Origins of impulsive choice

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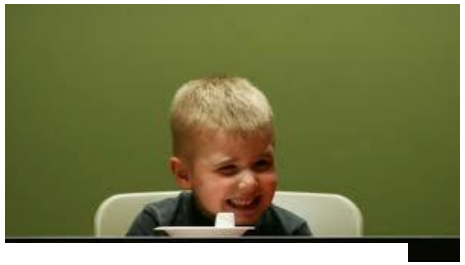
The Marshmallow Test

Smaller-Sooner (SS) →  "Impulsive"



"Impulsive choice is a **bias** to choose SS, when doing so is disadvantageous"

Larger-Later (LL) →  "Self-controlled"

= higher SAT scores
better social skills
better coping skills

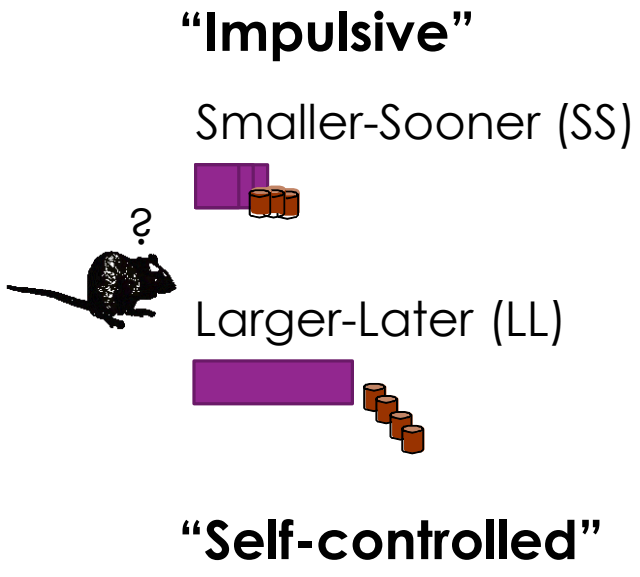
Mischel, Shoda & Rodriguez (1989)

Individual differences in impulsive choice

- Individual differences in impulsive choice are related to:
  - Substance abuse (e.g., Bickel & Marsch, 2001; Carroll et al., 2009; deWit, 2008)
  - Pathological gambling (e.g., Alessi & Petry, 2003; MacKillop et al., 2011; Reynolds et al., 2006)
  - Obesity (e.g., Davis et al., 2010)
  - ADHD (e. g., Barkley et al., 2001; Solanto et al., 2001; Sonuga-Barke, 2002)
- Impulsive choice is a trans-disease process (Bickel & Mueller, 2009)

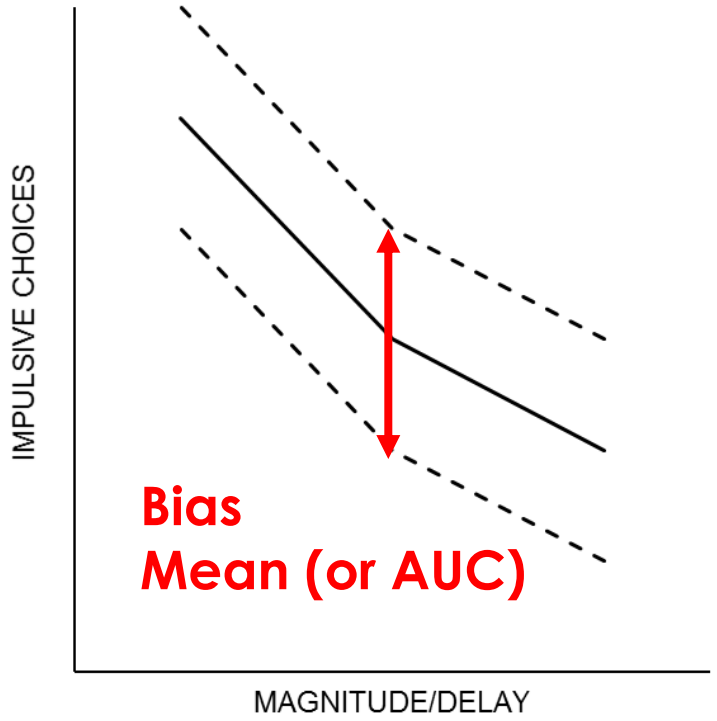
Impulsive choice: Method

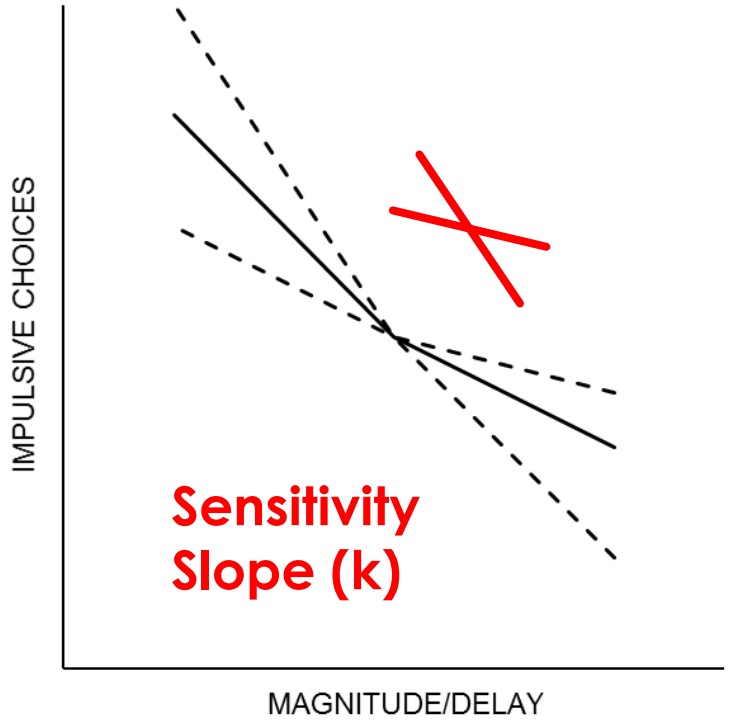
- Offer rats choices between smaller-sooner (SS) and larger-later (LL) rewards (based on Green & Estle, 2003)
  - SS = 1 pellet in 10 s
  - LL = 2 pellets in 30 s
  - ITI = 60 s
- Can manipulate delay to and/or magnitude of reward
- Choices of SS indicate impulsive choice in most cases as they earn fewer rewards



Bias versus sensitivity

Mean/AUC and Slope/k have a non-linear relationship (Mitchell et al, 2015)



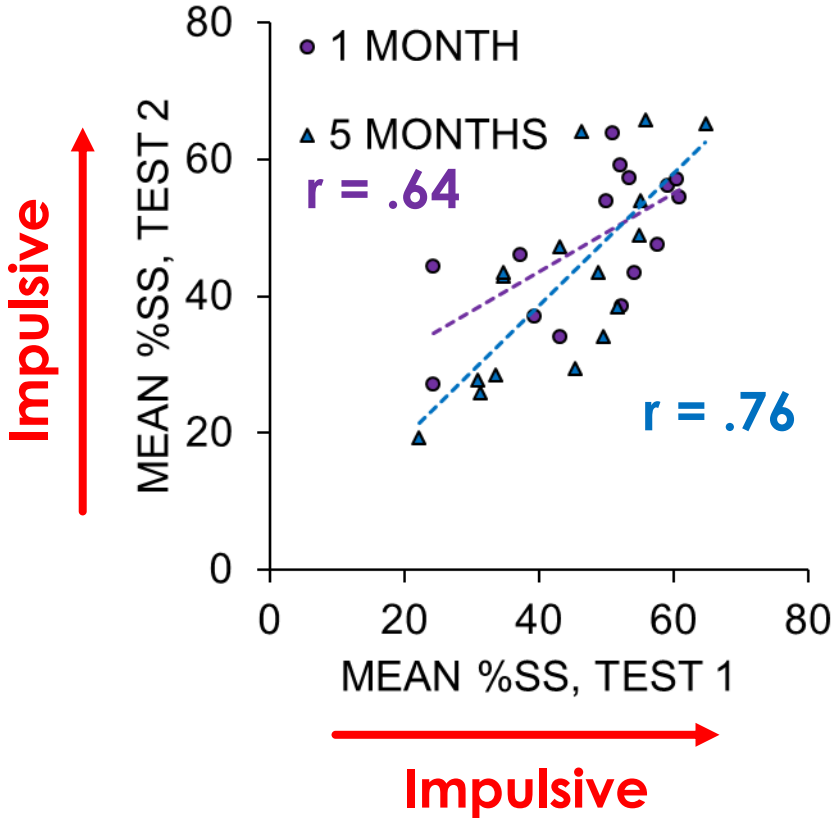


Individual differences

- In humans, impulsive choice appears to be a stable trait variable
- Are the most impulsive individuals at Time 1 also the relatively most impulsive individuals at Time 2?
- Test-retest correlations for humans in the .6-.7 range over periods from 1 week to 1 year; comparable to other trait variables (e.g., Jimura et al., 2011; Johnson, Bickel, & Baker, 2007; Kirby, 2009; Matusiewicz et al., 2013; Ohmura et al., 2006)

Individual differences in rats

- Broad spectrum of individual differences
  (see also Galtress, Garcia, & Kirkpatrick, 2012; Garcia & Kirkpatrick 2013)
- Significant test-retest reliability at 1-month and 5-month delays
  (Peterson, Hill & Kirkpatrick, 2015)



Peterson et al. (2015)

