Early-life unpredictability modulates planning horizon in a structured foraging task

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Abstract:

Early-life unpredictability (ELU) and post-traumatic stress symptoms (PTSS) are associated with multiple long-lasting impacts on decision-making under uncertainty. However, it is unclear whether these effects are distinct and what specific aspects of the decision-making process are affected. Normative analysis has demonstrated that when navigating uncertain state-spaces, individuals should respond to their uncertainty by reducing their planning horizon, a prediction that we have previously confirmed. Here, we examine whether long-term experiences of unpredictability or trauma amplify this rational sensitivity to uncertainty within a structured decision-making task. 297 participants were tasked with completing a patch-leaving task with a complex state-space that required inferring latent structure, along with the Questionnaire of Unpredictability in Childhood (QUIC) and the Post-Traumatic Stress Disorder Checklist (PCL-5). Our results reveal that ELU is associated with a greater decline in planning horizon, specifically in response to task uncertainty, and that this effect does not extend to PTSS, consistent with a theoretical model specifying a critical period of sensitivity to associative unpredictability. Moreover, unpredictability in parental and physical environment appears to be the key factors influencing individuals' planning behaviors. The results highlight how ELU impacts specific decision-making components..

Keywords: early-life unpredictability; decision-making; memory-guided behavior; post-traumatic stress symptoms

Introduction

Early-life unpredictability (ELU) and trauma exposure are known to influence decision-making under uncertainty (Allen, 2023; Harpaz-Rotem et al., 2017; Xu et al., 2023). However, the specific decision-making components affected by adversity and its impacts on individual's level of uncertainty tolerance, remain unclear. Recent work has shown that ELU has no effect on choices within a standard patch foraging task but does increase information-seeking behavior in a reward-choice task with uncertain horizons (Xu et al., 2023). A theoretical model proposes that individuals who experience unpredictability during a critical period of plasticity should "discount" future rewards (Harhen & Bornstein, 2023b), and a recent finding in a foraging task with a complex structure found that individuals adjusted their planning horizons in response to in-task uncertainty (Harhen & Bornstein, 2023a), consistent with theoretical models of normative behavior in uncertain state-spaces (Jiang et al., 2015). An open question raised by these findings: Do experiences of adversity amplify this sensitivity, potentially indicating a fundamental difference in responses to or coding of uncertainty? If so, is this effect specific to adversity during early sensitive periods (Harhen & Bornstein, 2023b), or throughout the lifespan?

Here, we collected participants' foraging behavior, and self-report measures of ELU and lifelong trauma exposure. We then analyzed the underlying component processes using a model previously shown to identify behavior changes in response to task uncertainty. We examined how these self-report measures corresponded to an individual's sensitivity to task uncertainty, and whether it was distinct from a general tendency to discount the future rewards or difficulty learning the state-space.

Materials and Methods

Patch-Leaving Task The Harhen and Bornstein (2023a) patch leaving task assessed how people plan under uncertainty. 297 participants (142 females, 144 males, 2 others, 9 unknown, 46.86 ± 0.89 years old) were instructed to maximize treasure collection by making a serial of stay vs. leave decisions to mine on planets across five 6-minute blocks (Fig. 1A). The task simulated naturalistic environments, offering varying levels of environmental richness (Fig. 1B) and higher transition probability to the planet of the same type (Fig. 1C).

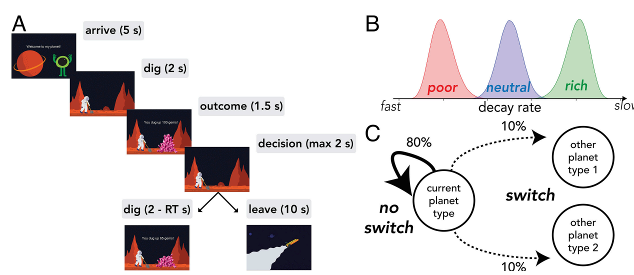

Figure 1: Patch-Leaving Task. (a) A serial of stay-leave decisions (b) Each planet type has a unique decay rate distribution. (c) Higher transition probability between the same type of planets.

Marginal Value Theorem and Overharvesting We compared participants' planet residence time (PRT) to the optimum PRT prescribed by MVT as a measure of overharvesting. Specifically, MVT prescribes that forager should leave the current planet when the local planet reward rate drops below the average reward rate of the environment, but it does not account for individual variation in learning the environment reward distributions.

Questionnaire of Unpredictability in Childhood (QUIC) is a 38-item self-report questionnaire that measures one's perceived unpredictability before the age of 18 (Glynn et al., 2019). 263 participants completed this measure, and the overall score is computed along with 5 subscale scores, with higher scores indicating greater early-life unpredictability (ELU).

