Cognitive, Affective, & Behavioral Neuroscience
https://doi.org/10.3758/s13415-026-01421-5

RESEARCH ARTICLE

Diverging influences of punishment motivation and negative affect on cognitive control

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Received: 8 September 2025 / Accepted: 6 February 2026

Abstract

The modulation of cognitive control by threat of punishment has been under-characterized relative to examinations of reward, with mixed findings reported in the literature. Across two experiments, we examined the balance of proactive and reactive control in the AX-CPT under several negative affect and punishment manipulations. In Experiment 1, we compared cognitive control performance between two task phases: an Affect phase, in which emotionally evocative images were used to induce either Fear, Anger, or Neutral affect; and a Punishment phase, in which the threat of receiving mild electric shocks was either performance-contingent, or noncontingent. In Experiment 2, we examined cognitive control under uncertain, noncontingent punishment, and whether effects of such punishment varied by individual differences in trait anxiety and intolerance of uncertainty. Across both experiments, we observed that threat of punishment was associated with increased proactive control and that this effect was heightened when punishment was performance-contingent. In contrast, punishment uncertainty did not appear to modulate cognitive control outcomes at the group level. However, exploratory analyses suggested that punishment uncertainty might interact with individual variability in trait anxiety, intolerance of uncertainty, and threat-related physiological arousal responses to shape control outcomes. Together, our findings support an account in which punishment motivation might facilitate increased proactive control, similar to prior observations with reward motivation. In contrast, the relationship between negative affect and cognitive control outcomes may be more complex, and vary both with task contextual factors and individual differences in response to threat.

Keywords Cognitive control · Punishment · Threat · Negative affect · Motivation

Introduction

In daily life, cognition and behavior are typically guided by the motivation to achieve pleasant outcomes and avoid unpleasant ones. Reflecting growing recognition of this principle, the study of *cognitive control*, the ability to regulate and direct thoughts and behaviors to achieve a goal, has increasingly incorporated examination of motivational states and their influences on performance. Extensive evidence indicates that controlled performance typically improves under reward incentive conditions (Krebs et al., 2010; Chiew & Braver, 2013; 2014; Fröber & Dreisbach, 2014; Boehler et al., 2014). However, changes in cognitive control under the influence of negative or aversive motivation, such as threat of punishment, have been less well characterized than changes in cognitive control under reward influences. Given ubiquitous motivators to avoid negative outcomes in day-to-day life (e.g., avoiding rejection in social contexts, or getting fired at work for poor performance), examining the impact of punishment threat on cognitive control is a key area for investigation.

A key theoretical question, that has been studied more extensively in the reward domain relative to the punishment domain, is whether emotional and motivational aspects of incentive anticipation differentially influence cognitive control outcomes (Chiew & Braver, 2011; Goschke & Bolte, 2014). It has long been acknowledged that reward versus punishment incentives typically give rise to motivation to obtain a desired outcome versus avoid an undesired outcome, respectively, and furthermore, that such incentives can give rise to positive and negative emotions depending on the current state of goal pursuit and its success (Cacioppo & Berntson, 1994; Carver, 2006; Roseman, 2008; Berridge

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et al., 2009; Cooper, 2019; Yee et al., 2022). While motivational and affective elements of incentive are closely related and interlinked, they have also been operationalized as separable constructs. *Emotion* has been defined in terms of affective experiences, characterized by a combination of the construal of that experience and associated physiological responses; in contrast, *motivation* may be characterized by the activation of specific, goal-directed behaviors that facilitate some actions and inhibit others in order to approach desirable states and avoid undesirable states (Chiew & Braver, 2011). While emotions may unfold alongside motivational processes (e.g., happiness resulting from successful obtainment of a reward, or fear resulting from the anticipation of punishment), they have been argued to be less specifically tied to the pursuit of a specific goal (Roseman, 2008; Chiew & Braver, 2011). While theoretical debate regarding the exact nature of the relationship between motivation and affect continues (Shenhav, 2024), distinguishing between momentary affective experience and motivated goal pursuit as dimensions of incentive has been important in advancing scientific understanding of incentive effects on cognitive performance.

Experimentally, one key distinction that has been set forward between motivation and emotion manipulations has been the presence (versus absence) of performance contingency in relation to positive and negative outcomes (Braem et al., 2013b; Chiew & Braver, 2014; Fröber & Dreisbach, 2014, 2016; Prével et al., 2021; Yang et al., 2023). When the occurrence of a positive or negative outcome is contingent on task performance, individuals should arguably have greater motivation to adjust their behavior to facilitate the desirable outcome. In contrast, when stimuli with positive or negative emotional valence are presented to participants, but in a fashion not contingent on task performance, the motivation to modulate performance to help facilitate a desirable outcome should be relatively lower. Importantly, while motivational and emotional experiences are typically not fully dissociated in such a comparison (e.g., motivation in performance-contingent conditions is likely accompanied by an affective experience, and other sources of motivation may be present in noncontingent affective manipulations), performance-contingent manipulations should induce relatively increased motivation to adjust task performance compared with noncontingent emotional manipulations, when holding other task features constant. Such relative differences in motivation have implications for cognitive control under differing experimental manipulations (Goschke & Bolte, 2014; Dreisbach & Fröber, 2019; Yang et al., 2023). While this argued distinction has been investigated in the context of reward incentives and positive affect, the extent to which a similar distinction is present when considering punishment and negative affect is less understood. Given that cognitive control demands are likely to be present in day-to-day contexts where individuals can avoid threatening outcomes by improving cognitive control, as well as in contexts where cognitive control is required alongside ongoing, unavoidable threats, investigation of this distinction in negative contexts as well as positive is important for developing a comprehensive and nuanced account of the affective modulation of cognitive control.