Origins of individual differences

- Given that individual differences are stable traits, what are the sources of the individual differences?
  - Approach 1: Distal factors
    - Genetic differences – may contribute to the formation of the impulsive phenotype
    - Rearing environment – may contribute to the expression of the impulsive phenotype
  - Approach 2: Proximal factors
    - Timing Processes – should be critical for processing the delay to reward
    - Reward Processes – should be critical for processing the magnitude of reward

Strain differences: SHR vs. WKY

- Increased activity, impulsivity, and deficits in sustained attention, and alterations in the dopaminergic system (Davids, Zhang, Tarazi, & Baldessarini, 2003; Sagvolden, 2000)
- However, there are inconsistencies in the literature in reporting the cognitive and behavioral differences in the SHR strain (Adriani, Caprioli, Granstrem, Carli, & Laviola, 2003; Orduña, Garcia, & Hong, 2010)

Strain differences: LEW vs. Wistar/F344

- Reduced reward system dopamine and serotonin function (Huskinson et al., 2012)
- Increased impulsive choice (e.g., Anderson & Diller, 2010; García-Lecumberri et al., 2010; Huskinson, Krebs, & Anderson, 2012; Stein et al., 2012)
- Increased self-administration of alcohol, cocaine, heroin, morphine, and nicotine (Brower, Fu, Matta, & Sharp, 2002; Kosten et al., 1997; Martin et al., 1999; Picetti, Caccavo, Ho, & Kreek, 2012; Suzuki, George, & Meisch, 1988)

Strain differences

Impulsive Choice: Delay

SS = 10→15→20 s, 1 p

LL = 30 s, 2 p

Impulsive Choice: Magnitude

SS = 10 s, 1 p

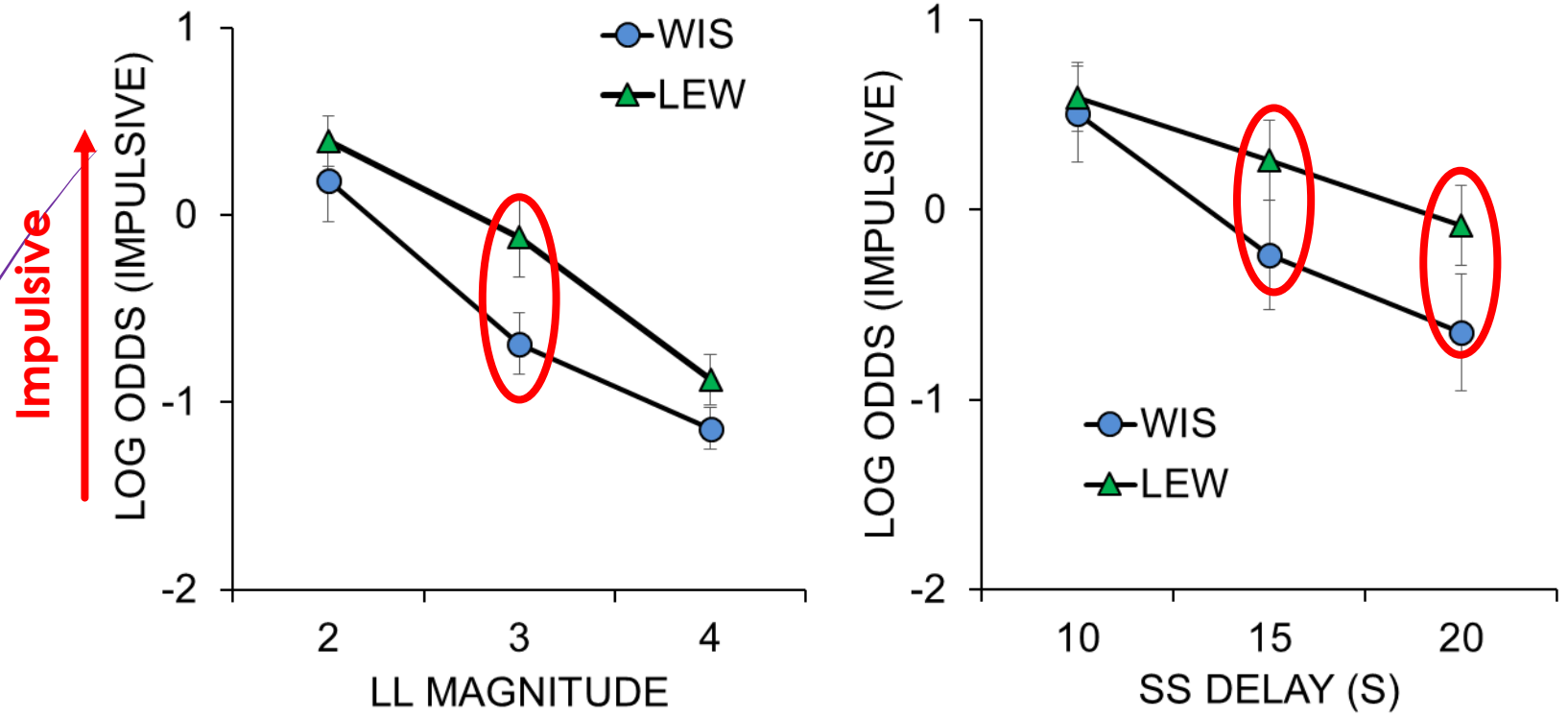
LL = 30 s, 2→3→4 p

- Spontaneously Hypertensive Rats (SHR) versus Wistar Kyoto (WKY)
- Lewis (LEW) versus Wistar (WIS)
- Tested delay versus magnitude tasks
- Examined bias versus sensitivity

Garcia & Kirkpatrick (2013)

Strain differences in impulsive choice

SHR rats did not differ from WKY
The LEW strain showed increased impulsive choice relative to WIS



Impulsive Bias (μ)

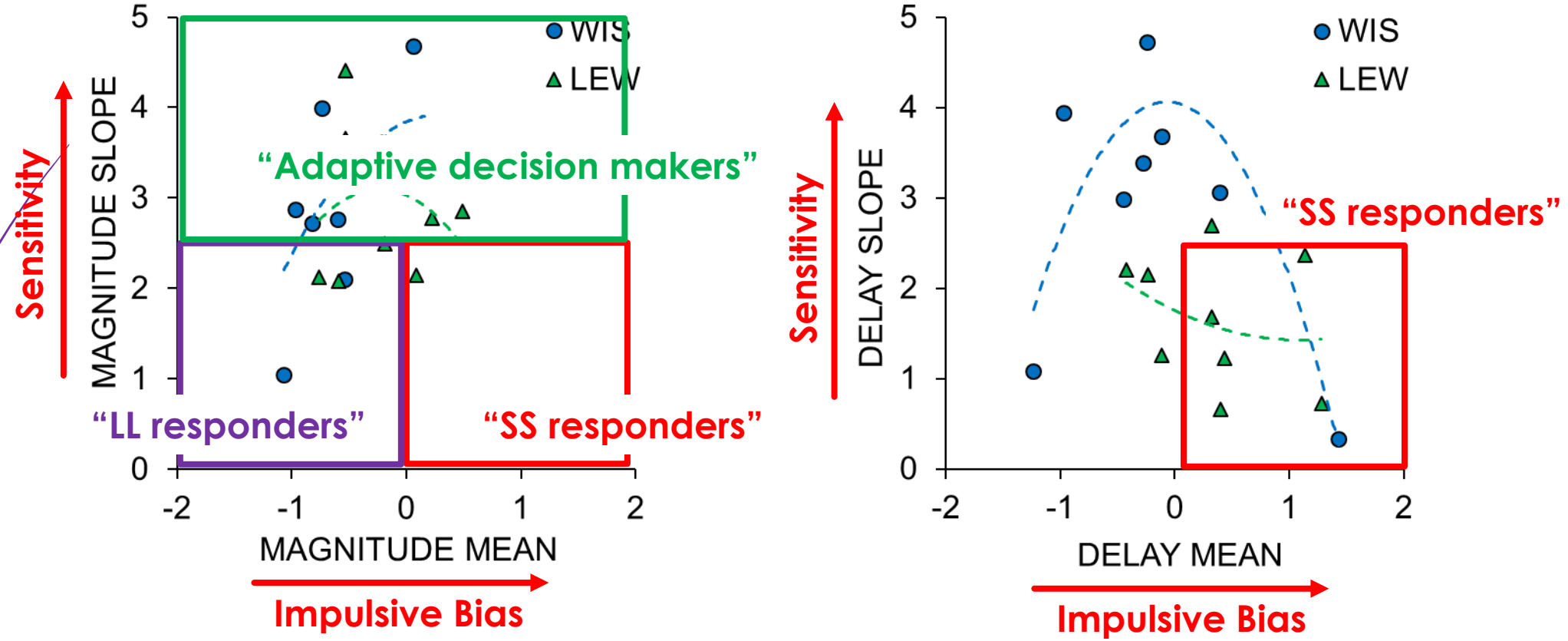
Sensitivity (slope)

Log Odds = log(N_{SS}/N_{LL})
Log Odds = 0 Neutral
Log Odds > 0 Impulsive
Log Odds < 0 Self-controlled

Garcia & Kirkpatrick (2013)

Strain differences in impulsive choice

LEW strain more likely to show biases to choose SS (SS responders)
Deficits are predominantly localized to the delay task



Garcia & Kirkpatrick (2013)

