Using interval schedules to promote self-control in rats

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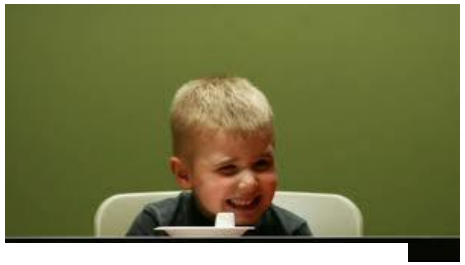
The Marshmallow Test

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
And, more recently, lower BMI

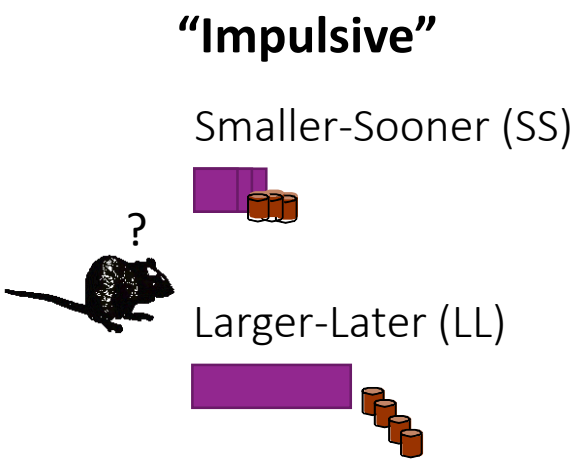
Mischel, Shoda & Rodriguez (1989)

Individual differences in impulsive choice

- In humans, impulsive choice appears to be a stable trait variable
  - 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 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)

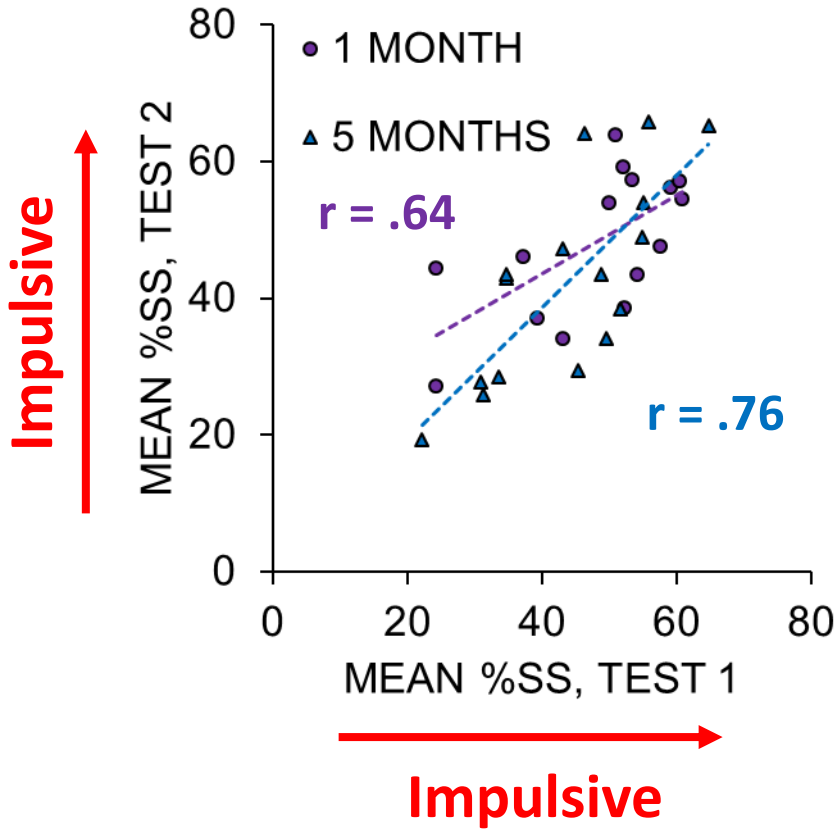
Impulsive choice: Method

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



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: Timing Processes

- 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)
- More impulsive humans:
  - Overestimate interval durations (Baumann & Odum, 2012)
  - Demonstrate poorer temporal discrimination abilities (Van den Broek, Bradshaw, & Szabadi, 1987)
- More impulsive rats:
  - Demonstrate poorer temporal discrimination abilities and weaker delay tolerance (Marshall et al., 2014; McClure et al., 2014)

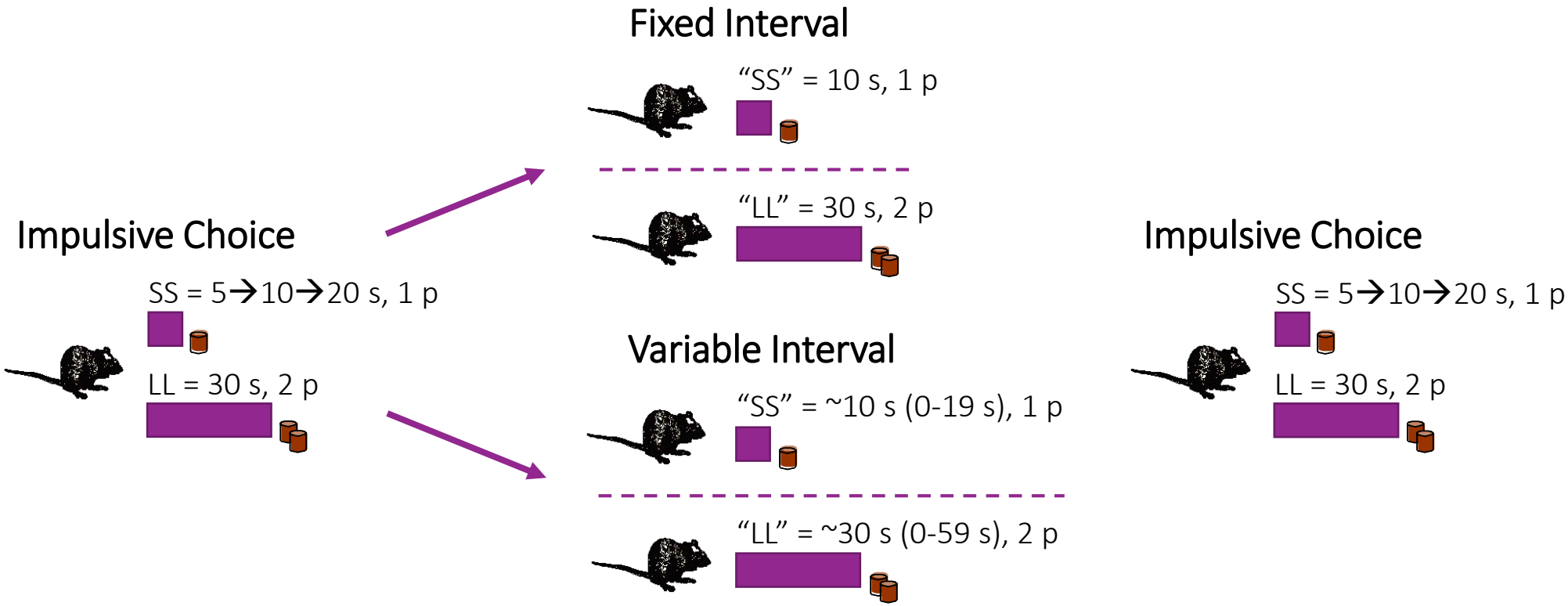
Altering individual differences: Time-based interventions

- 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)