In the current study, we examine performance-contingent and noncontingent punishment influences on cognitive control within the context of the Dual Mechanisms of Control (DMC) framework, extending a robust literature examining effects of reward incentives on cognitive control mechanisms using this conceptual approach. The DMC framework posits that cognitive control can be deployed in two different modes: proactive or reactive (Braver, 2012). *Proactive control* putatively involves the sustained maintenance of task goals and can be used to anticipate and prevent conflict between one's environment and one's goal in a preparatory fashion, before it arises. In contrast, *reactive control* putatively involves transient activation of goals when conflict is detected, resolving conflict as it occurs. There are proposed tradeoffs in using one type of control over the other, as proactive control may be more effective, but typically requires more cognitive resources; reactive control can be considered more flexible but may be less effective in contexts where control is required frequently and needs to be engaged repeatedly (Bugg & Crump, 2012). The relative use of these two control modes can be estimated based on certain dimensions of cognitive control task performance, as well as through the time course of biological metrics relating to control processes, such as prefrontal cortex activity (Braver et al., 2009) and pupil dilation (Chatham et al., 2009; Chiew & Braver, 2013).

The AX Continuous Performance Task (AX-CPT) is a well-established cognitive control paradigm providing relative indices of proactive and reactive control by comparing performance on different trial types. On each trial of the AX-CPT, participants are presented with a cue-probe stimulus pair (e.g., alphabet letters) and are asked to indicate whether the pair is the target AX sequence (i.e., "A" cue followed by "X" probe) or a nontarget sequence. Nontarget pairs can be AY trials (target "A" cue followed by any nontarget probe), BX trials (any nontarget cue followed by target "X" probe), or BY trials (nontarget cue followed by nontarget probe). Crucially, AY and BX trial types occur less frequently than the AX and BY trial types, and performance on those AY and BX trials can provide relative indices of proactive and reactive control use. On AY trials, greater proactive control would lead to increased anticipation of a target "X" probe following the "A" cue (due to the high frequency of target AX trials), and thus greater interference costs to accuracy and reaction time when responding to a nontarget probe on AY trials instead. Performance on BX trials, on the other hand, is argued to serve as an index of reactive control, which should facilitate the tendency to make a target response upon seeing the "X" probe, and thus increased interference on BX trials as participants must overcome that tendency and recall the presence of the "B" cue in order to make a nontarget response. Thus, in the AX-CPT paradigm, worsened performance on AY trials is thought to indicate increased proactive control, and worsened performance on BX trials is thought to indicate increased reactive control.

Converging studies utilizing the AX-CPT paradigm have demonstrated that performance-contingent rewards can enhance proactive control (Fröber & Dreisbach, 2014; 2016; Chiew & Braver, 2013; 2014; Jimura et al., 2010; Locke & Braver, 2008; Hefer & Dreisbach, 2016; Strang & Pollak, 2014). Furthermore, this paradigm has been used to characterize the extent to which manipulations of positive affect and reward motivation have similar or diverging influences on cognitive control (as discussed in Chiew, 2021). To address this question, two empirical studies (Chiew & Braver, 2014; Fröber & Dreisbach, 2014) used similar approaches to investigate whether performance-contingent monetary incentives and noncontingent positive affect inductions might differentially promote proactive or reactive control in the AX-CPT. Fröber & Dreisbach (2014) compared participants' performance on two iterations of the AX-CPT: an affective manipulation alone, and an affective manipulation in combination with a monetary reward. In an initial task block, participants completed the AX-CPT with either positive or neutral pictures, taken from the International Affective Picture System (IAPS; Lang et al., 1997), presented at the start of each trial as an affect induction. In a second task block, a monetary reward was offered on a subset of trials in combination with the IAPS pictures. For half of the participants, these rewards were performance-contingent, awarded for correct and fast performance (relative to a personalized reaction time cutoff) on a given trial. The other half of participants received noncontingent rewards, which were awarded regardless of performance speed and accuracy. Fröber & Dreisbach found that proactive control was lower for the positive affect group than for the neutral affect group. For participants in the noncontingent reward condition, reward prospect was associated with reduced proactive control relative to the neutral baseline condition. In contrast, for participants in the performance-contingent reward condition, reward prospect was associated with increased proactive control relative to both the neutral and positive affect baseline conditions. These results suggest that affective aspects of reward (i.e., positive affect) and motivational aspects of reward (such as performance contingency) can lead to different effects on the balance between proactive and reactive control. Chiew & Braver (2014) also used the AX-CPT paradigm and reported a similar distinction between the effects of monetary incentives and a positive affect induction, manipulated in separate experimental sessions and each compared with a within-session baseline, on cognitive control. Similar to Fröber & Dreisbach (2014), Chiew & Braver observed that performance-contingent rewards robustly increased proactive control in the AX-CPT. Interestingly, they also observed increased proactive control under a positive affect condition relative to baseline, but the magnitude of this increase was much smaller than that of performance-contingent reward incentives and, given completion of the positive affect condition following a neutral affect baseline, may have been driven by time-on-task effects (given observations that increasing time on task might be linked to increasing proactive control; Hefer & Dreisbach, 2020). Altogether, Chiew & Braver (2014) and Fröber & Dreisbach (2014) observed similar patterns of behavior, whereby performance-contingent reward motivation was associated with greater increases in proactive control compared with positive affect inductions (i.e., presentation of positively valenced stimuli or receipt of noncontingent rewards). Alongside such characterizations of affective and motivational dimensions of reward, initial efforts to characterize how performance-contingent versus noncontingent punishment might influence cognitive control have been reported (Yang et al., 2023). However, to our knowledge, effects of negative affect and performance-contingent punishment motivation on cognitive control have not been directly compared experimentally within the DMC framework. Conducting such a comparison to clarify potential distinctions between negative affective and motivational influences on cognitive control is the overarching goal of the present study.

