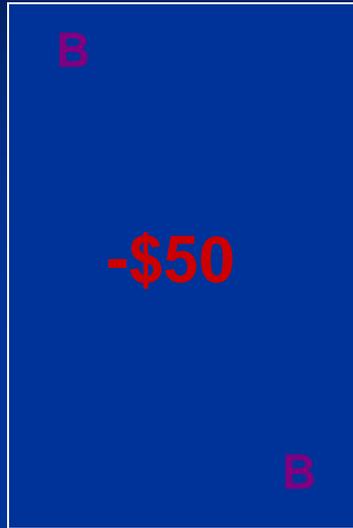
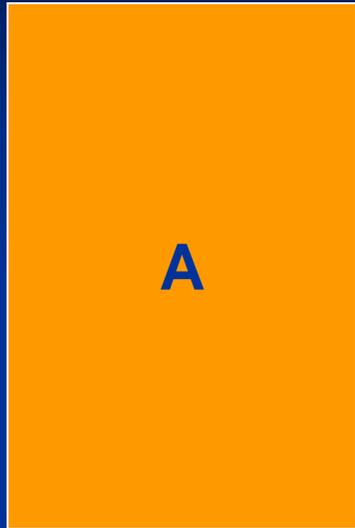
Play or
Pass?



You win!!!
Your total is \$2100



Play or
Pass?

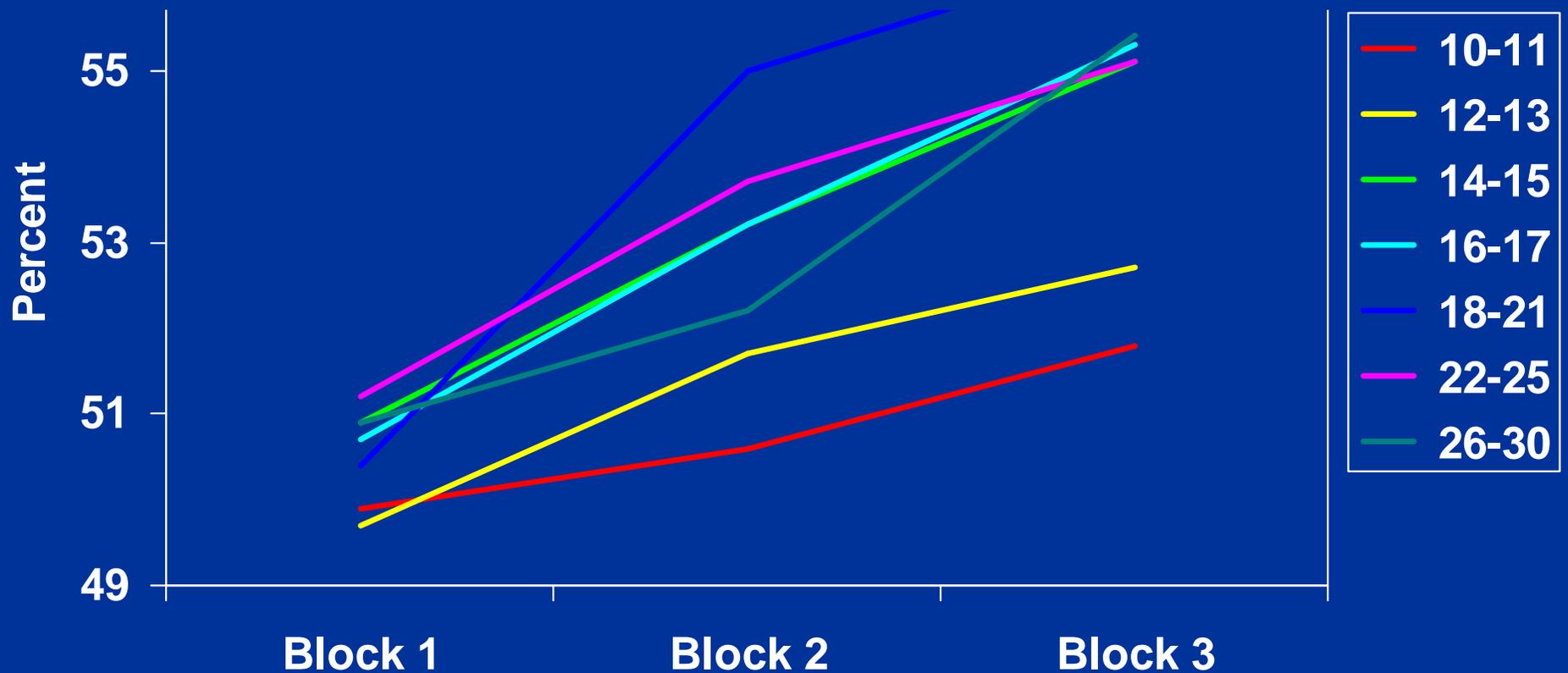


You lose!!!
Your total is \$2050

Iowa Gambling Task

- Losing decks pair large gains with large losses
- Winning decks pair small gains with small losses
- Choosing “bad” decks indicates decision-making that is excessively influenced by prospect of big reward
- Administered in 3 blocks of 40 trials

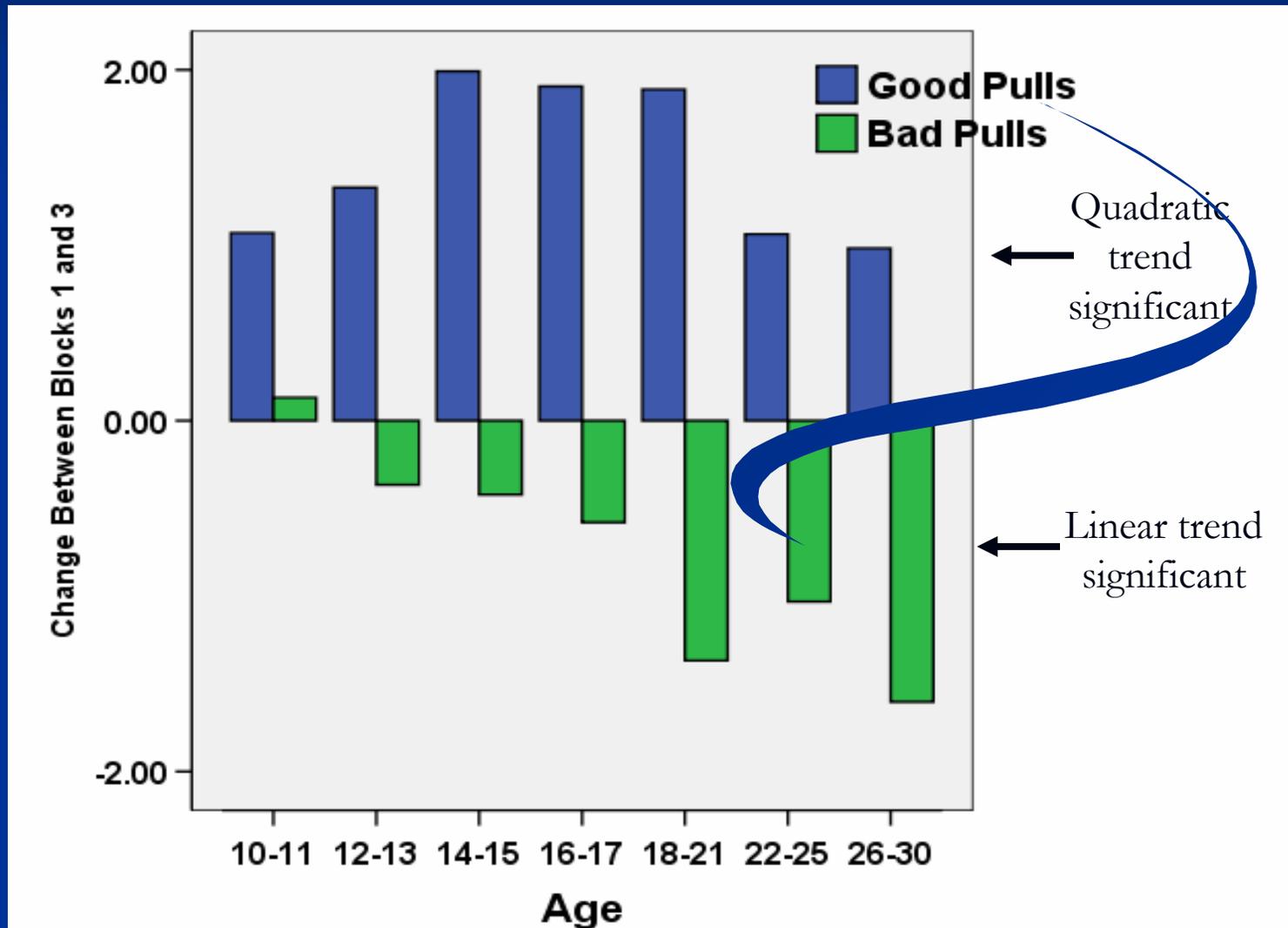
Proportion of Draws from Good Decks Increases More Slowly Among Younger Adolescents



Are Card Choices Driven By Reward or Punishment?

