Investigating Age-Related Flexibility in Cognitive Effort Allocation

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P2-A-13
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INTRODUCTION

o Rewards can serve as powerful motivators for cognitive performance across age[1].
o When engaging in tasks that tax higher-order cognition, such as inhibitory control[1], task-switching[2], and reinforcement learning[3], some studies demonstrate that adults tend to show a performance "boost" when there are rewards at stake.
o However, other research has shown that for select cognitive control tasks, like the antisaccade task, children and adolescents show larger reward-related "boosts" than adults.[4,5]
  o This suggests that the **beneficial effects of reward on cognitive performance may show differential developmental trajectories for specific cognitive control processes.**
o Here, we investigate how rewards influence performance on **working memory** tasks in youth to discover how and when reward-related benefits emerge with age to facilitate this form of executive function.

METHODS

Study Design:

o N=187 (ages 10-20, mean 15.7±3.2 years; 99F) typically developing subjects completed the experiment online. The experiment consisted of three parts.
  o Part 1: baseline N-back task: 1-back, 2-back, and 3-back; 2 blocks each (Figure 1).
  o Part 2: cognitive effort discounting paradigm[6] (COG-ED; Figure 2) to index willingness to engage in 1-back, 2-back, or 3-back tasks for differing levels of reward.
  o Part 3: rewarded N-back task: 1-back, 2-back, and 3-back blocks were rewarded for each correct response (12 blocks rewarded 3¢ or 15¢ per trial) (Figure 3)
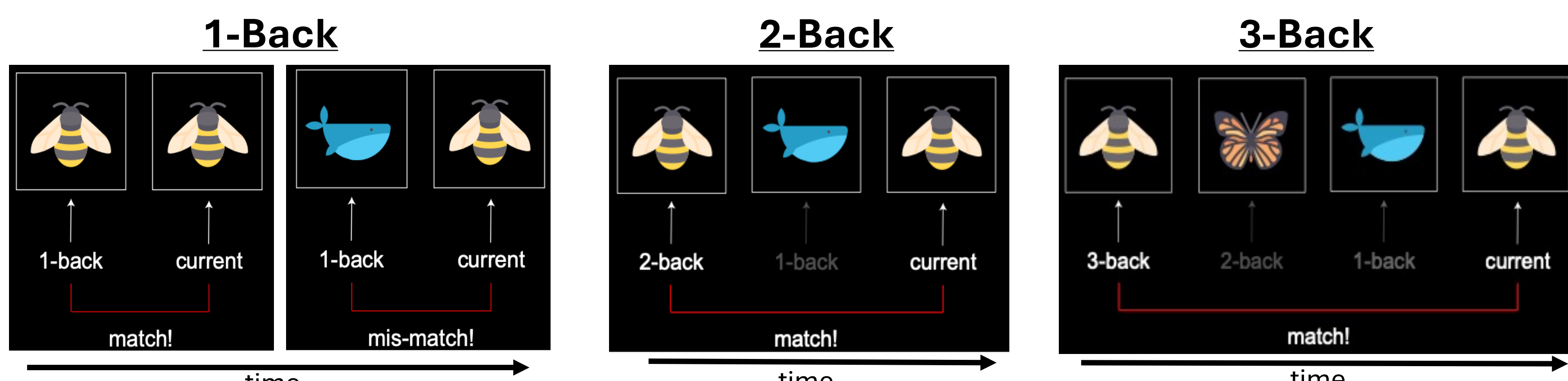
1-Back 2-Back 3-Back

Figure 1. Schema of N-Back Working Memory Task. Leftmost panel shows an example of a match and mismatch trial during 1-back, the middle panel shows a match trial during 2-back, while the rightmost panel shows a match trial during 3-back. Stimuli were presented one at a time in a pseudorandomized order on a black background screen for each trial.

