Absence of Systematic Effects of Trait Anxiety on Learning Under Uncertainty

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Abstract

Ignorance can be deadly, making learning essential to survival. However, learning also needs to be adjusted according to the prevailing uncertainty – with faster change or, in typical cases, a higher learning rate (LR), in environments that change quickly and a lower learning rate when the environment's latent state does not change. Failing to adjust the LR flexibly can lead to learning impairments – an affliction somewhat inconsistently found to affect behavior, particularly in individuals with high trait anxiety. We conducted five experiments (N=550 participants) using an online game-based variant of a predictive inference task to investigate whether high trait anxiety is associated with impaired LR adjustment. While finding model-based and model-agnostic evidence of uncertainty-related LR modulation across individuals, we did not find any relations to trait anxiety. We obtained consistent results in a control experiment with a binary reversal learning task. Using Bayes factors to test the null hypothesis, our results suggest that trait anxiety is not systematically associated with inflexible learning in uncertain and changing environments.

Keywords: anxiety; decision-making; learning; uncertainty; risk; volatility; computational psychiatry; Bayesian inference

Introduction

Learning about environments when uncertain is essential to decision-making and survival. Environments generate uncertainty in two critical ways: inherent irreducible outcome variability (risk) and unpredictable changes that reflect a true change in the latent state of the environment (the rate of which is quantified as volatility) (Behrens et al., 2007; Yu & Dayan, 2005).

From a conventional (albeit sometimes approximate) Bayesian perspective, uncertainty should regulate the extent of learning from prediction errors (PEs; the difference between newly observed outcomes and predictions; Bruckner et al., 2022; Nassar et al., 2010). How much is learned is quantified by the learning rate (LR), where completely replacing predictions with the last outcome corresponds to LR=1; and ignoring the last outcome corresponds to LR=0. When outcomes are risky, large PEs happen by chance and should be suppressed by setting a low LR. By contrast, in volatile environments, large PEs suggest potential change, which should be accommodated by having a high LR.

Several studies have suggested that clinical and trait anxiety are associated with an inability to adjust the LR flexibly (Aylward et al., 2019; Browning et al., 2015; Gagne et al., 2020; Wise & Dolan, 2020), or with faster switching between states (Zika et al., 2023). However, the exact relationship is not consistent across studies. Some studies found that anxious individuals use higher LRs, especially for negative PEs, leading to an overestimation of the probability of aversive events (Aylward et al., 2019; Piray & Daw, 2021). Other studies suggested that individuals with anxiety and depression adjust their LRs less flexibly to volatile environments (Browning

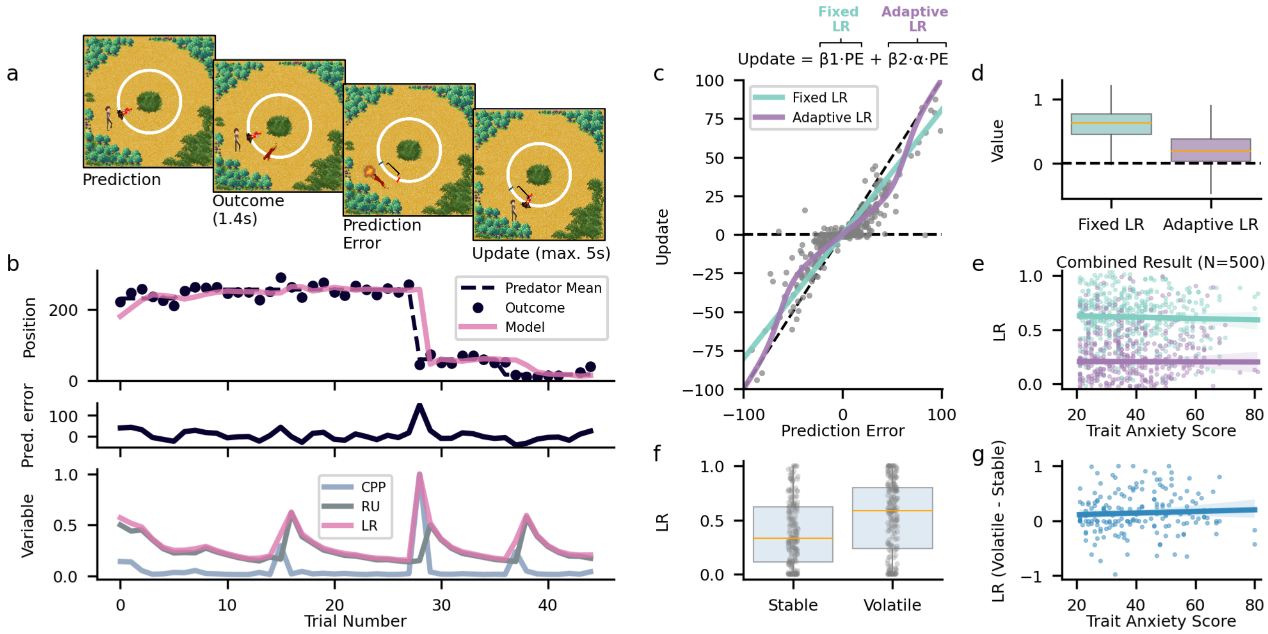

Figure 1: **Predator task and results a)** The predator task is a gamified predictive inference task, where participants save themselves from an attacking predator by placing a flame in its path. **b)** Predator attack locations are usually centered around a common position, but the exact location varies according to inherent risk and volatility in the environment (first panel). The model computes prediction errors (second panel) and scales them adaptively to update its predictions (bottom panel). **c)** Example data from one participant, showing the fits obtained with fixed and adaptive LRs. **d)** Regression analyses indicate that participants use a mixture of fixed and adaptive LRs to scale the influence of PEs on belief updating. **e)** Results from the predator task show no systematic association between trait anxiety and LRs. **f)** LRs in stable and volatile blocks of the binary reversal learning task. **g)** No systematic association between LR adaptation and trait anxiety scores in the reversal learning task.

et al., 2015; Gagne et al., 2020). Finally, another group of studies failed to find any anxiety-related learning impairments (Schindler et al., 2022; Ting et al., 2022).