- Improvement over time can be due to two different processes
 - Increasing choices from good decks over time
 - (i.e., paying attention to rewards)
 - Decreasing choices from bad decks over time
 - (i.e., paying attention to losses)

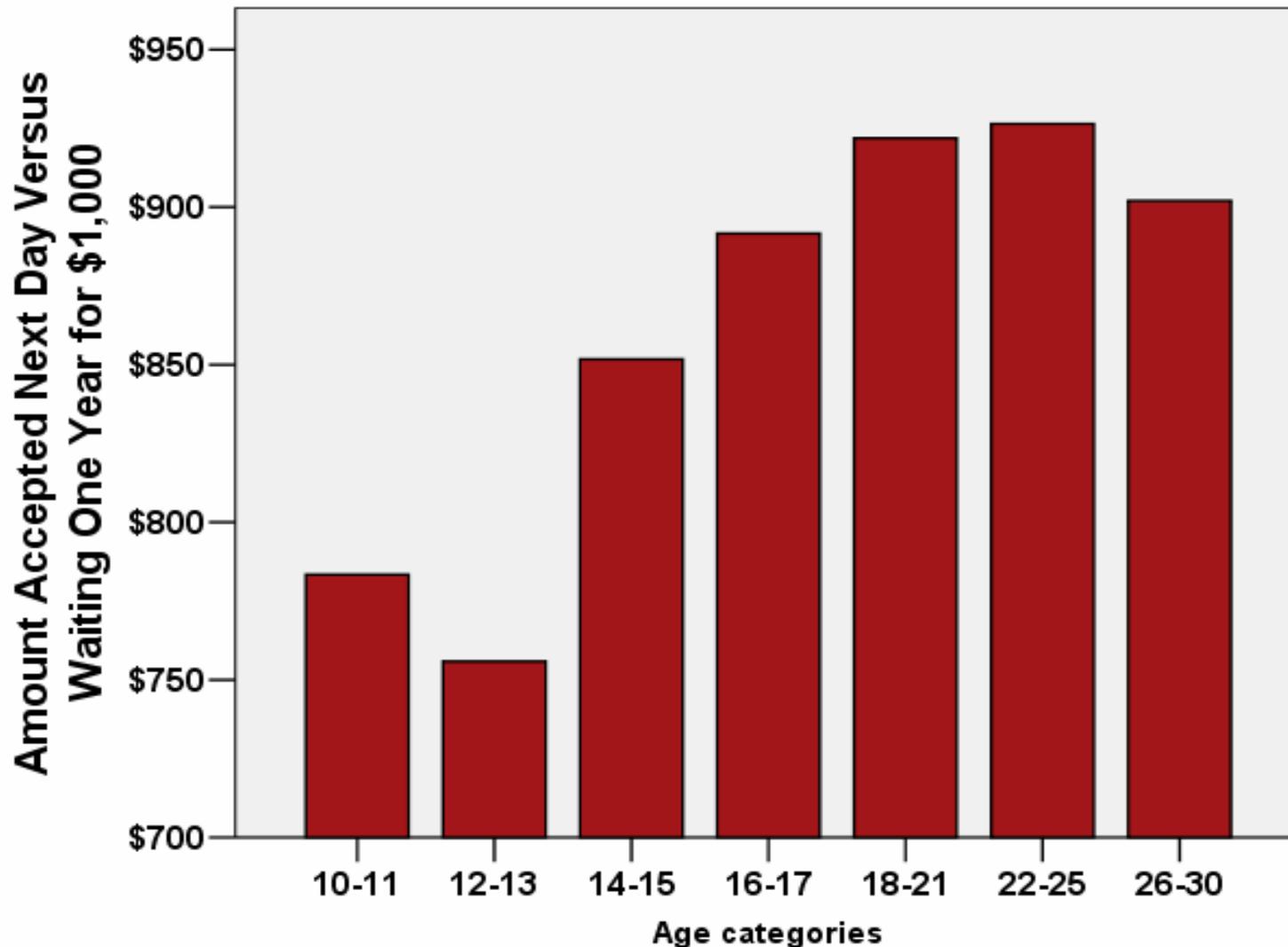
Younger Adolescents Pay More Attention to Rewards Than Losses



Delay Discounting

- Measures desire for immediate versus delayed rewards
- Would you rather have \$200 today or \$1,000 in six months?
- Lower figure raised or lowered to middle point depending on answer, and question repeated until no preference between immediate and delayed reward
 - \$600 today versus \$1,000 in six months
 - \$400 today versus \$1,000 in six months
- Repeated with 9 trials (with varying immediate amounts) in each of 6 different time intervals
 - 1 day, 1 week, 1 month, 3 months, 6 months, 1 year
- Lower amount accepted short-term indicates stronger need for short-term gratification

Young Adolescents Less Willing to Delay Gratification



Summary

- The “reward system” is especially sensitive early in adolescence
- Related to remodeling of dopamine system around puberty
- Adolescents become more attentive to rewards and are especially drawn to immediate rewards
- This is also seen in self-reports of sensation-seeking and risk preference

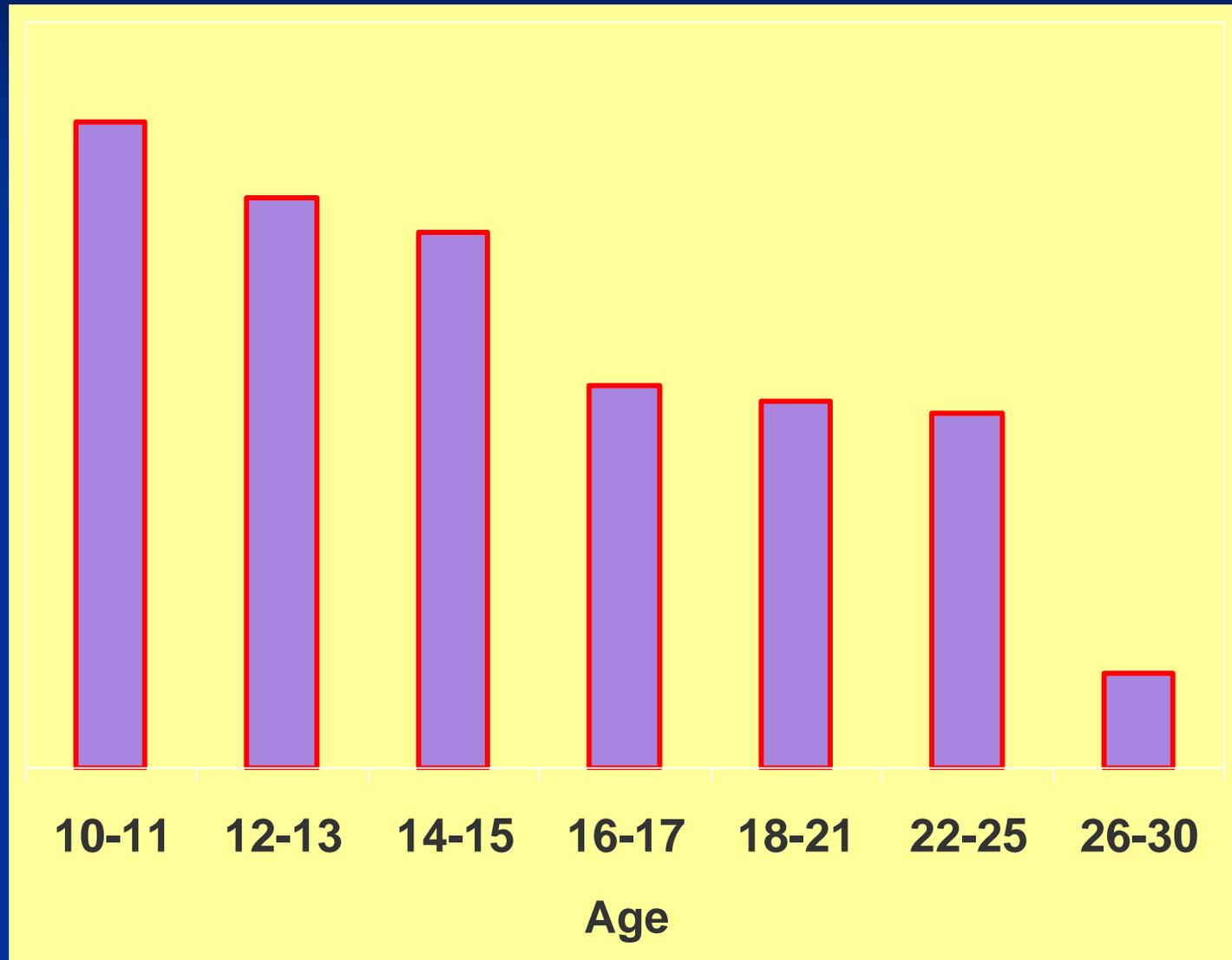
Timing is Everything

- The excitation of the reward system occurs early in adolescence, around puberty
- The maturation of the regulatory system occurs gradually over a long period