Initial work has begun to examine how negative affect, as induced by random, noncontingent punishment, may influence proactive and reactive cognitive control. Yang et al. (2018) observed that across two paradigms (the AX-CPT and the Stroop task), the threat of receiving random electric shocks was associated with reduced proactive control and increased reactive control. These findings suggest that the presence of an unavoidable, noncontingent punishment, which might induce negative affect (e.g., fear or anxiety) in the relative absence of motivation to avoid punishment by adjusting task performance, may facilitate reactive control and impair proactive control. Separately, the influence of performance-contingent punishments (i.e., including the motivational component of punishment) on proactive and reactive control has begun to be investigated. Some initial evidence suggests that performance-contingent punishment motivation may facilitate increased reactive control in a fashion similar to the effects of negative affect. Ličen et al. (2016) examined the use of proactive and reactive control in the AX-CPT paradigm under combined monetary gain and loss motivation, such that participants won money for every trial on which they responded quickly and correctly, and lost money on any trial on which they responded incorrectly. The combined incentives condition was linked to global improvement in task performance relative to a within-subject baseline condition. Ličen & colleagues argued that this global improvement reflected simultaneous increases in proactive control, driven by the prospect of monetary gain, and reactive control, driven by loss avoidance. Importantly, while proactive and reactive control are often thought of as trading off with one another, they can also vary independently (Chaillou et al., 2018; Mäki-Marttunen et al., 2019), allowing for the possibility that motivational incentives might increase both proactive and reactive control. While interpretation of Ličen et al.'s results is somewhat limited by the bundling of reward and punishment incentives, they suggest that performance-contingent punishment may be associated with increased reactive control in the AX-CPT paradigm, in contrast to the increases in proactive control observed with performance-contingent rewards.

However, in contrast to these findings that performance-contingent punishments might promote reactive control, conflicting observations have also been reported. Lindström et al. (2013) observed that stand-alone, performance-contingent punishments were associated with increased proactive control in an adapted Go/No-Go task. Specifically, this adapted task required a two-alternative forced-choice response, such that high-frequency "Go" responses required one button response and low-frequency "No-Go" responses required a different button response. The task was performed under conditions of varying risk of receiving mild electric shocks for errors. Under risk of shock, performance was impaired on trials with high-frequency "Go" stimuli, which depended on habitual responding, but performance was enhanced on trials with low-frequency "No-Go" stimuli, requiring inhibition of the habitual response. This pattern suggests that participants proactively adopted an inhibitory control mode under threat.

One possibility is that the use of differing punishment types (i.e., monetary loss versus primary punishment by electric shock) across these two studies might account for diverging observations of the modulation of cognitive control by performance-contingent punishment. Ličen et al. (2016) used monetary loss, a secondary punishment, whereas Lindström et al. (2013) used threat of shock, a primary punishment. To date, the broader literature examining reward and punishment influences on cognitive control has typically employed monetary (i.e., secondary) incentives. Much less work has examined the influence of so-called "primary" rewards and punishments (appetitive foods/liquids, aversive electric shock, etc.), despite arguments that primary incentives might engage motivational brain circuits more directly (Krug & Braver, 2014). In addition, monetary and nonmonetary incentives have been associated with different temporal dynamics of neural activity (Beck et al., 2010) and have been observed to activate different motivational circuitry (Murty et al., 2011). While electric shock, a primary threat, has been linked to greater activation in avoidance motivation neural circuitry, including the amygdala (Delgado et al., 2008, 2011), monetary losses have been observed to engage overlapping approach motivation networks to those activated by monetary rewards (Carter et al., 2009). Monetary loss, therefore, may arguably be experienced as a missed opportunity to obtain a reward, rather than as a punishment, per se, with associated neural differences in responses to primary and secondary punishments leading to potentially distinct downstream consequences for cognitive control performance. Taken together, initial evidence suggests that the effects of primary versus secondary punishments on cognitive control may diverge (Lindström et al., 2013; Ličen et al., 2016). However, further work is needed to verify whether monetary loss and primary punishments modulate cognitive control differently, especially given that these studies also differed in the experimental task used, and in the presence (or absence) of a bundled reward incentive. In the current study, we used a primary punishment, threat of electric shock, as an incentive manipulation in the AX-CPT paradigm to more directly examine the effect of a primary punishment on proactive and reactive control, and to compare such effects to those observed in prior work with monetary loss.

The literature reviewed so far suggests that negative affect, as induced with noncontingent punishment, may facilitate the use of reactive control in the AX-CPT paradigm. In contrast, observed effects of performance-contingent punishment have been more mixed, with monetary loss associated with increased reactive control, and primary punishments associated with increased proactive control. To our knowledge, no work to-date has directly compared the effects of performance-contingent and noncontingent punishments on the AX-CPT in matched experimental contexts. Furthermore, to our knowledge, the effect of primary, performance-contingent punishments on cognitive control has not been previously examined in the context of the AX-CPT paradigm.

The present study aims to address these knowledge gaps. In Experiment 1, our primary aim was to examine whether negative affect and performance-contingent punishment differentially modulate cognitive control. Using an experimental design adapted from Fröber & Dreisbach (2014), we directly compared the influence of image-based neutral and negative affect inductions, noncontingent punishment, and performance-contingent punishments on the modulation of proactive and reactive control in the AX-CPT. Punishment incentives were manipulated on both the block-level and on the trial-level, to capitalize on the multiple timescales on which incentives may influence cognitive control (following our prior work; Chiew & Braver, 2013; 2016). We hypothesized that negative affect, as induced by both the presentation of negatively valenced images and noncontingent punishment, would be associated with increased *reactive* control relative to a neutral condition. In contrast, we hypothesized that performance-contingent punishment motivation would be associated with increased *proactive* control relative to noncontingent punishment, neutral, and image-induced negative affect conditions. We further predicted that the effects of performance-contingent punishment might be present in a sustained fashion at the block-level, and further amplified transiently on trials with the immediate threat of punishment.