Here, we systematically investigated whether higher trait anxiety is associated with impaired LR adjustment across five experiments. We tested the three hypotheses that trait anxiety is associated (H1) with higher overall LRs, (H2) impaired adjustments to environmental changes, or (H3) is not systematically linked to the LR. For this, we designed an online game-based variant of a predictive inference task (predator task; Fig. 1a) (Nassar et al., 2019, 2021; Vaghi et al., 2017). Participants defended themselves against an attacking predator whose location varied unpredictably on a circle (ranging from 1 to 360 degrees) due to risk and occasional truly latent changes. Attack locations were typically clustered around a mean position (mean of a Gaussian), with risk represented by the distribution's standard deviation. The distribution's mean occasionally shifted, introducing unpredictable environmental changes (volatility) (Fig. 1b). We conducted five experiments with varying levels of risk (high/low random outcome variability) and volatility (high/low frequency of change). Participants (N=550) were recruited through Prolific (age 18-40) and completed a battery of questionnaires, including the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Ree et al., 2008) before starting the task.

We used a regression model to estimate the extent to which participants relied on adaptive and fixed LRs. The adaptive LR α_t (eq. (1)) was extracted from an approximate Bayesian changepoint-detection algorithm that learns according to the principles of an error-correcting delta rule (McGuire et al., 2014; Nassar et al., 2010, 2019). α_t dynamically reflects the probability of a change point (CPP) given the PE and hazard rate of change points h (eq. (2)), along with the current subjective estimates of uncertainty σ_t^2 and risk σ^2 encapsulated by a single term (RU, eq. (3), Fig. 1b):

$$\mu_{t+1} = \mu_t + \alpha_t \cdot PE_t \quad \text{where} \quad \alpha_t = CPP_t + RU_t \cdot (1 - CPP_t) \tag{1}$$

$$CPP_t = \frac{(1/360) \cdot h}{N(PE_t; 0, \sigma_t^2 + \sigma^2) \cdot (1-h) + (1/360) \cdot h} \tag{2}$$

$$RU_{t+1} = \frac{\sigma_{t+1}^2}{\sigma_{t+1}^2 + \sigma^2} \tag{3}$$

The regression explained belief updates based on a main effect of PE (β1) and the interaction $\alpha_t \cdot$ PE (β2) (Fig. 1c). β_1 represents a fixed LR, quantifying participants' average consideration of PE independent of the Bayesian model terms, and β_2 quantifies adaptive learning. An ideal learner exhibits $\beta_1 = 0$ and $\beta_2 = 1$, i.e., only relies on α_t. Both parameters had moderate to high split-half reliability ($r_{\beta 1} = 0.78,\ r_{\beta 2} = 0.61$).

In a control experiment (N=182), participants additionally performed a binary reversal learning task (a simplified version of that in Behrens et al. (2007)) so LRs could be compared across tasks and to ensure construct validity. The task comprised stable blocks with fixed reward probabilities and volatile blocks where probabilities switched every 20 trials. Participants' behavior was best modeled by a canonical Rescorla-Wagner model with split-half reliability for learning rate and inverse temperature of $r_\alpha = 0.49,\ r_\beta = 0.35$, respectively.

Results

We found that participants used a mixture of fixed and adaptive LRs (Fig. 1d). That is, learning was driven by both normative factors (CPP and RU) and a fixed influence of PEs (which can be seen as a simplified learning strategy). We subsequently applied a linear regression model on the fixed and adaptive LR coefficients and trait anxiety (STICSA scores). In this model, we also controlled for age and gender, and here we show results for data combined across all our studies (Fig. 1e). We found no significant relationship between fixed LR and trait anxiety (b=-0.0112, 95% CI=-0.035 to 0.013, p=0.364, BF_{10}=0.078). Similarly, there was no significant association between adaptive LR and trait anxiety (b=0.0027, 95% CI=-0.028 to 0.034, p=0.866, BF_{10}=0.052).

In the binary reversal learning task, we found a significant main effect of block type on learning rate (b=0.21, 95% CI=0.12 to 0.314, $p <$0.001), with participants having elevated learning rates in the volatile block compared to the stable block (Fig. 1f). However, we did not find a significant association between LR adaptation ($\Delta\alpha = \alpha_{volatile} - \alpha_{stable}$) and trait-anxiety scores, controlling for age and gender (b=0.0197, 95% CI=-0.034 to 0.074, p=0.473, BF_{10}=0.107; Fig. 1g).

Discussion and Conclusion

Previous work suggests that trait anxiety affects the regulation of LRs in uncertain and changing environments, but results are inconsistent across studies. Across five studies featuring continuous predictive inference (with good psychometric properties) and binary reversal learning tasks (with low to moderate split-half reliability), we found no systematic evidence of impaired LR adaptation in individuals with trait anxiety (in line with H3, assuming no systematic relationship). It might be that the effects of trait anxiety show up in specific task settings that we have not tested here or in clinical populations with pathological anxiety levels; certainly, paying attention to the psychometric properties of learning tasks (Karvelis et al., 2023; Loosen et al., 2022) is essential.

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