Hard choices: Children's understanding of the cost of action selection

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Abstract

When predicting or explaining another person's actions, we often appeal to the physical effort they require; a person who works hard for something, for instance, must really like it (Liu, Ullman, Tenenbaum, & Spelke, 2017). But people are not only motivated to avoid physical effort; they also seek to avoid mental effort (Shenhav et al., 2017; Kool & Botvinick, 2018). Here, we ask whether mental effort enters into preschoolers' understanding of other people's actions. Across 4 experiments (N=112), we presented 4- and 5-year-old children with an agent (naive in Exp 1, 2 and 4, and knowledgeable in Exp 3) who can either move through a simple or complex maze environment with a specific goal (in Exp 1-3, to reach a play structure beyond the mazes, and in Exp 4, to practice solving the mazes). We found that children were sensitive to the physical and mental effort associated with more complex mazes, and to the trade-offs between effort and gain in skill. The intuition that choices impose costs on our bodies and minds appears to guide children's understanding of other people.

Keywords: intuitive psychology; cognitive development; decision-making

Introduction

Observing other people try hard tells us something about their desires, beliefs, competence, and what is worth trying for ourselves. All of these abilities rely on the the basic intuition that actions carry cost in the first place. This intuition is an early-emerging component of our human social intelligence: Infants, children, and adults consider the physical effort behind other people's actions as one variable in their plans to maximize utility (Jara-Ettinger, Gweon, Schulz, & Tenenbaum, 2016; Gergely & Csibra, 2003; Baker, Saxe, & Tenenbaum, 2009), and use how hard people try to infer their goals, beliefs, competence, and the value of effort in general (Jara-Ettinger, Tenenbaum, & Schulz, 2015; Baker, Jara-Ettinger, Saxe, & Tenenbaum, 2017; Leonard, Lee, & Schulz, 2017; Liu et al., 2017).

Is our understanding of action cost restricted to the physical exertions of body, or does it also encompass the costs of mental exertion? Everyday activities like thinking, writing, and learning are not physically costly (in fact, our bodies are usually still when engaging in them), but they incur a similar subjective disutility–in other words, a sense of exhaustion. More specifically, cognitive operations like loading information into working memory, transforming and maintaining it over long delays, and task switching–in other words, all the elements of rational planning–carry an intrinsic cost (Kool & Botvinick, 2018; Shenhav et al., 2017; Westbrook & Braver,

2015). Because of this cost, we do not always engage in rational planning; sometimes we use computationally cheaper heuristics, such as selecting actions proportional to their historical rewards. Experiments show that while people often often avoid costly rational planning, they become more likely to bear this cost when it is associated with a sufficiently large prospect of reward (Kool, Gershman, & Cushman, 2017).

What is the role of mental effort in our analysis of other people's actions? Do we assume that mental effort is costly? Do we assume that others would seek to avoid mental effort, all else being equal? Some recent research offers circumstantial evidence in adults (Gershman, Gerstenberg, Baker, & Cushman, 2016): When participants are asked what someone with a strong habit (e.g., to take a certain route to work, or turn a doorknob clockwise) will do in a new situation, they respond that the person is likely to rely on habit, especially under time pressure. This is consistent with the possibility that adults associate cognitive effort with model-based control, and use this association to predict and explain other people's actions.

There is, however, strong reason to believe that the ability to represent and reason about mental effort develops slowly over childhood. Although preschool-aged children understand that other people have emotional states, perceptions, beliefs, and knowledge (Wellman, 2002), they do not reliably know when people are thinking, struggle to make reasonable inferences about what they might be thinking about, and do not reliably report the content of their own thoughts (Flavell, Green, & Flavell, 1995). Furthermore, children are relatively poor at monitoring their own comprehension, memory, and learning, at least in ways that can be measured through explicit questioning (Flavell, Friedrichs, & Hoyt, 1970). If the ability to monitor one's own cognition develops slowly, then children may come to reason about the role of mental effort in others' plans at a later age than they reason about physical effort in these plans.