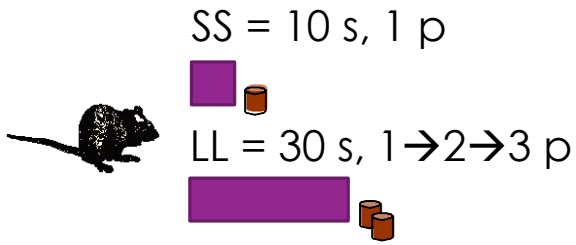
Early rearing environment

- Early rearing in an enriched environment:
  - Reduces self-administration of stimulants, opiates, and ethanol (e.g., Bardo & Dwoskin, 2004; Cain, Mersmann, Gill, & Pittenger, 2012; Coolon & Cain, 2009; Deehan et al., 2011; Green, Gehrke, & Bardo, 2002; Smith et al., 2005; Stairs & Bardo, 2009)
  - Decreases reward sensitivity and novelty-seeking (e.g., Bowling, Rowlett, & Bardo, 1993; Brenes, Padilla, & Fornaguera, 2009; Cain, Green, & Bardo, 2006; Gill & Cain, 2010)
  - Reduces impulsivity (Kirkpatrick et al., 2013; Marusich & Bardo, 2009; Perry, Stairs, & Bardo, 2008)

Rearing effects on impulsive choice

- How does rearing environment alter individual differences in impulsive choice behavior?
- Bias versus sensitivity

Impulsive Choice: Magnitude



Rats reared from PND 21-51

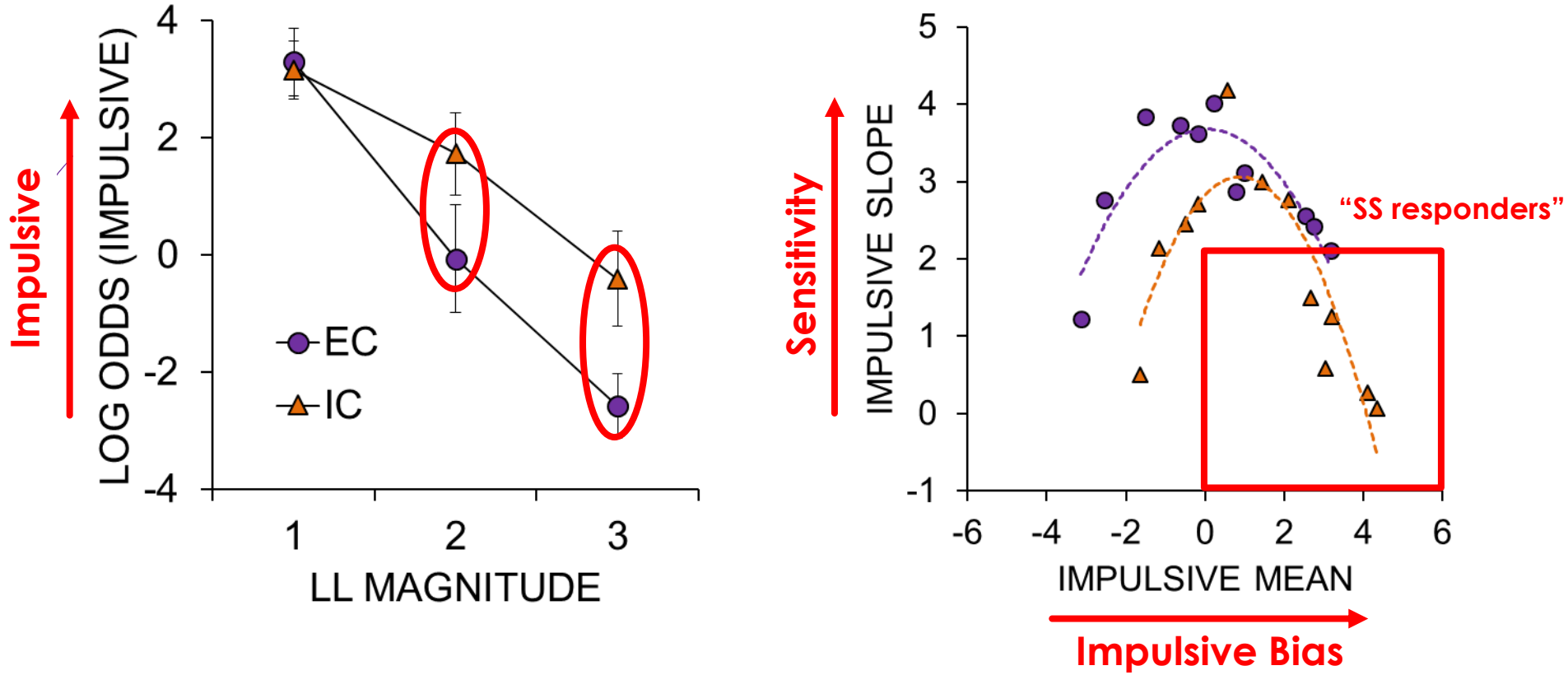
ENRICHED CONDITION (EC)

ISOLATED CONDITION (IC)

Kirkpatrick et al. (2014)

Rearing effects on impulsive choice

IC rearing increased impulsive choice relative to EC
IC rats more likely to exhibit biases to choose SS (SS responders)



Kirkpatrick et al. (2014)

Distal factors summary

- Strain differences were present in impulsive bias in the Lewis versus control strains
  - Localized to delay task (timing processes?)
- Environmental rearing conditions influenced impulsive biases
  - Isolate rats more SS-biased with magnitude manipulations
  - Possibly due to reward deficits?
- Could SS responders be driving the drug self-administration effects?

Origins of individual differences

- Given that individual differences are stable traits, what are the sources of the individual differences?
  - Approach 1: Distal factors
    - Genetic differences – may contribute to the formation of the impulsive phenotype
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  - Approach 2: Proximal factors
    - Timing Processes – should be critical for processing the delay to reward
    - Reward Processes – should be critical for processing the magnitude of reward

Timing Processes

- More impulsive humans:
  - Overestimate interval durations (Baumann & Odum, 2012)
  - Demonstrate poorer temporal discrimination abilities (Van den Broek, Bradshaw, & Szabadi, 1987)
- Adolescents with ADHD:
  - Exhibit poorer temporal discrimination abilities (Barkley et al. 2001; Smith et al. 2002)
  - Display steeper impulsive choice functions than controls (e.g., Barkley et al. 2001; Scheres et al. 2010; Wilson et al. 2011)

Impulsive choice: Correlations with timing

Impulsive Choice: Delay

SS = 30→10→5→2.5 s, 1 p

LL = 30 s, 2 p

Temporal Discrimination (Bisection)

Short = 4 s

Long = 12 s

Test with
Intermediate values

Progressive Interval

PI = 2.5, 5, 10, 30 s

… Breakpoint

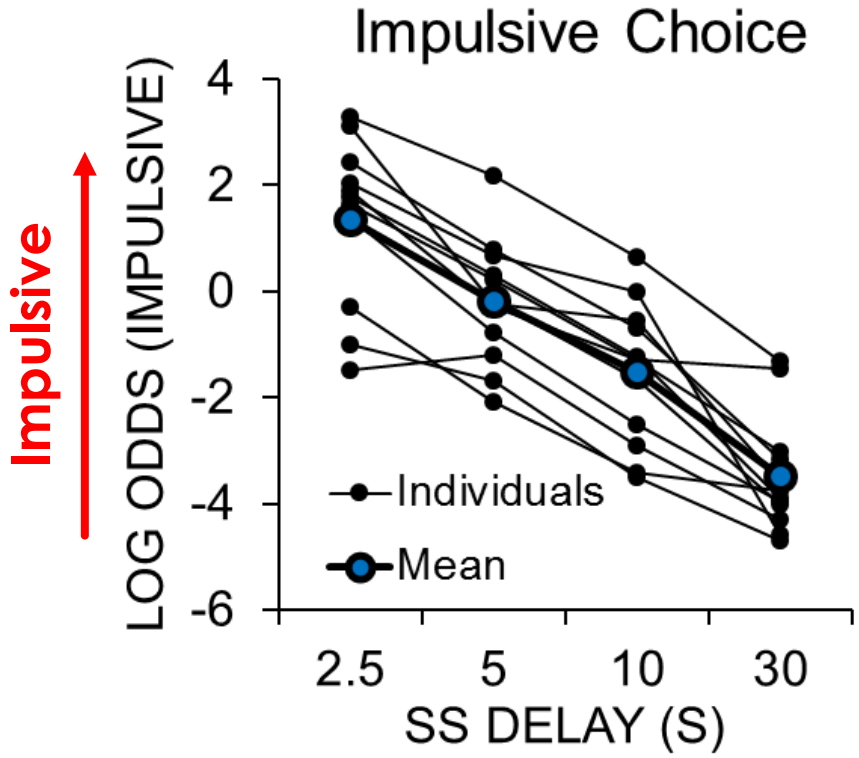
Marshall et al. (2014)

Impulsive choice: Individual differences

Log Odds = $\log(N_{SS}/N_{LL})$
Log Odds = 0 Neutral
Log Odds > 0 Impulsive
Log Odds < 0 Self-controlled

Impulsive Bias (μ)

Sensitivity (slope)



