The Role of Timing Processes in Delay Discounting

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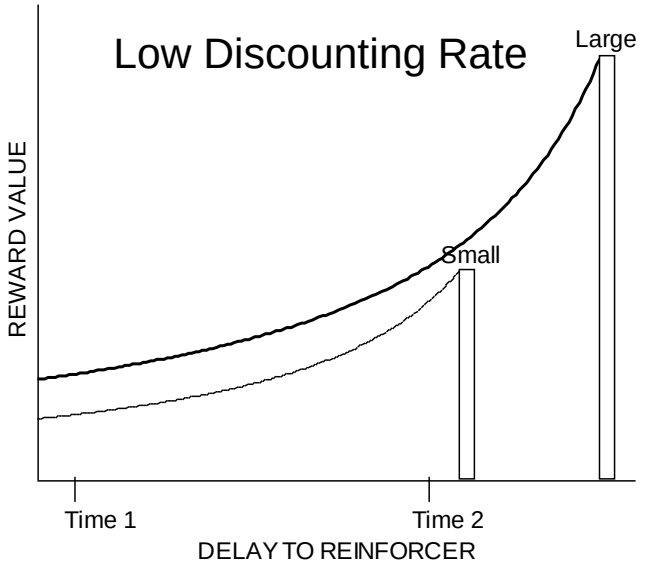
Delay discounting and daily life

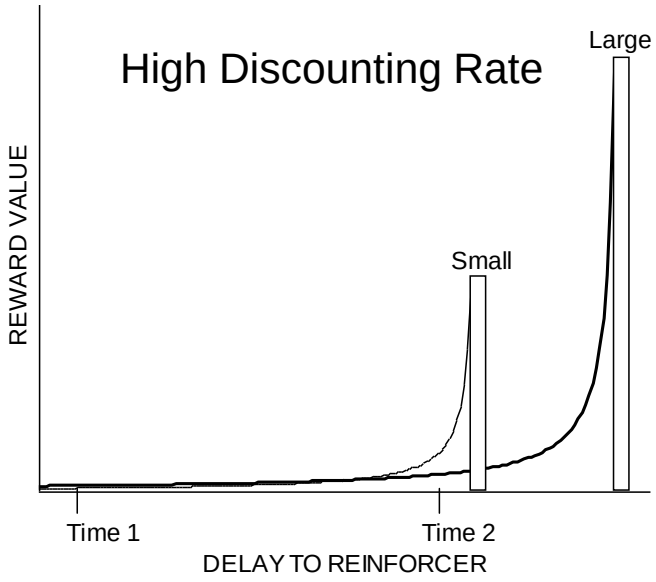
200 Food Choices per Day!

Temporal discounting functions and choice

Hyperbolic Discounting: V = A / (1 + kD)
V = Subjective Value
A = Amount
D = Delay
k = discounting rate



Prefers LL



Prefers SS

Individual differences in delay discounting

- Delay discounting 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)
  - Test-retest correlations in the .6-.7 range for rats over periods of 1 to 5 months (Peterson, Hill, & Kirkpatrick, 2015)
- Individual differences in delay discounting 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)
- Delay discounting is a trans-disease process (e.g., Bickel & Mueller, 2009)

Origins of Individual Differences: Timing Processes

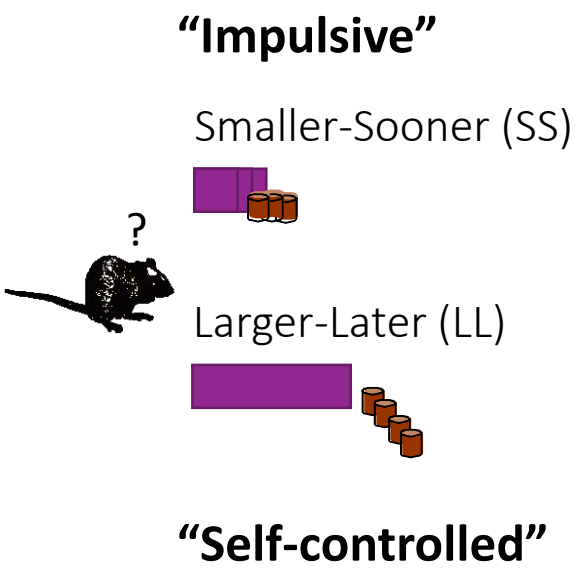
- Adolescents with ADHD:
  - Exhibit poorer temporal discrimination abilities (Barkley et al. 2001; Smith et al. 2002)
  - Display steeper impulsive choice functions than controls (e.g., Barkley et al. 2001; Scheres et al. 2010; Wilson et al. 2011)
- More impulsive humans:
  - Overestimate interval durations (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)

Choice: Measurement

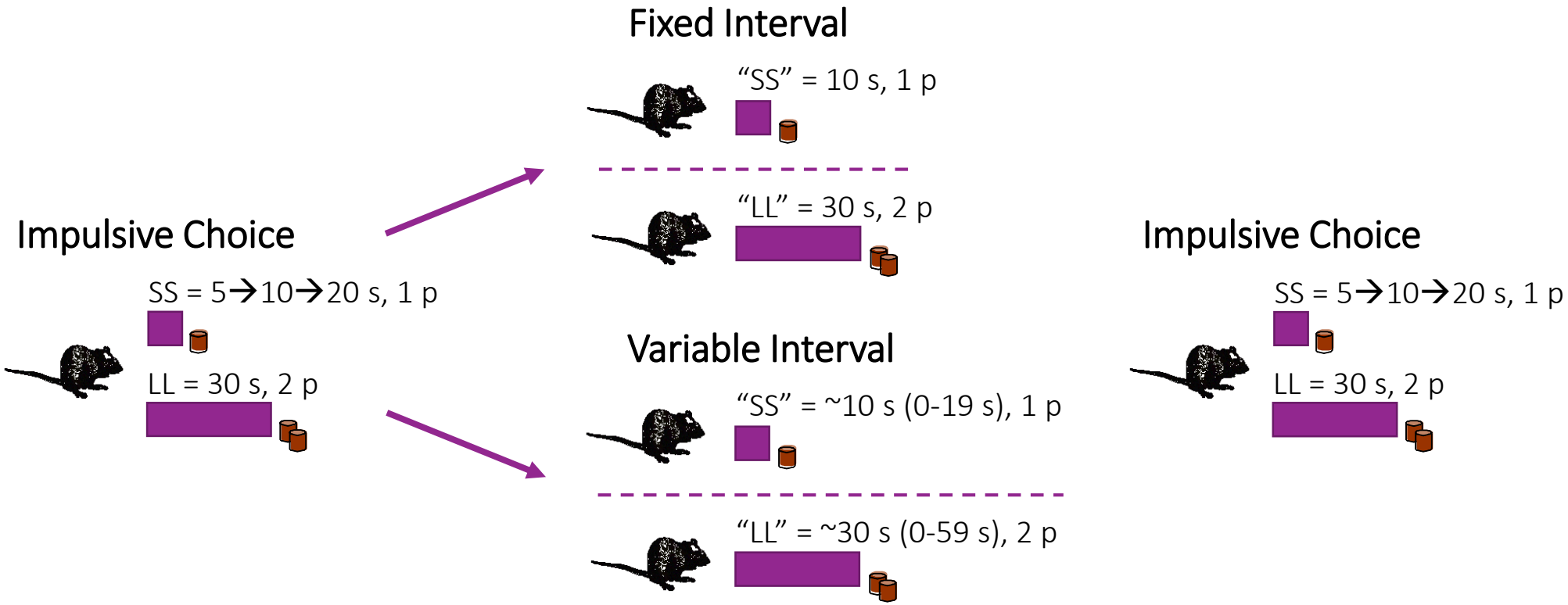
- Offer rats choices between smaller-sooner (SS) and larger-later (LL) rewards (based on Green & Estle, 2003)
  - SS lever = 1 pellet in 10 s
  - LL lever = 2 pellets in 30 s
  - ITI = 60 s
- Can manipulate delay to and/or magnitude of reward
- Choices of SS indicate impulsive choice in all cases as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