Time-based interventions: Questions

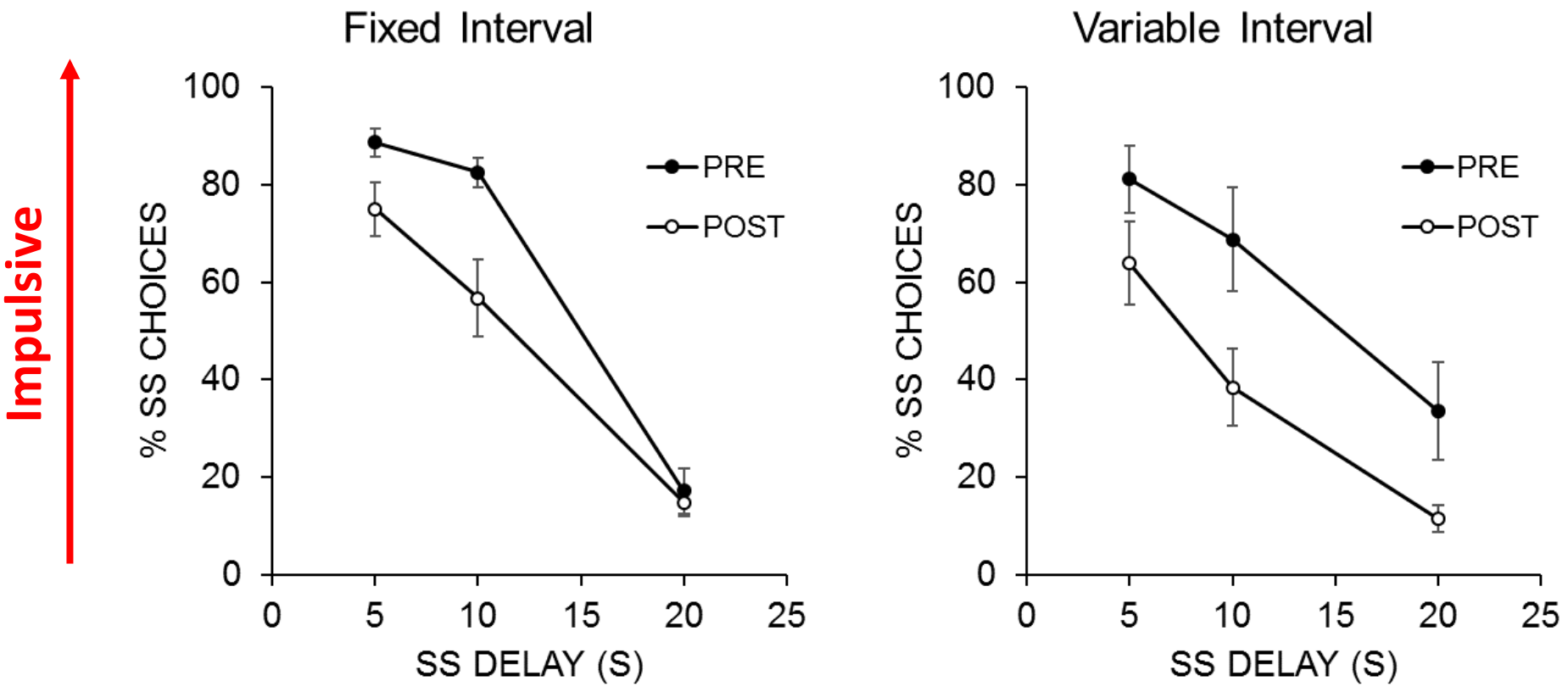
- Is mere delay exposure is sufficient?
- Or, does the nature of the delay exposure matter?

Time-based intervention: Interval schedules



Smith, Marshall, & Kirkpatrick (2015)

FI and VI Interventions: Choice



Both FI and VI interventions significantly decreased impulsive (SS) choices

Smith, Marshall, & Kirkpatrick (2015)

Longevity of Intervention Effects

Fixed Interval

"SS" = 10 s,1 p

"LL" = 30 s, 2 p

Variable Interval

"SS" = ~10 s (0-29 s), 1 p

"LL" = ~30 s (0-59 s), 2 p

No Delay

"SS" = 0 s, 1 p (70 s ITI)

"LL" = 0 s, 2 p (90 s ITI)

Bailey et al. (in prep)