In Experiment 1, we additionally tested the exploratory hypothesis that while the presentation of fear-inducing images would be associated with increased reactive control relative to a neutral condition, anger-inducing images might not show the same pattern, and might even be associated with increased proactive control instead. While fear and anger are both negatively valenced emotions, fear has been argued to promote avoidance-oriented action tendencies, whereas anger has been associated with approach-oriented action tendencies (Carver & Harmon-Jones, 2009; Han et al., 2007; Harmon-Jones & Sigelman, 2001). Given this, an open question is whether anger-based and fear-based negative affect result in similar effects on proactive versus reactive cognitive control: specifically, anger inductions might promote reactive control, as previously observed with fear-based negative affect inductions, or anger inductions might facilitate approach-oriented action tendencies and promote proactive control, similar to effects of reward incentives. We tested this exploratory question in the current study by comparing effects of neutral affect, fear, and anger on cognitive control across three image-based conditions.

To provide a partial preview of our findings from Experiment 1, we observed that, contrary to predictions, noncontingent punishment was associated with increased proactive (rather than reactive) control relative to the neutral and negatively valenced affective conditions. In considering this surprising result, we identified that one key methodological difference between Experiment 1 and previous literature reporting increased reactive control with negative affect (Yang et al., 2018) was that the threat cues in our Experiment 1's noncontingent punishment condition were fully deterministic in predicting punishment, rather than probabilistic or uncertain. Uncertainty with regards to the occurrence of negative outcomes is hypothesized to amplify the experience of threat (Grupe & Nitschke, 2013) and may be a crucial contextual factor that might trigger the shift towards increased reactive control under threat of noncontingent punishment (Yang et al., 2018). Interestingly, uncertainty has also been argued to signal a need for increased control (Bland & Schaefer, 2012; Mushtaq et al., 2011; Wu et al., 2020), but whether uncertainty might specifically enhance reactive control at the expense of proactive control has, to our knowledge, yet to be tested empirically. Additionally, the extent to which uncertain punishment might influence cognitive control might further be modulated by individual differences in anxiety and related psychological constructs (Braem et al., 2013a; Grupe & Nitschke, 2013; Yang et al., 2018; Hur et al., 2020). Elevated intolerance of uncertainty is a hallmark characteristic of anxiety disorders (Carleton, 2014), suggesting that affective responses to uncertain threat might be exacerbated in high-anxiety individuals. Additionally, using fMRI, Fales et al. (2008) investigated differences in brain activity during performance of a working memory task as a function of trait anxiety and observed that high-anxiety individuals demonstrated increased transient neural activity and reduced sustained neural activity, consistent with increased reactive control and reduced proactive control, relative to low-anxiety individuals. Despite these findings, to our knowledge, the modulation of cognitive control by trait anxiety specifically in the context of uncertain, noncontingent punishment has yet to be examined.

To investigate whether punishment uncertainty could account for inconsistencies between our Experiment 1 findings and those observed by Yang et al. (2018), we conducted a second experiment modifying our noncontingent punishment condition such that trial-level threat was administered in a probabilistic (i.e., uncertain) fashion, rather than deterministically. We hypothesized that uncertain, noncontingent punishment would be associated with increased reactive control relative to a neutral baseline condition, with this pattern amplified on trials with immediate threat of shock. In addition, we hypothesized that in a cross-experiment comparison, the uncertain noncontingent punishment condition from Experiment 2 would be associated with increased reactive control, relative to the deterministic noncontingent punishment condition from Experiment 1. Finally, we hypothesized that individuals higher in trait anxiety and intolerance of uncertainty would display greater increases in reactive control on threat versus safe trials under uncertain, noncontingent punishment in Experiment 2.

Our primary aim across the two experiments was to compare the influence of negative affect and motivational influences on proactive control under threat of punishment. We did so by assessing cognitive control performance under affect inductions and punishment contexts varying as a function of performance-contingency (serving as a manipulation of the motivational dimension of punishment) and punishment uncertainty (serving as a manipulation of affective experience). As secondary goals, we further investigated whether negative affect as induced by

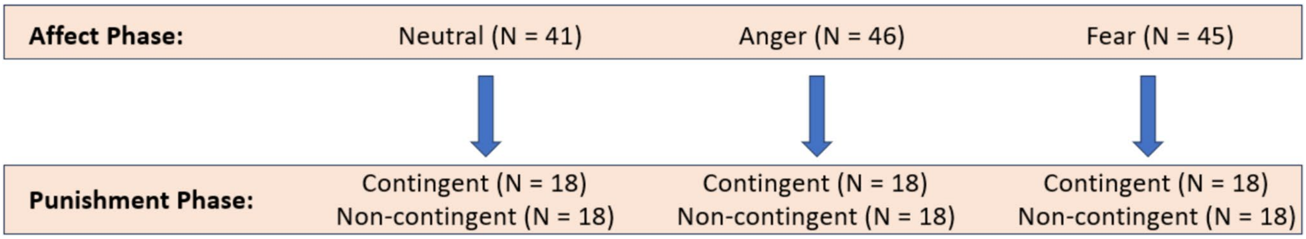

Fig. 1 Overview of Experiment 1 design, including the conditions assigned across the Affect and Punishment phases, with final participant counts (i.e., following exclusions for low-accuracy performance).

fear-based images, anger-based images, and performance noncontingent threat of electric shock differentially influenced cognitive control outcomes in Experiment 1, and whether individual differences in trait anxiety and intolerance of uncertainty influenced cognitive control outcomes under uncertain, noncontingent punishment in Experiment 2. Across both experiments, we investigated these questions employing a study design closely matching that used by Fröber & Dreisbach (2014) to help enable a comprehensive comparison to their reported results regarding the influence of positive affect and performance-contingent rewards on cognitive control.