Time-based interventions: Questions

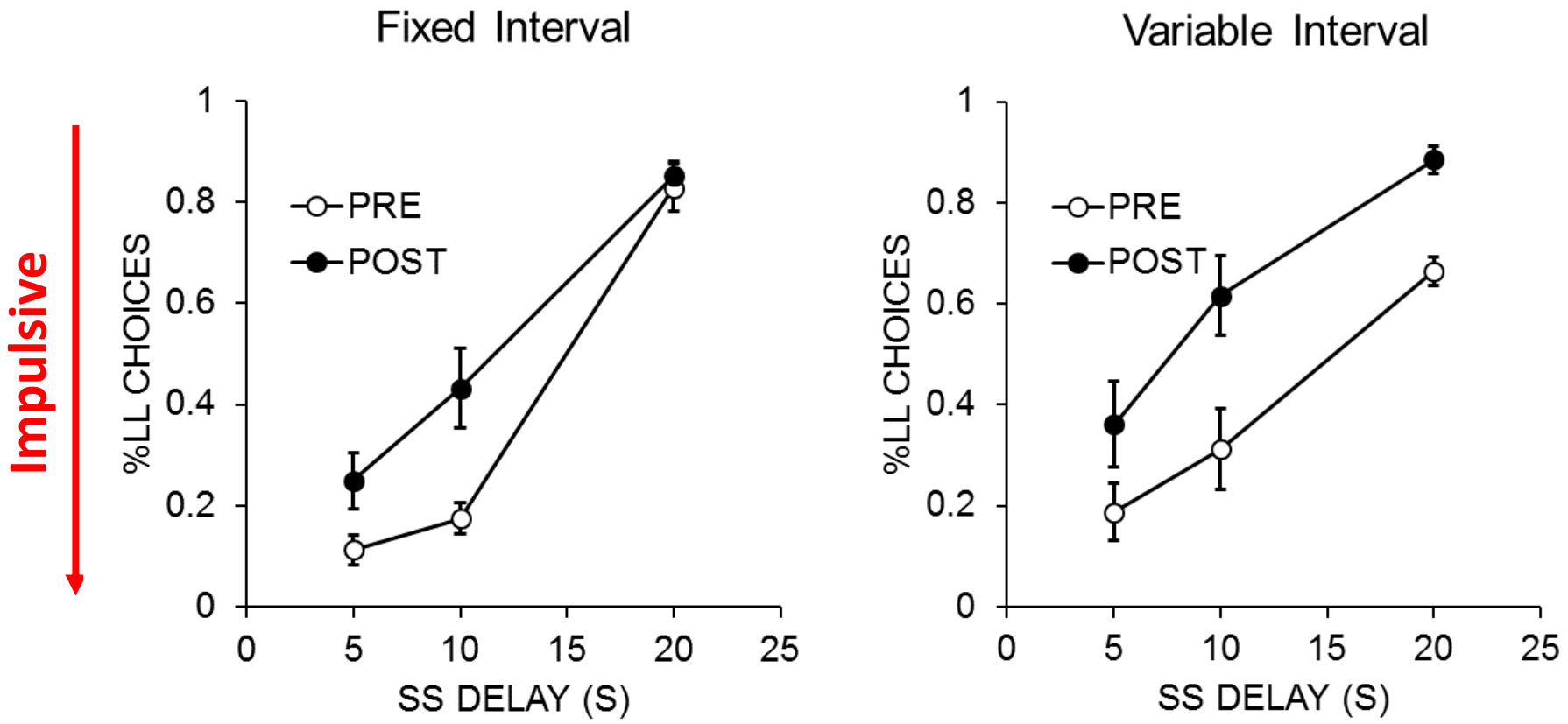
- Is mere delay exposure is sufficient?
- Or, does the nature of the delay exposure matter?

Time-based intervention: Interval schedules



Smith, Marshall, & Kirkpatrick (2015)

FI and VI Interventions: Choice



Both FI and VI interventions significantly increased LL choices

Smith, Marshall, & Kirkpatrick (2015)

Interlude: ANOVA to Mixed Model Transition

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Discussion

The anova to mixed model transition

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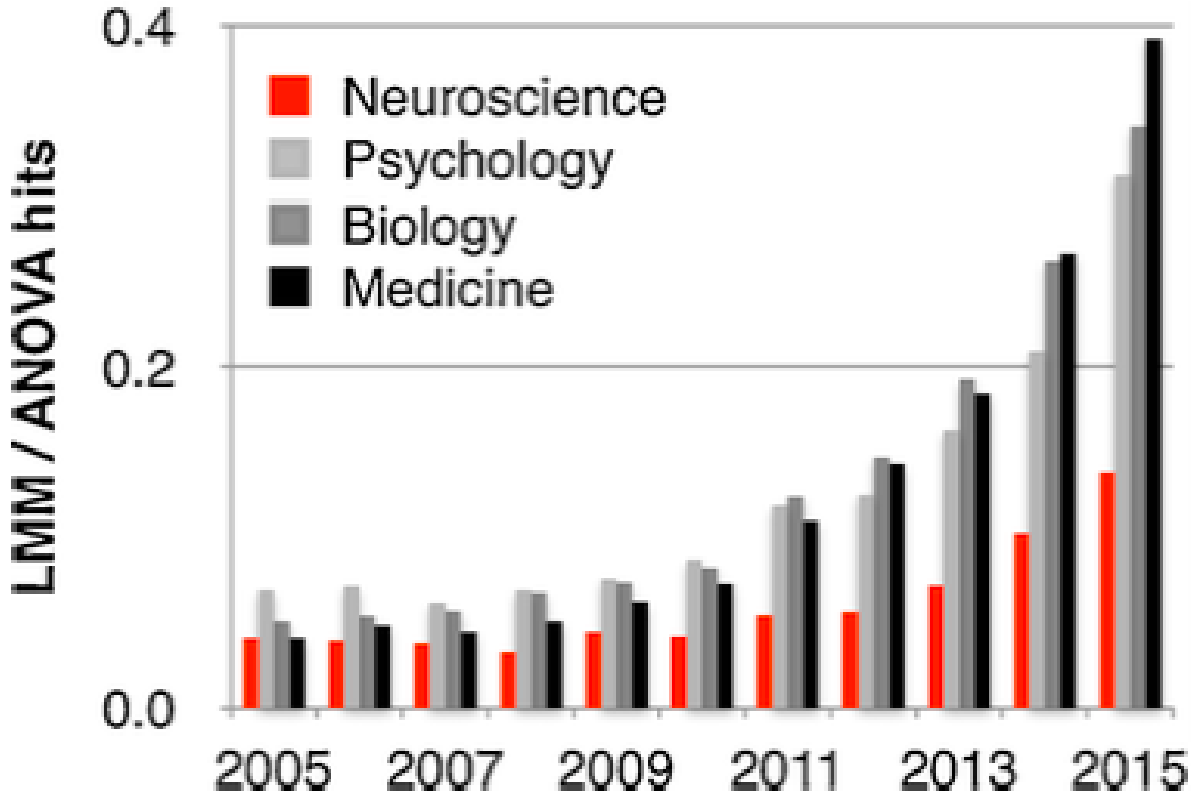
PROOF

ANOVA to Mixed Model Transition



Mixed Effects Regression Models vs. ANOVA

- ANOVA treats delay or magnitude as categorical
- As a work-around, researchers fit a continuous equation (e.g., hyperbolic) to collapsed data and then analyze k-values with t-tests or ANOVA
  - However, the statistical analysis does not have any information regarding the precision of the estimates provided by the curve fitting analysis
- Mixed effects models are repeated measures regression models, so continuous variables can be readily included in the models
- Our choice dependent measures are logistic
  - Choice data are binary (SS vs. LL)
- Can use all choices
- Adding random effects (fits to individuals) can increase power to detect fixed (group-level) effects
  - Outliers are pulled towards the group fits (shrinkage), and they carry less weight in the group estimates
  - Uses population-level estimates to reduce Type I error (important for replication crisis)

Why use all of the choices?

- Confidence and likelihood
- Increased power

OR

Choice of Cake = 2 times
Choice of Fruit = 1 time

Choice of Cake = 20 times
Choice of Fruit = 10 times

Choice of Cake = 200 times
Choice of Fruit = 100 times

All = .67

Mixed Effects Regression Models vs. ANOVA

- Can deal with non-systematic data **without participant removal!!!**

Mixed-Effects Models and Non-Systematic Data

- 106 Participants
- Completed Kirby questionnaire
  - 27 different amount-delay combination
- Analyzed choice functions using mixed effects model
- Individual choices (SS = 0 ; LL = 1) were entered into the model
- The predictor variable was Log k-value
  - Tested the slope and intercept of the choice function
  - The intercept was centered on the median k-value

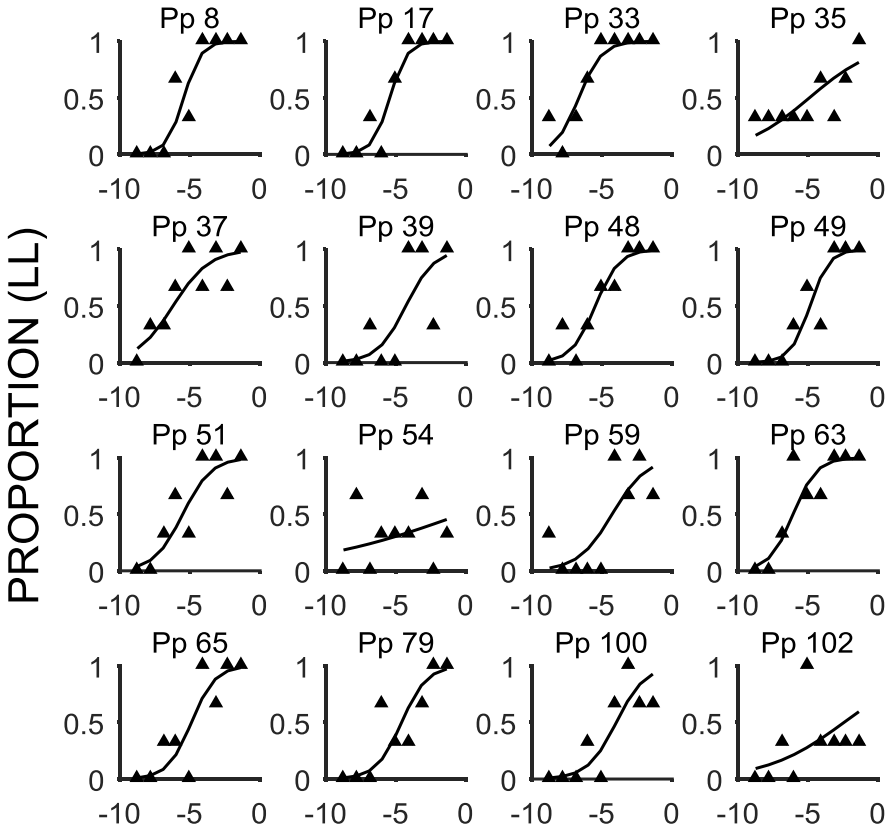
Kirkpatrick et al.. (in press)