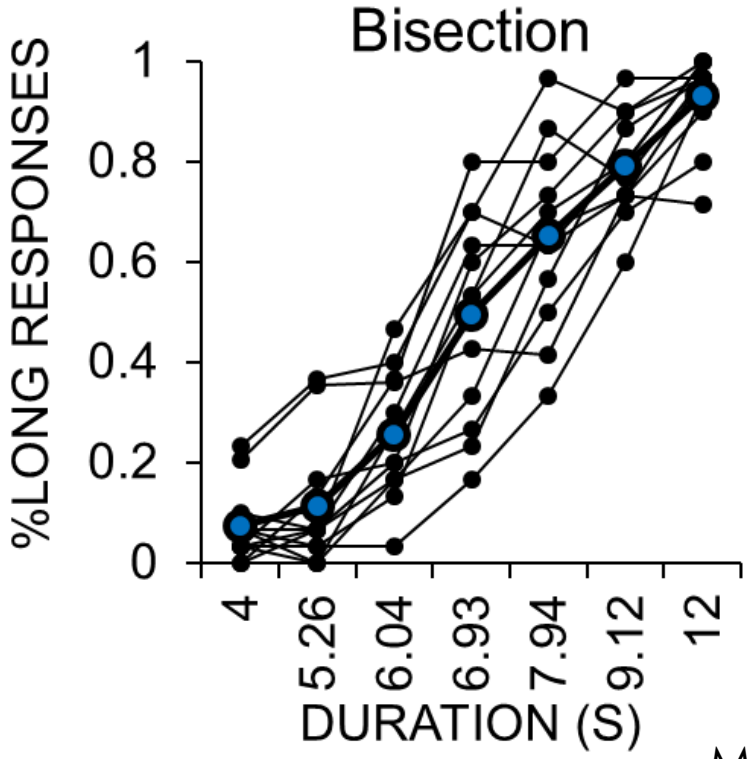
Marshall et al. (2014)

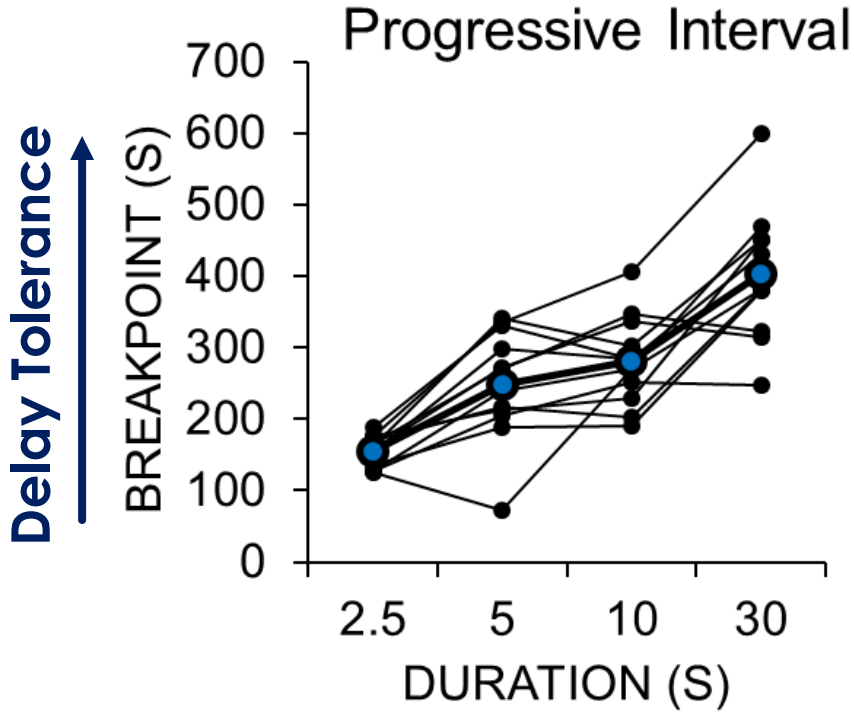
Impulsive choice: Correlations with timing

Timing Accuracy (μ) ↔

Temporal Discrimination (σ) ✗

Delay Tolerance (μ) ↕

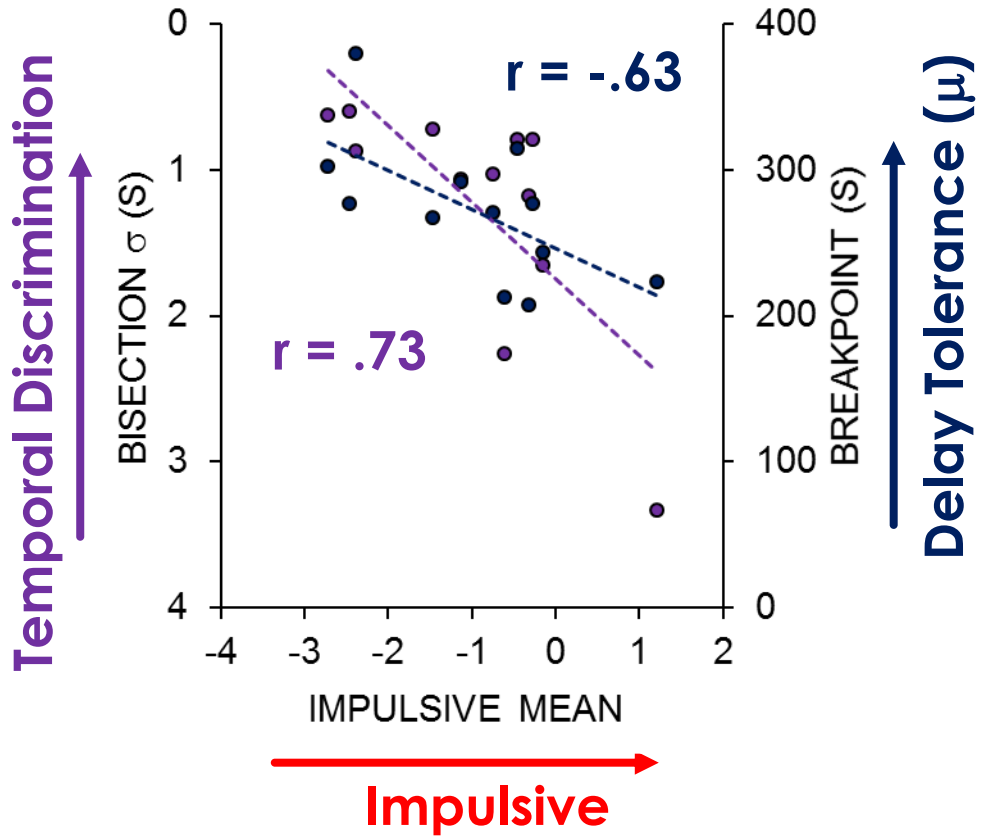




Marshall et al. (2014)

Impulsive choice: Correlations with timing

- Rats with poor temporal discrimination were more impulsive
- Rats with poor delay tolerance were more impulsive
- No relationship with impulsive slope (sensitivity)
- Therefore, poor timing predicts biases towards making impulsive choices



Marshall et al. (2014)

Reward Processes

- Impairments in reward processing are associated with ADHD (Holroyd, Baker, Kerns, & Maller, 2008; Johansen et al., 2002; Johansen et al., 2009; Luman et al., 2005; Scheres et al., 2007)
- Rearing environment acts upon both reward sensitivity and impulsive choice (Bowling, Rowlett, & Bardo, 1993; Brenes, Padilla, & Fornaguera, 2009; Cain, Green, & Bardo, 2006; Gill & Cain, 2010; Lore & Levowitz, 1966; Kirkpatrick et al., 2013, 2014; Marusich & Bardo, 2009; Perry, Stairs, & Bardo, 2008; Zimmermann et al., 2001)
- Therefore, we would expect to see a relationship between reward processes and impulsive choice