Impulsive Choice: 0 months

SS = 5→10→20 s, 1 p

LL = 30 s, 2 p

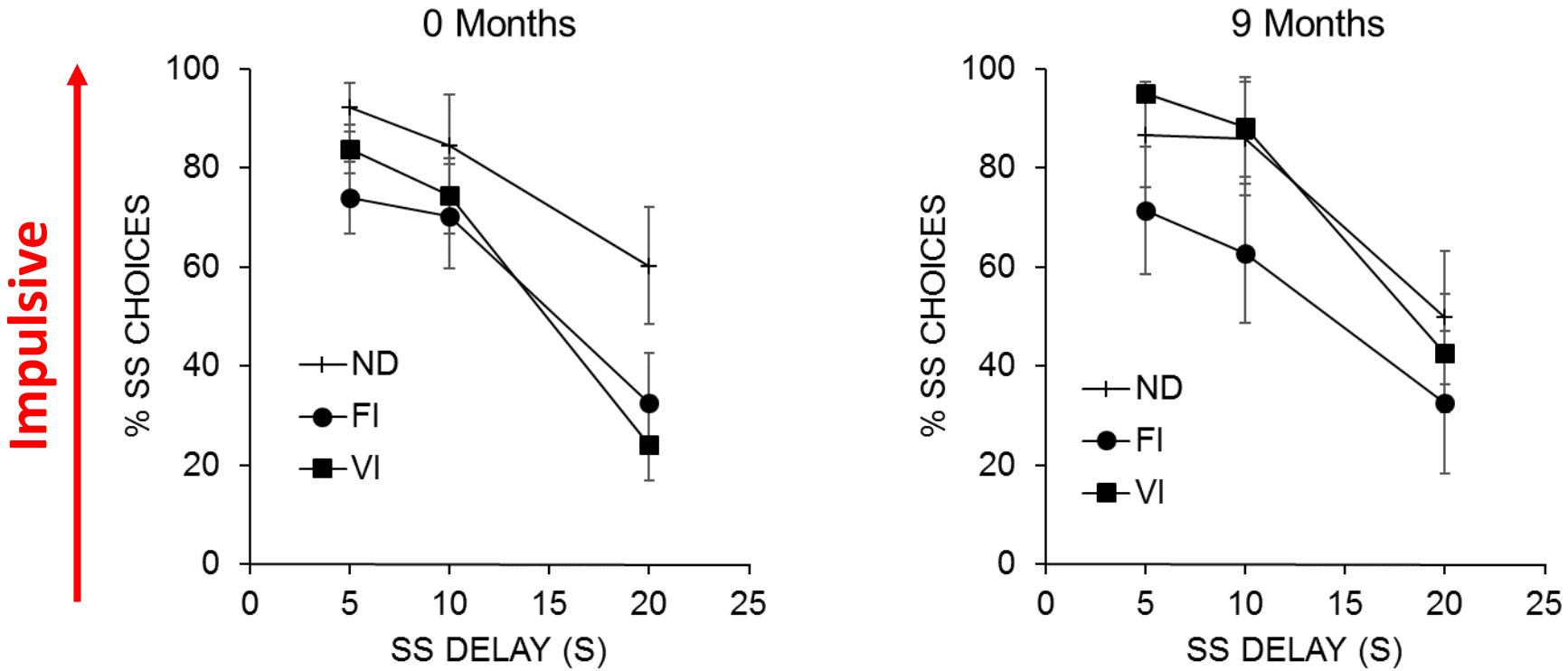
9 months

Impulsive Choice: 9 months

SS = 5→10→20 s, 1 p

LL = 30 s, 2 p

Longevity of Intervention Effects

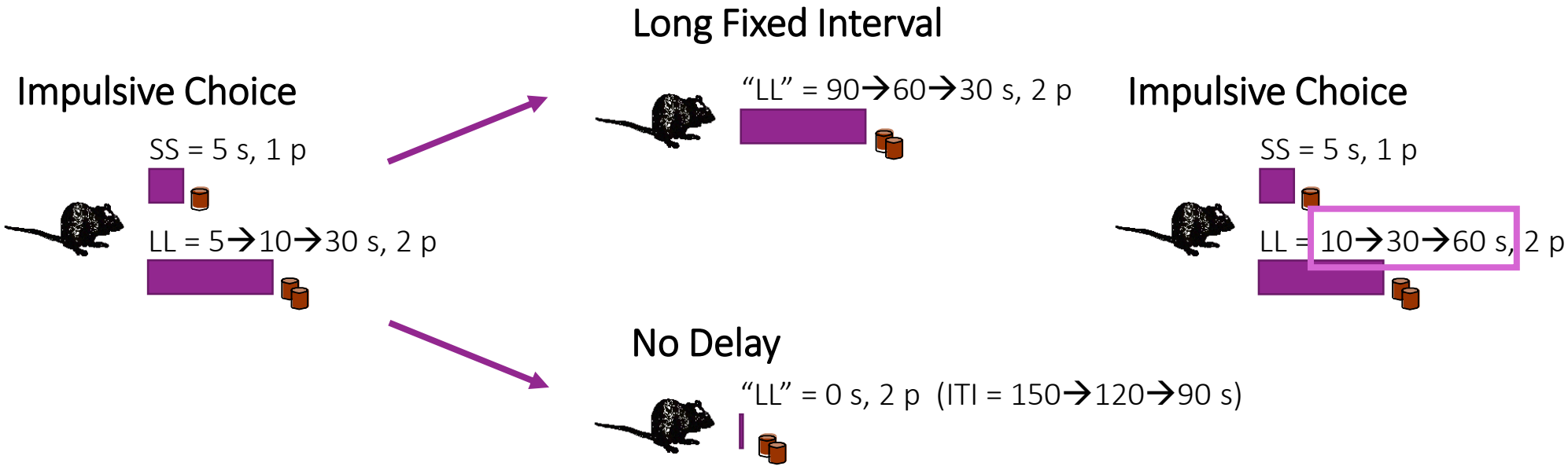


Both interventions significantly decreased impulsive (SS) choices at 0 months

FI intervention effects were sustained after a 9-month delay

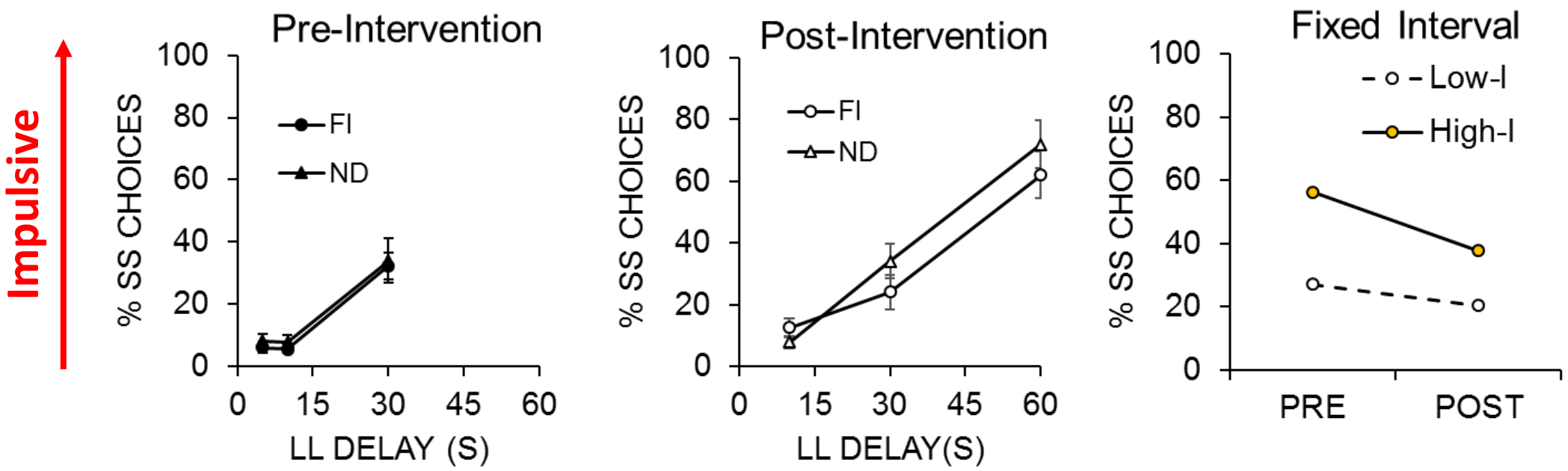
Bailey et al. (in prep)

Time-based intervention: Long “LL” exposure



Peterson et al. (in prep)

Long FI intervention with control



Long FI intervention significantly decreased impulsive (SS) choices

The most impulsive rats in the pre-intervention phase benefitted the most

Peterson et al. (in prep)

