Moderating sub-optimal choices in delay discounting tasks in rats

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Every day decisions: 35,000

$20-30 per day

1-2 drinks per day

15-20 bites per day
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 sub-optimal “impulsive” choice as they should earn fewer rewards
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 and humans (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 sufficient?

Or, does the nature of the delay exposure matter?
Time-based intervention: Interval schedules

Fixed Interval
- "SS" = 10 s, 1 p
- "LL" = 30 s, 2 p

Variable Interval
- "SS" = ~10 s (0-19 s), 1 p
- "LL" = ~30 s (0-59 s), 2 p

Impulsive Choice
- SS = 5 → 10 → 20 s, 1 p
- LL = 30 s, 2 p

Smith, Marshall, & Kirkpatrick (2015)
Both FI and VI interventions significantly increased LL choices

Smith, Marshall, & Kirkpatrick (2015)
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**
- "LL" = 0 s, 2 p (70 s ITI)

**Impulsive Choice: 0 months**
- SS = 5→10→20 s, 1 p
- LL = 30 s, 2 p

**Impulsive Choice: 9 months**
- SS = 5→10→20 s, 1 p
- LL = 30 s, 2 p

Bailey et al. (2018)
Impulsive

Both FI and VI increased LL preference
FI reduced sensitivity to SS delay (delay discounting rate)

Bailey et al. (2018)
Longevity of Intervention Effects

FI increased LL preference
FI reduced sensitivity to SS delay
VI no longer showed any intervention effect

Bailey et al. (2018)
Generalizability of Intervention Effects

**Fixed Interval**
- "SS" = 10 s, 1 p
- "LL" = 30 s, 2 p

**No Delay**
- "SS" = 0 s, 1 p (70 s ITI)
- "LL" = 0 s, 2 p (90 s ITI)

**LL Delay Task**
- SS = 10 s, 1 p
- LL = 15→30→45 s, 2 p

**LL Magnitude Task**
- SS = 10 s, 1 p
- LL = 30 s, 2→3→4 p

Bailey et al. (2018)
Generalizability of intervention effects

FI increased LL choices
FI reduced sensitivity to LL delay

Bailey et al. (2018)
Generalizability of intervention effects

FI increased LL choices
FI reduced sensitivity to LL magnitude

Bailey et al. (2018)
FI Intervention: Questions

Does the FI intervention actually increase food earning?

Or, does the FI just increase LL choices?
Choice and Food Earning

- Offered 48 free choices per session, plus interspersed forced choice trials
- Rats have 2 hr to complete a session at which point the session terminates
  - Rats did not always complete all trials
- This means that increased LL choices may not mean more food earning
  - FI could improve efficiency so that the rats earn the same amount of food per session but in fewer trials

Bailey et al. (2018)
Choice and Food Earning: Hypothetical Examples

• Rat 1 makes 40 LL choices and completes 40 trials
  • 100% LL, 80 pellets

• Rat 2 makes 40 LL choices and completes 48 trials
  • 83.33% LL, 88 pellets
Measurements of Food Earning

• Percent of possible food earned on choice trials
  • 48 free choice, so maximum food is 96 pellets

• Total trials completed

• Food earning efficiency
  • Percent LL choices
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

**Impulsive Choice: 0 months**
- SS = 5→10→20 s, 1 p
- LL = 30 s, 2 p

**Impulsive Choice: 9 months**
- SS = 5→10→20 s, 1 p
- LL = 30 s, 2 p

**No Delay**
- "SS" = 0 s, 1 p (70 s ITI)
- "LL" = 0 s, 2 p (90 s ITI)

**Bailey et al. (2018)**
FI completed more trials at the longer SS delays
FI earned more food at all SS delays

Bailey et al. (2018)
Generalizability of Intervention Effects

Fixed Interval

“SS” = 10 s, 1 p

“LL” = 30 s, 2 p

No Delay

“SS” = 0 s, 1 p (70 s ITI)

“LL” = 0 s, 2 p (90 s ITI)

LL Delay Task

SS = 10 s, 1 p

LL = 15→30→45 s, 2 p

LL Magnitude Task

SS = 10 s, 1 p

LL = 30 s, 2→3→4 p

Bailey et al. (2018)
There were no intervention effects on trials completed or food earning

Bailey et al. (2018)
FI group completed more trials at the smaller LL magnitudes
FI group earned more food at the smaller LL magnitudes

Bailey et al. (2018)
Rats showed signs of possible delay intolerance (delay tasks) and satiety (magnitude task) in their food earning patterns.

The intervention combatted these effects in the SS delay and LL magnitude tasks.

- The intervention may have increased persistence and efficiency in food earning.

The intervention did not promote food earning in the LL delay task, even though LL choices were increased.

- The LL delay task (15→30→45) made the LL less attractive across phases.
- The SS delay (5→10→20) and LL magnitude (2→3→4) tasks made the LL more attractive across phases.
- Possible anchor effect of the preferred LL.
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

Impulsive Choice
- Short Standards (SS): 5 → 10 → 20 s, 1 p
- Long Standards (LL): 30 s, 2 p
- Peak trials: SS = 90 s, 0 p

Fixed Interval
- Short Standards (SS): 10 s
- Long Standards (LL): 30 s

Variable Interval
- Short Standards (SS): ~10 s (0-29 s)
- Long Standards (LL): ~30 s (0-59 s)

Impulsive Choice
- Short Standards (SS): 5 → 10 → 20 s, 1 p
- Long Standards (LL): 30 s, 2 p
- Peak trials: SS = 90 s, 0 p

Smith, Marshall, & Kirkpatrick (2015)
FI and VI Interventions: Timing

Both interventions decreased Timing Accuracy (Peak Time)

Both interventions increased Peak Rate

Timing Error ($\sigma$) No intervention effects

Smith, Marshall, & Kirkpatrick (2015)
Overall summary

Pathways to disease/disorder development

Impulsive Phenotype

Increased LL choices and increased food earning (mostly)
Decreased sensitivity to delay (discounting rate)

Time-based intervention

Impulsive
SS Responders
LL Responders
Self-controlled

SS Responder
Time-based interventions: Future Directions

- Identify and target specific mechanisms within the timing system
- Global versus local maximizing
- Develop human translational applications
  Implement interventions to alter pathways to disease
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