Mixed-Effects Models and Non-Systematic Data

- Identified participants based on Johnson and Bickel (2008)
- Systematic functions
- Non-systematic Type 1 – functions with one or more changes in direction
- Non-systematic Type 2 – functions with minimal change between the lowest and highest k-value

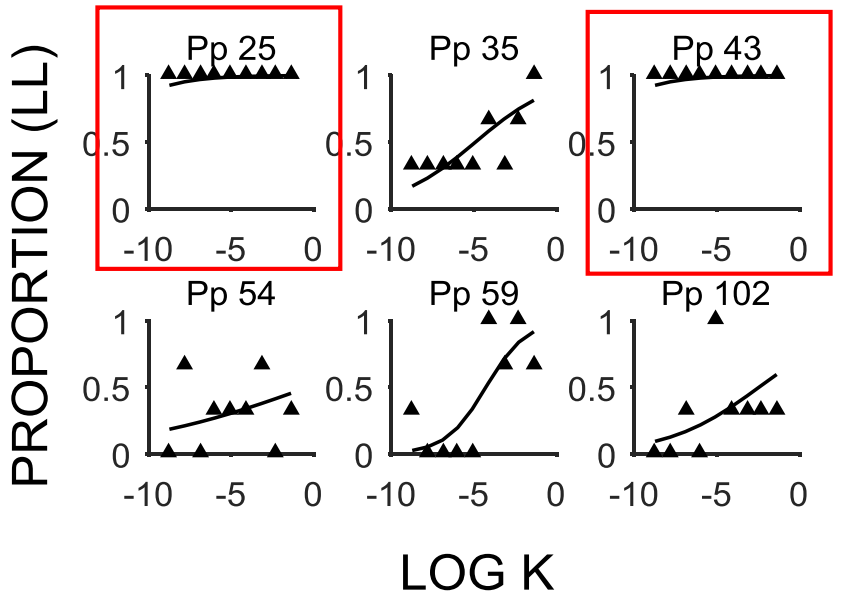
Kirkpatrick et al.. (in press)

Non-systematic Type 1



Kirkpatrick et al.. (in press)

Non-systematic Type 2

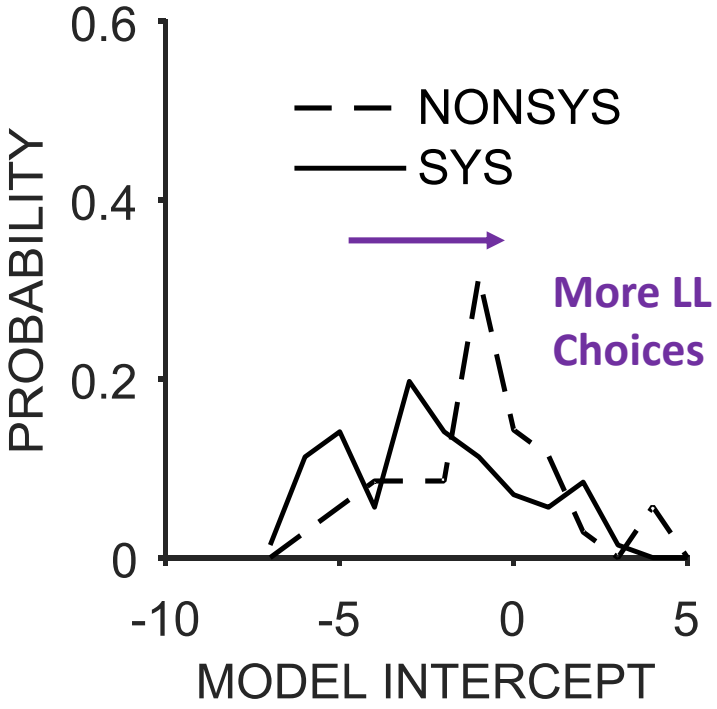


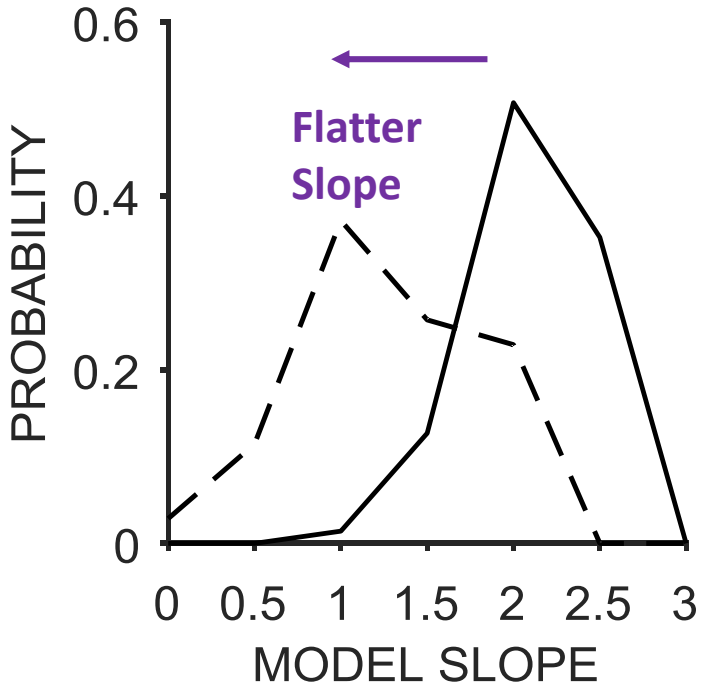
Shrinkage

Kirkpatrick et al.. (in press)

Systematic vs. Non-systematic functions

The non-systematic participants made more LL choices at the intercept
The non-systematic participants had a flatter slope (i.e., less sensitive to k-value)





Kirkpatrick et al.. (in press)

ANOVA vs. Mixed Effects Models

- One more thing…
- They resolve the conflict between pressures:
  - The need to conduct group-level statistics
  - Focus on individuals
- Mixed models focus on both the individual and the group in an integrated framework

Time-based interventions: Questions

- How long do the interventions last? (longevity)
- Do the interventions only promote delay processes within the choice procedure? (generalizability)
  - Or does the intervention affect choice overall?

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 press)

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

Mixed Effects Regression Models vs. ANOVA

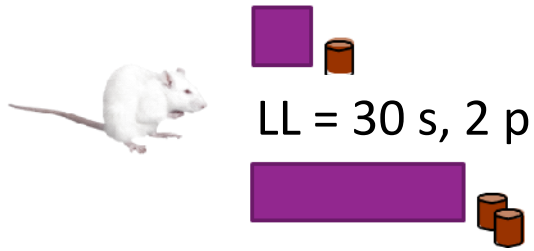
- Mixed effects regression models can also be used to parse out different mechanisms of the interventions within the choice task

Delay Processing: Analysis Methods

- Test the slope
  - Sensitivity to SS delay
  - Should map most closely onto delay discounting
- Test the intercept at 0 s
  - Preference for immediacy
- Test the intercept at 30 s
  - Preference for larger magnitude