Experiment 1: Methods

In Experiment 1, we compared the effects of image-based negative affect inductions, performance-contingent punishments, and noncontingent punishments on cognitive control in a design adapted from Fröber & Dreisbach (2014), with mild electric shock utilized as a punishment incentive. This experiment was preregistered on the Open Science Framework (https://osf.io/kjmqg). Following Fröber & Dreisbach's design, participants completed two phases of the AX-CPT paradigm. In the first phase, they were assigned in a between-subjects manner to one of three Affect conditions (Neutral, Fear, or Anger) and were shown an emotionally evocative image at the beginning of each task trial to elicit the assigned emotion (according to norming from a previous study: Barke et al., 2012). In the second phase, participants were assigned to one of two Punishment conditions (contingent or noncontingent). In the contingent condition, participants received mild electric shocks as a punishment on trials in which they answered incorrectly or too slowly. In the noncontingent condition, participants received unavoidable mild electric shock on a subset of trials, regardless of performance. These condition assignments resulted in six different combinations of Affect phase and Punishment phase manipulations that participants could undergo (Fig. 1). This design allowed us to examine differences in cognitive control by assigned Affect and Punishment inductions (i.e., between-subjects Neutral vs. Fear vs. Anger conditions, as well as between-subjects Contingent vs. Noncontingent conditions), as well as comparing performance across the Affect vs. Punishment phases for each of our six groups.

Participants

A power estimate conducted in G*Power version 3.1.9.7 for alpha = 0.05, power > 0.80, and a medium effect size ($f = 0.25$), yielded a goal sample size of 108. The power estimate was based on the expected effect of the within-between subjects interaction between punishment condition (Contingent, Noncontingent) and trial type (AX, AY, BX, BY) on error rates in the Punishment phase.[1] Fröber & Dreisbach (2014) found a large effect ($f = 0.89$) for the interaction between reward contingency and trial type. We chose to use a more conservative medium effect size for our power analysis ($f = 0.25$), given that this effect has not yet been investigated with punishment (as opposed to reward) incentives. We collected a total sample of 133 participants. Of these participants, 24 people were unable to complete the Punishment phase of the AX-CPT due to technical issues with the electric shock and were excluded from that task phase. This resulted in a final sample of 109 participants with full task data and an additional 24 with partial task data (Affect phase only).

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[1] Given the lack of prior studies contrasting effects of negative affect inductions and punishment manipulations on proactive control, we chose to conduct our a priori power analysis to focus on the key comparison of contingent vs. noncontingent punishment on proactive control. Given our additional conducted analyses (see *Results*), we conducted post-hoc power analyses for these as well. These post-hoc tests did suggest that some marginal effects observed in additional analyses may have been the product of low power (i.e., power = 0.3–0.5). While these power concerns were not present for analyses addressing our primary research aims, the implications of these low-powered analyses are discussed further in the interim Experiments 1 and 2 discussions and the *General Discussion*, especially with regards to the interpretation of null and marginally significant effects.

Participants were recruited via the University of Denver SONA participant pool and posted flyers. To meet inclusion criteria, all participants were fluent English speakers, had normal or corrected-to-normal vision, and no reported current psychological illness, history of neurological illness or injury, current psychotropic medication use, and pacemaker use. Data collection was completed between February and July 2023. Our final sample, including all 133 participants with at least partial usable data, had an age range of 18–28 years (*M* = 19.49, *SD* = 1.43), with an average of 13.6 years of education (*SD* = 1.31). Biological sex at birth was reported as 80 females and 52 males (one participant chose not to respond). Gender identification was reported as 72 women, 52 men, and 6 gender queer/gender nonconforming (three participants chose not to respond or to self-describe). Self-reported racial identity was 1.5% "American Indian," 9.1% "Asian," 3.8% "Black," 75.8% "White/Caucasian," 5.3% selected more than one race, and 4.5% chose not to respond or to self-describe. Self-reported ethnicity was 18.2% "Hispanic or Latino/a" and 81.8% "NonHispanic or Latino/a." Participants were compensated either $10/hour or with course credit for completing the study. The study protocol was approved by the University of Denver Institutional Review Board.

Procedure

Upon arriving for the experiment, participants provided informed consent. They were then set up for monitoring of skin conductance levels (SCL). They were instructed on the rules of the AX-CPT and completed ten practice trials. Next, participants completed two task blocks of the AX-CPT in the Affect phase (either Neutral, Fear, or Anger condition, assigned in a counterbalanced fashion across participants). This was followed by completion of the demographic and questionnaire measures. The level of stimulation for the electric shock was then calibrated before participants completed two task blocks of the AX-CPT in the Punishment phase (either Contingent or Noncontingent condition, again counterbalanced across participants). Finally, participants were debriefed and compensated for their time. Details on each step of the procedure are provided below.

AX-CPT paradigm

The AX-CPT paradigm was presented on a Dell PC computer using E-prime software (Psychology Software Tools, Pittsburgh, PA), with participant responses collected using an E-prime button box connected to the stimulus presentation computer. In all task versions, participants were presented with an image at the start of each trial for 600 ms, followed by an inter-stimulus interval (ISI) for 200 ms, the cue letter for 300 ms, another ISI for 200 ms, three distractor letters for 300 ms each, an ISI for 200 ms, the probe letter, which remained on the screen until the participant made a button response, and finally performance feedback for 1,500 ms, followed by an intertrial interval (ITI) with a fixation cross for 500 ms before the next trial began (Fig. 2). Following Fröber & Dreisbach (2014), distractor letters were clearly distinguished from the cue and probe letters by presentation in a different ink color and font size (black, size 34 Consolas font for the distractor letters vs. purple, size 40 Consolas font for the cue and probe letters). The three distractor letters were randomly selected out of the 26 letters of the alphabet for each trial. Participants were instructed to press button 1 if the cue-probe pair was the target AX sequence or press button 2 if the cue-probe pair was any nontarget sequence, using their index and middle fingers of the dominant hand. The frequency of each trial type, not made explicit to participants, was as follows: 40% AX, 10% AY, 10% BX, and 40% BY (following Richmond et al., 2015). Trials were presented in randomized order.