This paper presents a case study of the developmental origins of reasoning about mental effort. Specifically, we ask whether children understand that making choices can lead to both physically and mentally costly outcomes, and whether they understand the trade-offs people make between effort and reward in the context of learning.
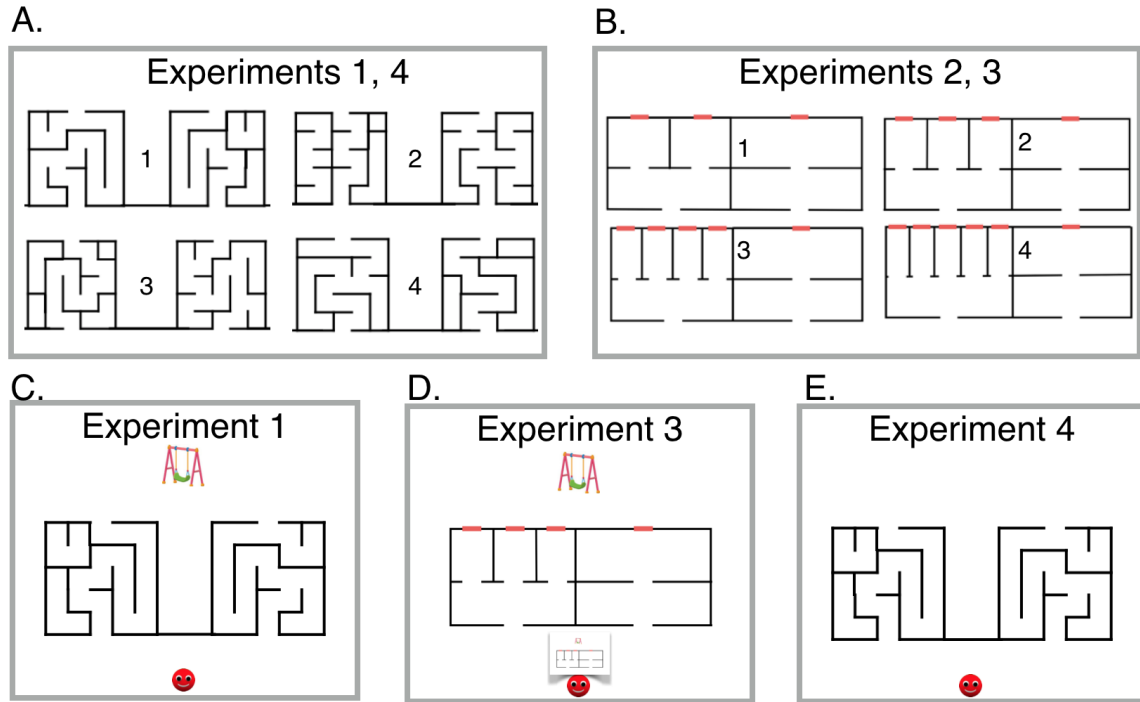
Figure 1: All mazes shown to participants on test trials in (A) Experiments 1 and 4, and (B) Experiments 2 and 3, as well as examples of individual trials from (C) Experiment 1, where a naive agent had the goal of getting to a specific location (D), Experiment 3, where a knowledgeable agent had the goal of getting to a specific location, and (E) Experiment 4, where a naive agent had the goal of getting better at solving mazes.

Experiment 1

In Experiment 1, we investigated whether young children whose attention is drawn to the difficulty of various mazes will choose easier rather than harder mazes for another agent to navigate.

Methods

Participants N=32 children (20 girls, Mean age = 58.94 months, range = 49.63-70.67 months) were included in our final sample of participants. All were recruited through a database of participants in the Boston area, participated at the Harvard Lab for Developmental Studies with the written consent of their parents, and received a small gift and travel compensation for their participation. One participant was excluded and replaced in our sample due to experimenter error. All data collection methods and procedures were approved by the Committee on the Use of Human Subjects at Harvard University. We chose our sample size based on a power analysis from a pilot study. For a pre-registration of the methods and analysis for this experiment, see https://osf.io/fx8yt/.

Materials and Procedure We built our maze stimuli using an online maze generator (http://www.mazegenerator.net/), using a width and height of 5 (4 mazes from test trials) or 6 (1 maze from introduction), an inner width and height of 0, an E-value of 50 (parameter that controls length of solution,

relative to size of maze), and an R-value of 50 (parameter that controls length of dead ends subpaths). For the test trials, we selected 4 mazes that had at least 1 wrong turn, with 1 and only 1 solution, hereafter the harder' or more complex' mazes. To generate the simpler versions of these mazes, we added walls blocking all wrong turns, leaving only one available path through the maze. Throughout the experiment, each complex maze was always presented with the simpler version of itself flipped across the vertical axis. See Figure 1A. We presented all experimental materials using Keynote.

