The Development of Superstitions in Uncontrollable Environment

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Abstract

Superstitions are false beliefs about causality and illusory control over outcomes. Although previous research has explored factors that influence superstitious beliefs, the cognitive processes underlying their formation remain unclear. We designed a task environment allowing free exploration of a vast number of actions with uncontrollable outcomes to understand the development of superstitions over experience. Participants (*N*=281) played a game where they attempted to produce rewarding keypress sequences across 100 trials with randomly assigned reward contingencies, reporting perceived reward probability and controllability. We found that perceived controllability increased non-linearly with reward rates, plateauing after 50%. Reward predictions and controllability showed a bidirectional feedback loop, reinforcing each other. Personality traits such as superstition proneness, locus of control, and schizotypy also influenced perceived controllability. Our results delineate how superstitious beliefs emerge from an interplay between environmental reward statistics, exploratory tendencies, and psychological traits, involving distorted perceptions of causality.

Keywords: Superstitious beliefs; Illusion of control; Decision-Making; Reward processing; Exploration

Introduction

Superstitions are a large set of false beliefs about causality, often related to an illusory control of luck (Langer, 1975; Vyse, 2020). Although superstitions are ubiquitous and relevant to our everyday lives, previous research has mainly focused on their historical and cultural background, individual differences, and influencing factors (see Ichino, 2020; Risen, 2016; Vyse, 2020). The cognitive processes underlying the formation and persistence of superstitions remain unclear.

The illusion of control, a common superstitious belief, has been studied typically with the contingency judgment task (Matute et al., 2015). Research has shown that participants often overestimate the associative strength even when given the null contingency. Such overestimation inflates when the probability of potential positive outcomes rises (Blanco & Matute, 2019; Kool, Getz, & Botvinick, 2013; Rudski, 2000), and when people have more personal and active involvement (Blanco, Matute, & Vadillo, 2011; Langer, 1975; Yarritu, Matute, & Vadillo, 2014). Real-life superstitions are diverse, but the typical task of illusory control limits the action repertoire of participants even in the active version. The relationship between explorative behaviors and superstitious beliefs is understudied. Moreover, how reward processing dynamically affects superstition has not been systematically assessed due to the limited reward probability conditions and infrequent measurement of beliefs of the typical design.

In this study, we aimed to investigate the formation of superstition in a freely explorable but uncontrollable environment and examine how reward processing and personality traits would influence superstition.

Methods

We recruited 150 English-fluent participants aged 18 to 44 online via Prolific. After filtering for inattention, each experimental condition retained approximately 28 participants (141 in total).

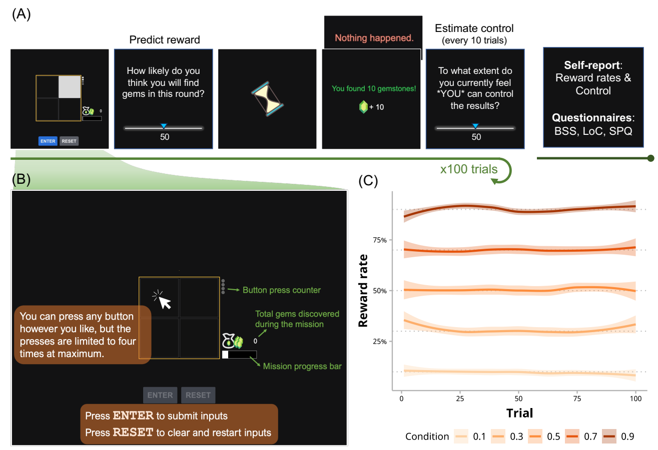

Figure 1: (A) Schematic of the experiment task. (A) Procedure of the task. (B) Keypress interface. (C) Five reward contingencies were used in the experiment. Colored lines are LOESS-smoothed.

We designed a 100-trial decision game to track the evolution of reward and controllability estimation (Figure 1). In each trial, participants submitted rewardable keypress sequences using any combination of four keys and predicted the likelihood of rewards. The outcome was revealed after a short wait. In every 10 trials, participants reported their perceived control over the outcomes. Unbeknownst to them, the outcomes were randomized and uncontrollable, reflecting different expected reward rates across five conditions (Figure 1C).

After the main task, participants reported their perceived controllability and reward rates. They also completed questionnaires including the Belief in Superstition Scale (BSS), Locus of Control Scale (LoC), and Schizotypy Personality Questionnaire (SPQ), which measure constructs closely linked to illusory control (Brugger, Dowdy, & Graves, 1994; Na et al., 2022; Yon, Bunce, & Press, 2020).