Impulsive choice: Correlations with reward discrimination

Impulsive Choice: Magnitude

SS = 10 s, 1 p

LL = 30 s, 1→2→4 p

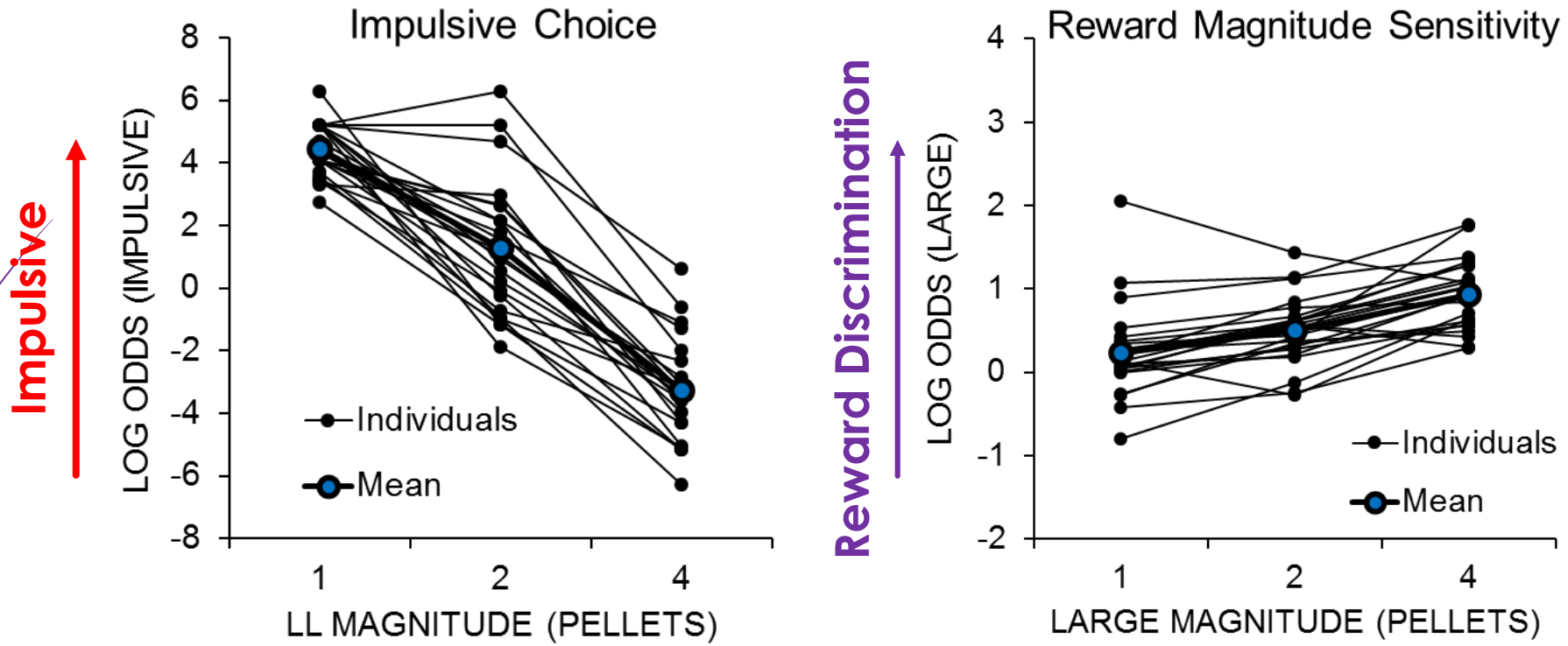
Reward Magnitude Sensitivity

Small: RI 30 s, 1 p

Large: RI 30 s, 1→2→4 p

Marshall & Kirkpatrick (2016)

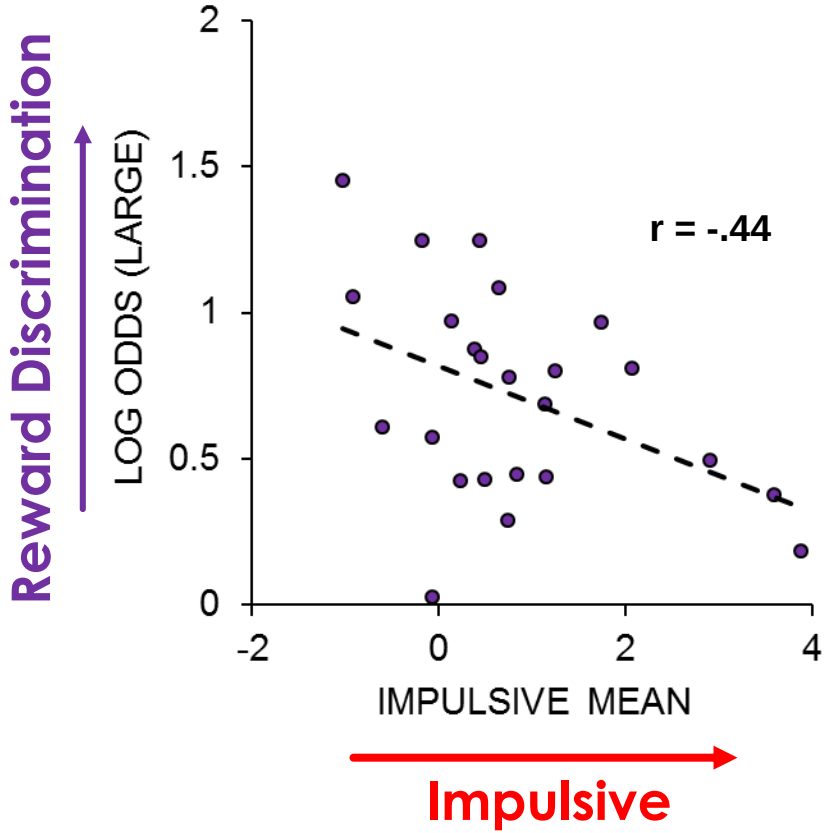
Choice and Reward Discrimination



Marshall & Kirkpatrick (2016)

Impulsive choice-reward correlation

- Rats with poor reward discrimination were more impulsive
- No relationship with impulsive slope (sensitivity/adaptability)
- Therefore, poor reward discrimination predicts biases towards making impulsive choices



Marshall & Kirkpatrick (2016)

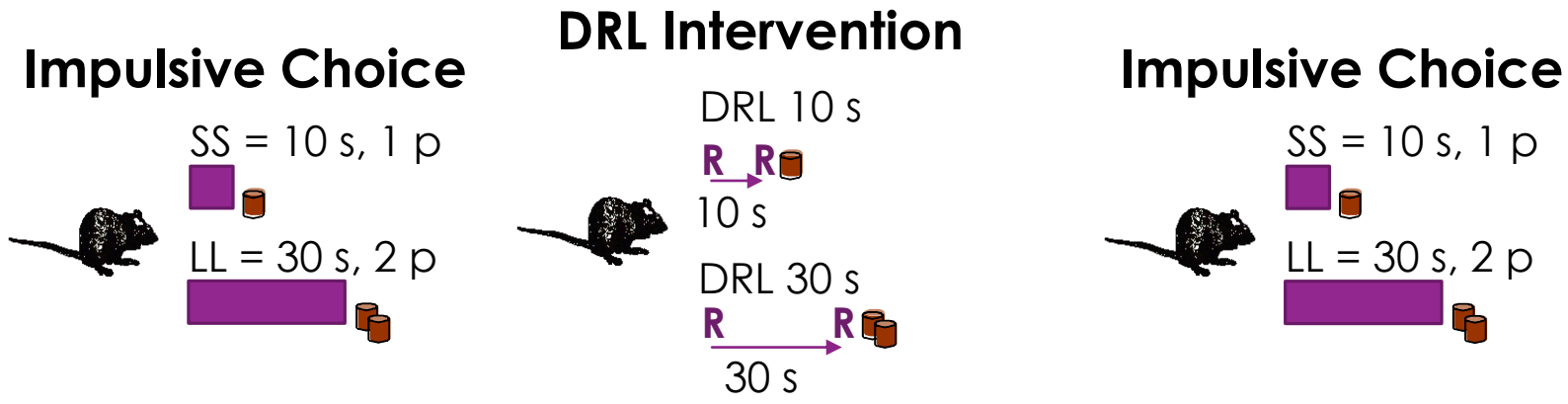
Altering individual differences

- Given the clear relationship between impulsive choice and:
  - Temporal discrimination, delay tolerance
  - Reward discrimination
- Sought to decrease impulsive biases by delivering:
  - Time-based intervention
  - Reward-based intervention

Time-based interventions

- Exposure to delays reduces impulsive choice in rats (Madden et al. 2011, Stein, Johnson, et al. 2013, Stein et al. 2015) and humans (Eisenberger and Adornetto 1986)
- Gradually increasing the delay to the LL reward maintained preference for the LL outcome in:
  - Adults with development disabilities (Dixon et al. 1998)
  - Children with ADHD (Binder, Dixon, and Ghezzi 2000; Neef, Bicard, and Endo 2001)
  - Adults with moderate to severe intellectual disabilities (Dixon, Rehfeldt, and Randich 2003)
- Previous studies did not measure any effects of the intervention on timing processes

