Environmental Conflict Modulates Pavlovian Bias: A Computational Account

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Abstract

While actions are often modeled as instrumental responses shaped by reinforcement learning, behavior is also controlled by stimulus-outcome associations known as Pavlovian responses. When these Pavlovian biases align with instrumental goals, behavior is facilitated but when they conflict, decision-making can become suboptimal. Such conflicts are particularly relevant in psychopathologies like anxiety, addiction, and depression, where exaggerated Pavlovian biases contribute to maladaptive behaviors. These biases are notoriously difficult to suppress, and current training-based interventions have shown limited success, even with training. To address this, we developed a novel approach-avoidance task with probabilistic outcomes, systematically varying the level of conflict both across trials and in the environment. Participants exhibited Pavlovian avoidance bias in the absence of any conflict in a low-conflict environment. However, interestingly, as environmental conflict increased this bias was suppressed. Notably, individuals with high trait anxiety showed the strongest initial biases but also demonstrated the greatest improvement in high-conflict environment. These findings highlight environmental conflict as a powerful modulator of maladaptive Pavlovian biases, offering new insights into the development of more effective behavioral interventions for psychopathology.

Keywords: Decision making; Pavlovian bias; Approach-avoidance Conflict; Anxiety

Introduction

Human behavior is shaped by multiple learning systems, notably Pavlovian and instrumental learning (Daw & O'Doherty, 2014). Pavlovian responses are reflexive and driven by stimulus-outcome associations, whereas instrumental actions are more flexible and goal-directed, shaped through experience and reinforcement (Carlson, 1929; Dickinson, 1985). Although these systems operate in parallel, the final behavioral output at any moment is their relative influence (Dorfman & Gershman, 2019).

Under conditions of uncertainty where the optimal action is ambiguous the Pavlovian system often takes precedence, favoring rapid, stimulus-driven responses(Mobbs et al., 2015; Zbozinek et al., 2022). While this can be adaptive in some contexts, Pavlovian avoidance tendencies can lead to suboptimal behavior when overgeneralized. Such maladaptive responses have been implicated in the persistence of various psychopathologies, including excessive avoidance in anxiety, compulsive behaviors in addiction, and cognitive inertia in depression (Dymond, 2019; Goldman et al., 2024).

Suppressing Pavlovian biases, however, remains a significant challenge. Although recent studies suggest that certain interventions such as semantic framing (Ereira et al., 2021) or extended task repetition (Fleming et al., 2023) can attenuate these biases, their effects are often limited, and consistent, flexible modulation is difficult to achieve. Given the clinical significance of exaggerated Pavlovian responses, identifying effective strategies to reduce them is essential for advancing targeted interventions in affective disorders.

To explore this, we developed a novel approach -avoidance task that simulates sequential, probabilistic decision-making under varying levels of Pavlovian -instrumental conflict. By systematically manipulating environmental conflict (Figure 1), we observed that individuals particularly those with high trait anxiety can adaptively modulate their Pavlovian biases in real-time. These findings offer new insights into the mechanisms of cognitive control and point to promising directions for behavior-based modulation of maladaptive responses.

Methods

A total of 116 participants completed a novel sequential decision-making task. Based on median State-Trait Anxiety Inventory (STAI) scores (median = 43), they were split into low (LTA; n = 64) and high trait anxiety (HTA; n = 52) groups. Participants made approach-avoidance decisions in response to colored tree stimuli representing three conflict levels: No Conflict (NC: 1R/0P + 0S), Low Conflict (LC: 2R/1P + 1S), and High Conflict (HC: 3R/2P + 2S), varying in reward-punishment contingencies and shock intensity.

Participants completed the task with 4 environments (5 minutes each; total 20 minutes) with varying levels of environmental conflict. A low conflict environment (LCE; NC: 45%, LC: 35%, HC: 20% trials), while a high conflict environment (HCE; NC: 20%, LC: 35%, HC: 45%).