In a follow-up study, we recruited another 150 participants online (140 post-inattention check) for the *No in-task report* version of the task, which omitted in-task reward prediction or controllability estimation (cf., the *In-task report* version above).

Results

Reward processing and superstitions

We analyzed the participants' post-task reports of their controllability and perceived reward rates (Figure 2). Controllability was significantly higher in more rewarding conditions but did not simply increase linearly with reward rates, instead plateauing after a 50% reward rate. Moreover, we found strong evidence in favor of the distorted perceived reward rates over the actual reward rates to better predict the reported controllability ($BF_{10} = 11.13$). Participants overestimated the low reward rates and underestimated the high reward rates. The distortion was significantly more pronounced for those who reported higher controllability, particularly in low reward rate conditions ($\beta_{0.1} = 0.79$, $t = 4.32$, $p < .001$; $\beta_{0.3} = 0.33$, $t = 2.74$, $p = .011$; $\beta_{0.5} = 0.39$, $t = 3.51$, $p = .001$; $\beta_{0.7} = 0.05$, $t = 0.54$, $p = .59$; $\beta_{0.9} = -0.07$, $t = -0.80$, $p = .53$). Following this finding, we found that participants in the *In-task report* study had a more accurate estimation of reward rates and lower reported controllability, compared with those in the *No in-task report* study.

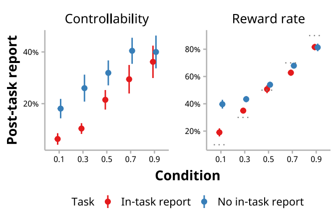

Figure 2: Post-task reports of perceived controllability and reward rate. Error bars are standard errors.

Then, we looked into the in-task reports of reward prediction and controllability from the *In-task report* task. Both in-task reward predictions and controllability estimation converged quickly into the experiment (Figure 3AB). We found participants would predict a higher rewarding probability for action if this action was the same as the last one ($M = 5.29$, $t = 5.53$, $p < .001$) or followed a winning outcome ($M = 6.03$, $t = 8.70$, $p < .001$), or interestingly this action was an attempted old action. Particularly, brand-new actions were assigned with an even lower reward probability than old ones in higher reward conditions (Brand-new×Condition: $F(4, 128.5) = 3.50$, $p = .009$; Figure 3C). This further indicated that the participants' choices in more rewarding conditions converged to a smaller but satisfying collection of action sequences. Each participant reported the current controllability estimation every 10 trials (i.e., nine reports per participant). We found the reward probability prediction over the 10 trials before controllability reports could significantly predict controllability ($\beta = 0.32$, $t = 6.63$, $p < .001$). Moreover, the reported controllability could predict the reward prediction over the next 10 trials, even controlling for the previous reward prediction. This might suggest a reciprocal causality between reward processing and controllability, which could contribute to the formation and maintenance of superstitions.

Exploratory tendency changes with environmental reward statistics

First, we counted action frequencies and calculated the entropy for each participant as the measure of exploration during the task (Figure 4A). We found that the action entropy was significantly higher in the 10% condition and decreased along with the increase of the condition reward rate. The participants

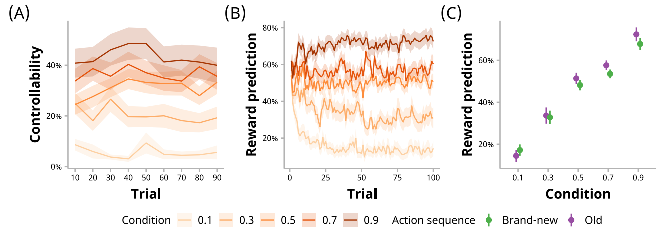

Figure 3: (A & B) In-task reports of controllability and reward prediction. (C) Reward prediction after a brand-new or old action sequence. Shaded areas and error bars are standard errors.