SS Delay Task

SS = 5→10→20 s, 1 p

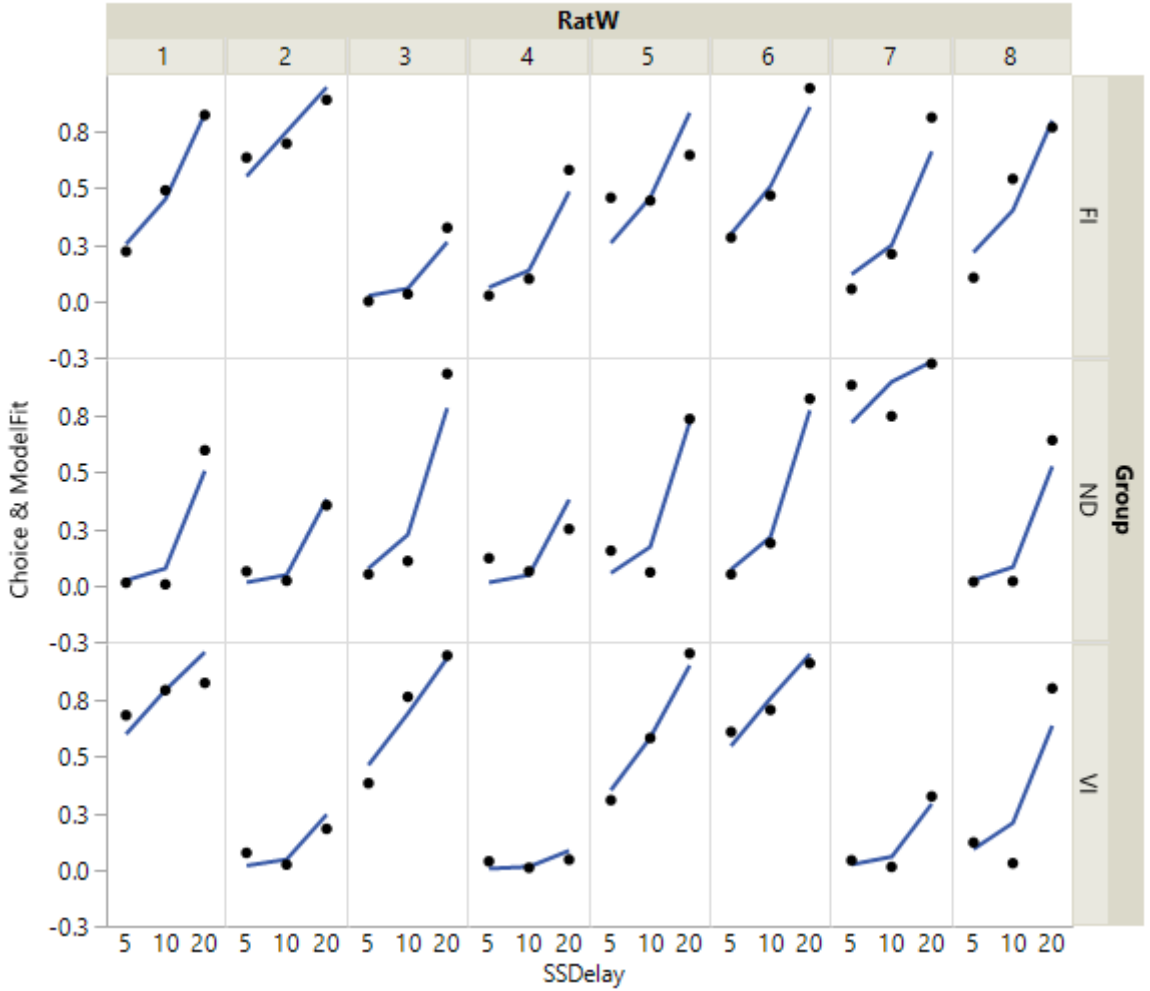


LL = 30 s, 2 p

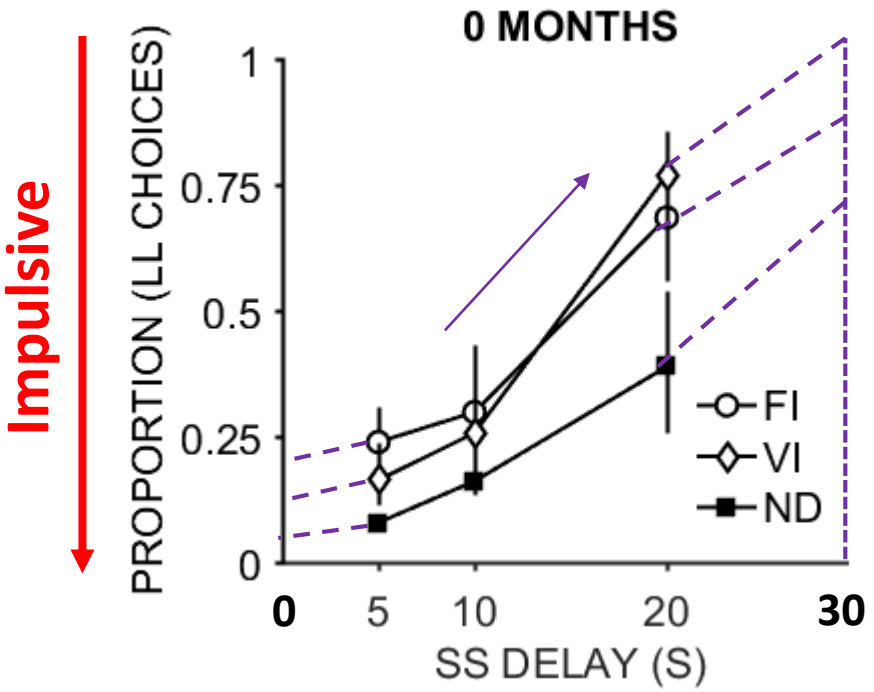
You can also compute k-values!

Wileyto et al. (2004); Young (2017)

Mixed Effects Model Fits to Individual Rats: 0 Months



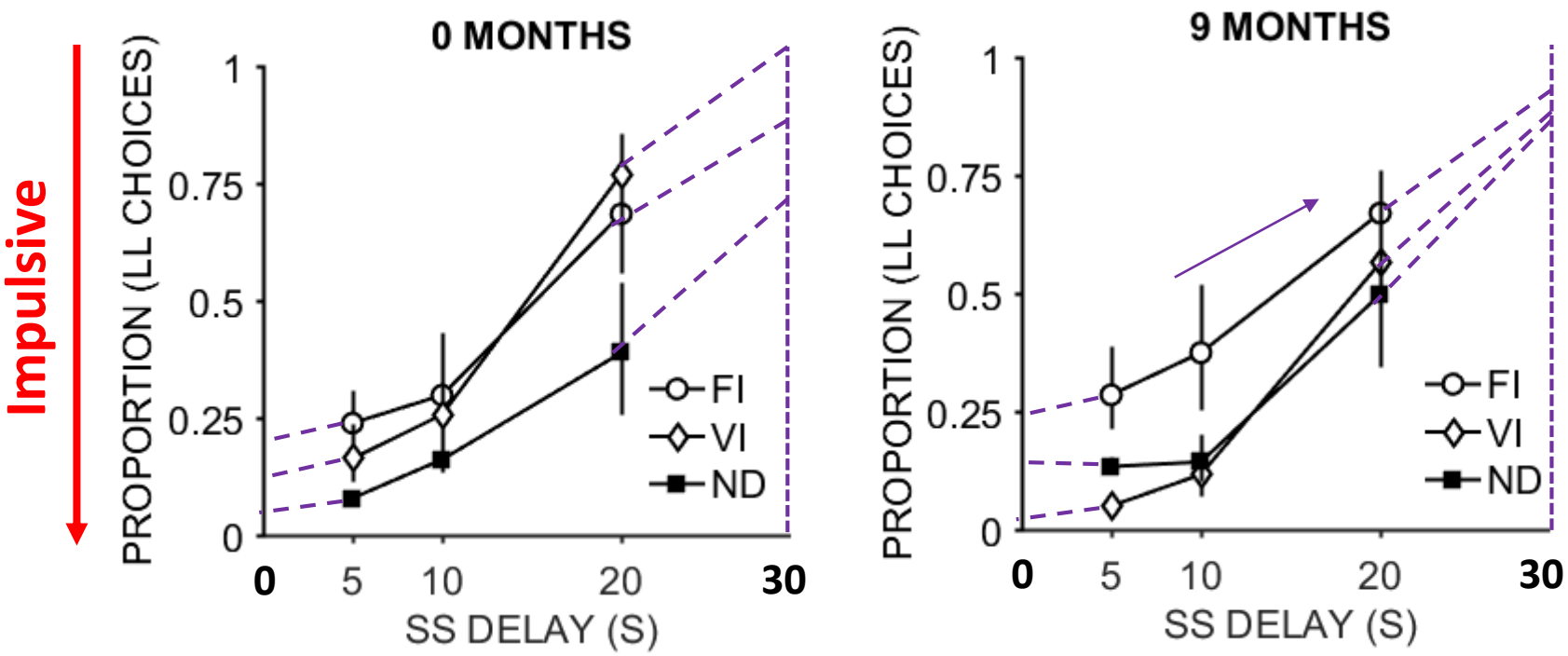
Longevity of Intervention Effects



Both FI and VI reduced preference for immediacy
VI increased preference for the larger magnitude
FI decreased sensitivity to SS delay

Bailey et al. (in press)

Longevity of Intervention Effects

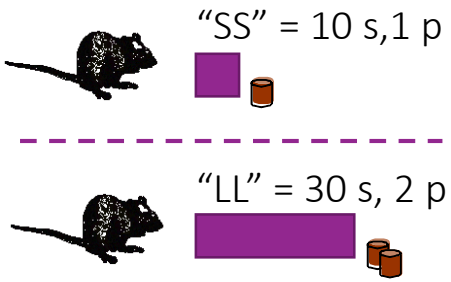


No significant group differences at either intercept
FI group showed reduced sensitivity to SS delay
VI group no longer showed any intervention effect