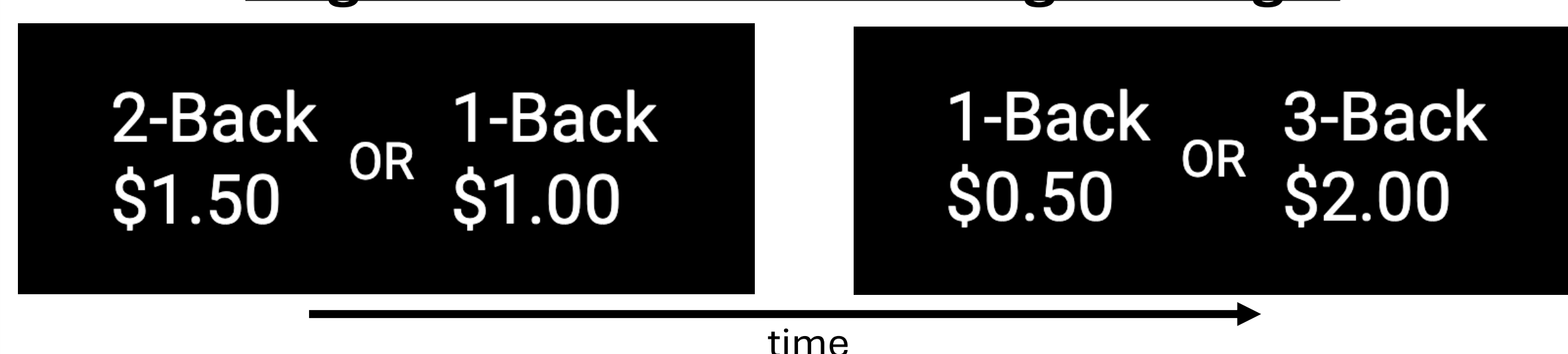### Cognitive Effort Discounting Paradigm

Figure 2. Schema of COG-ED Paradigm. The figure shows two examples of choices the subjects were presented with one at a time. Subjects completed 54 choices in total, with money and difficulty options updating dynamically based on previous choices.
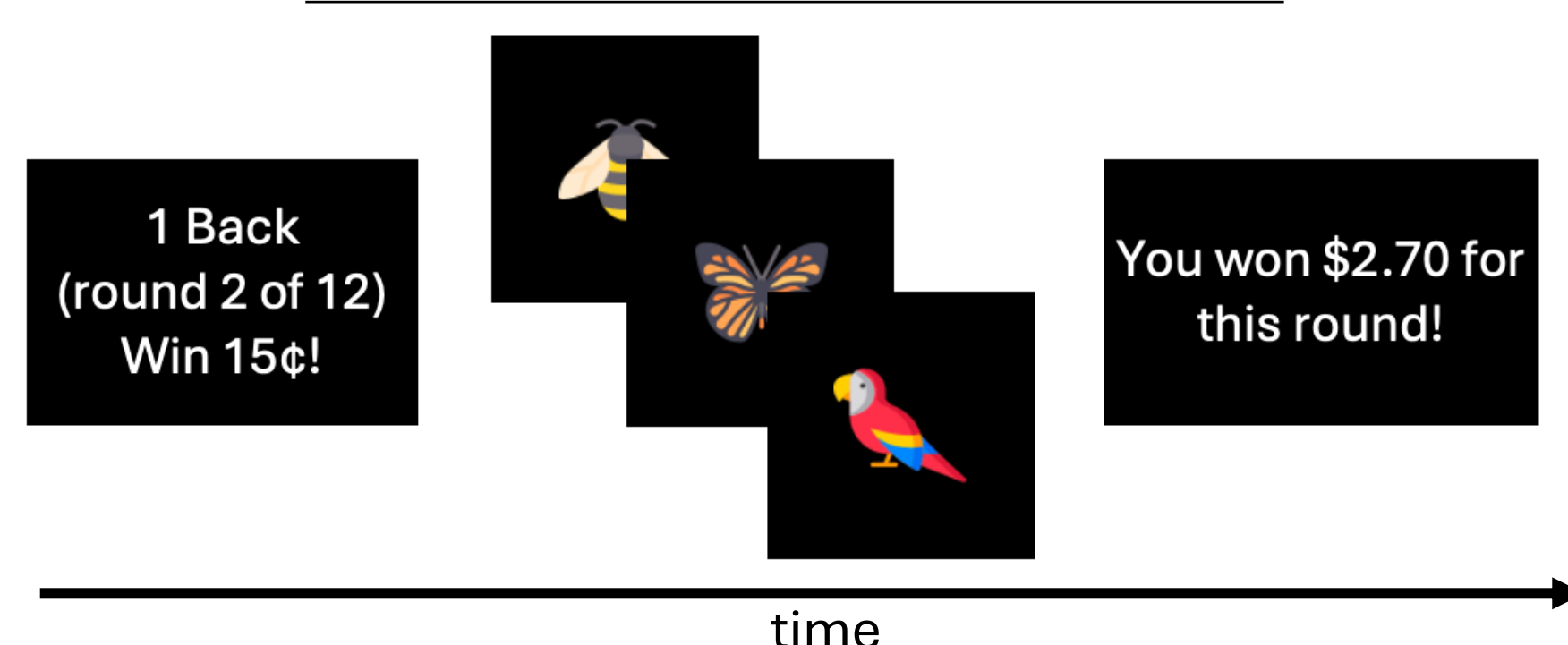
Rewarded N-Back Blocks