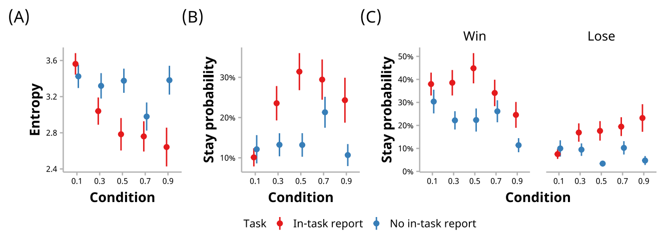

Figure 4: (A)Entropy of action sequences. (B) Probability of staying with the same action. (C) Stay probability following a win or loss. Error bars are standard errors.

who reported during the task also showed a lower entropy. We also found participants adopted a win-stay/lose-shift strategy, a heuristic to maximize their rewards: participants tended to stay with the same action after winning more than losing (Figure 4BC). This difference was less evident when the condition reward rates became higher, particularly in the 90% condition ($M_{\text{Win}} - M_{\text{Lose}} = 0.04$, $t = 1.34$, $p = .18$; other conditions: $M_{\text{Win}} - M_{\text{Lose}} > 0.153$, $ts > 5.33$, $ps < .001$). The participants of the *In-task report* study also had a higher staying probability overall. Together, these two measures suggested participants in higher reward conditions attempted a smaller selection of action sequences and were prone to stick with 'good old' actions.

Personality traits also predict superstitions

Furthermore, we conducted a comprehensive linear regression model that included action generation metrics, personality traits, and perceived reward rates to predict the post-task reported controllability. The analysis showed that apart from the reward rates, $P(\text{Stay}|\text{Win}) - P(\text{Stay}|\text{Lose})$ could significantly predict the controllability ($\beta = 0.14$, $t = 2.18$, $p = .030$) along with all the personality traits ($\beta_{\text{BSS}} = 0.15$, $t = 2.59$, $p = .010$; $\beta_{\text{LoC}} = -0.20$, $t = -3.53$, $p < .001$; $\beta_{\text{SPQ}} = 0.14$, $t = 2.52$, $p = .012$). The model suggested that when participants had a larger difference in staying probability after winning and losing, stronger beliefs in everyday superstitions, more internal locus of control, and more pronounced schizotypal traits, they felt they had more control over the task outcomes.

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References

Blanco, F., & Matute, H. (2019). Base-rate expectations modulate the causal illusion. *PLOS ONE*, *14*(3), e0212615. doi: 10.1371/journal.pone.0212615

Blanco, F., Matute, H., & Vadillo, M. A. (2011). Making the Uncontrollable Seem Controllable: The Role of Action in the Illusion of Control. *Quarterly Journal of Experimental Psychology*, *64*(7), 1290–1304. doi: 10.1080/17470218.2011.552727

Brugger, P., Dowdy, M., & Graves, R. (1994). From superstitious behavior to delusional thinking: The role of the hippocampus in misattributions of causality. *Medical Hypotheses*, *43*(6), 397–402. doi: 10.1016/0306-9877(94)90015-9

Ichino, A. (2020). Superstitious Confabulations. *Topoi*, *39*(1), 203–217. doi: 10.1007/s11245-018-9620-y

Kool, W., Getz, S. J., & Botvinick, M. M. (2013). Neural Representation of Reward Probability: Evidence from the Illusion of Control. *Journal of Cognitive Neuroscience*, *25*(6), 852–861. doi: 10.1162/jocn$_{a0}0369$

Langer, E. J. (1975). The illusion of control. *Journal of Personality and Social Psychology*, *32*, 311–328. doi: 10.1037/0022-3514.32.2.311

Matute, H., Blanco, F., Yarritu, I., Díaz-Lago, M., Vadillo, M. A., & Barberia, I. (2015). Illusions of causality: How they bias our everyday thinking and how they could be reduced. *Frontiers in Psychology*, *6*.

Na, S., Blackmore, S., Chung, D., O'Brien, M., Banker, S. M., Heflin, M., ... Gu, X. (2022). Computational mechanisms underlying illusion of control in delusional individuals. *Schizophrenia Research*, *245*, 50–58. doi: 10.1016/j.schres.2022.01.054

Risen, J. L. (2016). Believing what we do not believe: Acquiescence to superstitious beliefs and other powerful intuitions. *Psychological Review*, *123*(2), 182–207. doi: 10.1037/rev0000017

Rudski, J. M. (2000). Illusion of Control Relative to Chance Outcomes. *Psychological Reports*, *87*(1), 85–92. doi: 10.2466/pr0.2000.87.1.85

Vyse, S. (2020). *Superstition: A Very Short Introduction*. Oxford, New York: Oxford University Press.

Yarritu, I., Matute, H., & Vadillo, M. A. (2014). Illusion of Control: The Role of Personal Involvement. *Experimental Psychology*, *61*(1), 38–47. doi: 10.1027/1618-3169/a000225

Yon, D., Bunce, C., & Press, C. (2020). Illusions of control without delusions of grandeur. *Cognition*, *205*, 104429. doi: 10.1016/j.cognition.2020.104429