Affect and punishment manipulations

For the Affect phase of the AX-CPT, participants were assigned to one of three conditions: Neutral, Fear, or Anger. The image presented at the start of each trial was randomly selected from a set of ten images from the IAPS database (Lang et al., 1997) corresponding to the assigned valence condition. The Neutral (normed valence: *M* = 4.99, normed arousal: *M* = 2.45) images were the same images utilized by Fröber & Dreisbach (2014) for their Neutral condition. The Fear images (valence: *M* = 3.19, arousal: *M* = 6.15) and Anger images (valence: *M* = 2.95, arousal: *M* = 6.00) were matched on valence ($t_{(18)} = -1.31$, $p = 0.21$) and arousal ratings ($t_{(13)} = -0.73$, $p = 0.48$) and were selected based on the primary emotion they induced in a previous study, defined as the mostly frequently selected category chosen by participants to represent a given image (Barke et al., 2012). Fear-inducing images included depictions of threatening animals, weapons, and natural disaster threats, while anger-inducing images included depictions of armed militants, riots, and criminals. A full list of IAPS image files used, identified by image number, is included in the supplementary materials (Table S1), along with valence and arousal norms for each image. Participants were not given any specific instructions regarding attending to the images.

Each participant completed two task blocks in the Affect phase, with 80 trials per block. Following each block, participants were asked to report their emotional state, on 5-point Likert scales, in terms of their current valence (1 being happy, 5 being unhappy), current arousal level (1 being calm, 5 being excited), how motivated they felt during the task (1 being not at all, 5 being extremely), and how much effort they put into the task (1 being none, 5

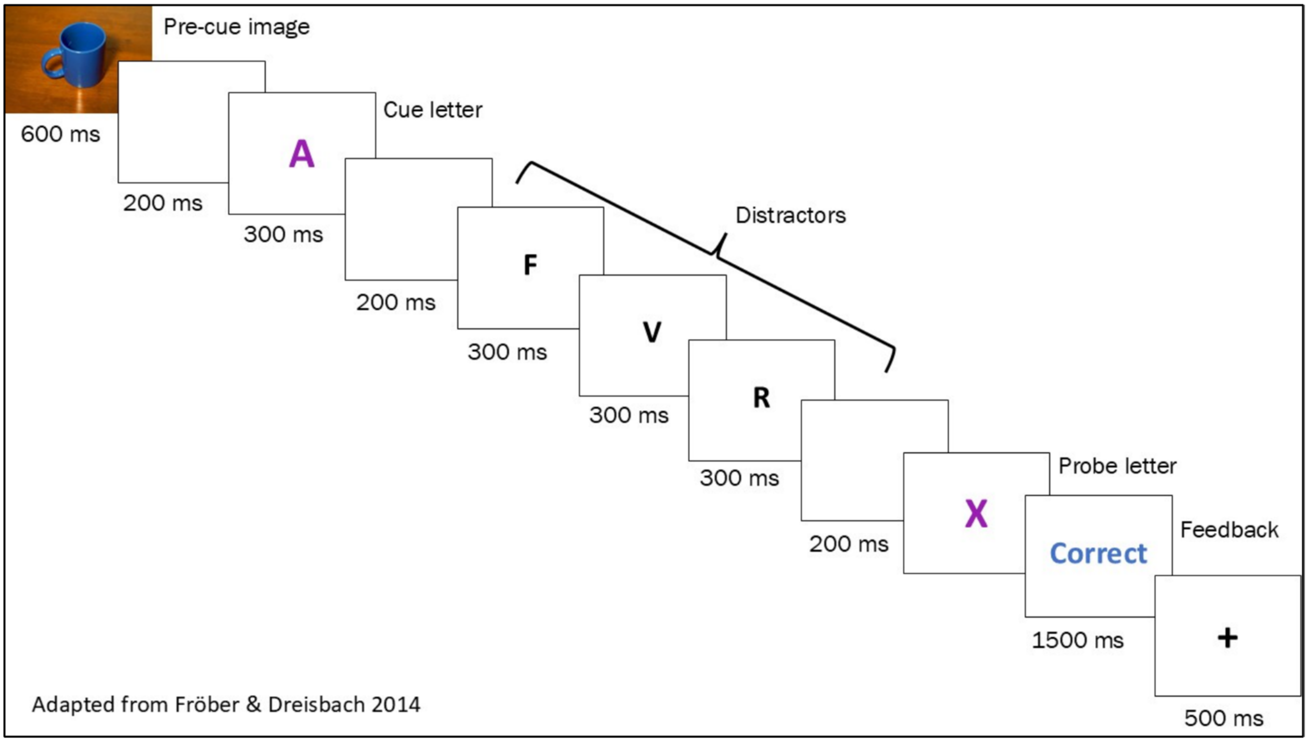

Fig. 2 Trial structure of the AX-CPT paradigm, with an example pre-cue image taken from the Neutral Affect condition. In the Punishment phase, the pre-cue image indicated whether there was a threat of receiving mild electric shock on each trial. The trial structure was adapted from Fröber & Dreisbach (2014).

being a great deal). The Likert scale was presented using manikin images (Bradley & Lang, 1994) for the valence and arousal ratings, and numerical options for the motivation and effort ratings. Following these reports, participants were offered a short break prior to continuing the experiment. Prior to completing the two Affect task blocks, participants completed a series of ten practice trials, performance on which was not analyzed. All participants were shown the ten IAPS images from the Neutral condition during the practice trials.

For the Punishment phase of the AX-CPT, participants were assigned to one of two conditions: Contingent or Noncontingent. At the beginning of each trial, instead of an image from the IAPS stimulus set, participants were presented with an image indicating whether there was a possibility that they would receive a mild electric shock after making their response on the upcoming trial or not. The presented image was a yellow lightning bolt on trials where there was a chance of receiving an electric shock, and a blue cloud on trials where participants were safe and would not receive an electric shock. Threat and safe trials were randomly intermixed. In the Contingent condition, there were equal numbers of threat and safe trials, such that there was a possibility of receiving an electric shock on 50% of the trials. On threat trials, the participant received an electric shock if they responded incorrectly or failed to respond faster than an individualized reaction time cutoff. This cutoff was calculated as the 30th percentile reaction time for correct responses for each participant across their two Affect task blocks. If the participant responded correctly and faster than their individualized reaction time cutoff, they avoided the electric shock.