During the introduction to the experiment, children saw an animated agent, Bob, travel through an easier and harder maze. The agent's actions were realistic: he traveled through the easier maze without pause, but reached 2 dead ends in the harder maze before finding the solution. Children were asked Which maze took longer to go through?" and Which maze was harder to go through?" with feedback to check and reinforce their understanding of these scenes (e.g., "Yup, that one is harder!" or "Actually, *this* one is harder because it has more paths and ways to get lost").

In Experiment 1, children were told the following cover story: *Bob is at a playground and needs to go through mazes to get to things he wants to play with. He wants to play with as many things as possible before having to go home. He needs your help because he doesn't know anything about these mazes.*

On each test trial, Bob faced a choice between an easier and harder maze that lead to a piece of playground equipment (swings, monkey bars, slide, and a seesaw). Children were first asked to identify the easier (2 trials) or harder (2 trials) maze with feedback. Then, children were asked to help the agent choose which way to go. After participants chose a maze, they were asked to provide explanations for their response. Children viewed a bouncing animation of the agent next to his goal after every test trial, regardless of how they answered, and did not receive feedback for their choice.

We counterbalanced the order of the 4 maze pairs and the left-right position of the easier/harder maze, resulting in 8 different conditions of the procedure. The experiment lasted about 5 minutes.

Data and analysis   All comprehension checks and test trials were coded on-line, and then checked offline from videos of the testing session.

We used the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) in R (Team, 2015) to implement all generalized linear mixed effects models (GLMMs). All models with repeated measures included a random intercept for participant identity and maze identity. We used the ggplot2 package (Wickham, 2009) to produce Figure 2. The results sections of this paper were written in R Markdown (Allaire et al., 2014) to enhance reproducibility.

Results

In the introductory phase, prior to any feedback, children correctly identified the more difficult maze at a rate of 0.688, and the maze that would take longer to travel through at a rate of 0.969. During the test phase, which included feedback, children correctly identified the more difficult room at a rate of 0.586.

Our main question was whether children would preferentially choose the easier maze for the agent to travel through. We found that during test trials, children were more likely to select the easier maze than the hard maze, 95% confidence interval (CI) [2.262,10.05], B(SE)=4.932(2.526), z=1.952, p=0.026, one-tailed, OR=138.64, model syntax: `response ∼ 1 + (1|subj) + (1|maze)`. Removal of influential cases yielded similar results. See Figure 2.

Discussion

Building on previous findings that infants and children expect agents to minimize the physical effort of their actions (Gergely & Csibra, 2003; Liu et al., 2017), the results of Experiment 1 suggest that children choose lower-effort tasks for others. Nevertheless, the question remains whether children were responding to the physical or the mental effort demands of the complex mazes. The more complex mazes presented a greater planning challenge for the mind, but were also associated with greater travel time and distance (variables that determine physical effort). We conducted Experiment 2 to ask whether children understand that actions can impose cognitive effort in the absence of differences in physical effort.
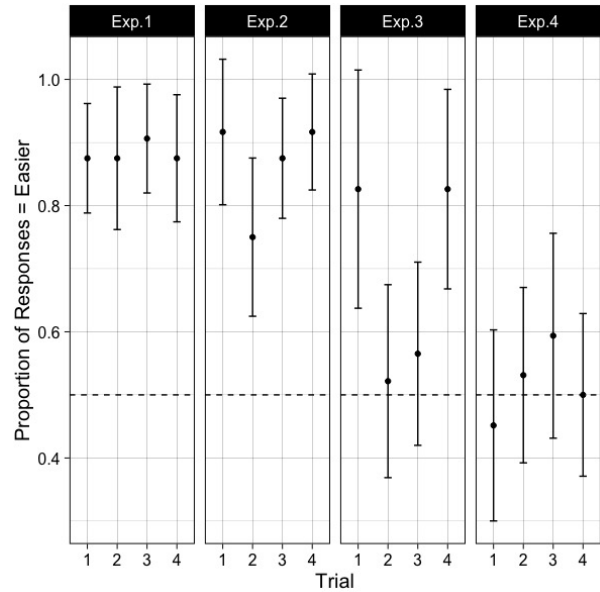

Figure 2: Proportion of choices for the easier maze or room during test trials (4 trials per participant; N=447 responses) across Experiments 1-4. Error bars indicate within-subjects 95% confidence intervals.