Figure 3. Schema of Rewarded N-Back Blocks. The figure shows an example of a 1-back block in the rewarded part of the experiment during which the participant could earn 15 cents for each correct response. Subjects were explicitly told what reward was at stake beforehand and were given feedback on their performance at the end of each block.

Preregistered Hypotheses:

1. We predicted that older participants would show the largest reward-related improvements. We anticipated that this effect would emerge with age, such that younger participants would be less likely to adjust performance when rewards are at stake.
2. We predicted that there would be no age differences in how participants made choices about engaging in cognitively difficult tasks.
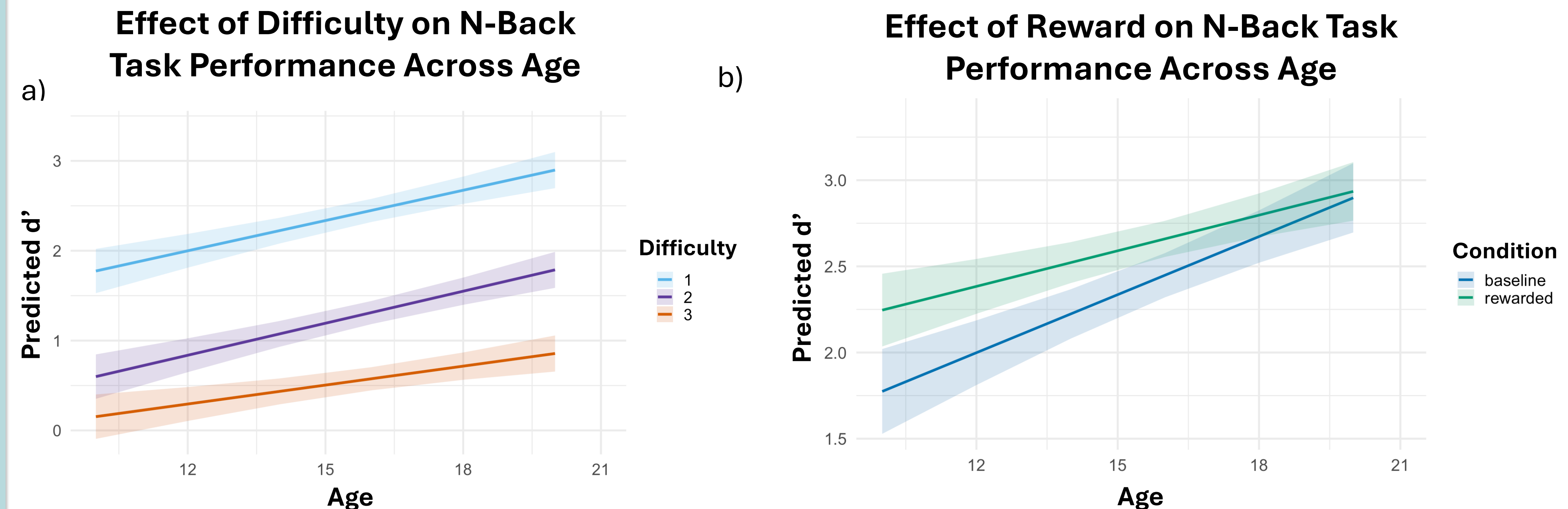
RESULTS

Figure 4. Working Memory Performance. a) Predicted d-prime scores plotted against age (continuous) with separate linear regression lines for each difficulty level of the working memory task. b) Predicted d-prime scores plotted against age (continuous) with separate linear regression lines for each experiment condition.

o Consistent with previous research[1], N-back accuracy decreased as n-back load increased (main effect of load, p<0.0001) (Figure 4a).
o N-back performance improved with age (main effect of age, p<0.001) (Figure 4a).
o The effects of age on N-back performance decreased significantly as difficulty increased (age by difficulty interaction, p<0.01) (Figure 4a).