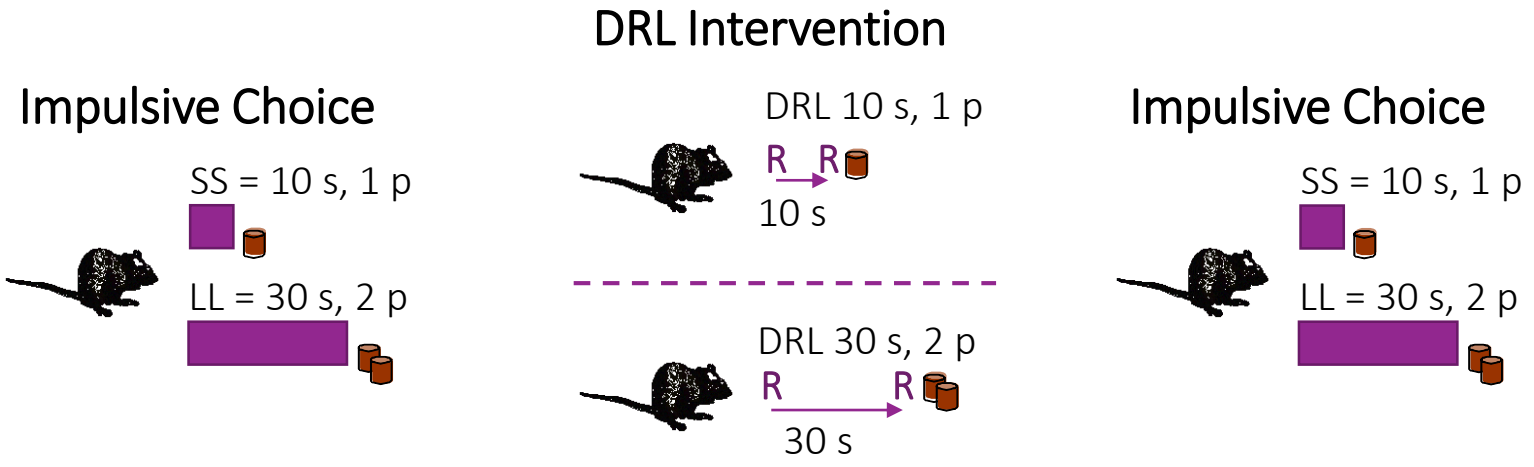
Inhibition and Self-control

Maggiano's Chocolate Zuccotto Cake

1880 Calories!

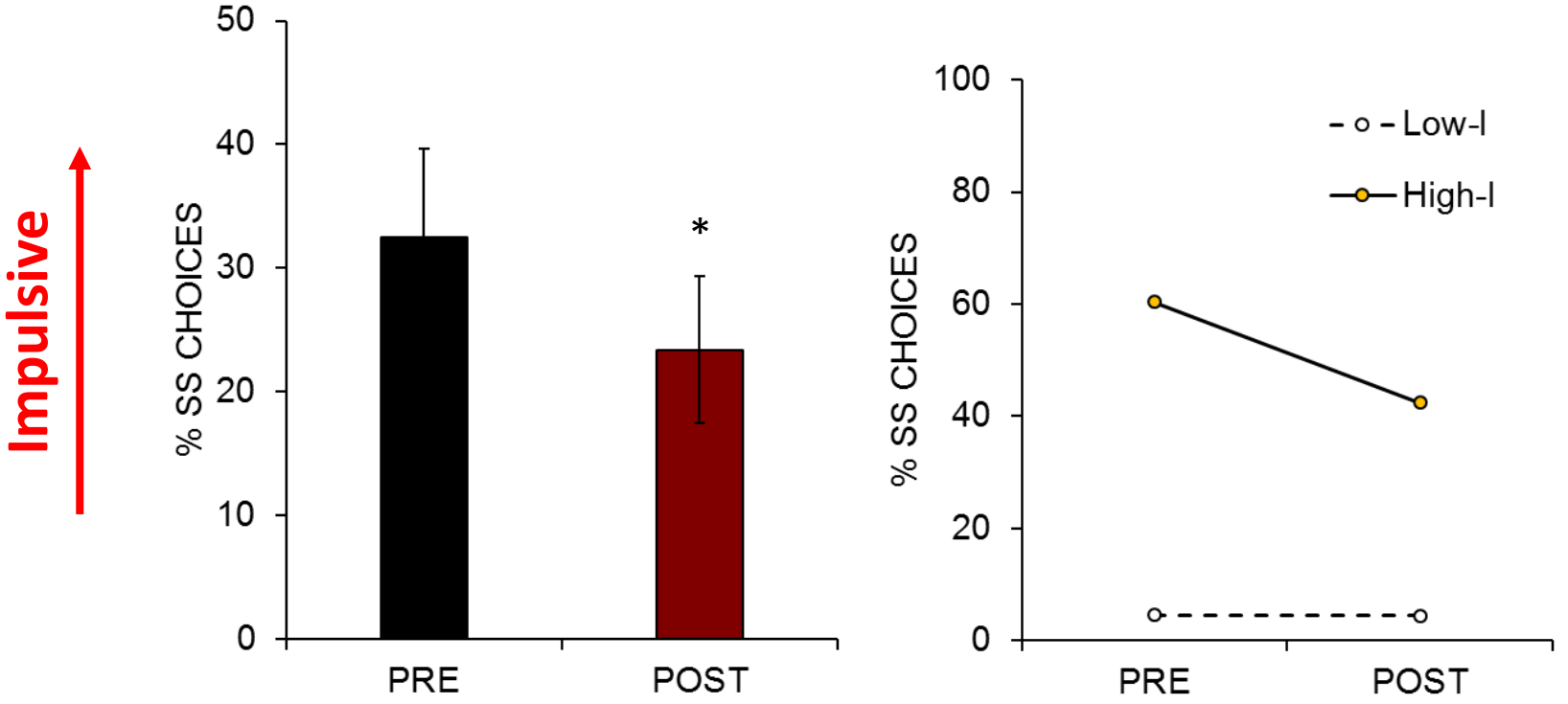
Source: NY times (4/20/17)

Inhibitory time-based intervention



Smith, Marshall, & Kirkpatrick (2015)

Intervention effects on choice



The intervention significantly decreased impulsive choices
The most impulsive rats benefitted the most

Smith, Marshall, & Kirkpatrick (2015)

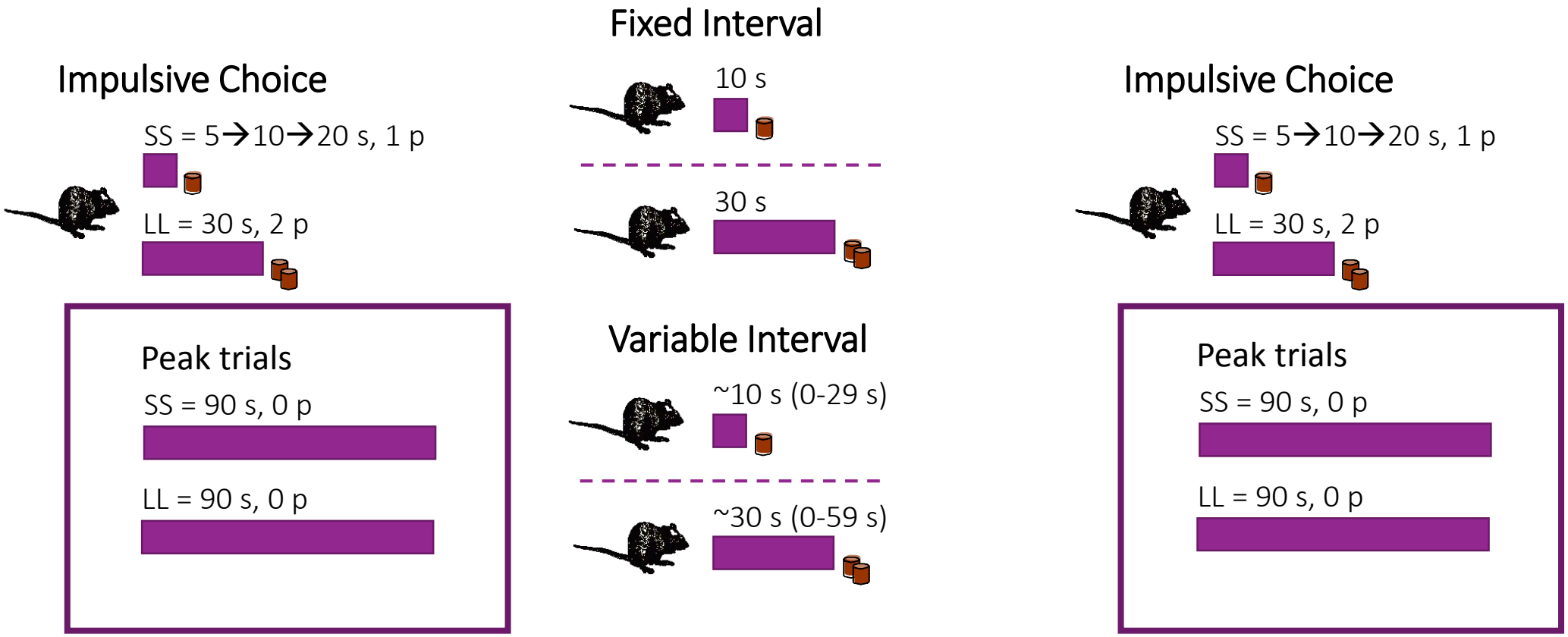
Time-based interventions: Summary

- FI, VI, and DRL schedules all induced increases in self-control
  - Most impulsive rats benefitted the most
- FI lasted for at least 9 months, but not the VI
- Long LL produced significant effects suggesting that long interval (LL) training alone is effective
- DRL produced similar effects to FI and VI suggesting that explicit inhibitory schedules are not necessary to produce intervention effects
  - Caveat: We haven't directly compared DRL and FI