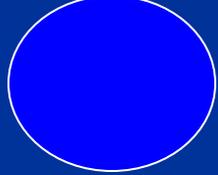
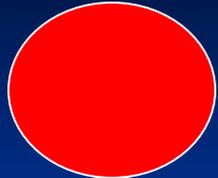
Outcomes Influenced by the Cognitive Control System

Impulsivity Declines Linearly With Age

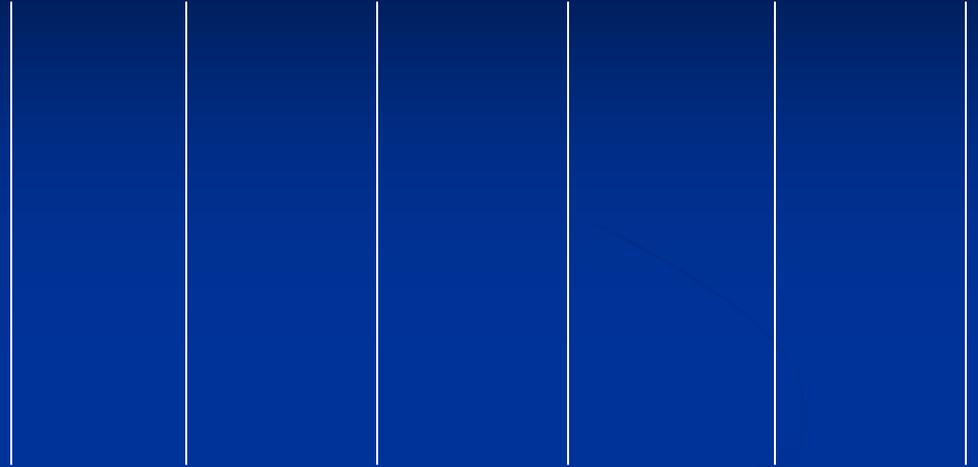
e.g., “I do things without thinking.”



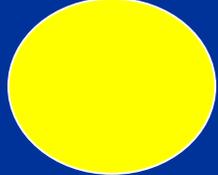
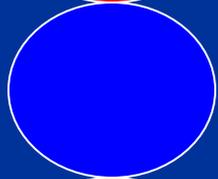
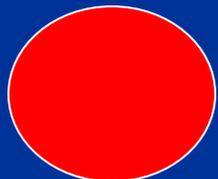
Tower of London



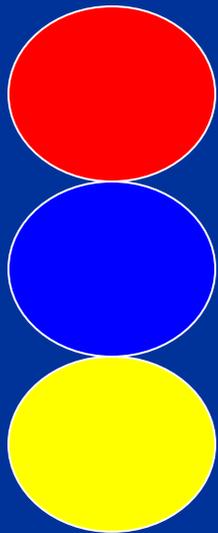
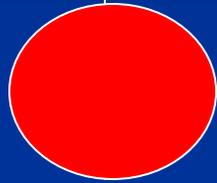
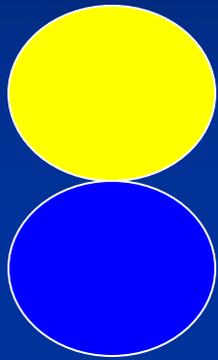
Start



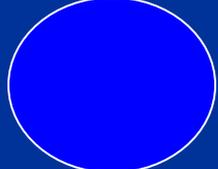
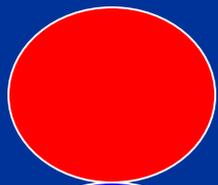
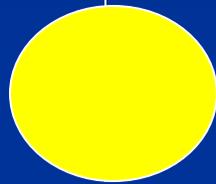
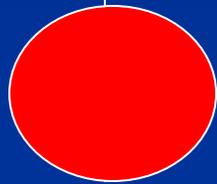
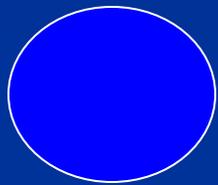
Place Holders



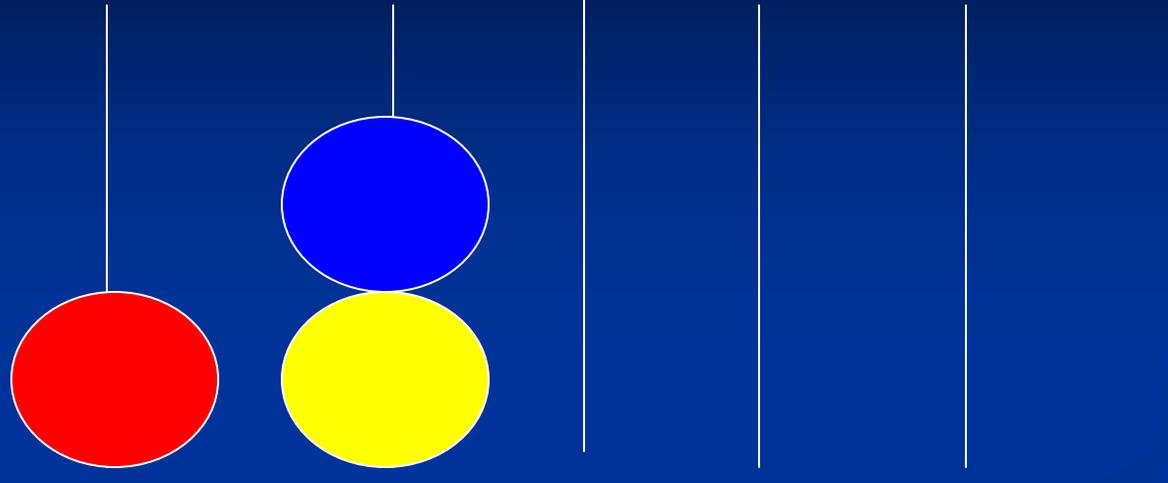
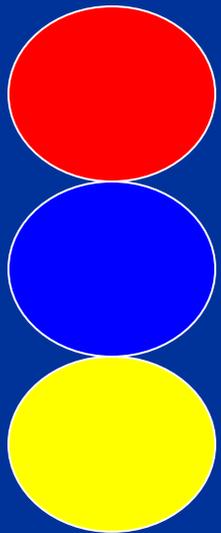
Goal



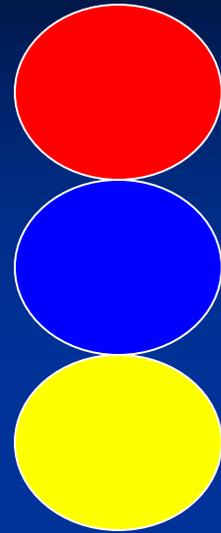
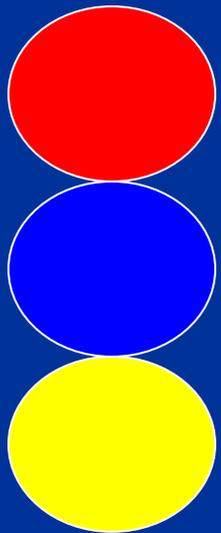
First Move