o Reward boosted N-back performance overall (main effect of reward, p<0.0001) (Figure 4b). However, the effect of reward on performance was moderated by age (age by reward interaction, p<0.05) (Figure 4b).
o **Contrary to our hypothesis, younger participants showed the greatest boost in performance when there were rewards at stake**, while older participants exhibited an attenuated effect of reward on performance.
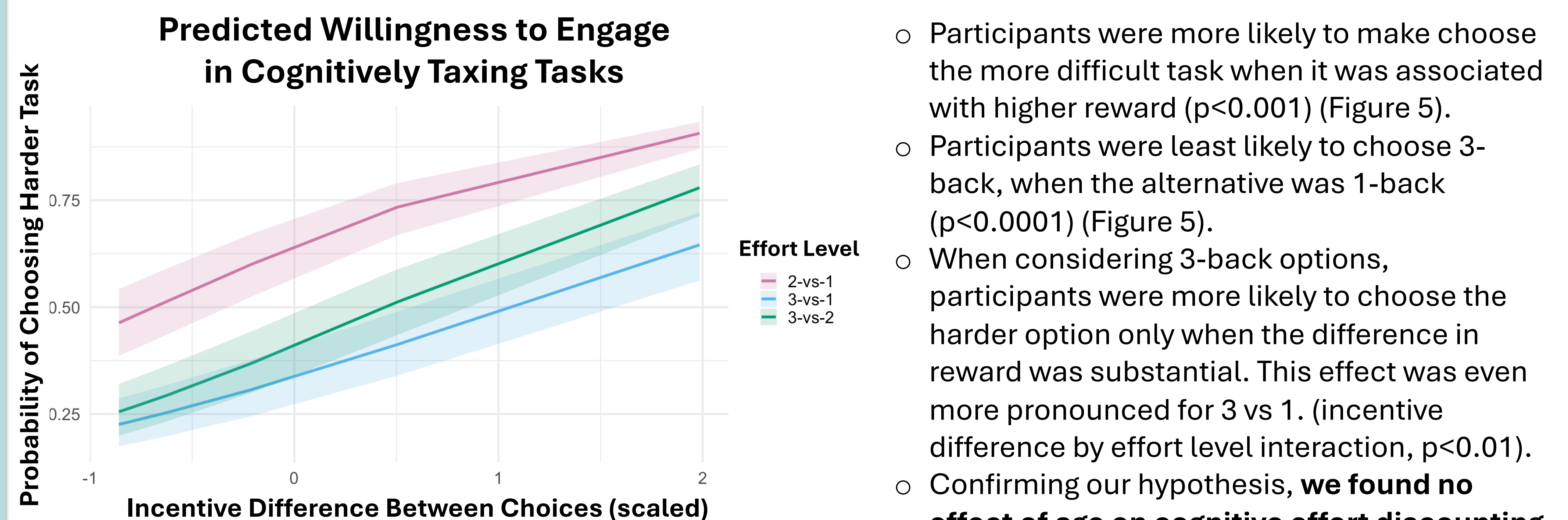

Figure 5. COG-ED Paradigm Results. Predicted probabilities of choosing harder task based on effort level and the incentive difference between choices. Age was included in the model but left out of visualizations due to non-significance.

o Participants were more likely to make choose the more difficult task when it was associated with higher reward (p<0.001) (Figure 5).
o Participants were least likely to choose 3-back, when the alternative was 1-back (p<0.0001) (Figure 5).
o When considering 3-back options, participants were more likely to choose the harder option only when the difference in reward was substantial. This effect was even more pronounced for 3 vs 1. (incentive difference by effort level interaction, p<0.01).
o Confirming our hypothesis, **we found no effect of age on cognitive effort discounting** (age by incentive difference by effort level interaction, p=0.6) (Figure 5).

DISCUSSION

o Our results reveal that for working memory, children and younger **adolescents benefit the most from prospective rewards**.
  o This suggests that the beneficial effects of reward incentives may vary across development depending on the cognitive domain and specific task features.
o Our results also reveal that despite age-related differences in N-back performance, **participants of all ages exhibit similar preferences about engaging in cognitively demanding tasks when reward is at stake**.
o Future research will investigate how this effect is related to aspects of metacognition and reward sensitivity.

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