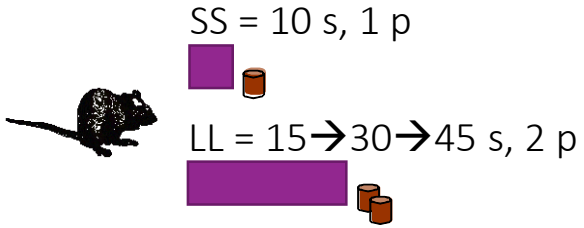
Bailey et al. (in press)

Generalizability of Intervention Effects

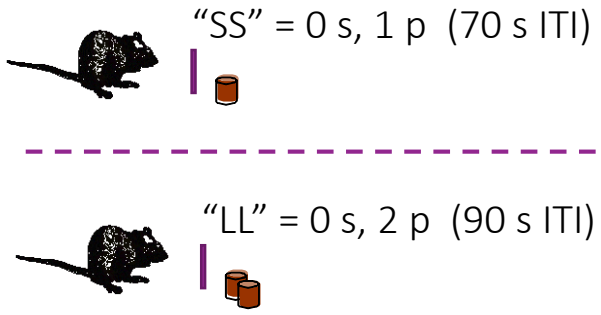
Fixed Interval



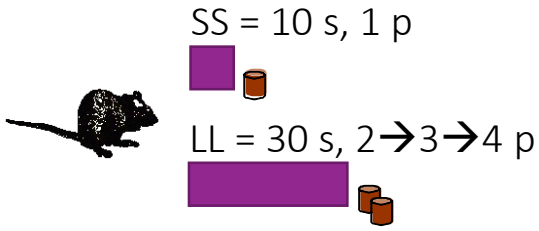
LL Delay Task



No Delay



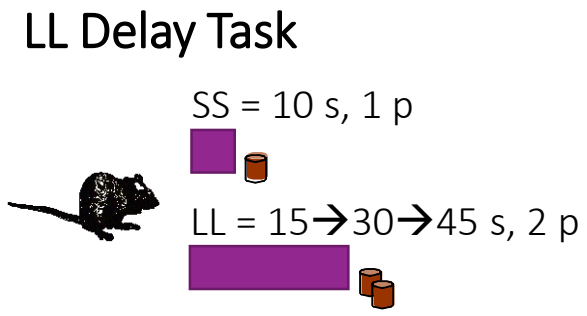
LL Magnitude Task



Bailey et al. (in press)

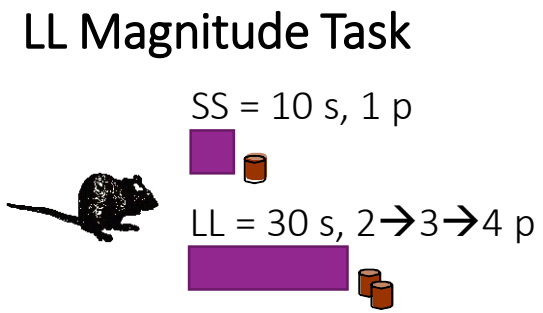
Analysis Methods: LL Delay Task

- Test the slope
  - Sensitivity to LL delay
  - Should map onto delay discounting rate
- Test the intercept at 10 s
  - Preference for the larger magnitude

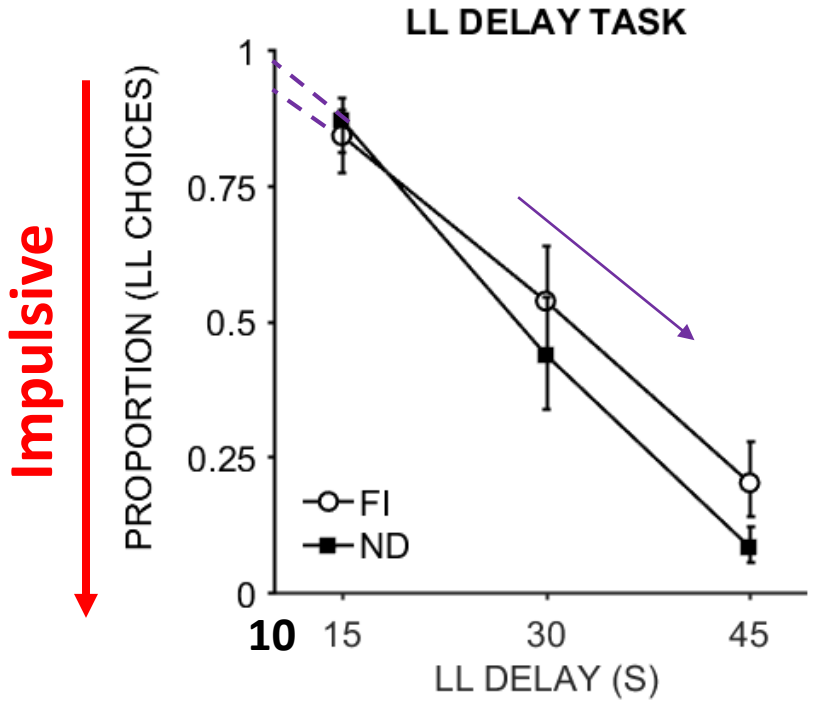


Analysis Methods: LL Magnitude

- Test the slope
  - Sensitivity to LL magnitude
  - Should map onto delay discounting rate
- Test the intercept at 1 p
  - Preference for the shorter delay



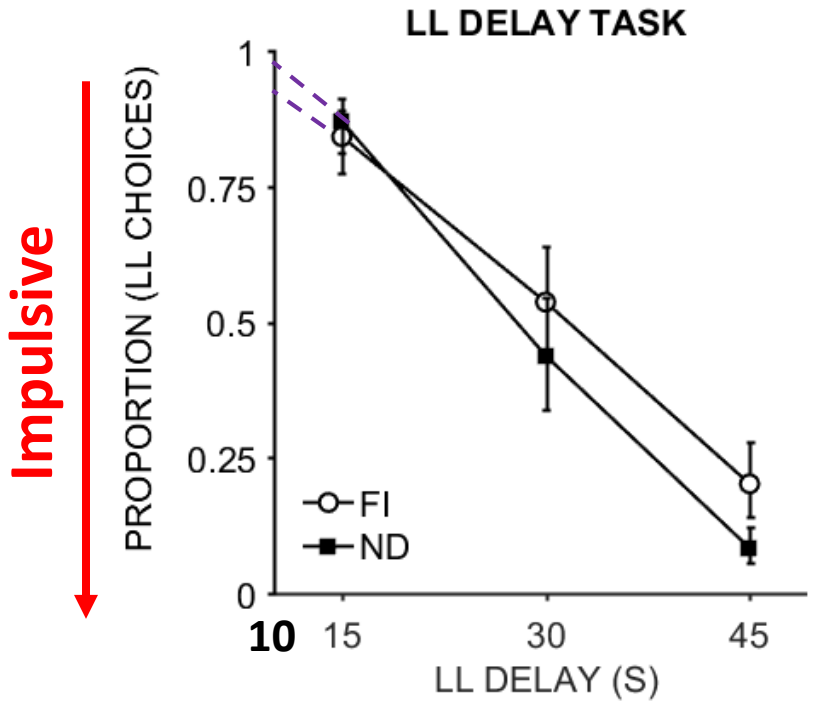
Generalizability of intervention effects

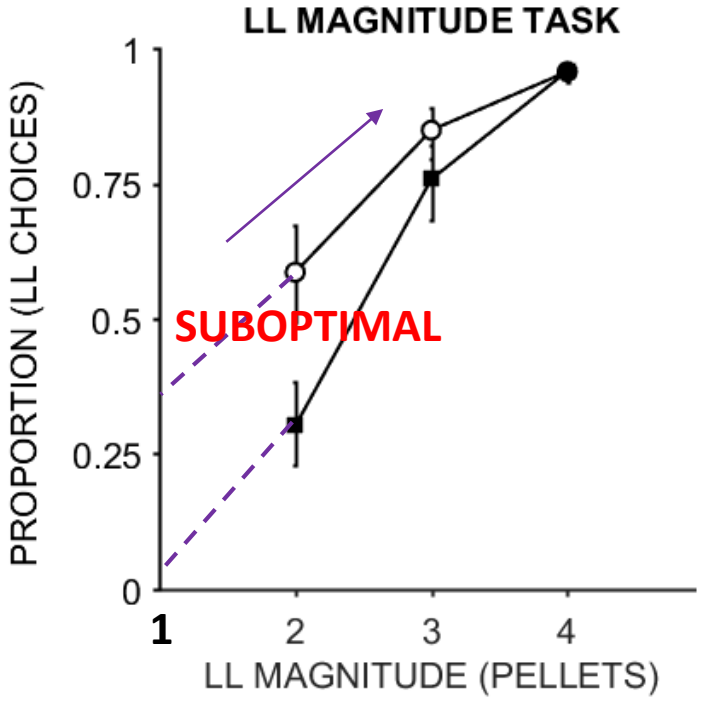


No group differences in magnitude preference
FI group showed reduced sensitivity to LL delay

Bailey et al. (in press)