Second Move

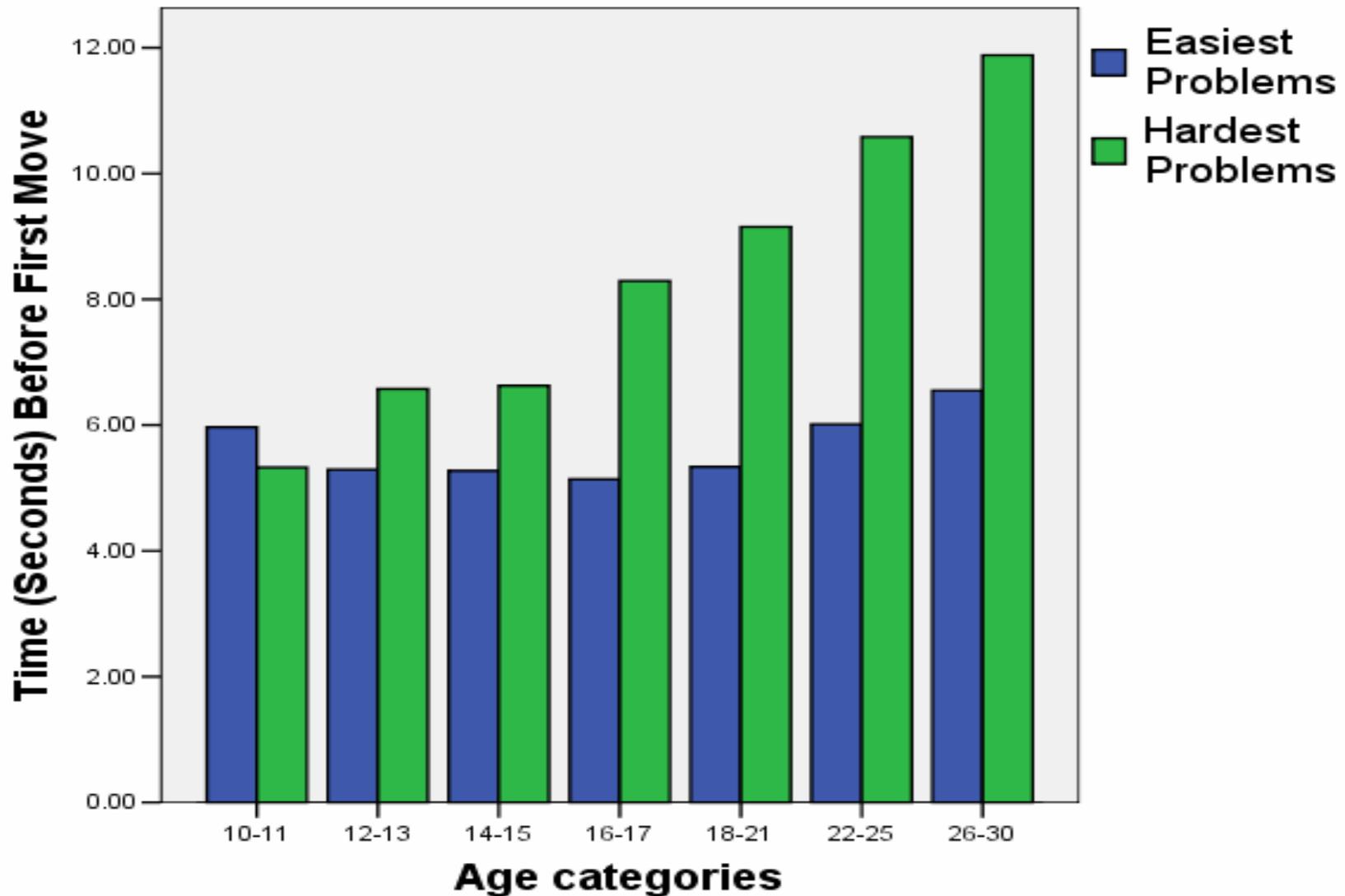


Third Move



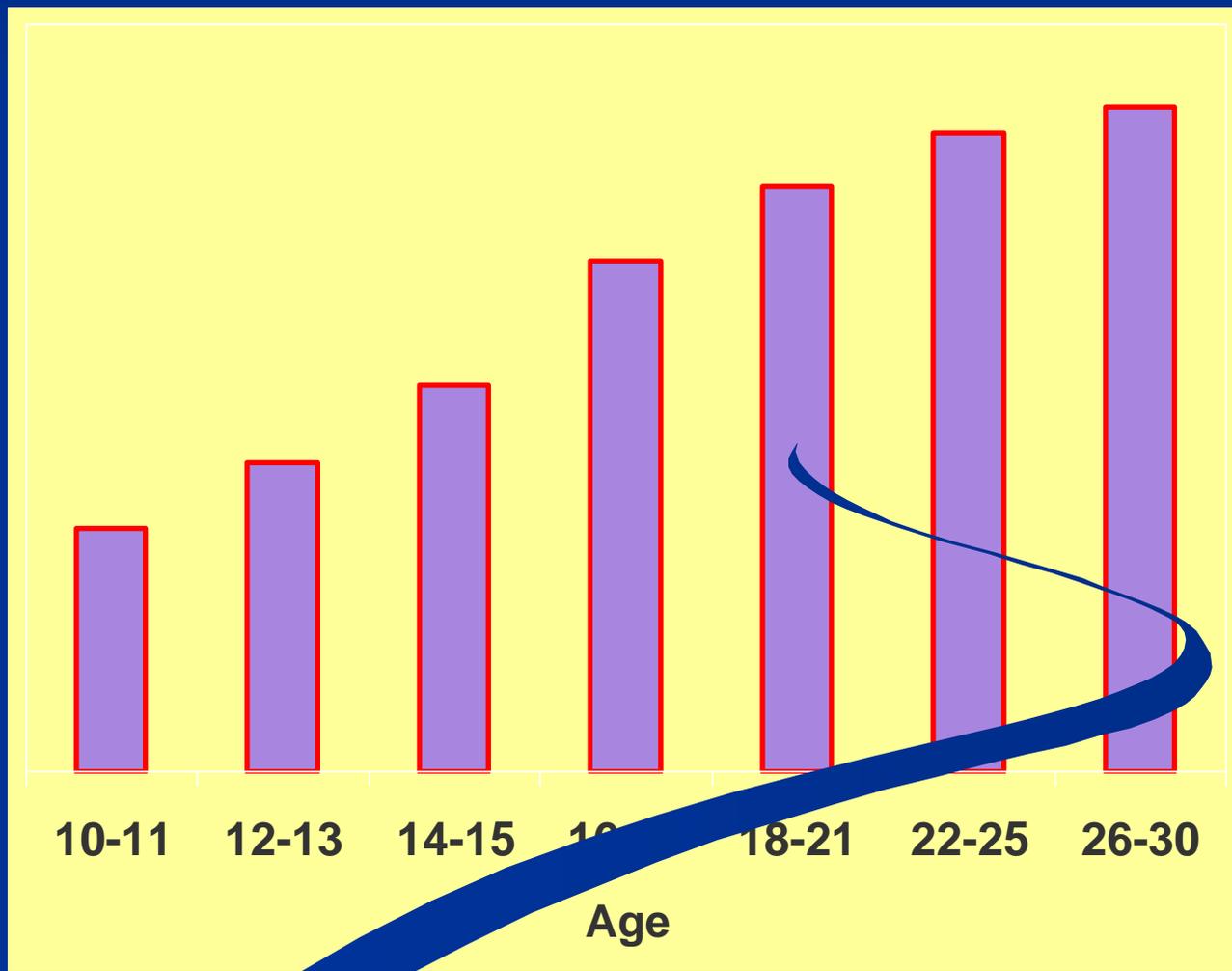
Fourth Move

With Age, Longer Time Spent Thinking Before Acting on Difficult Problems



Resistance to Peer Pressure Increases Linearly with Age

e.g., “Some people think it's better to be an individual even if people will be angry at you for going against the crowd.”



Adolescent Risk-Taking Usually Occurs in Groups

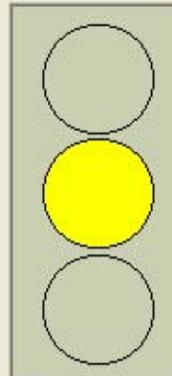
- Peers use of alcohol or illicit drugs is one of the strongest predictors of an adolescent's own substance use
- Risk of a serious automobile accident significantly increases with presence of same-aged passengers
- Adolescents are more likely to be sexually active when their peers are
- Adolescents are far more likely than adults to commit crimes in groups than by themselves

The “Chicken” Game

- Subject “drives” a car across screen
- The longer the car is in motion, the more points are accumulated
- Subject told that a yellow light will appear, signaling that at some point after the yellow signal, a wall will pop up out of the ground
- If subject stops, accumulated points are retained
- If subject crashes, all points are lost
- Performance correlated with self-reported inclination toward antisocial activity
- Subjects randomly assigned to play game with or without friends present

Your Bank Account: 0 points

Points This Round: 50 points



Points:

25

50

75

100

125

150

175

200

Your Bank Account: 39 points

Points This Round: points



YOU STOPPED IN TIME!

