

Sensitivity to the instrumental value of agency increases across development

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Abstract

People of all ages value having agency, the opportunity to exert control over their environments. However, there are situations where the costs of exerting control exceed its benefits. It is not well understood how individuals develop the ability to evaluate the costs and benefits of agency. Here, we used a novel probabilistic reinforcement task to examine developmental changes in sensitivity to the utility of agency. Participants encountered choices between two bandits in three different contexts in which the utility of control varied. Participants could either accept a variable offer amount and have the computer choose between the bandits for them or reject the offer and choose between the bandits themselves. We found that participants across age tended to overvalue control. However, participants also demonstrated sensitivity to the utility of agency, such that they preferred to make their own choices when doing so had higher instrumental value. Sensitivity to the utility of agency increased with age, such that older participants were more likely to adaptively give up their agency when agency had little value.

Keywords: reinforcement learning; utility of agency

Introduction

Individuals of all ages tend to value having agency, the capacity to causally influence their environments. However, exercising control can be costly, requiring time and mental resources (Bobadilla-Suarez et al., 2017; Ackerlund et al., 2015; Dunlap et al., 1994). Thus, to behave adaptively, individuals must consider the instrumental utility of agency, and choose to exercise control only in contexts in which the benefits of doing so outweigh the costs. Prior work has suggested that adults do choose to give up agency to maximize reward (Wang et al., 2021), but it remains unclear how sensitivity to the value of agency develops from childhood to adulthood. The present study aimed to investigate this question by examining how the relative contributions of intrinsic value and instrumental utility to the subjective value of agency may shift across development. To accomplish this, we designed a novel child-friendly paradigm that allowed us to measure participants' subjective value of agency in contexts where the utility of exerting control varied.

Methods

Participants and Task. 92 participants between the ages of 10 and 25 years completed a reinforcement-learning task (Figure 1) in which they repeatedly encountered three different rooms in an arcade, each of which had a pair of slot machines that were associated with fixed reward probabilities. In each room, participants decided to either choose a machine

themselves (exert agency) or accept a token offer and let the computer choose a machine for them (forfeit agency). The value of agency varied based on the reward probabilities of the slot machines and token offer amounts.

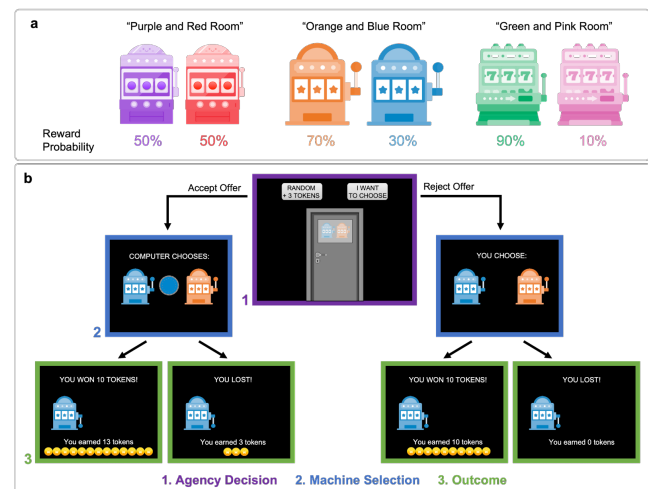


Figure 1. a. Each room had two slot machines paired together, where each machine probabilistically paid out a 10-token reward. One room was unpredictable with a 50% chance of yielding a reward on each machine, while the other two rooms were predictable with one machine having a 70 or 90% chance of yielding a reward and the other machine having a 30 or 10% chance of yielding a reward. Participants aimed to win as many tokens as possible by choosing the "luckier" machines. b. Each trial involved two stages of decisions. In the first *Agency Selection Stage*, they viewed the arcade room and were offered a variable number of tokens (between 0 and 6) to let the computer randomly select a slot machine for them or they could reject the offer and choose a machine themselves. If they chose agency, they proceeded to the second *Machine Selection Stage* where they manually selected a machine to play. If they accepted the offer, they played the machine selected by the computer.

Reinforcement Learning Models To analyze how participants learned and made decisions throughout the task, we fit several variants of a temporal-difference (TD) reinforcement learning model to our choice data. The model assumes that participants learn the values of the slot machines through experience. After selecting (or seeing the computer select) a machine and observing its outcome, participants update their estimated value of the bandit, such that:

$$V_{machine} = V_{machine} + \alpha(R - V_{machine})$$

, where R is the reward and α is the participant-specific learning rate. The model assumes that participants consider



these estimated machine values when making their first-stage choices. At this *Agency Selection Stage*, the value of choosing agency is simply:

$$\max(V_{machine1}, V_{machine2})$$

The value of giving up agency and letting the computer choose is:

$$0.5(V_{machine1}) + 0.5(V_{machine2}) + offer$$

At both decision stages, values are converted to choice probabilities via softmax functions with inverse temperature parameters that are fitted to each participant's data. Our best-fitting model included five free parameters: separate inverse temperature parameters for each decision stage (β_{Agency} , β_{Bandit}) and separate learning rates for trials in which the participants chose agency versus those in which they chose to have the computer make the second-stage choice (α_{Agency} , $\alpha_{Computer}$). In addition, an agencyBonus free parameter was added to the value of choosing agency to capture the intrinsic value that each participant placed on exerting control during the *Agency Selection Stage*. A positive value of this parameter reflects overvaluation of control, while a negative value indicates undervaluation of control.