Time-based interventions: Questions

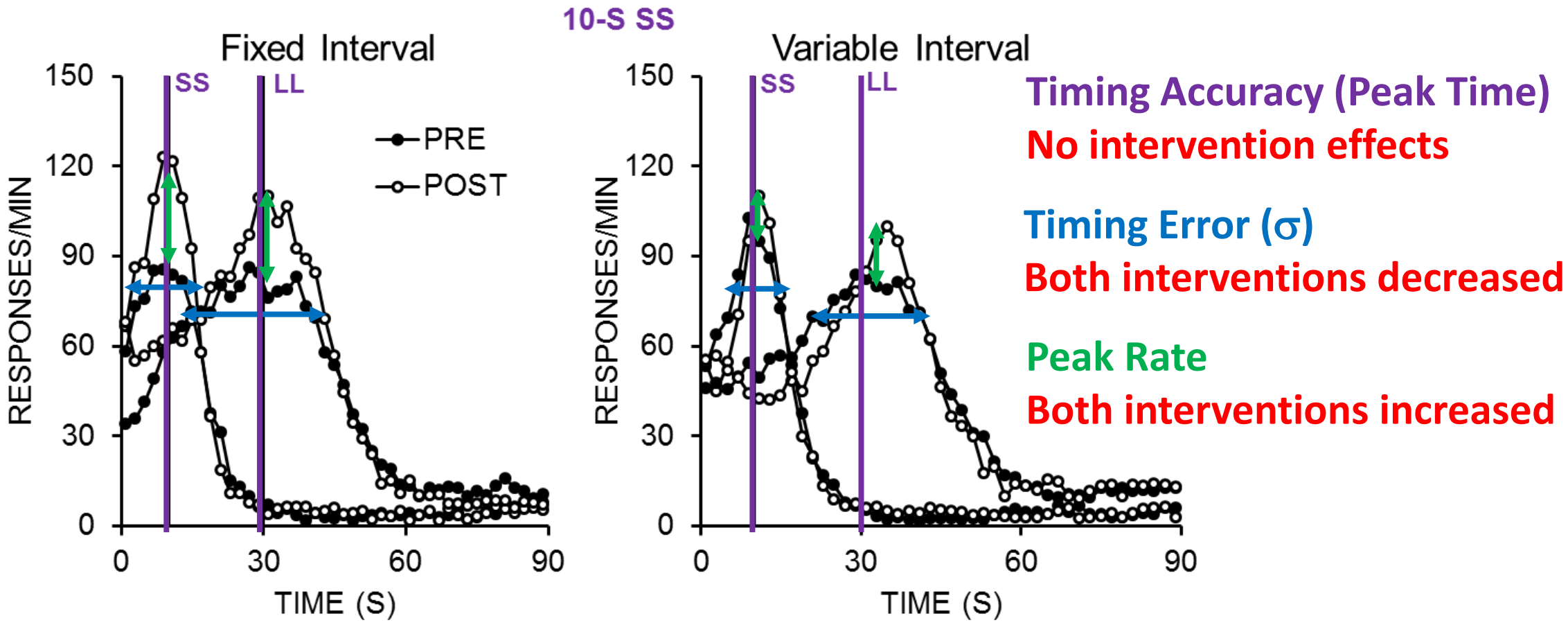
- Are the interventions merely inducing self-control (or perhaps delay tolerance)?
- Or, are there effects on timing processes?

Time-based intervention: Interval schedules



Smith, Marshall, & Kirkpatrick (2015)

FI and VI Interventions: Timing



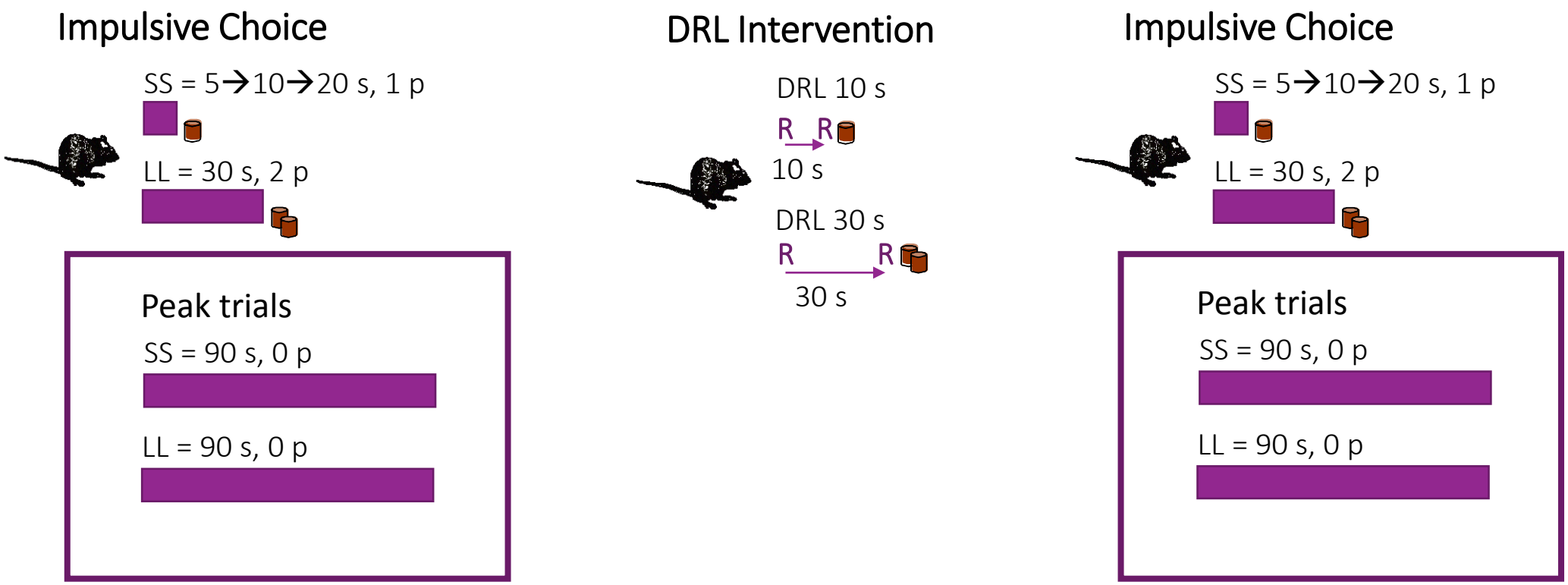
Timing Accuracy (Peak Time)
No intervention effects