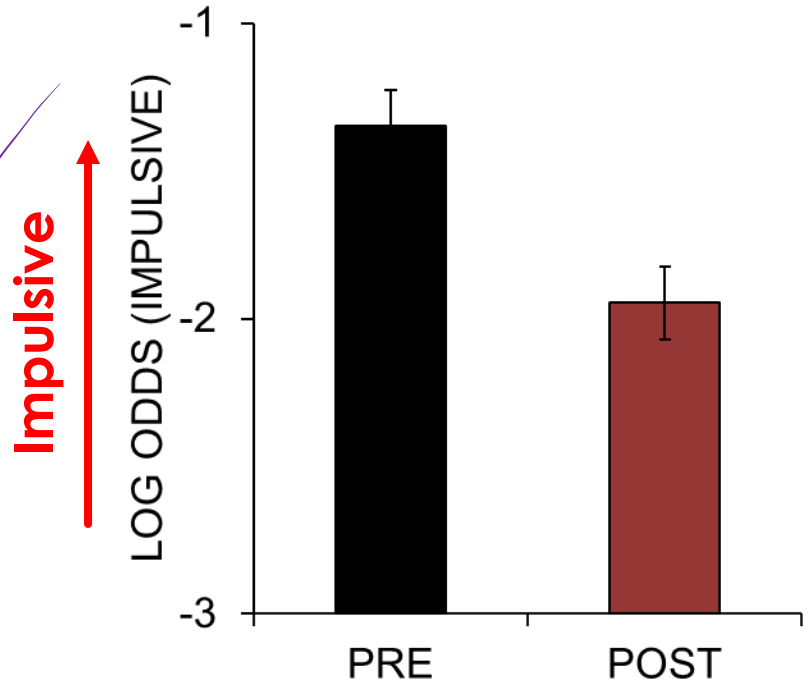
Time-based intervention



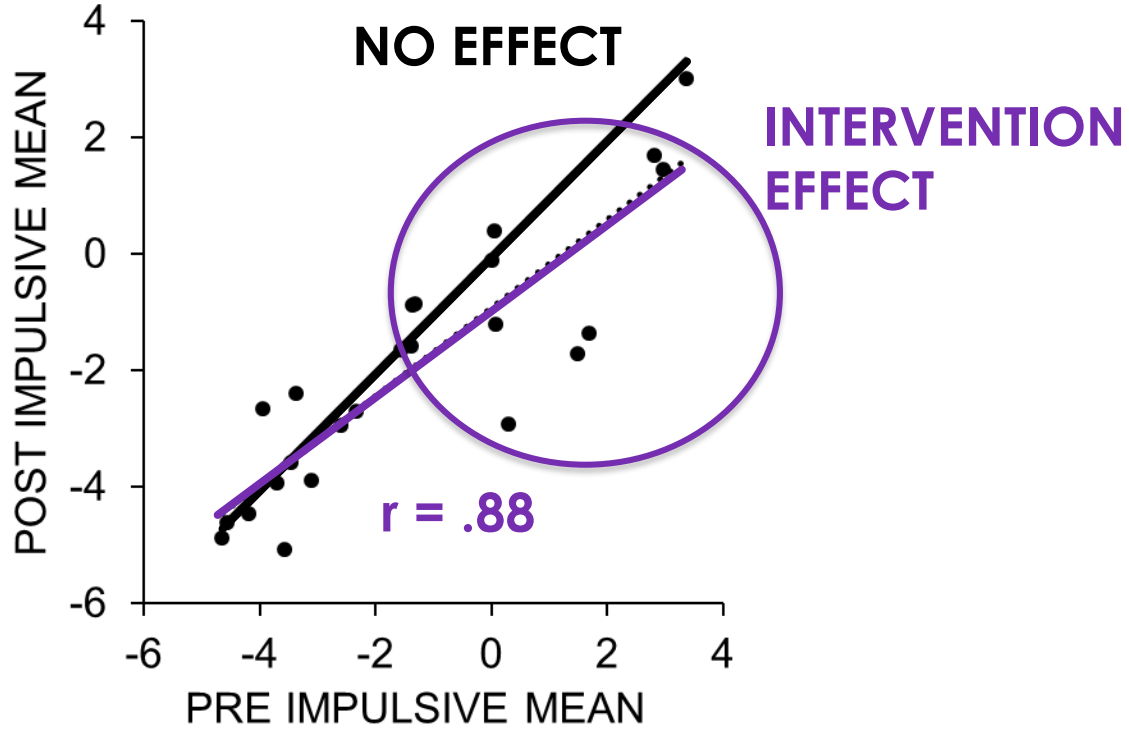
Smith, Marshall, & Kirkpatrick (2015)

Intervention effects on choice

The intervention decreased impulsive choices

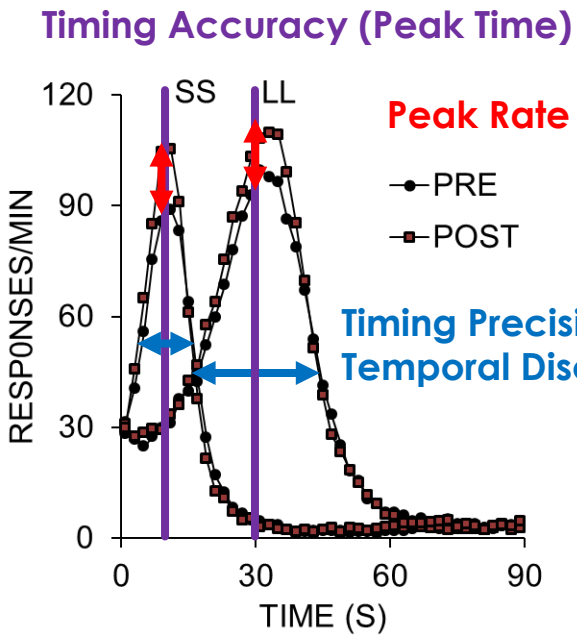


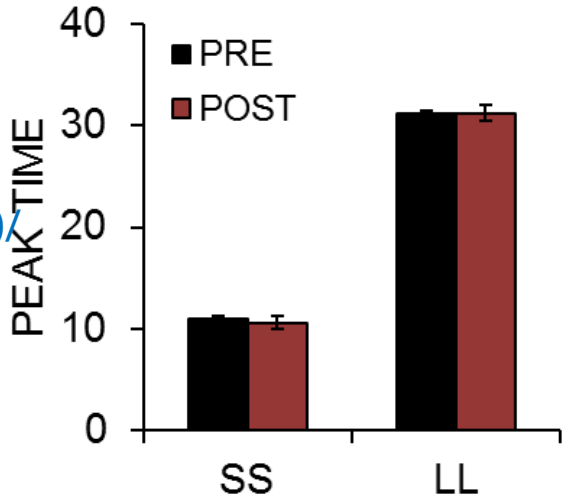
Individual differences still remained
Most impulsive rats benefitted the most

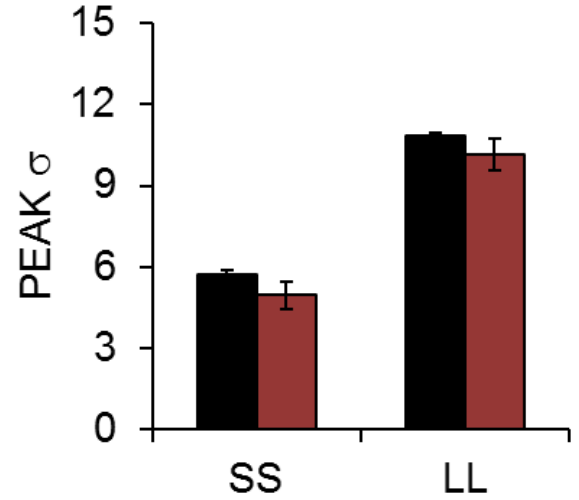


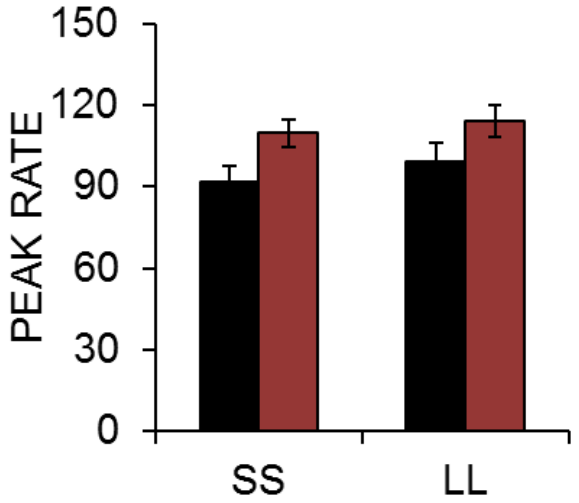
Smith, Marshall, & Kirkpatrick (2015)

Intervention effects on timing









Smith, Marshall, & Kirkpatrick (2015)

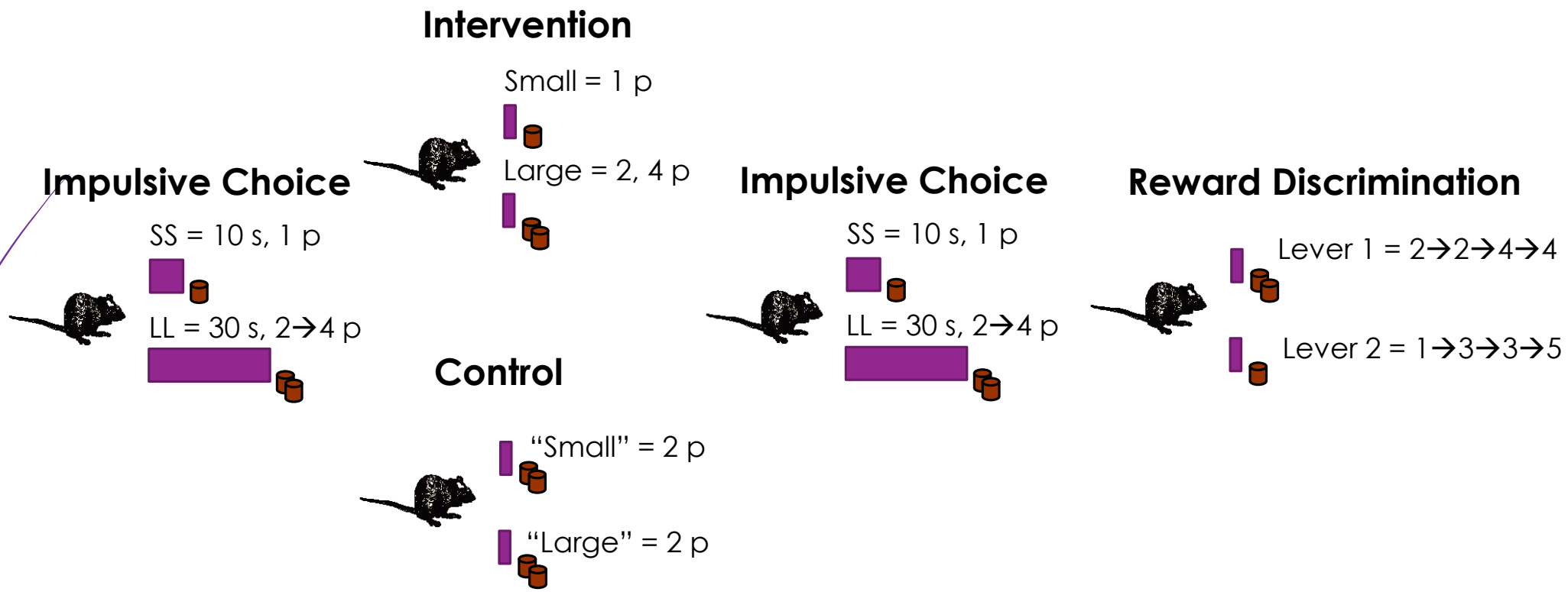
Time-based interventions

- We have also demonstrated intervention effects on impulsive choice and timing:
  - Using fixed and variable interval schedules (Smith et al. 2015; Peterson & Kirkpatrick, in press; Stuebing, Marshall, Triplett, & Kirkpatrick, in preparation)
    - With middle aged male rats and young female rats
  - Using long fixed interval schedules (Peterson & Kirkpatrick, in preparation)
- The FI intervention effects last at least 9 months, but not the VI (Turpen, Peterson, Marshall, & Kirkpatrick, in preparation)
- Currently working to translate to humans