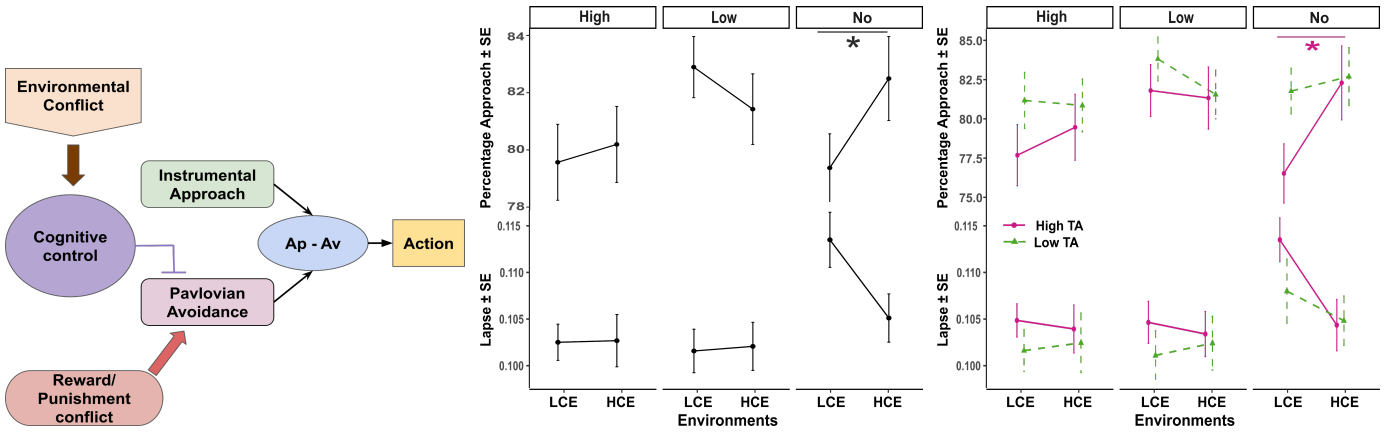

Figure 1:Schematic showing role of environmental and stimulus specific conflict on approach-avoidance action selection. Figure 2: **a.** Mean percentage approach ± SEM (N= 116), **b.** Mean Lapse value ± SEM **c.** Mean percentage approach ± SEM after splitting the group into High (pink; N= 52) and Low (green, N= 64) trait anxiety subgroups **d.** Mean Lapse value ± SEM for high and low trait anxiety group.

These manipulations allowed us to examine behavioral adaptation under varying environmental conflict. The task also included reversals of color-conflict associations and increased outcome aversiveness. We used hierarchical Bayesian modeling in Stan (R) to fit a 7-parameter reinforcement learning model (adapted from Mkrtchian et al., 2017), estimating learning rates, sensitivity, Pavlovian bias, go bias, and decision noise.

Results

We hypothesized that approach behavior would decrease with punishment magnitude: approach tendency (~100%) towards the no-punishment trees which would decrease for high-punishment trees. However, participants approached the no-punishment trees also less than expected (79.4 ± 1.1%, fig 2a, right panel) in LCE; which indicates the presence of maladaptive Pavlovian avoidance bias.

Interestingly, however, when the same participants encountered no-punishment trees in HCE, their approach behavior increased (82.5 ± 1.4%, p = 0.05, fig 2a, right panel), suggesting that global conflict suppresses maladaptive Pavlovian bias.

Using a regression model, we showed that as the encounter rate of high-punishment trees increased (across participants), avoidance of no-punishment trees decreased (β = -0.005, p = 0.002), supporting the role of environmental conflict in reducing Pavlovian bias.

Lapse parameter from the reinforcement learning model which captures the decisions that are not based on value indicative of Pavlovian avoidance, was greater for high and no punishment trees in LCE, but it significantly decreased in HCE (Fig 2b).

Finally we examined the impact of trait anxiety, consistent with the generalized avoidance in high trait-anxious individuals, a linear regression showed a significant negative association between general approach bias and trait anxiety (β = -0.23, SE = 0.11, t(114) = -2.13, p = 0.035). However, the high trait anxious individuals, who displayed a greater avoidance bias for no-punishment trees in LCE (76.52 ± 1.88%, fig 2c, right panel), underwent a greater suppression of Pavlovian bias in HCE (82.29 ± 2.35%, p=0.05, fig 2c, right panel). Similarly, a significant reduction in lapse for NC trees in HCE for HTA (Fig 2d, right panel).

Manipulation of stimulus color reversal and increased aversiveness (70P/30R) in subsequent environments did not show any significant effect on these parameters.

Conclusions

Our findings reveal that decisions are influenced by the encounter frequency of high conflict stimuli that define environmental conflict. Notably, increasing the frequency of high-punishment trees reduced Pavlovian bias. Further, high-anxiety individuals who showed a greater maladaptive avoidance were more sensitive to environmental conflict and displayed greater reduction in Pavlovian bias. We suggest that environmental conflict sets a higher, perhaps more optimal, norepinephrine tone which then facilitates the suppression of Pavlovian bias.

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