Timing Error (σ)
Both interventions decreased

Peak Rate
Both interventions increased

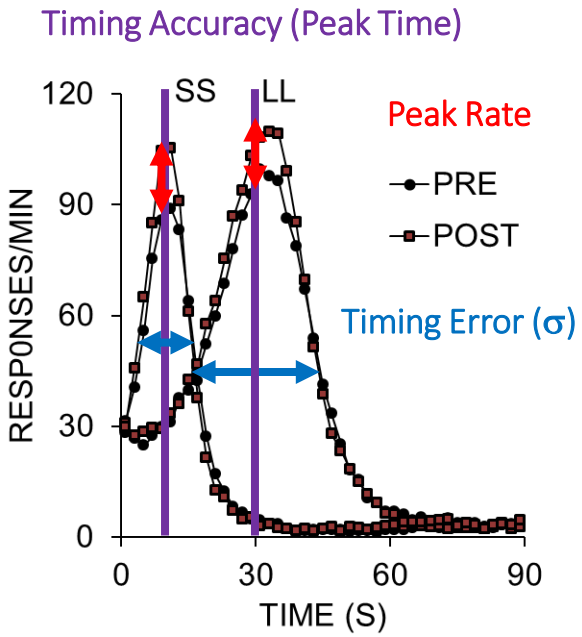
Smith, Marshall, & Kirkpatrick (2015)

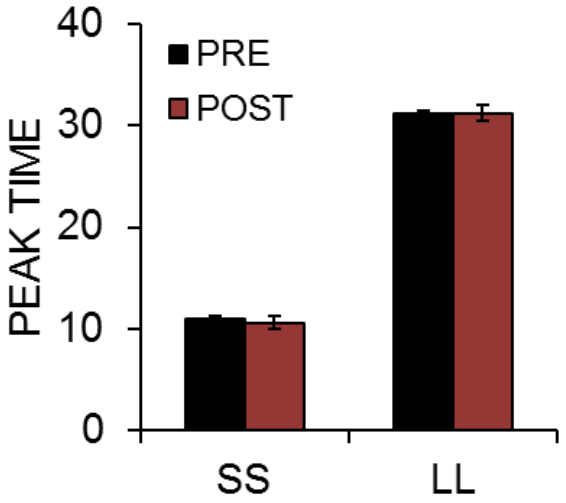
Inhibitory time-based intervention

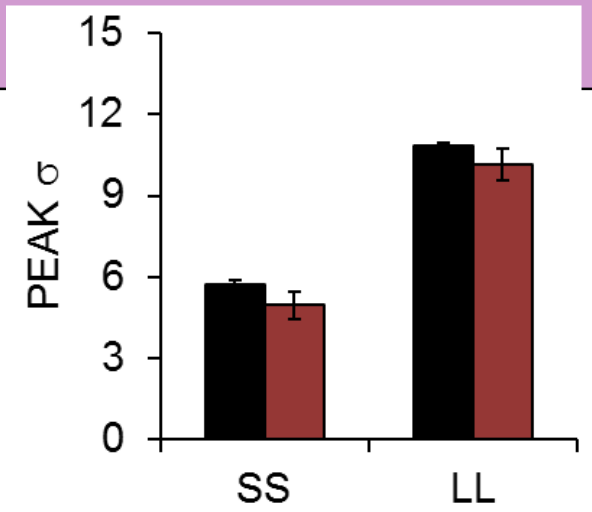


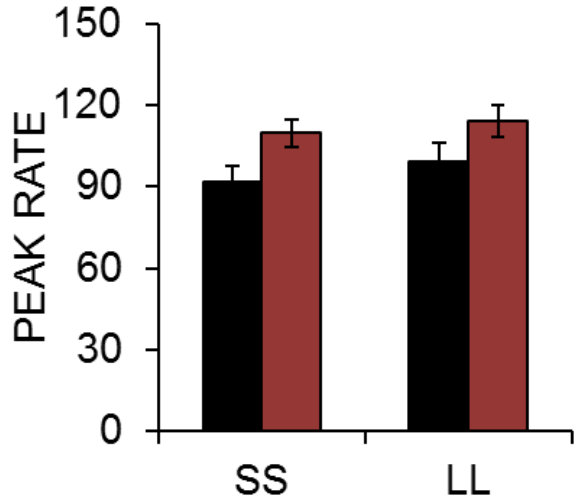
Smith, Marshall, & Kirkpatrick (2015)

DRL intervention: Timing









Smith, Marshall, & Kirkpatrick (2015)

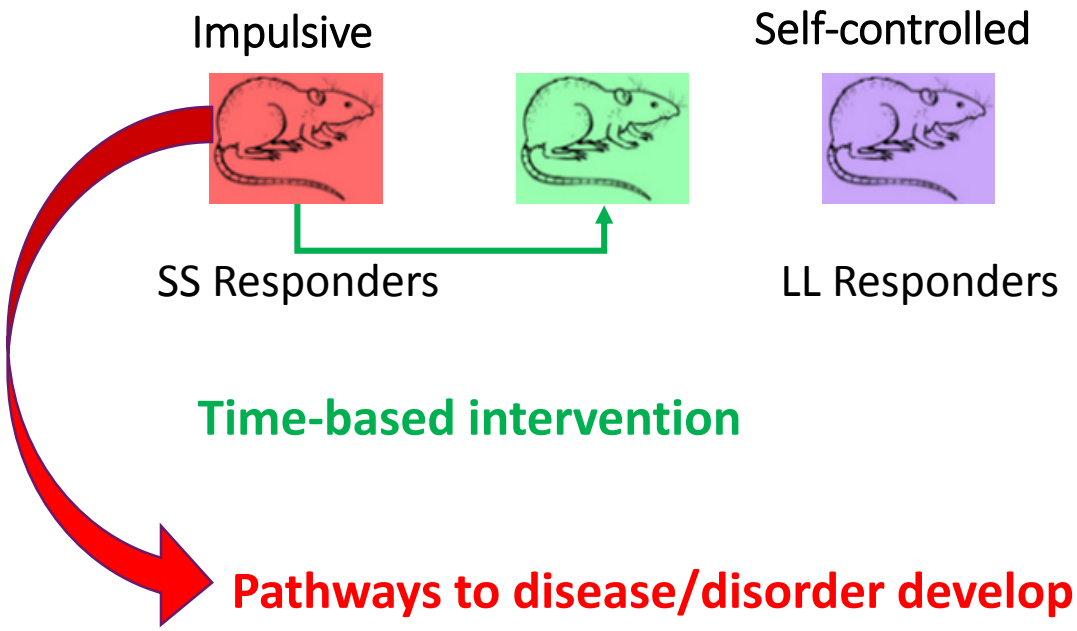
Time-based interventions: Summary

- FI, VI, and DRL inventions improved timing precision while also improving self-control
  - Peaks were had smaller standard deviations (narrower) and higher peak rates
- Combined with the individual differences patterns, these results suggest that poor (noisy) timing may be an important target for intervention work
  - Rats (and people) utilize timing processes when performing on FI, VI, and DRL schedules, and timing appears to improve as a result
  - FI may better target poor timing due to extensive practice with timing specific intervals, which may explain the longevity of effects

Overall summary

Impulsive Phenotype

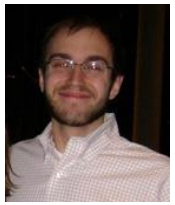
SS Responder



Time-based interventions: Extensions

- We have also demonstrated intervention effects on impulsive choice using fixed and variable interval schedules with:
  - ADHD/drug abuse model – Lewis rats (Smith et al., 2015)
  - Middle aged male rats (Peterson & Kirkpatrick, in press)
  - Young female rats (Stuebing et al., in prep)
- Future directions:
  - Identify and target specific mechanisms within the timing system
  - Develop human translational applications
  - Implement interventions to alter pathways to disease (diet-induced obesity)
  - Examine neural substrates of intervention effects