Generalizability of intervention effects





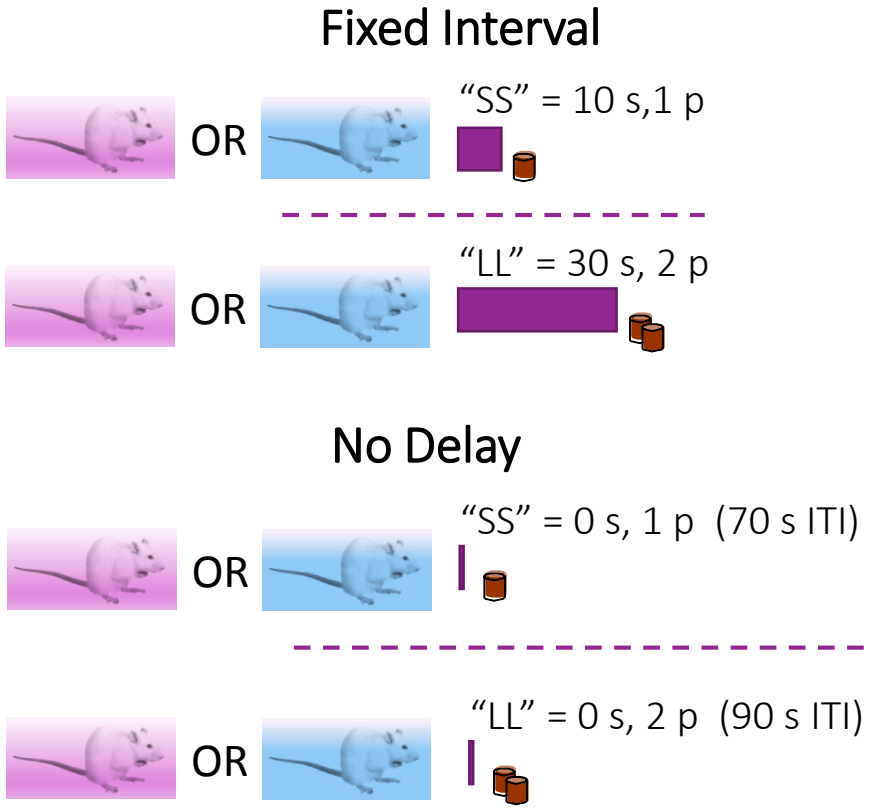
FI group showed reduced preference for the shorter delay
FI group showed reduced sensitivity to LL magnitude

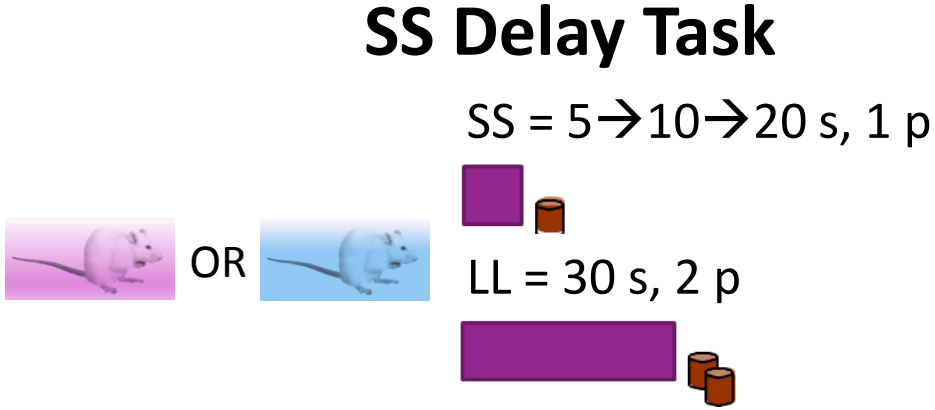
Bailey et al. (in press)

Time-based interventions: Questions

- Are female rats sensitive to the intervention effects as well as male rats?
- Are there any sex differences in intervention efficacy?

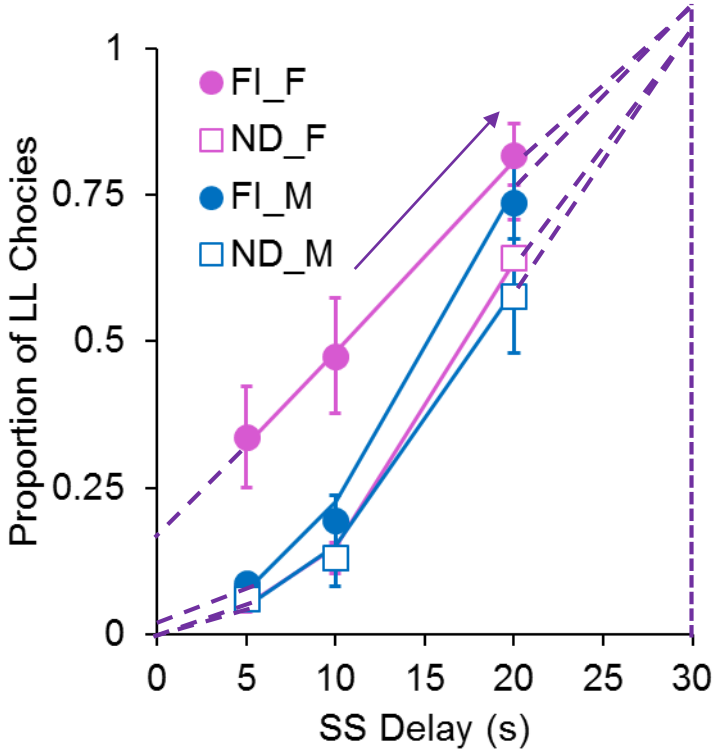
Sex Effects on Intervention Efficacy





Bailey et al. (in prep)

Sex effects



FI rats showed reduced preference for immediate rewards
Females FI rats showed less preference for immediate rewards than male FI rats

FI rats showed greater preference for larger rewards
The females did not differ from the males

FI rats showed less sensitivity to delay
Female FI rats showed less sensitivity to delay than male FI rats

Bailey et al. (in prep)

Interim summary: FI Intervention

- Reduced preferences for immediacy in SS delay task and reduced preferences for shorter delays in LL magnitude task
  - This suggests that the FI intervention may increase the preference for longer delays, even when those preferences are suboptimal
- Reduced sensitivity to delay in SS and LL delay tasks and reduced sensitivity to magnitude in LL magnitude task
  - This suggests that the FI intervention may decrease the delay discounting rate
- Produced increases in preferences for larger magnitudes
  - This was not consistently observed
- Persisted for at least 9 months
- Produced stronger effects in females compared to males

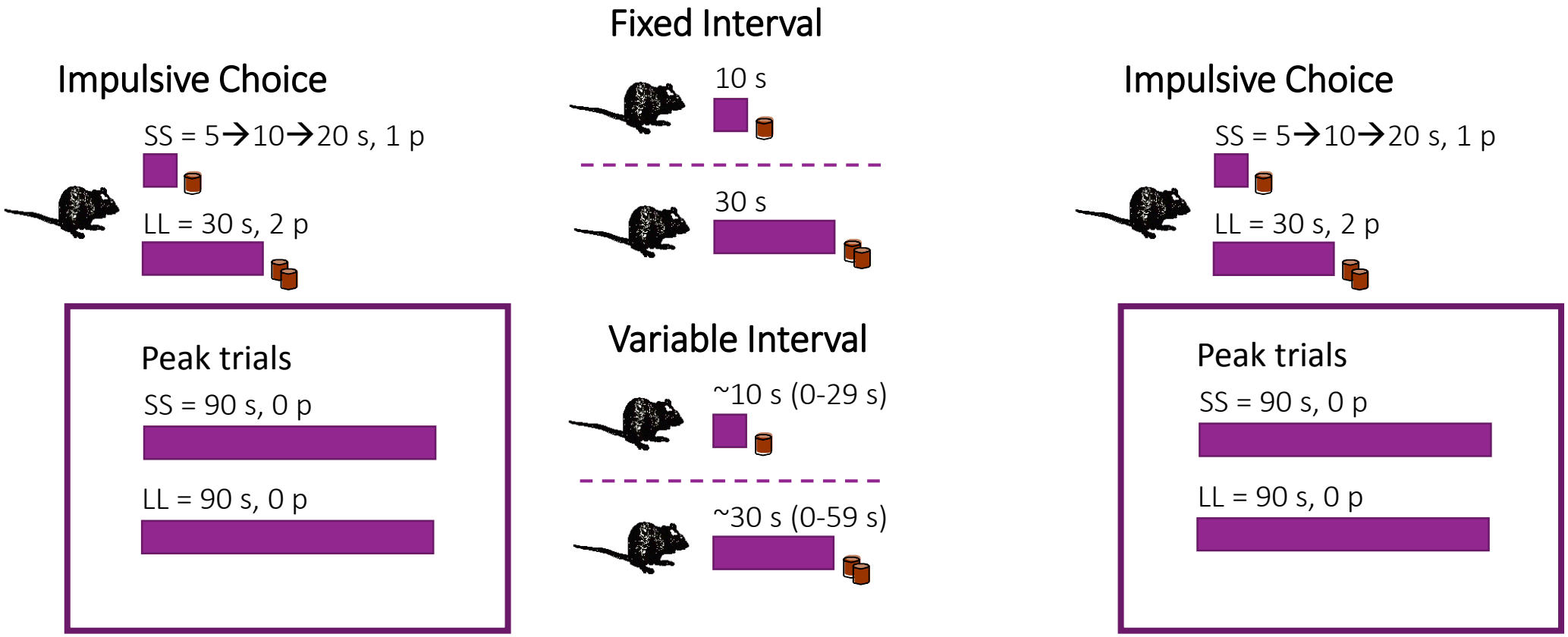
Interim summary: VI Intervention

- Reduced preferences for immediacy in SS delay task
  - This suggests that the VI intervention may increase the preference for longer delays
- Reduced sensitivity to delay in SS delay task
  - This suggests that the VI intervention may decrease the delay discounting rate
- Did not persist when tested after a 9-month delay – suggests that training with specific delays is more effective
  - We have not tested intermediate delays
- Haven’t tested this intervention for sex differences