39 points have been added to your bank account!

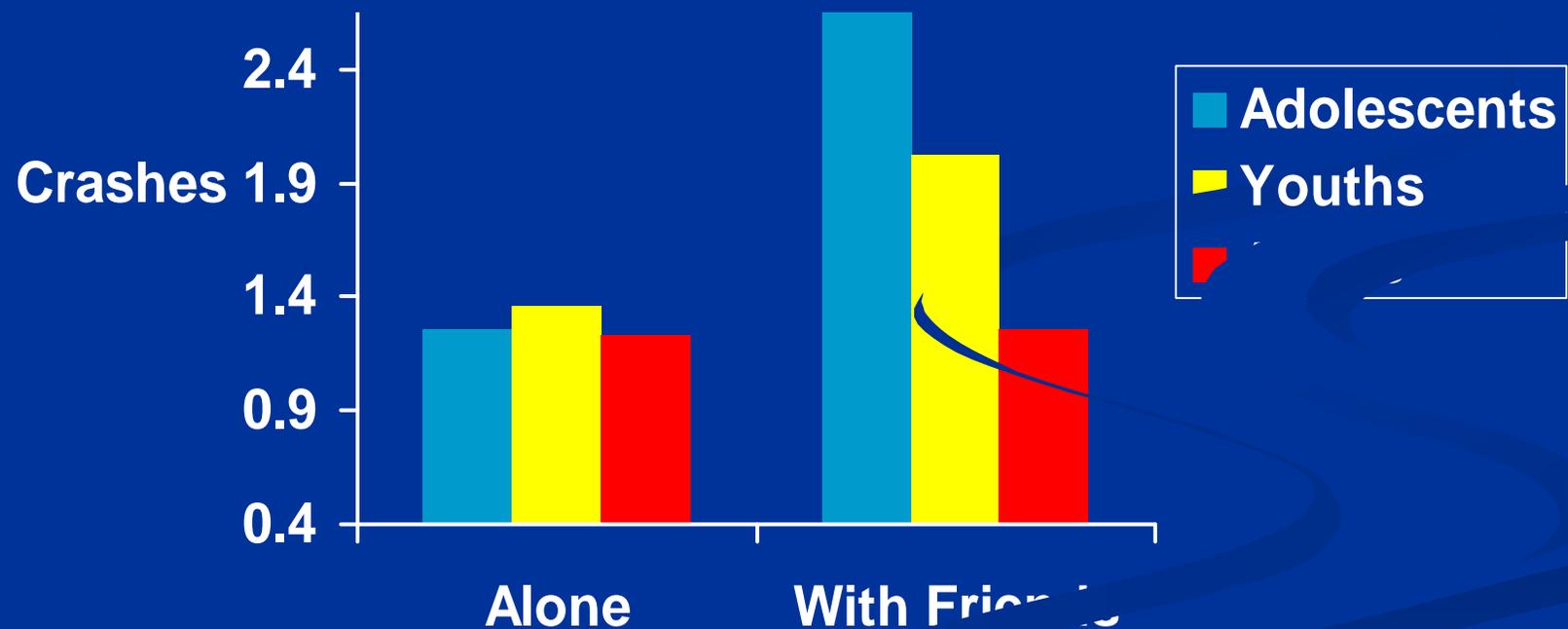
OK



Points:

25

Impact of Presence of Peers

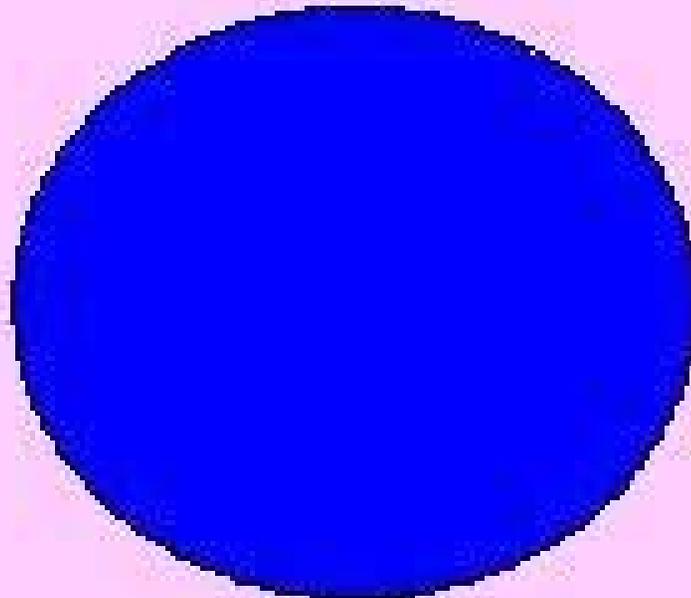


From Gardner & Steinberg, 2005

New Study of Peer Influences

- Funded by NIDA
- Goal: Examine neural underpinnings of peer influence
- Currently testing new procedure in which peers are not in room but subject is made aware when they are watching performance
- Administered in within-subjects design
 - Peer followed by alone or alone followed by peer
- Pilot data in behavioral lab on 39 subjects
(avg. age =19 years)
- Pilot data in fMRI context on 2 subjects (19 years)

Balloon Analog Risk Task (BART)



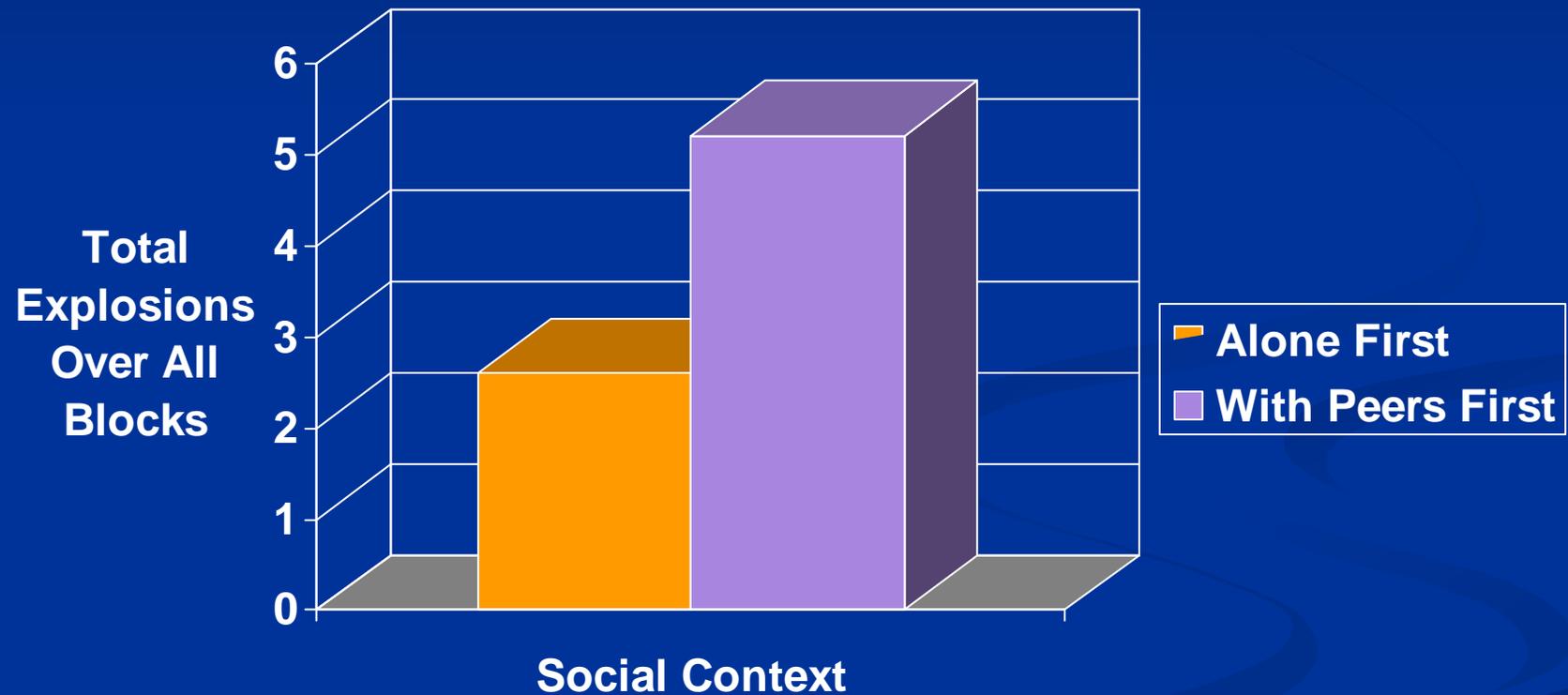
Press to
Collect \$\$\$

Press this button to pump
up the balloon.