Acknowledgments



Andrew Marshall

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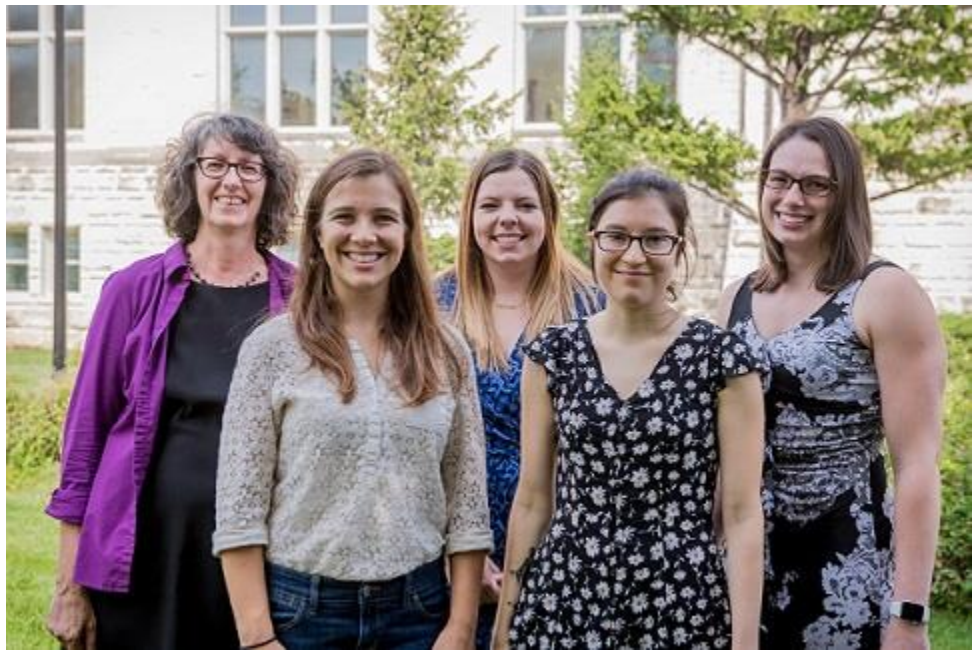

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R01-MH085739


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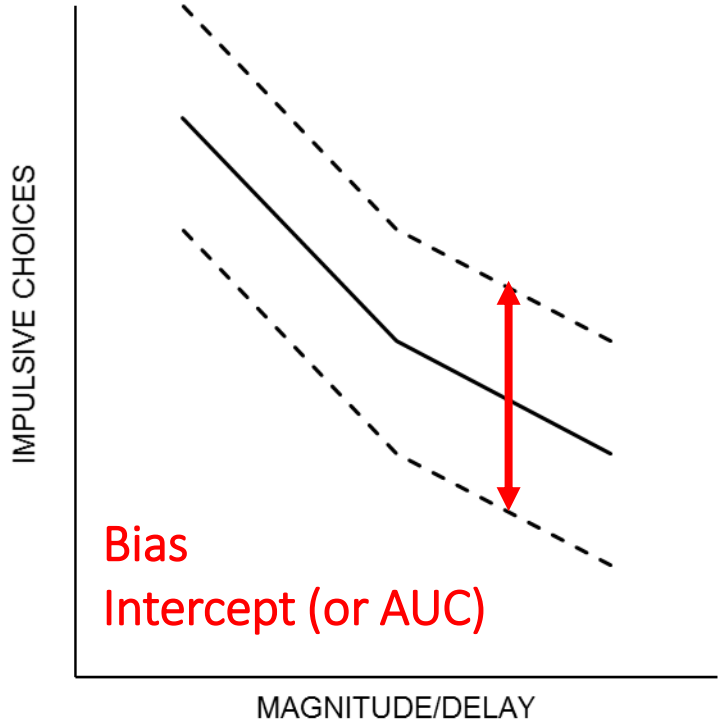
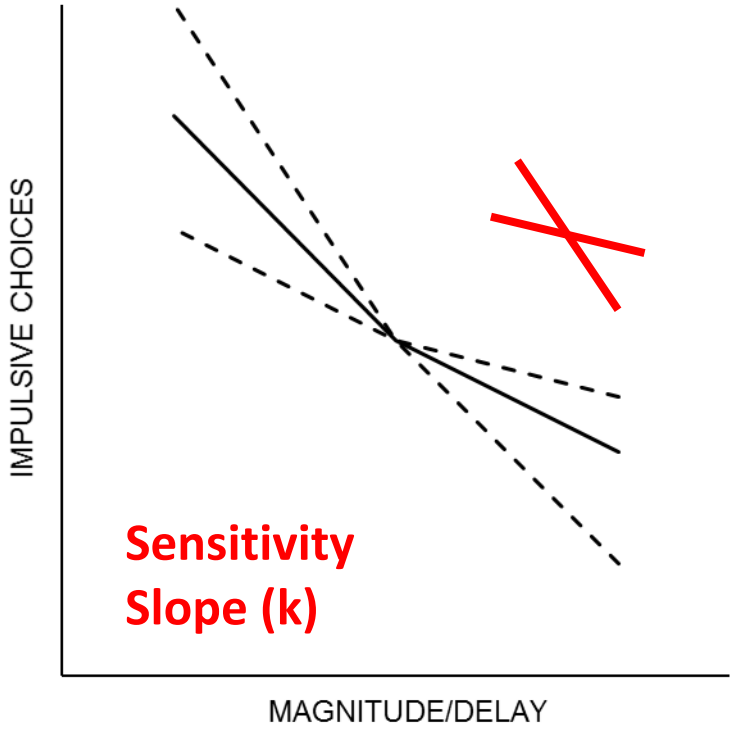
Bias versus sensitivity

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





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

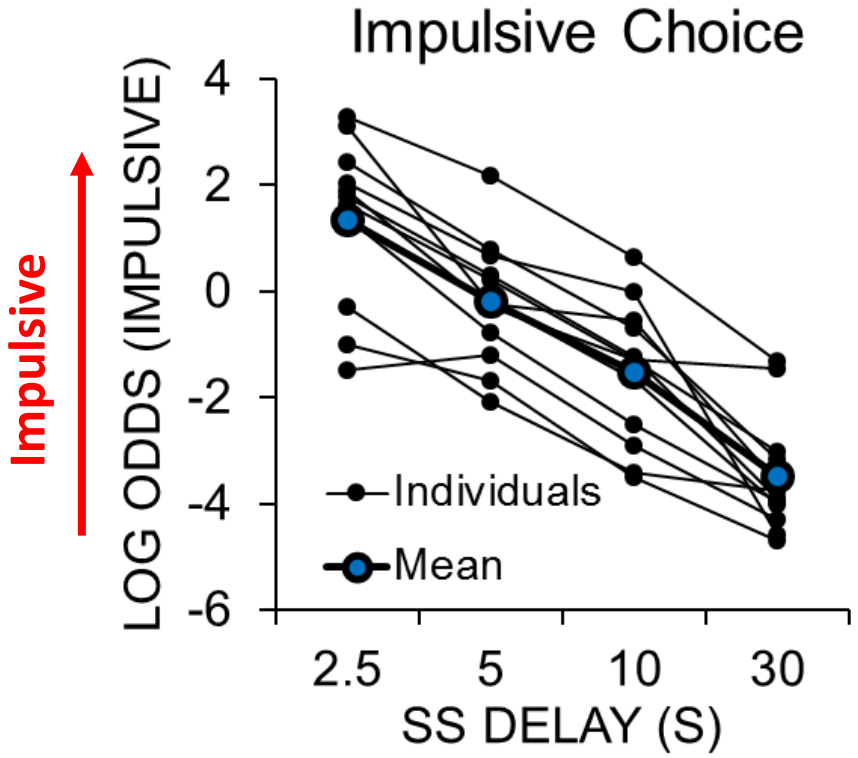
Marshall et al. (2014)