Furthermore, Experiment 1 asked children to choose a maze for an agent who was unaware of the effort involved in each choice, but did not ask children to predict which maze a knowledgeable agent would choose for themselves. We conducted Experiment 3 to ask whether children predict the actions of knowledgeable agents the same way they choose to help naive agents.

Lastly, Experiment 1 leaves open the question of whether children always regard mental and physical effort as negative, or whether they understand that harder actions can sometimes generate positive value. Thus, we conducted Experiment 4 to ask whether children appreciate the value of effort in the context of learning.

Experiment 2

In Experiment 2, we asked whether children appreciate that making a decision carries a unique cost, even when equating for physical effort across decision contexts. For a preregistration of the methods and analysis of this experiment, see https://osf.io/9dr7m/.

Methods

Participants   N=24 children (14 girls, Mean age = 61.09 months, range = 48.5-71.43 months) were included in our final sample of participants. This sample size was chosen based on a power analysis from Experiment 1. One participant was excluded and replaced in the final sample due to parental interference.

Materials, Procedure, and Analysis Experiment 2 differed from Experiment 1 in three ways. First, the mazes from Experiment 1 were replaced with rooms (see Figure 1B). Pairs of rooms differed in the number of choices available: The more complex room featured multiple hallways for the agent to choose from, and the simpler room consisted of only one path. To equate for the dead ends, we designed these rooms so that all hallways were direct exits; regardless of whether the agent chose the easier or harder room, the agent would exit the first hallway she chose, reaching her goal. To prevent children from reasoning about the agent's line of sight through the rooms, we covered each outlet with a door, which opens only when the agent approaches it. Like in Experiment 1, children were told that the agent was naive about the contents of the rooms, and had the goal of reaching something beyond them. Second, during the introduction of the experiment, the agent moved through the easier and harder room in exactly the same way. This differed from Experiment 1, where the agent took several wrong turns in the harder maze. Third, before each test trial, children were asked to point at the room the agent thinks is harder or easier (2 questions of each kind), and which room the agent thinks has more or less choices (2 questions of each kind) with feedback.

Results

During the introduction to the experiment, prior to any feedback, children correctly identified the more difficult room at a rate of 0.667, and correctly identified the room with more choices at a rate of 0.917. During the test phase, which included feedback, children correctly identified the harder/easier room at a rate of 0.896, and the room with more/less choices at a rate of 0.667.

As in Experiment 1, children were more likely to select the easier room for the agent to travel through, 95% CI [2.278,13.514], B(SE)=7.432(2.871), z=2.588, p=0.005, one-tailed, OR=1689.047[1]. Removal of influential cases yielded similar results. Children's responses did not differ between Experiments 1 and 2, 95% CI [-3.057,2.364], B(SE)=-0.35(1.249), z=-0.28, p=0.779, two-tailed, OR=0.705[2]. See Figure 2.

Discussion

In Experiment 2 we asked whether children appreciated differences in decision complexity between two situations matched for physical path features like travel length and dead ends. As in Experiment 1, children discriminated between these decision structures and chose the simpler option for the naive agent. Together, Experiments 1-2 show that children appreciate the cognitive cost that enters decision-making. Nevertheless, it is less clear whether children expect other agents to willfully minimize their own mental effort, when asked to make a prediction about what a knowledgeable agent would do. Experiment 3 addresses this question.

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[1]model syntax: `response ~ 1 + (1|subj) + (1|maze)`
[2]model syntax: `response ~ experiment + (1|subj) + (1|maze)`

Experiment 3

In Experiment 3, children predicted the choice of a knowledgeable agent in the same physical situations as in Experiment 2. For a pre-registration of the methods and analysis of this experiment, see https://osf.io/jyag8/.

Methods

Participants N=24 children (9 girls, Mean age = 60.27 months, range = 48.83-70.7 months) were included in our final sample of participants. This sample size was chosen based on a power analysis from Experiment 2. One participant was excluded due to experimenter error.

Materials, Procedure, and Analysis Experiment 3 was identical to Experiment 2 except that instead of helping the agent, children were asked to predict which room the agent will pick to go through in order to reach the goal, given that he knows everything about both of the rooms. To convey that the agent was knowledgeable, the agent on each test trial always had a map of the two rooms, and children were told explicitly that he knows everything about these rooms". See Figure 1D.