Post-Traumatic Stress Disorder Checklist (PCL-5) is a 20-item self-report questionnaire providing individualized measures of post-traumatic stress symptoms (PTSS) (Weathers et al., 2013). 147 participants responded on a scale from 0 ("Not at all") to 4 ("Extremely") on how much they were bothered by each symptom. The total symptom severity score (max 80) is computed along with 4 subscale scores, with a higher score indicating more severe PTSS.

Adaptive Discounting Model The Adaptive Discounting Model (Harhen & Bornstein, 2023a) consists of two components: structure learning and uncertainty-sensitive adaptive discounting. Structure learning is modeled as an infinite mixture model. The model categorizes the current patch's type and infers the total number of patch types based on the sequence of rewards received. The number of possible patch types is dependent on the clustering parameter α. More concretely, a patch type can be added to the forager's representation with probability proportional to α, allowing for a flexible representation of environmental complexity (single type: $\alpha = 0$; multiple types: $\alpha > 0$). When foragers are uncertain about which cluster the current planet belongs to, and hence, the future rewards they'll receive on the current planet, it is rational for them to adjust their planning horizon by discounting future rewards proportionally (Jiang et al., 2015). The effective discount factor $\gamma_{effective}$ is implemented as a linear function of representational uncertainty U with the intercept γ_{base} and slope γ_{coef} (Eq. 1). A smaller $\gamma_{effective}$ (larger γ_{base} and/or γ_{coef}) indicates greater discounting in future rewards associated with leaving the current planet. The three parameters provide insights into individual's prior assumptions regarding environmental complexity and their subjective perception of uncertainty (e.g., sensitivity to uncertainty).

$$\gamma_{effective} = \frac{1}{1+e^{(-\gamma_{base}+\gamma_{coef}*U)}} \qquad (1)$$

Results

Individuals with higher ELU or QUIC scores exhibited higher discounting for future values associated with leaving the current planet, shortening their planning horizon in response to uncertainty. None of the parameters except for γ_{coef}, an uncertainty-sensitive discounting factor, significantly correlated with the QUIC total score, indicative of an individual's exposure to unpredictable childhood experiences (Fig. 2A, $\tau = 0.084$, $p = .048$; all other $p > 0.58$). Higher discounting of future rewards implies a greater chance of staying on the planet when faced with uncertainty about the current patch type. Indeed, individuals with higher γ_{coef} overharvested more when there was a switch in the patch type (Fig. 2B, $\tau = 0.126$, $p = .001$). We further decomposed the QUIC total score into five different subscores to identify the key factors influencing individuals' discounting behaviors. Notably, two subscales related to environmental unpredictability — parental and physical environments — positively correlated with γ_{coef} (Fig. 2C, parental environment subscore and γ_{coef}: $\tau = 0.154$, $p = .001$; Fig. 2D, physical environment subscore and γ_{coef}: $\tau = 0.16$, $p = .001$), while the other three subscales (parental involvement and monitoring, parental predictability, and safety and security) did not. Importantly, there is no effect of post-traumatic stress symptoms observed on participants' foraging behaviors (all $p > 0.13$).

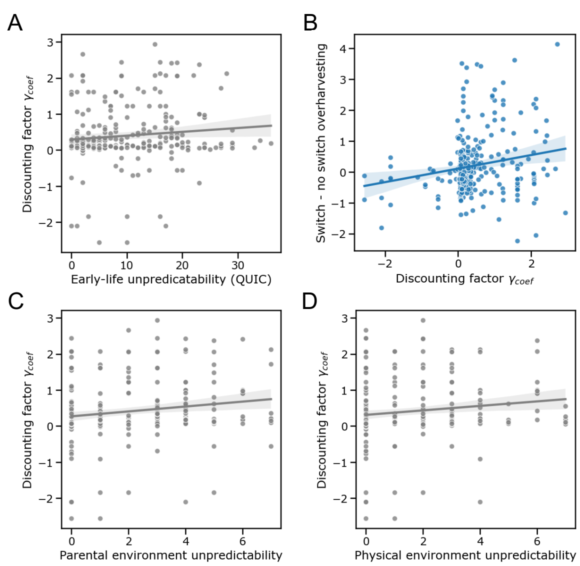

Figure 2: (a) Correlation between QUIC and γ_{coef}, (b) γ_{coef} and overharvesting, (c) parental environment unpredictability and γ_{coef}, and (d) physical environment unpredictability and γ_{coef}.

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