Reward-based interventions

- Only previous study in rats looked at reward bundling (Stein et al., 2013)
  - Choice of SS → bundled delivery of SS rewards spaced apart by LL delay
  - Choice of LL → bundled delivery of LL rewards spaced apart by LL delay
- Found that more bundling resulted in better self-control
- Appeared to be due to exposure to the LL delay

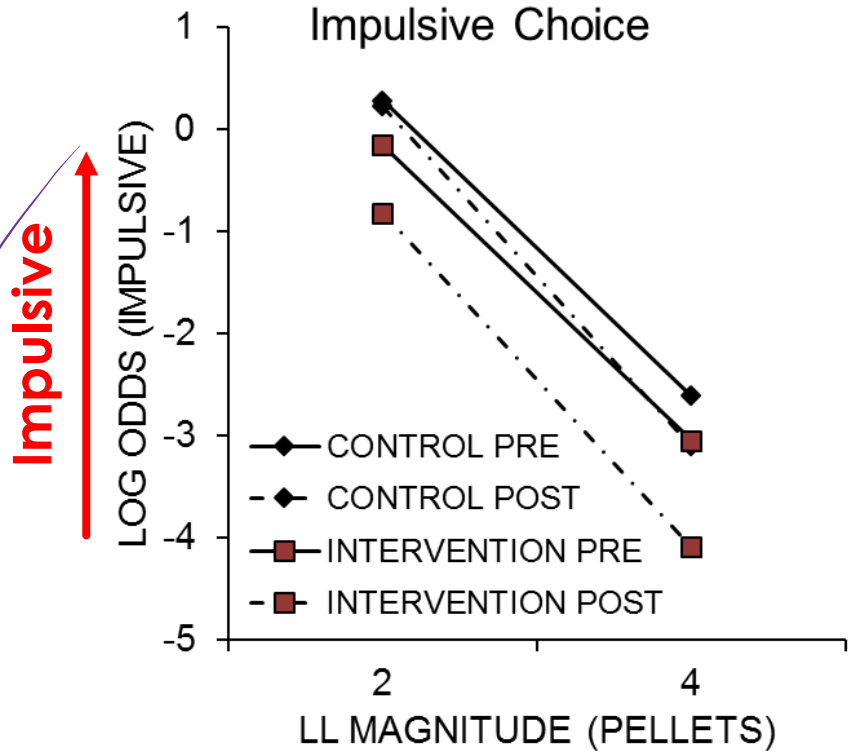
Reward-based intervention



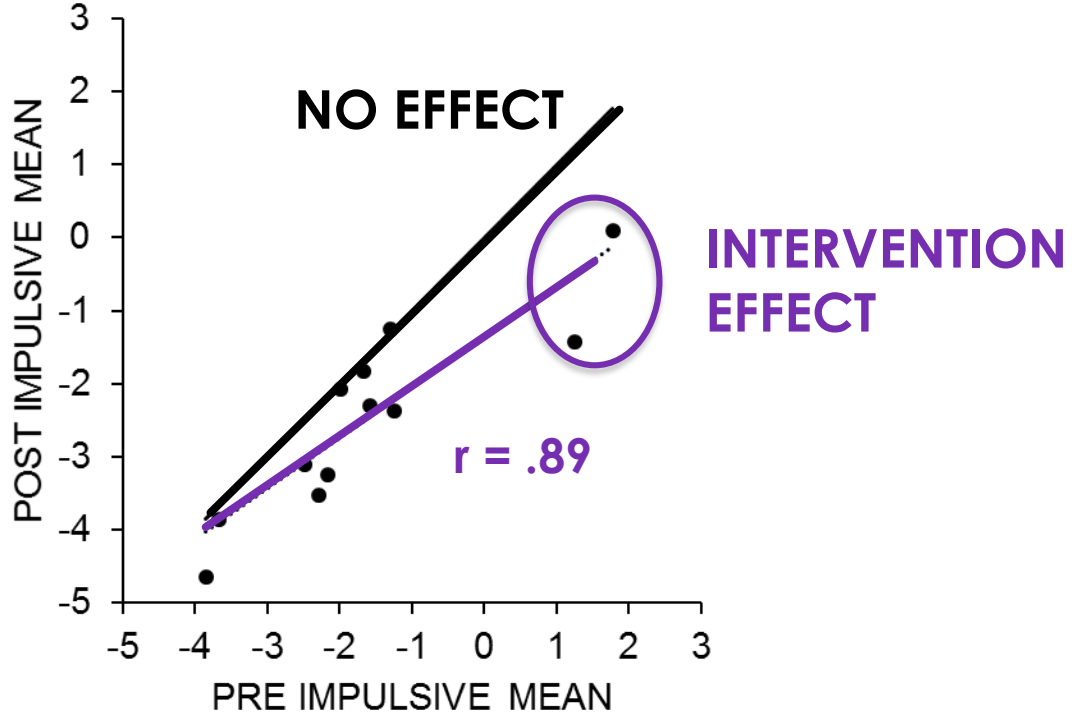
Marshall & Kirkpatrick (2016)

Intervention results

The intervention decreased impulsive choice biases



Individual differences still remained
Most impulsive rats benefitted the most, but broader benefits were seen here

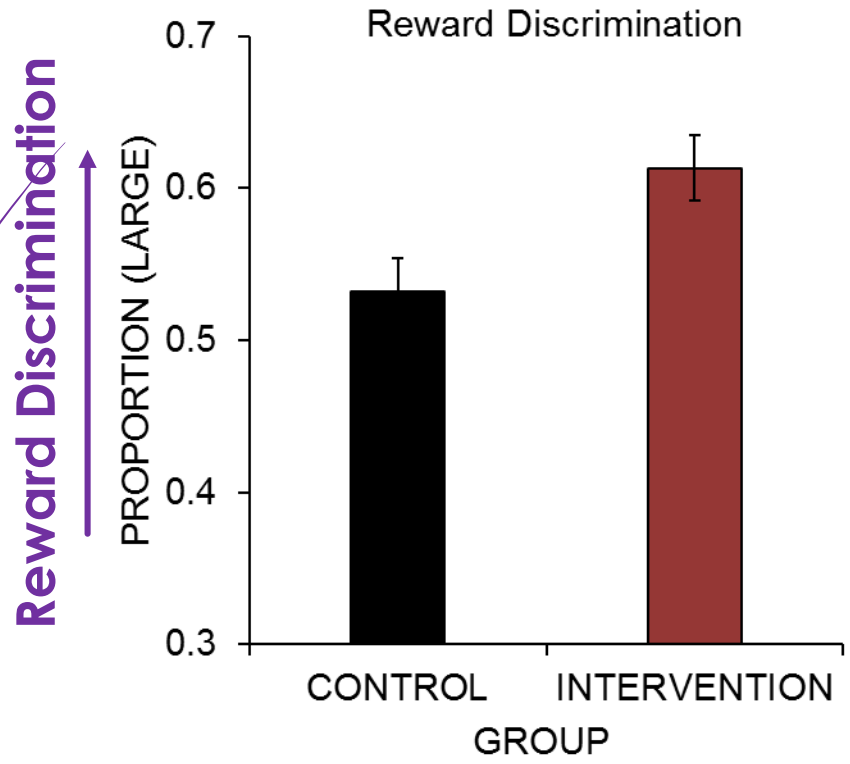


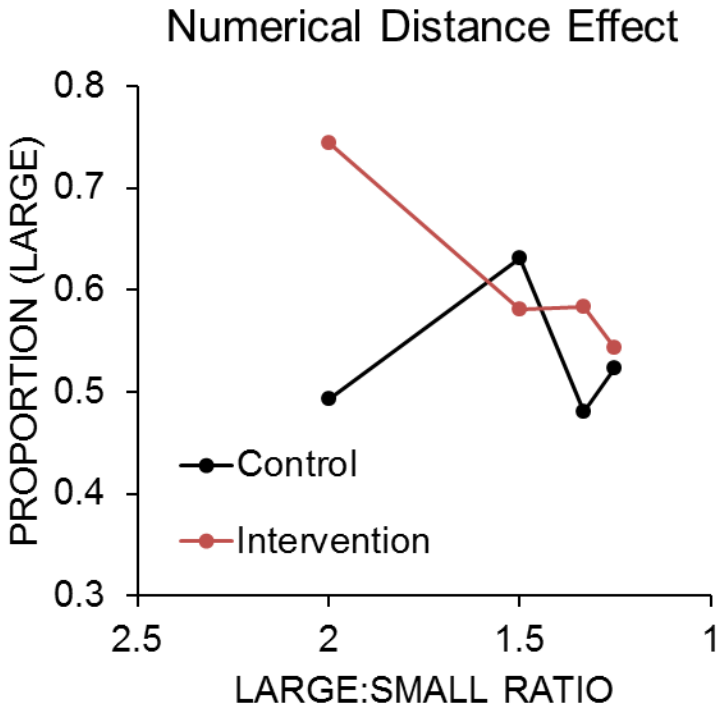
Marshall & Kirkpatrick (2016)

Intervention and reward discrimination

Intervention rats discriminated reward magnitudes significantly better than control rats