Results

In the introduction to the experiment, prior to any feedback, children correctly identified the more difficult room at a rate of 0.375[3], and the room with more choices at a rate of 0.792. During the test phase, which included feedback ("Yup that's right!" or "Actually, *this* room is easier/harder because he doesn't have to think about where to go") children correctly identified the more difficult room at a rate of 0.781 and the room with more/less choices at a rate of 0.698. As in Experiments 1 and 2, children were more likely to select the easier room for the agent to travel through, 95% CI [-0.296,2.642], B(SE)=1.026(0.598), z=1.716, p=0.043, one-tailed, OR=2.789[4]. Removal of influential cases yielded the same results. However, this effect was significantly weaker than the responses of children from Experiment 2, 95% CI [-4.7,-0.833], B(SE)=-2.397(0.914), z=-2.623, p=0.009, two-tailed, OR=0.091[5]. See Figure 2.

Discussion

In Experiment 3, we asked whether children expect knowledgeable agents to choose to minimize the mental effort of their actions. While we found a positive result, this effect was weaker than when children were asked to help a naive agent in identical environments. There are several possible interpretations of this finding. First, the agent's knowledge about the environments in Exp 3 could have affected children's responses: If a rational agent faces a false choice and knows it, and has a map of the rooms and has already analyzed the

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[3]We too are puzzling over why this rate was lower than .5, and lower than in the other experiments.
[4]model syntax: `response ~ 1 + (1|subj) + (1|maze)`
[5]model syntax: `response ~ experiment + (1|subj) + (1|maze)`

choice structure of the two rooms, she may choose randomly. It is also possible that children's expectations about how others spend their mental effort is truly noisier than their intuitions about what is optimal. Regardless of these open questions, Experiments 2-3 provide evidence that children expect other agents to minimize the mental effort of their actions, both when predicting their actions, and when recruited to help them choose an action.

Experiment 4

In Experiment 4, we ask whether children appreciate the tradeoffs between mental effort and information gain. In other words, do children understand that sometimes, it is worthwhile to think and work hard? For a pre-registration of the methods and analysis of this experiment, see https://osf.io/w3kh9/.

Methods

Participants N=32 children (17 girls, Mean age = 61.72 months, range = 50.0-71.0 months) were included in our final sample of participants. This sample size was chosen based on a power analysis from Experiment 1. Two participants were excluded and replaced in the final sample, 1 for not responding to any test trial questions, and 1 for experimenter error.

Materials, Procedure, and Analysis Experiment 4 was identical to Experiment 1, except that children were told a different cover story: *Bob wants to learn as much as he can about mazes. Which maze should he go through if he wants to practice solving mazes?* Children were asked what they thought the word practice' meant (19/32 produced passable definitions, like learning something you don't know how to do" and doing something until you know it so much"), and all children were told that to practice meant to try and try again so that you can get better at something". All goals were removed from test trials, and on each trial, and as in Exp 1-2, children were asked which way Bob should go.

Results

During the introduction to the experiment, prior to any feedback, children correctly identified the more difficult maze at a rate of 0.969, and correctly identified the maze that took a longer time to navigate at a rate of 0.875. During the test phase, which included feedback (e.g., "Yup, that one is harder!" or "Actually, *this* one is harder because it has more paths and ways to get lost"), children correctly identified the harder/easier room at a rate of 0.7086.

In contrast to Experiment 1, children in Experiment 4 did not preferentially choose the harder or easier room for the agent, 95% CI [-0.627,0.999], B(SE)=0.15(0.354), z=0.424, p=0.672, two-tailed, OR=1.162[6]. Removal of influential cases yielded similar results. As predicted under the hypothesis that children understand that effort trades off against increases in skill, their tendency to choose the easier maze in Experiment 4 was substantially lower than in Experiment

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[6]model syntax: response ∼ 1 + (1|subj) + (1|maze)

1, 95% CI [-4.368,-1.503], B(SE)=-2.936(0.731), z=-4.016, p<.001, one-tailed, OR=0.053[7]. See Figure 2.

Results, Experiments 1-4

Effects of experimental manipulations First, we asked which manipulations affected children's responses across all experiments. We found that children chose the easier vs harder action at comparable rates when shown the mazes from Experiments 1 and 4, and the rooms from Experiments, 2 and 3, 95% CI [-0.57,0.87], B(SE)=0.15(0.367), z=0.409, p=0.682, two-tailed, OR=1.162, that children were more likely to choose harder environments for a naive (Exp 3) than a knowledgeable agent (Exp 1, 2, 4), 95% CI [-1.566,-0.117], B(SE)=-0.842(0.369), z=-2.278, p=0.023, two-tailed, OR=0.431. Finally, we found that children were more likely to choose the harder environment when the agent had a learning goal (Exp 4) than an efficiency goal (Exp 1-3), 95% CI [0.793,2.122], B(SE)=1.457(0.339), z=4.298, p<.001, two-tailed, OR=4.293[8].