Total
Earned \$0.00

Last
Balloon \$0.00

Impact of Presence of Peers (Pilot Data, N=39)



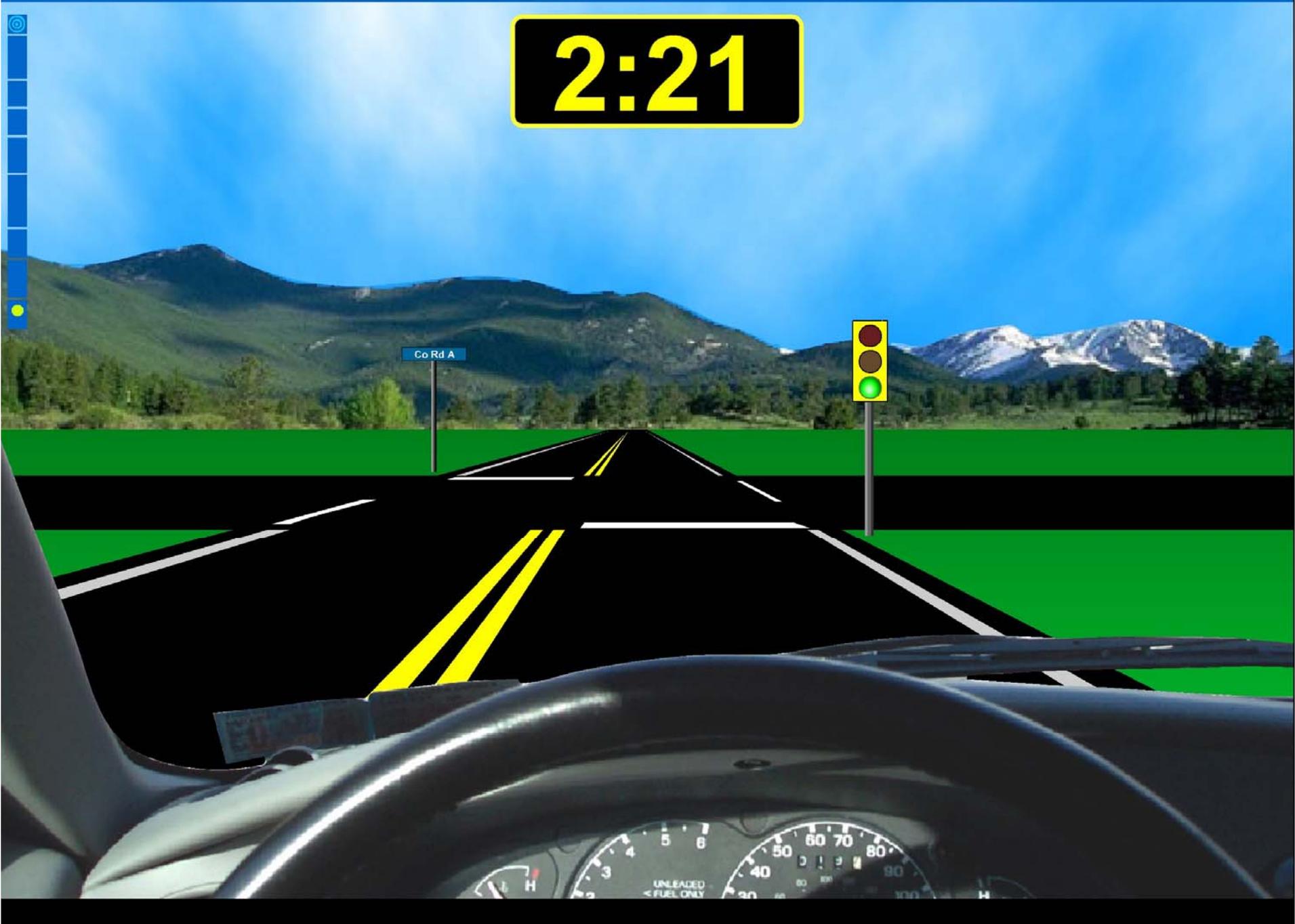
The Stoplight Game

- Video “driving” game
- Subject plays game either alone or with two friends watching
- Subject is encouraged to travel through a series of intersections as quickly as possible
- Must decide whether to “run” a yellow light or stop
- Three possibilities
 - Runs intersection successfully (no time lost)
 - Stops and waits for green light (some time lost)
 - Crashed in intersection (much time lost)
- Risky Driving Index: Ratio of Not Braking / Braking