Time-based interventions: Questions

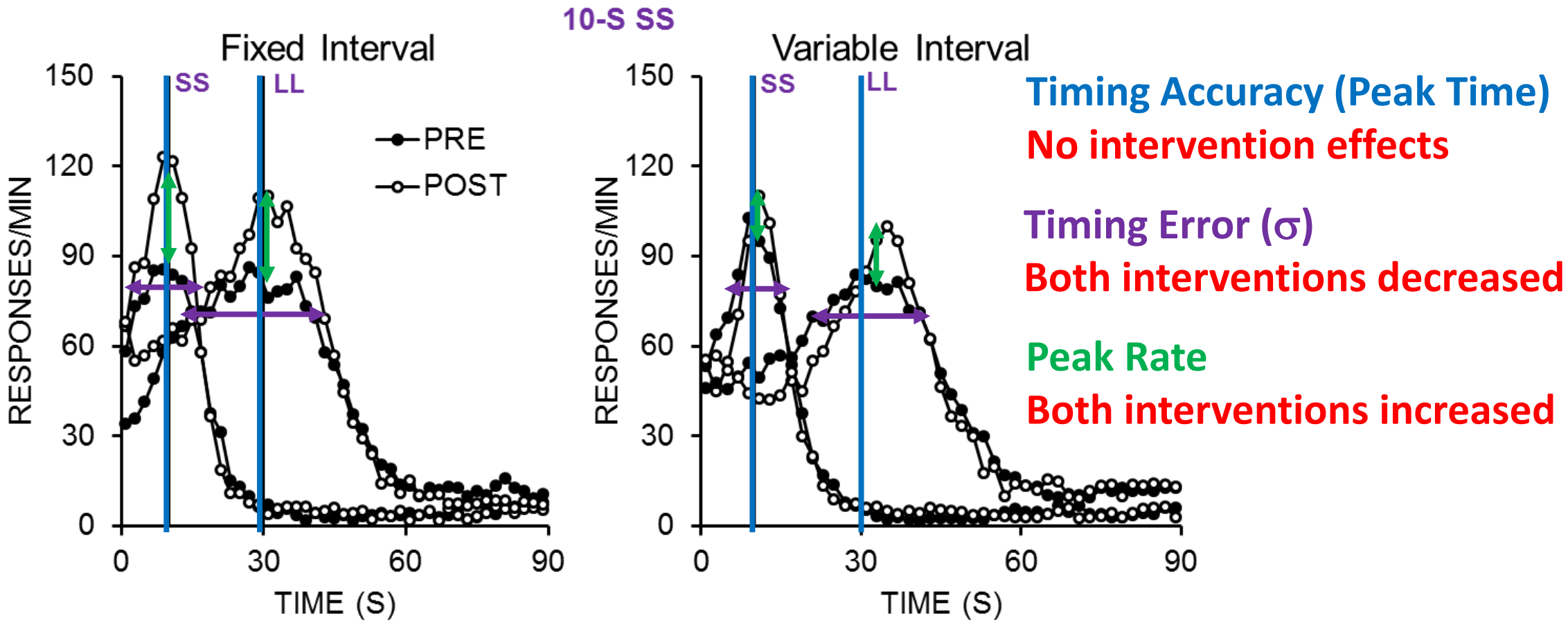
- Are the interventions merely inducing self-control (or perhaps delay tolerance)?
- Or, are there effects on timing processes?

Time-based intervention: Interval schedules



Smith, Marshall, & Kirkpatrick (2015)

FI and VI Interventions: Timing



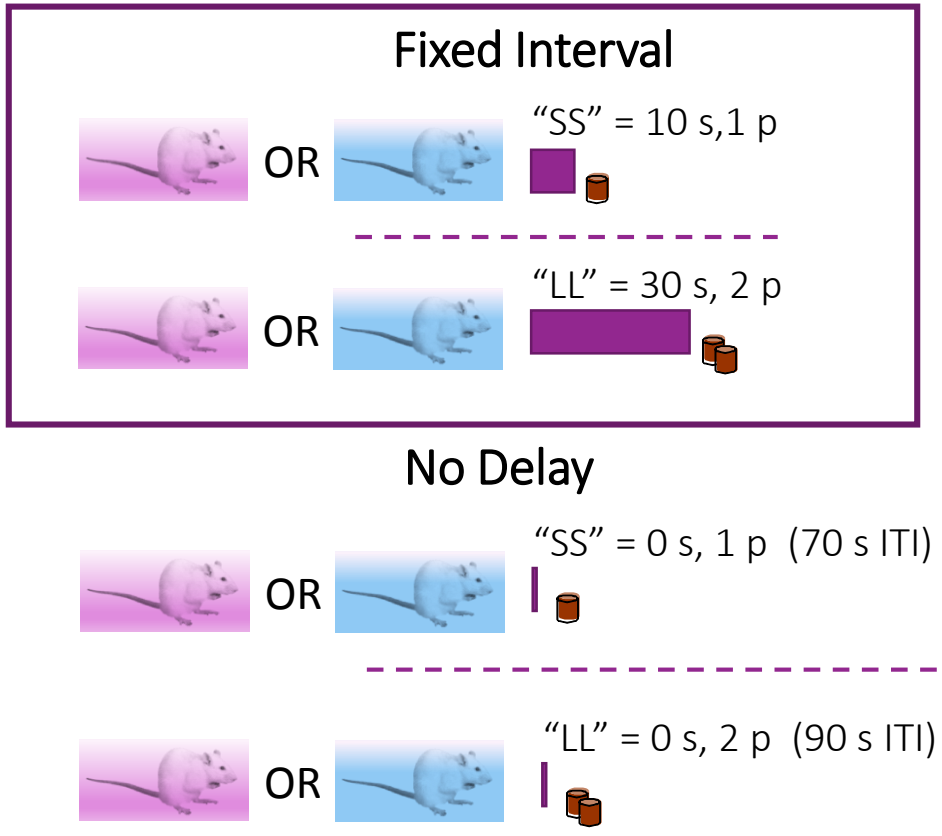
Timing Accuracy (Peak Time)
No intervention effects

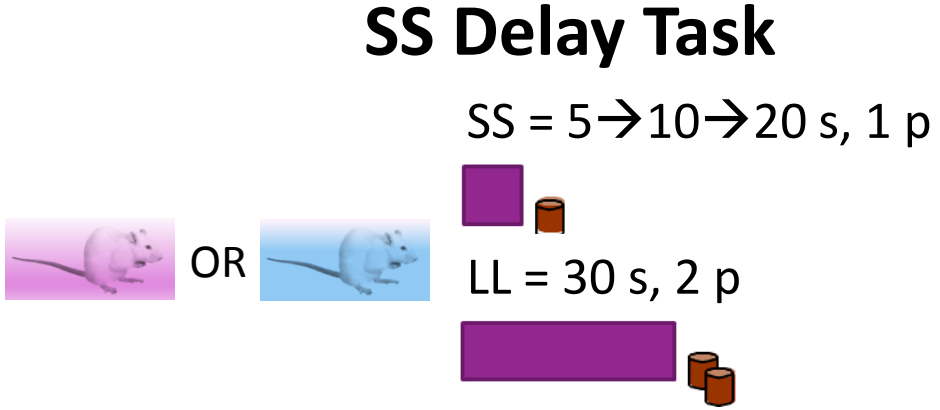
Timing Error (σ)
Both interventions decreased

Peak Rate
Both interventions increased

Smith, Marshall, & Kirkpatrick (2015)