Intervention rats demonstrated a numerical distance effect, a hallmark of numerical processing

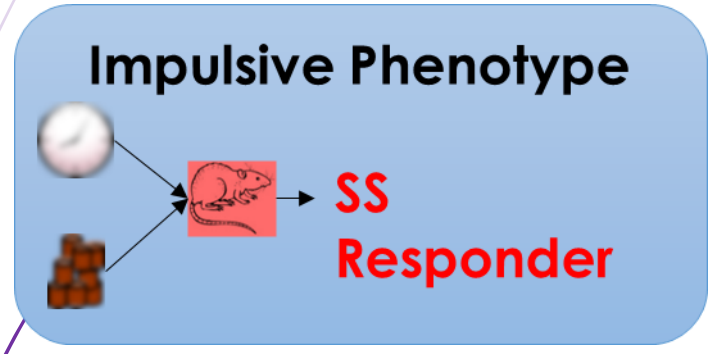




Marshall & Kirkpatrick (2016)

Overall summary

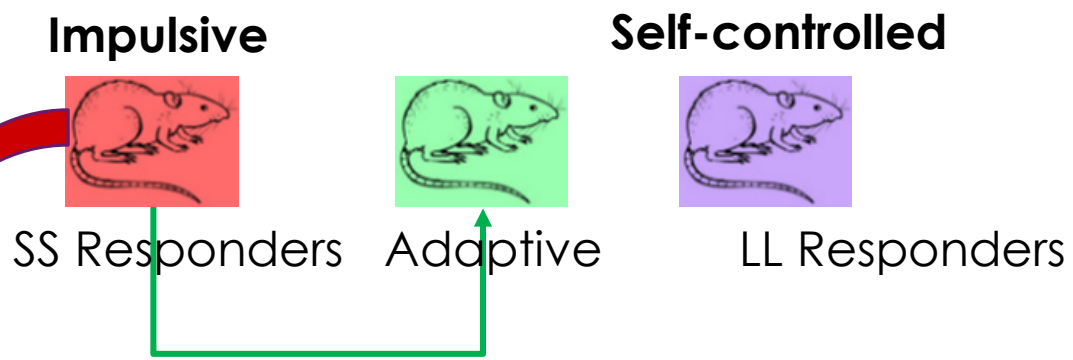
"Proximal factors"



"Distal factors"

Genetic differences

Environmental rearing

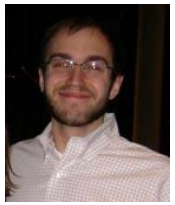


Time-based intervention

Reward-based intervention

Pathways to disease/disorder development

Acknowledgments



Andrew Marshall

Jen Peterson

Catherine Hill

Aaron Smith

Tiff Galtress

Ana Garcia

- Other RTD lab members and collaborators
  - Mary Cain, Juraj Koci, Yoonseong Park
  - Lots of undergrads
- Funding: R01-MH085739

NIMH
National Institute of Mental Health

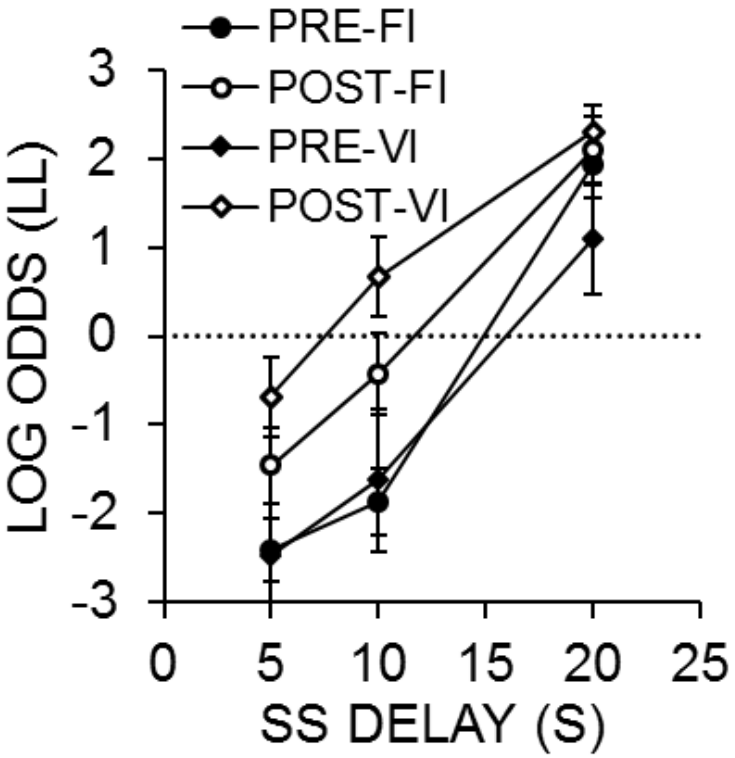
Thinking of going to grad school?

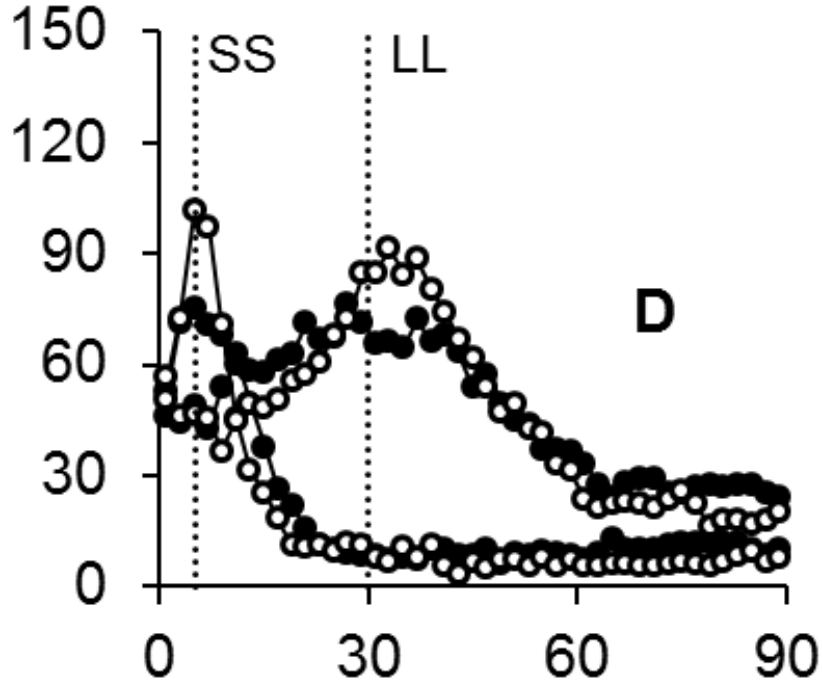
We are recruiting students for our PhD program in Behavioral Neuroscience!

- Dr. Mary Cain – studies enrichment effects on reward system function and relationship with drug and alcohol abuse
- Dr. Charles Pickens – studies the neurobiology of behavioral flexibility, goal-directed behavior, and alcohol abuse
- Dr. Kimberly Kirkpatrick – studies the behavioral and neural mechanisms of timing, reward processes, and choice

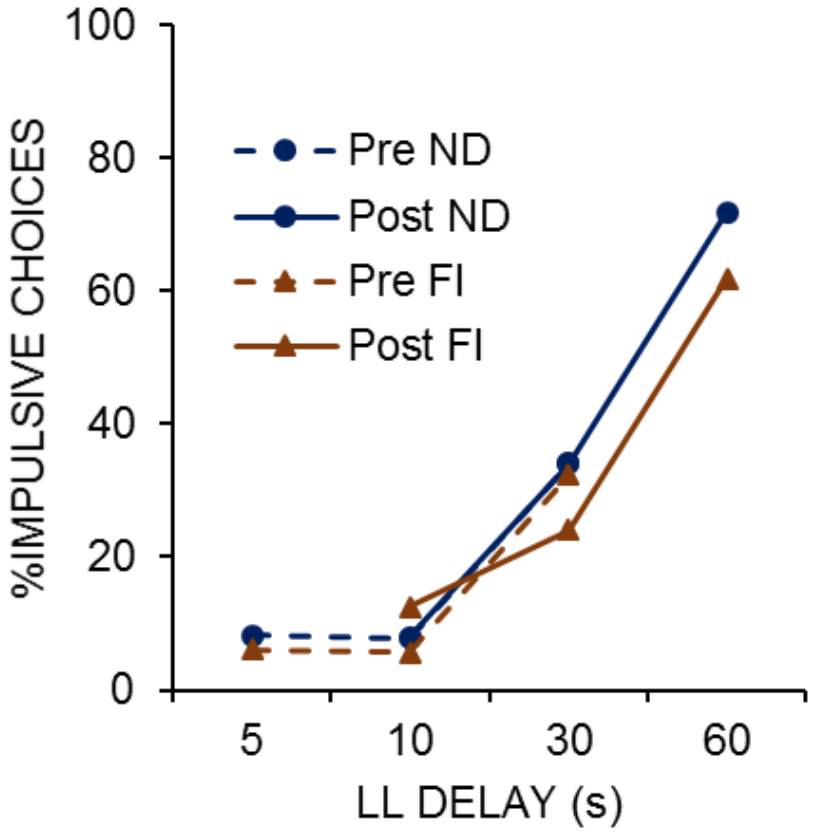
http://www.k-state.edu/psych/graduate/programs/bnal/

FI and VI Interventions – Sprague-Dawleys





Long FI intervention with control



Temporal tracking and impulsive choice in adjusting and systematic procedures