In the Noncontingent condition, the lightning bolt image, indicating a threat trial, was only presented on 25% of trials. The remaining 75% of trials were safe from electric shock, designated by the cloud image, and were randomly intermixed with the threat trials. In this condition, the lightning image was fully deterministic of receiving electric shock on that trial. While participants were still asked to respond faster than their individualized cutoff across all trials in this condition, they were not given the opportunity to avoid the electric shock. We kept the speeded response deadline consistent between the two punishment conditions, as prior evidence suggests that such a deadline might increase proactive control (Ličen et al., 2016); retaining this design element allowed us to more clearly interpret any differences between Contingent and Noncontingent conditions as reflecting performance-outcome contingency. In both the Contingent and Noncontingent conditions, the electric shock was administered following the button box response to the probe letter, at the same time as the feedback slide was presented. Feedback indicated whether responses were correct, incorrect, or too slow, as well as whether an electric shock had been received. As in the Affect phase, participants completed two blocks of their assigned Punishment condition, with 80 trials per block, and rated their current emotional state in terms of valence, arousal, motivation, and effort levels following each block. At the very end of the experiment, participants were asked to rate how threatening they found the electric shock, on a scale from 1 (not at all) to 10 (extremely).

Electric shock protocol

The electric shocks were administered using a BIOPAC MP160 system (BIOPAC Systems, Santa Barbara, CA) to the forearm of the nondominant hand. General purpose electrodes were placed on the arm, with the electrode leads attached to a STM200 Constant Voltage Stimulator. A saline based gel (Sigma Gel: Parker Laboratories, Fairfield, NJ) was used as an electrolyte conductor. Each electric shock event consisted of a single, 1ms pulse.

Prior to the punishment condition, the appropriate level for the electric shock was calibrated for each participant using an ascending staircase procedure, following prior threat conditioning protocols (Murty et al., 2016). The calibration procedure started off with a low 10 V voltage level that was not reported as perceptible by any participant, and was gradually increased in increments of 10 V until the point where the participant could feel the shock, then in increments of 5 V until a level the participant reported as "uncomfortable, but not painful." The maximum voltage administered was 100 V.

Skin conductance measure

Participants' SCL was monitored during each block of the AX-CPT, using a BIOPAC Systems MP160 skin conductance module. Data was recorded at a sampling rate of 2,000 Hz. Electrodes with isotonic gel were placed on the index and ring fingers of the nondominant hand. A 30-second baseline recording was taken immediately prior to the start of the first block of the AX-CPT for each participant.

Questionnaires

Between the Affect and Punishment phases of the AX-CPT, participants completed a set of individual differences questionnaires, as well as a demographics measure. The questionnaires consisted of the State Trait Anxiety Inventory (STAI; Spielberger, 1983), Intolerance of Uncertainty Scale (IUS; Buhr & Dugas, 2002), and the Behavioral Inhibition Scale/Behavioral Activation Scale (BIS/BAS; Carver & White, 1994). The questionnaires were administered via Qualtrics.

Data analysis plan

The planned analyses were adopted from the procedures used by Fröber & Dreisbach (2014) and were preregistered on the Open Science Framework (https://osf.io/kjmqg). In a departure from the preregistration, the results reported in the main manuscript use inverse efficiency scores (IES; described further below) as our primary outcome measure, instead of reaction time and error rate. We chose to use IES here to capture overall performance differences between conditions while helping to account for potential speed-accuracy tradeoffs and to streamline the results. Full analyses with reaction times and error rates as outcome measures, as well as visualizations of task performance using these outcomes, are reported in the supplementary materials. There were no major differences in results using IES compared with reaction times and error rates. However, some additional patterns, including suggestions of potential speed-accuracy tradeoffs in the comparison of certain conditions, emerged in analyses of reaction time and error rate and provide further insights into the influences of punishment on cognitive control. These patterns are noted in our *General Discussion*. All analyses were performed in R (version 4.2.2; R Core Team, 2022) using the tidyverse, psych, ggplot2, ez, lme4, lmerTest, effectsize, emmeans, and afex packages.

Data exclusions

Twenty-four participants completed the Affect phase but were not able to complete the Punishment phase of the AX-CPT due to technical issues. These 24 participants were included in analyses of between-group differences in the Affect phase (i.e., comparing performance across Neutral, Fear, and Anger conditions), for which they had intact data, but were not included in analyses of the Punishment phase or in between-phase (Affect versus Punishment) analyses. In addition, participants with accuracy scores below 50% for any task block, or with overall accuracy less than 3 standard deviations below the sample mean, were fully excluded from analysis. One participant was excluded on the basis of low accuracy using these criteria.

AX-CPT outcome measures

AX-CPT performance was examined in terms of IES, calculated by dividing correct response reaction time by proportion correct (Bruyer & Brysbaert, 2011) for each experimental condition. IES is therefore a corrected reaction time measure, with larger values indicating worse performance. In addition, we used IES outcomes to calculate a composite measure of cognitive control, the Proactive Behavioral Index (PBI). The PBI is computed as a normalized difference score of performance on AY and BX trial types, using the formula [AY-BX]/[AY+BX], with a range from −1 to +1 (Gonthier et al., 2016). By integrating performance on both AY and BX trial types, the PBI measure provides an index of the relative use of proactive versus reactive control. Positive PBI values indicate relatively greater proactive control, whereas negative PBI values indicate greater reactive control. A PBI value of zero is thought to indicate relatively equal levels of proactive and reactive control.