Role of feedback To address a concern that children's response to the test questions were influenced by the feedback they received during comprehension checks, we asked whether children's comprehension in Experiments 1-4 was different before they received any feedback (during the introduction) and after they began receiving feedback (during test trials 1-4). We found that children responded similarly prior to and after feedback (and if anything, performed less well with feedback), 95% CI [0.845,2.26], B(SE)=-0.243(0.186), z=-1.306, p=0.192, two-tailed, OR=0.785[9].

We also asked whether children's response to the main test question changed across the 4 trials of the experiment. If their responses were influenced by reinforcement during the comprehension checks, these responses should shift towards the direction of the hypothesis over the 4 trials. We tested this by fitting a model using Helmert contrasts, comparing children's responses on each test question (Which way should / will Bob go?") with their average responses on all preceding trials. Relative to all preceding trials, children did not clearly shift their response on trials two 95% CI [-0.669,0.036], B(SE)=-0.316(0.18), z=-1.76, p=0.078, two-tailed, OR=0.729, three 95% CI [-0.145,0.263], B(SE)=0.059(0.104), z=0.567, p=0.57, two-tailed, OR=1.061, or four 95% CI [-0.061,0.235], B(SE)=0.087(0.076), z=1.149, p=0.251, two-tailed, OR=1.091[10]. See Figure 1.

Discussion

Across Experiments 1 and 4, we found that children were more likely to choose a costly action in a context where the

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[7]model syntax: response ∼ experiment + (1|subj) + (1|maze)
[8]model syntax: response ∼ maze.or.room + knowledge + goal + (1|subj) + (1|maze) + (1|experiment)
[9]model syntax: response ∼ phase + (1|experiment)+ (1|subj)
[10]model syntax: response ∼ trial + (1|subj) + (1|experiment)

actor's goal was to improve their planning abilities, versus when their plans were means to an end. Our findings show that children appreciate the trade-off between effort and information gain that working and thinking hard can generate.

General Discussion

Across four experiments, we asked whether children are sensitive to the mental and physical consequences of action selection in the context of mazes and rooms. Building on previous evidence that young children expect other people to minimize the physical cost of their actions (Gergely & Csibra, 2003; Liu & Spelke, 2017), we found that children assume complex maze environments are costly (relative to simpler ones), and that having to make choices is costly (relative making no choices). We also found that children do not expect agents to minimize effort in all situations, but instead appear to understand that trying hard is more likely to generate increases in knowledge and skill.

Within the limits of our experimental context, these results begin to reveal how young children reason about other's subjective mental effort costs. Specifically, in these experiments, children appear to place a cost on the process of action selection. This comports with a large literature showing that action selection by planning is, indeed, experienced by most people as costly (Kool & Botvinick, 2018; Westbrook & Braver, 2015; Shenhav et al., 2017). Nevertheless, the mechanisms by which children read out judgments of difficulty and use them to make predictions are not explored in this paper. In the domain of physical effort, past work suggests that even young infants represent action cost as force applied over a path, rather than as any single perceptual feature that correlates with more or less effortful actions (Liu et al., 2017). What information supports similar judgments in the domain of mental effort? Furthermore, it is unclear how much or how little children rely on processes of simulation to solve the tasks in our experiment. Most of the preschoolers in our sample probably came into the lab with prior experience solving mazes, and many of them traced paths through the mazes as part of their explanations for why they answered the way they did. Thus, one important remaining question is what role our experiences of choosing, thinking, and learning play in the development of our understanding of mental effort.

Of course, action selection is not the only costly step of rational planning, or the only difference between habits and plans. Our results thus suggest important new directions for future research. For instance, do children understand that the closer 2 options are in utility, the harder it is to choose between them, or that habits are lower in cost than plans? Our findings also opens the door to studies of children's intuitive theories of other people's and their own knowledge and learning. For instance, do children understand that learners have an optimal zone of task difficulty in which to gain knowledge? Future work in this area can address the many open questions regarding how we conceptualize the mental lives of other people, and its development.

Acknowledgments

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