Results

People overvalue agency across development

To investigate whether individuals across different age groups placed a different subjective value on exerting control, we computed the probability of choosing agency as a function of choice utility. Participants demonstrated a tendency to overvalue control, such that they often chose agency even when the value of control was 0 (Figure 2).

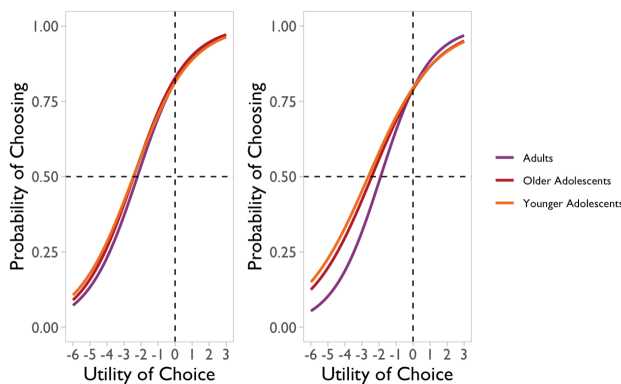


Figure 2: Probabilities of agency choice, plotted by age group for the first (left) and second (right) halves of the task. The VoC model was fit without age to show performance differences over time. Subject-level random effects were added, and probabilities were calculated using an inverse logit function. The intercept with the $x=0$ line is the probability of choosing agency with no utility, and the intercept at $y=.5$ reflects when participants were equally likely to choose or not choose agency. Negative x -intercepts indicate that participants were more likely to choose agency even when choice was costly. The steeper slopes for older participants reflect increased sensitivity to the utility of choice with age.

Predicting Agency Decision with Value of Choice (VoC)

First, we analyzed whether participants learned to select higher-reward machines when making their second-stage choices. We performed a mixed-effects logistic regression analyzing choice accuracy in *Machine Selection* trials in predictable arcade rooms as a function of Age, Trial, and Room predictability (90/10 vs. 70/30). Participants were more accurate in the 90/10 condition compared to the 70/30 condition ($X^2 = 20.86$, $df = 1$, $p < .001$), and their accuracy improved across trials ($X^2 = 60.59$, $df = 1$, $p < .001$). Having established that participants learned to select the more rewarding machines, we next asked whether they were sensitive to the value of control at the *Agency Selection Stage*. We computed the expected value (EV) for choosing between the machines (EV_{choice}) as the maximum expected value between the two machines on each trial, and the EV for letting the computer choose (EV_{comp}) as the average of the two machines plus the offer amount. We then computed the value of making a choice (VoC) as:

$$VoC = EV_{choice} - EV_{comp} = \max(EV_{left}, EV_{right}) - \left(\frac{EV_{left} + EV_{right}}{2} + offer \right)$$

We ran a mixed-effects logistic regression to analyze the influence of VoC, Trial, and Age on participants' agency decisions. Our findings indicate that participants were more likely choose agency on trials with higher VoC ($X^2 = 144.4$, $df = 1$, $p < .001$) and became better at using VoC information over the course of the task ($X^2 = 50.21$, $df = 1$, $p < .001$). We also found that older participants' agency decisions were more influenced by VoC ($X^2 = 4.17$, $df = 1$, $p = .041$) relative to younger participants, and that this age difference grew stronger across trials ($X^2 = 9.590$, $df = 1$, $p = .002$).

Modeling Results

Our results indicate that sensitivity to value of control increases over development. However, our VoC measure assumes that participants had perfect knowledge of reward probabilities from the start of the task, which may confound age differences in agency valuation with age differences in reward learning. In our reinforcement learning model, estimates of β_{Agency} reflect the strength of participants' sensitivity to the value of control, while accounting for differences in their learning of the machine values. We found that β_{Agency} significantly increased with age ($F(1, 90) = 4.60$, $p = .035$). We also examined the relationship between age and the agencyBonus parameter, which reflects participants' intrinsic valuation of agency. Here, we found no significant effect of age ($F(1, 90) = 1.23$, $p = .271$), suggesting that participants across our age range similarly overvalued control.

Conclusion

Our results indicate that individuals from childhood to young adulthood exhibit a similar tendency to overvalue control across different contexts. We observed no evidence that people place a greater or lesser subjective value on agency as they develop. Rather, our findings suggest that people increasingly rely on the instrumental value of choice to inform their decisions to exert control from childhood to early adulthood.

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