intersection: 1 of 8

time

2:21



Co Rd A

UNLEADED
FUEL ONLY

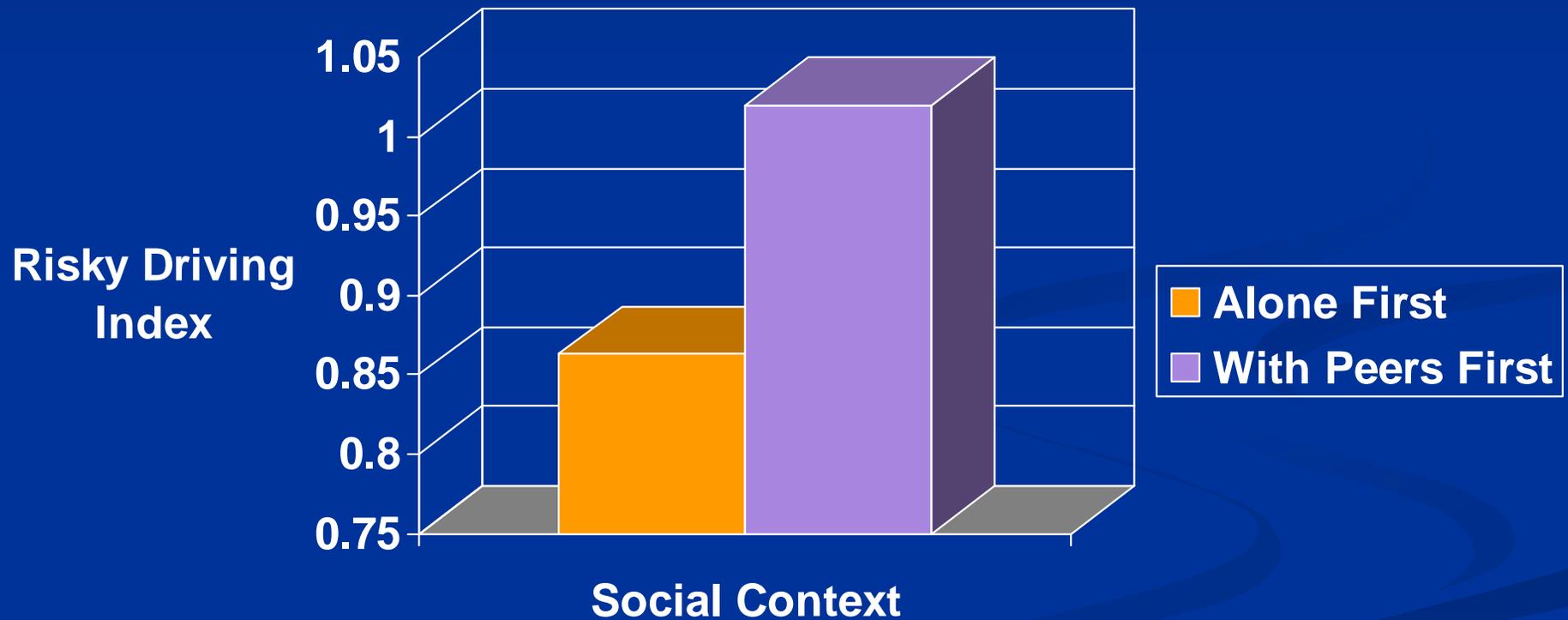
intersection: 1 of 8

time

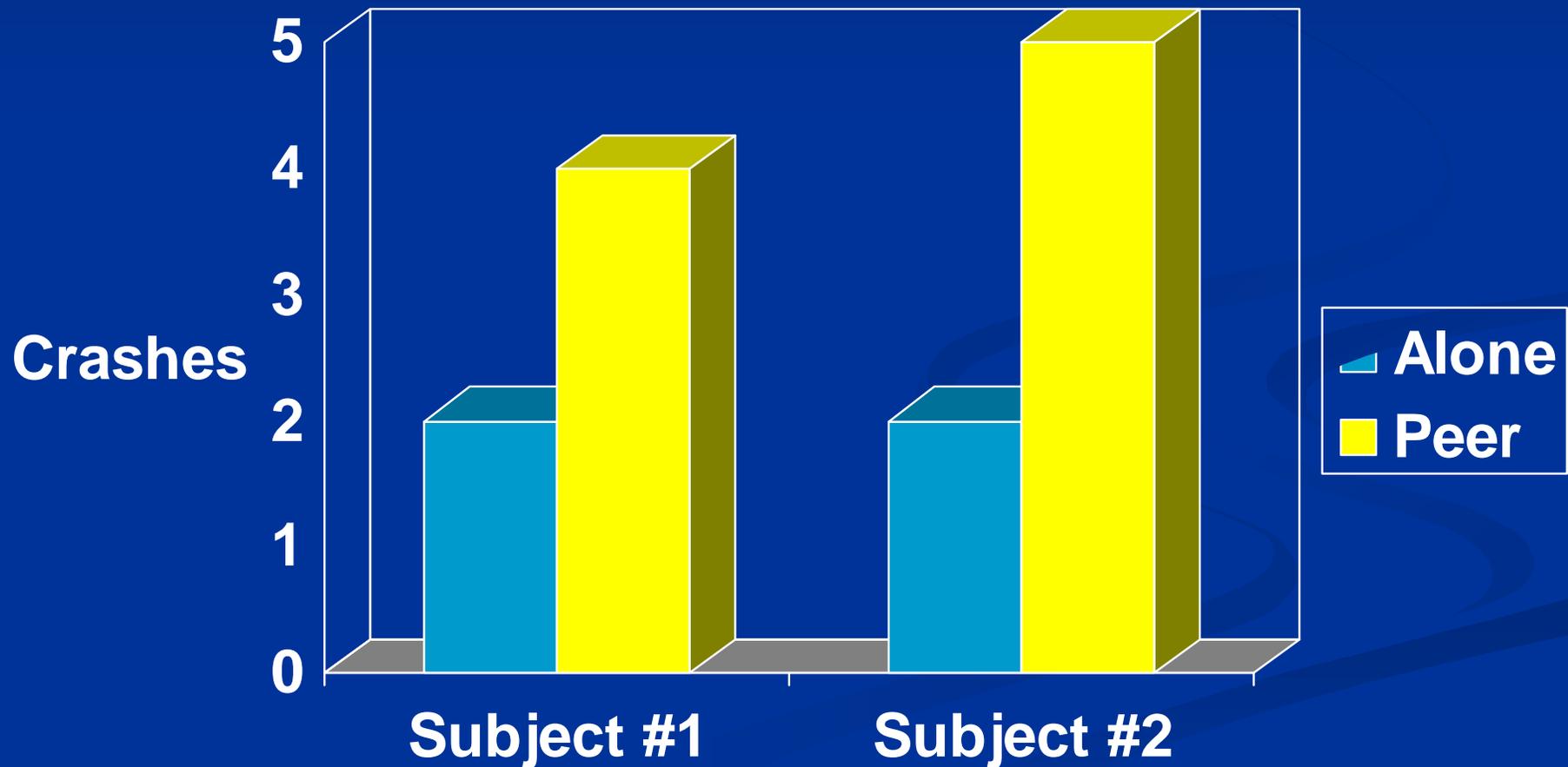
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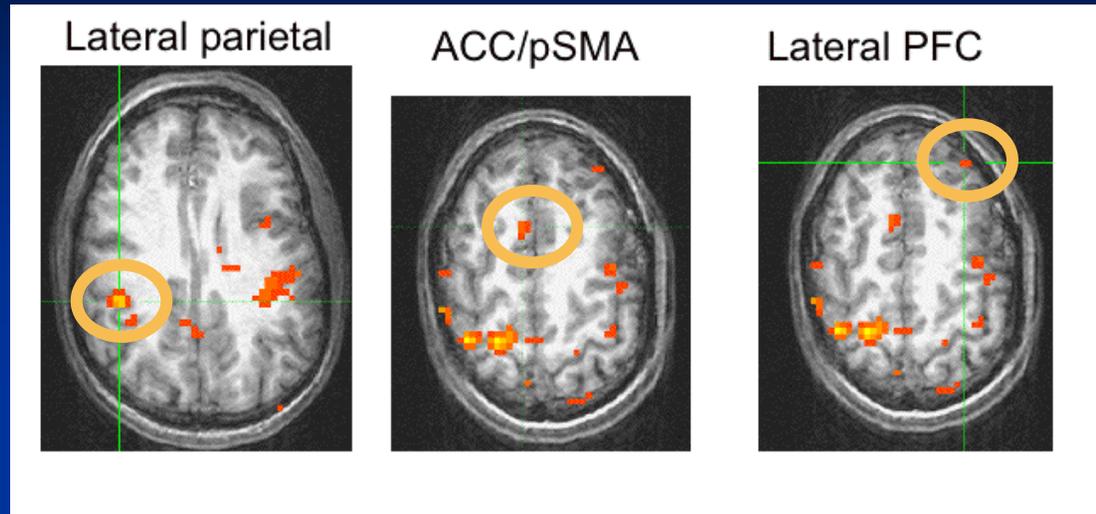
Impact of Presence of Peers (Pilot Data, N=39)