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)



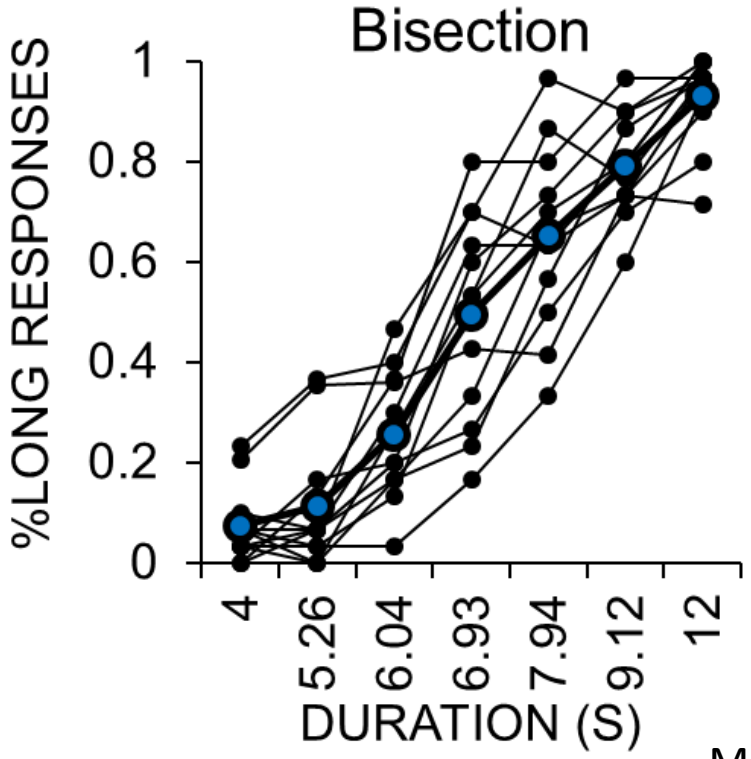
Marshall et al. (2014)

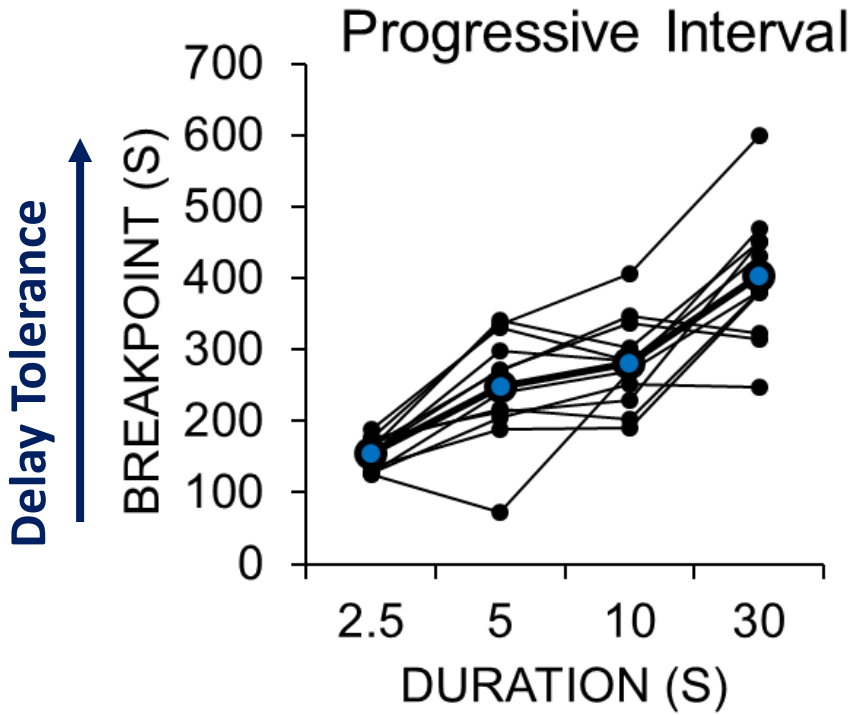
Impulsive choice: Correlations with timing

Timing Accuracy (μ) ↔

Temporal Discrimination (σ) ≠

Delay Tolerance (μ) ↕

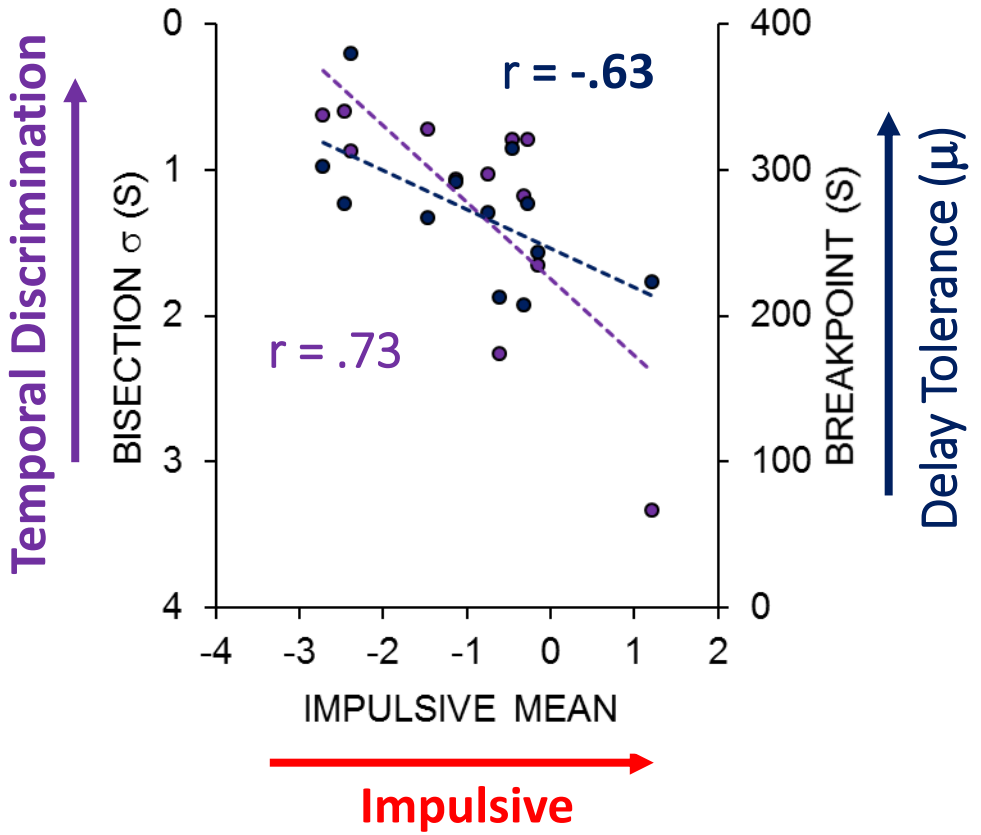




Marshall et al. (2014)

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)