Absence of Systematic Effects of Trait Anxiety on Learning Under Uncertainty

Muhammad Hashim Satti (m.hashim.satti@maxplanckschools.de)
Department of Education and Psychology, Freie Universität Berlin, Berlin, Germany
Max Planck School of Cognition, Leipzig, Germany

Katharina Wille (k.wille@fu-berlin.de)
Department of Education and Psychology, Freie Universität Berlin, Berlin, Germany

Matthew R. Nassar (matthew.nassar@brown.edu)
Department of Neuroscience, Brown University, Providence, United States
Robert J. & Nancy D. Carney Institute for Brain Science, Brown University, Providence, United States

Radoslaw M. Cichy (rmcichy@zedat.fu-berlin.de)
Department of Education and Psychology, Freie Universität Berlin, Berlin, Germany

Nicolas W. Schuck (nicolas.schuck@uni-hamburg.de)
Institute of Psychology, Universität Hamburg, Hamburg, Germany
Max Planck Research Group NeuroCode, Max Planck Institute for Human Development, Berlin, Germany

Peter Dayan (dayan@tue.mpı.de)
Max Planck Institute for Biological Cybernetics, Tübingen, Germany
University of Tübingen, Tübingen, Germany

Rasmus Bruckner (rasmusb@zedat.fu-berlin.de)
Department of Education and Psychology, Freie Universität Berlin, Berlin, Germany
Institute of Psychology and Hamburg Center of Neuroscience, Universität Hamburg, Germany

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...
The predator task is a gamified predictive inference task, where participants save themselves from an attacking predator by placing a flame in its path. 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). Example data from one participant, showing the fits obtained with fixed and adaptive LRs. Regression analyses indicate that participants use a mixture of fixed and adaptive LRs to scale the influence of PEs on belief updating. Results from the predator task show no systematic association between trait anxiety and LRs. LRs in stable and volatile blocks of the binary reversal learning task. No systematic association between LR adaptation and trait anxiety scores in the reversal learning task.

We used a regression model to estimate the extent to which participants relied on adaptive and fixed LRs. The adaptive LR $\alpha_t$ (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). $\alpha_t$ 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 $\sigma^2_t$ and risk $\sigma^2_t$ encapsulated by a single term (RU, eq. (3), Fig. 1b):

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

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

$$RU_{t+1} = \frac{\sigma^2_{t+1}}{\sigma^2_{t+1} + \sigma^2_t}$$  \hspace{1cm} (3)

The regression explained belief updates based on a main effect of PE ($\beta_1$) and the interaction $\alpha_t \cdot$ PE ($\beta_2$) (Fig. 1c). $\beta_1$ represents a fixed LR, quantifying participants’ average consideration of PE independent of the Bayesian model terms, and $\beta_2$ quantifies adaptive learning. An ideal learner exhibits $\beta_1 = 0$ and $\beta_2 = 1$, i.e., only relies on $\alpha_t$. 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 $\alpha = 0.49$, $r_p = 0.35$, 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 ($\Delta r = \alpha_{volatile} - \alpha_{stable}$) 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.

**References**


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