Crashes During Stoplight Game in fMRI Context



Brain Activity During Task

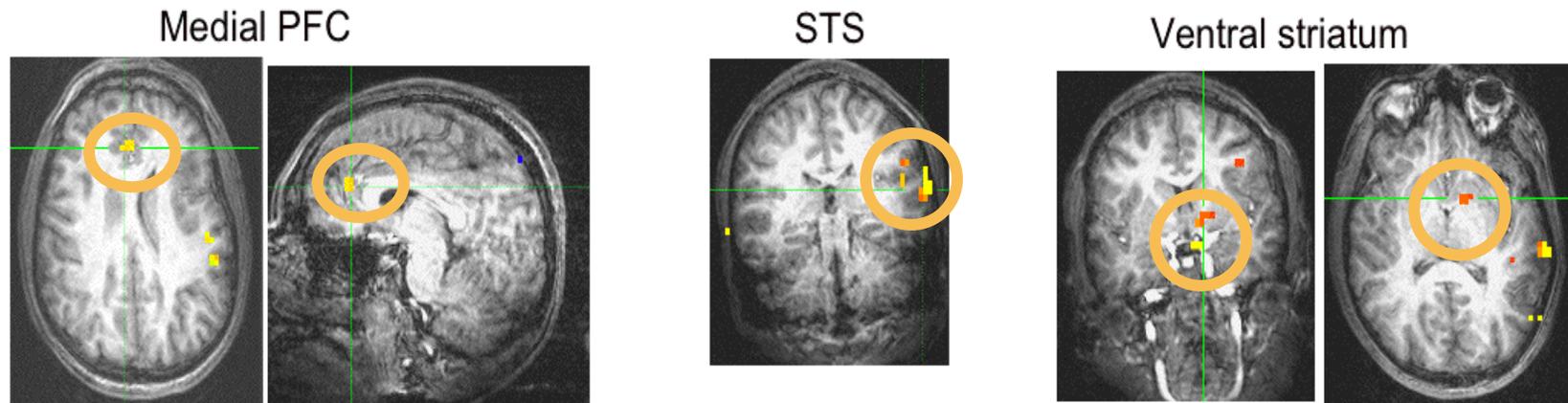


- Cognitive Control Network is active in both social contexts

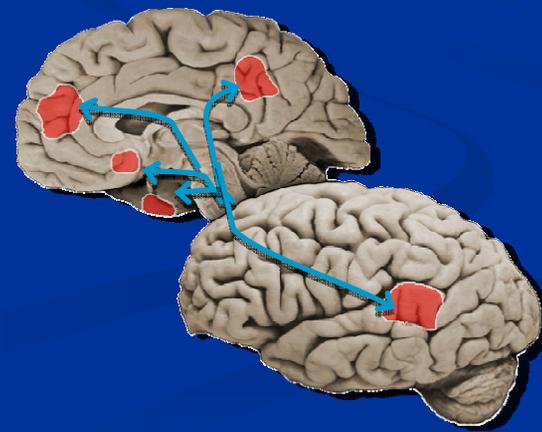


Brain Activity Only in Presence of Peers

Peer effect @ $p < .001$ - (Peer > No peer) - Trial-based analysis



- ◆ “Presence” of peers increases activation of Socio-Emotional Network

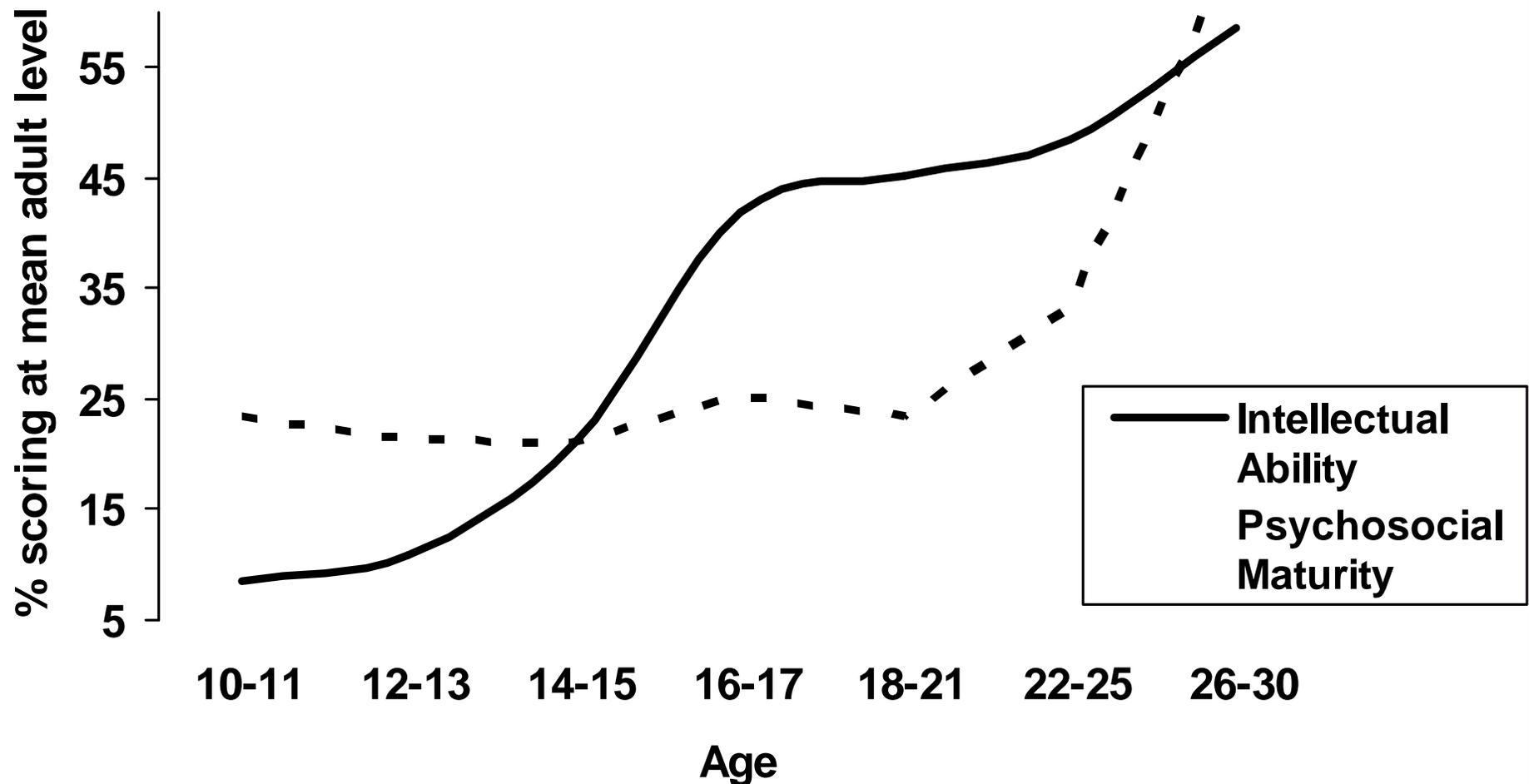


Main Conclusions

- Developmental course of intellectual and psychosocial maturity follow different patterns
- Intellectual abilities increase in early adolescence but plateau around age 16
- Psychosocial maturity stable from 10 to 14, then steadily increases from 14 into late 20s (gains in impulse control, delay of gratification, planning, future orientation, resistance to peer influence, risk perception, risk aversion)
- Certain situations may exacerbate age differences in decision-making
 - Social arousal
 - Emotional arousal

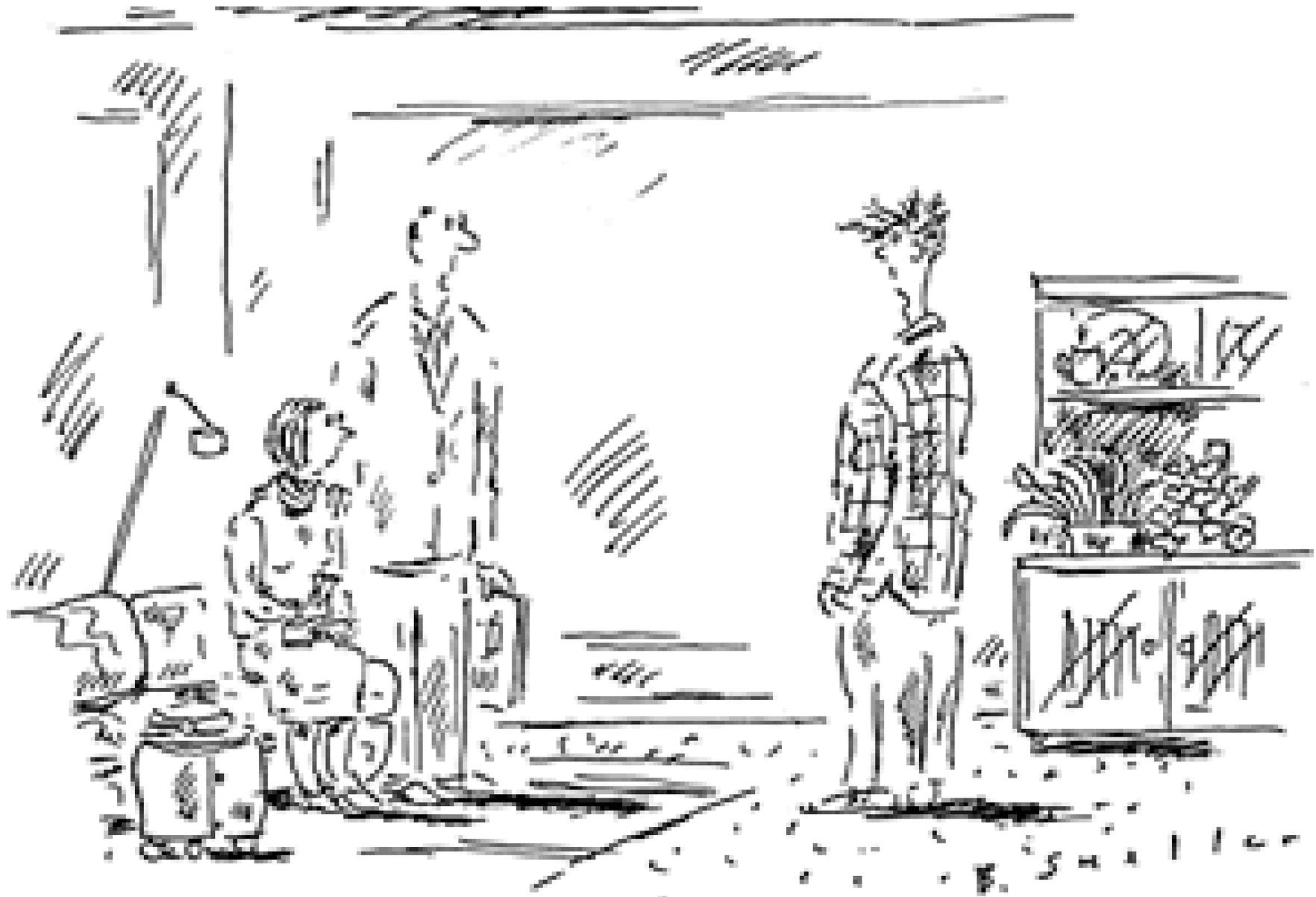
***If Adolescents Are as Smart as Adults,
Why do They Do Such Stupid Things?***

Individuals Mature Intellectually Before They Mature Socially and Emotionally



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

The Winter's Tale, III.iii



“Young man, go to your room and stay there until your cerebral cortex matures.”

Some Implications

- Middle adolescence a period of heightened vulnerability to emotional and behavioral problems
- Due to a timing gap between normative development of two brain systems
- Without self-regulation, adolescents need regulation by others
- Change the context (through regulation, enforcement) rather than the adolescent (through education)