Sex Effects on Intervention Efficacy



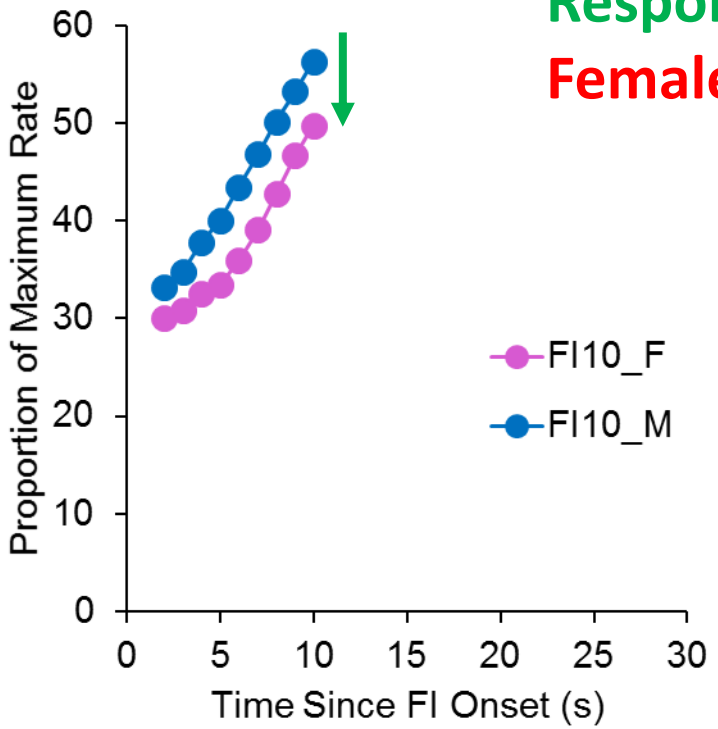


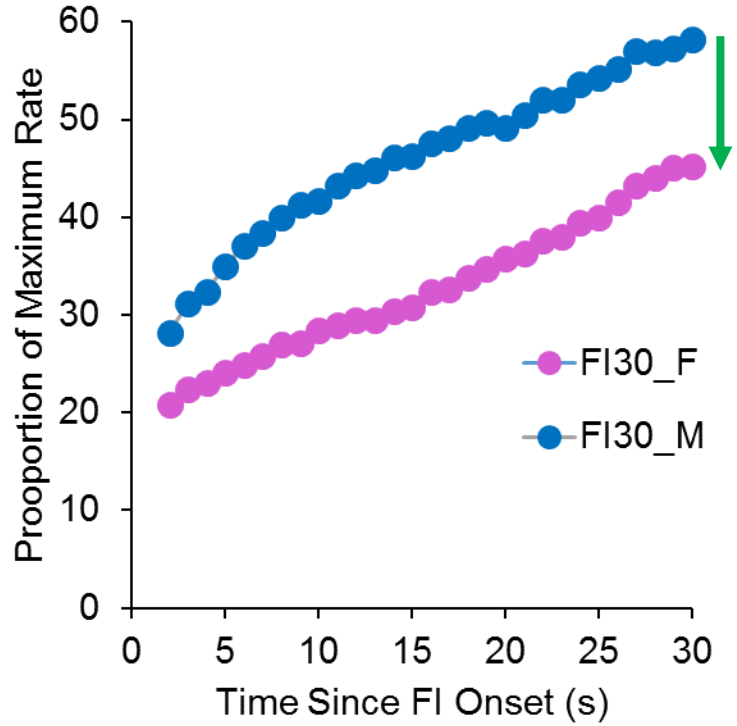
Bailey et al. (in prep)

Sex differences in FI intervention efficacy

Response Rate

Females are lower





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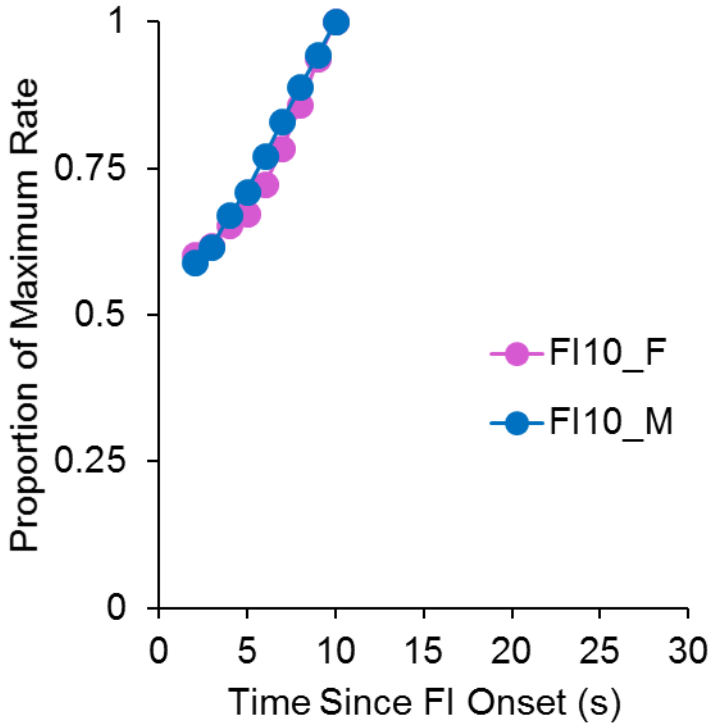
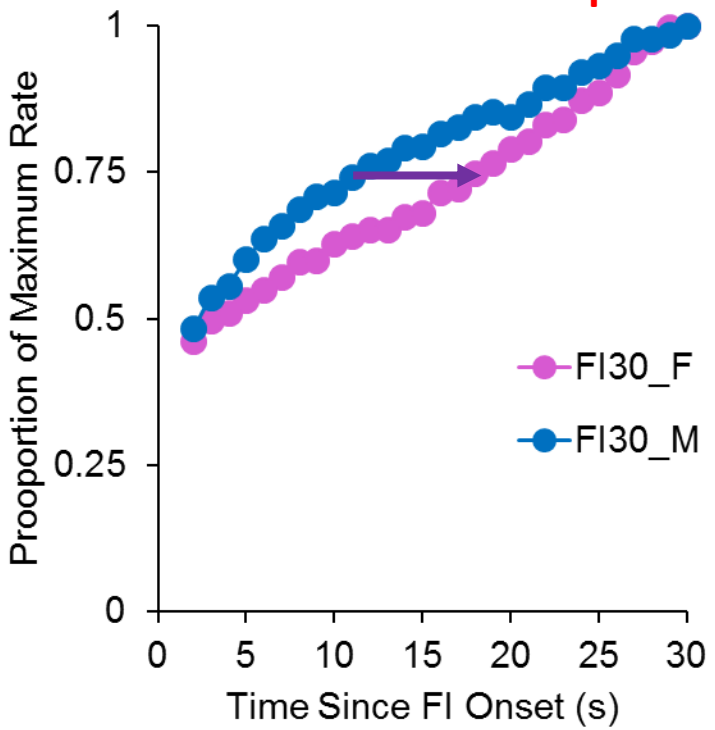
Sex differences in FI intervention efficacy



Timing Error

Females are more precise on FI 30



Bailey et al. (in prep)

Time-based interventions: Summary

- FI and VI inventions improved timing precision while also improving self-control
  - Peaks were had smaller standard deviations (narrower) and higher peak rates
- Females rats show better timing precision on the FI 30 (“LL”) compared to male rats during the intervention
  - This may explain the greater intervention efficacy in the female rats
- 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 and VI 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

Reduced discounting rate
Reduced preference for immediacy/short delays

Impulsive

Self-controlled

SS Responders

LL Responders

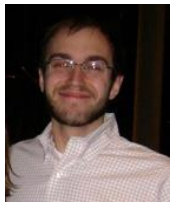
Time-based intervention

Pathways to disease/disorder development

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, 2016)
- 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



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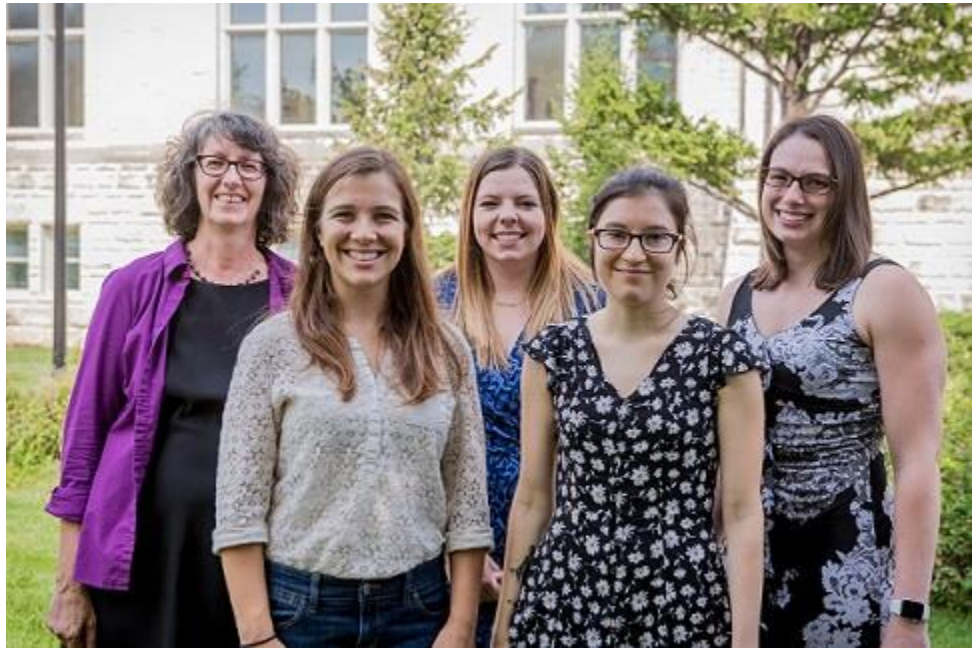

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