Given prior findings that proactive and reactive control can also vary independently of one another (Mäki-Marttunen et al., 2019), we computed two additional indices from IES outcomes, BX-interference and A-cue bias, allowing for separate evaluations of reactive and proactive control, respectively. We report results with these indices as outcomes in the supplementary materials. The results of these analyses aligned with our findings using the PBI measure as an outcome and are not discussed further.

Affect Phase: How do fear- and anger-based negative affect modulate proactive and reactive control, relative to a neutral affect condition?

To examine task performance during the Affect phase, we used a 3 (Affect condition: Neutral, Fear, Anger) × 4 (trial type: AX, AY, BX, BY) mixed-factors ANOVA. IES was examined as the dependent variable. An additional ANOVA was used to analyze the effect of Affect condition (Neutral, Fear, Anger) on PBI. We planned to follow-up on any significant effects using Tukey's Honestly Significant Difference (HSD) test for pairwise comparisons.

Punishment Phase: Is performance-contingent punishment associated with increased proactive control relative to noncontingent punishment? If so, is this effect amplified on threat trials?

To examine task performance during the Punishment phase, we used a 2 (Punishment condition: Contingent, Noncontingent) × 4 (trial type: AX, AY, BX, BY) × 2 (Threat-of-Shock: safe, threat) mixed-factors ANOVA with IES as the dependent variable. An additional 2 (Punishment condition: Contingent, Noncontingent) × 2 (Threat-of-Shock: safe, threat) ANOVA was with PBI as the dependent variable. Again, we planned to follow-up on any significant effects using Tukey's HSD test for pairwise comparisons.

Within-group differences in Affect vs. Punishment Phase: Are sustained (block-level) performance-contingent and noncontingent punishment contexts associated with differences in proactive and reactive control, relative to each other and to performance under affect inductions?

We examined whether performance differed between the Affect and Punishment phases by conducting two linear mixed-effects regression analyses (using the *lmer* command in the *lmerTest* package, Kuznetsova et al., 2017). Only safe trials were included from the Punishment phase, in order to examine the sustained (i.e., block-level) effect of the threat of punishment context relative to the Affect phase. In the first analysis, we examined whether IES was predicted by the following fixed effects: task Phase (Affect, Punishment), Trial Type (AX, AY, BX, BY), and between-subject Group (Anger-Contingent, Anger-Noncontingent, Fear-Contingent, Fear-Noncontingent, Neutral-Contingent, Neutral-Noncontingent). In the second analysis, we examined whether the composite PBI score (calculated from IES measures) was predicted by the following fixed effects: phase and between-subject group. Subject was included as a random intercept in both analyses. Maximum likelihood estimation was employed.

To determine whether each of the two analyses should include interaction terms between the fixed effects of interest or not, model comparison procedures were conducted (following best practice recommendations in Meteyard & Davies, 2020) whereby simpler models, including fixed main effects only, were iteratively compared with more complex models, including two-way and three-way interaction terms using the ANOVA function (R stats library; provides likelihood ratio test statistics and related p-values). If the inclusion of two-way and three-way interaction terms led to a statistically better fit for the outcome variable, such interactions were retained in the final model. Models for the two analyses were examined in three stages (with subjects as a random intercept at all stages): fixed main effects only, fixed main effects and two-way interactions between them, and fixed main effects, two-way interactions, and (for the first analysis only) the three-way interaction. After identifying the best-fit model for each analysis, we assessed the significance of each fixed effect using Type III F-tests with Satterthwaite's approximation for degrees of freedom. Significant effects and interactions were followed up with using estimated marginal means and pairwise contrasts between factor levels, computed with the *emmeans* R package (Lenth & Piaskowski, 2025). Contrasts were adjusted for multiple comparisons in *emmeans* using the Tukey HSD procedure for main effects and the Šidák method for interaction effects.

To preview results of these analyses, we observed consistent differences in proactive control between Affect and Punishment phases across all six between-subjects groups in Experiment 1. Detailed results of analyses conducted separately for each combination of Affect and Punishment manipulations are included in the supplementary materials for reference. Given that our Affect and Punishment phases occurred in a set order, and prior evidence suggests that proactive control might increase with time on task (Fröber & Dreisbach, 2016; Hefer & Dreisbach, 2020), we also ran additional analyses including task block number as an additional factor, to help control for potential time on task effects on PBI, reported in the supplementary materials.

Experiment 1: Results

Data Exclusions

No participants had accuracy less than 50% on any task block. However, one participant had overall task accuracy less than 3 standard deviations below the sample mean and was excluded from analysis. In addition, as noted above in *Methods: Participants*, 24 participants' Punishment phase data could not be used because of technical difficulties with shock administration. Our analysis of the Affect phase therefore had a sample of 132 participants, and analysis of the Punishment phase and between-phase (Affect versus Punishment) effects had a sample of 108 participants.

Affect Phase: How do fear- and anger-based negative affect modulate proactive and reactive control, relative to a neutral affect condition?

For analysis of the Affect phase, we used a 4 (Trial Type: AX, AY, BX, BY) by 3 (Affect condition: Neutral, Fear, Anger) mixed-factors ANOVA, examining IES as the outcome measure (results shown in Fig. 3a). There was a significant main effect of trial type ($F(3, 384) = 61.37$, $p < 0.0001$, $\eta^2_p = 0.33$); follow-up comparisons using the Tukey HSD test revealed that IES was significantly higher on AY trials ($M = 638$, $SD = 205$) than on BX ($M = 520$, $SD = 256$; $p < 0.0001$, 95% confidence interval [CI] [50.49, 187.28]), AX ($M = 493$, $SD = 161$; $p < 0.0001$, 95% CI [76.96, 213.49]), and BY ($M = 492$, $SD = 229$; $p < 0.0001$, 95% CI [77.86, 214.39]) trials ($F(3) = 13.78$, $p < 0.0001$). No other significant trial type differences were observed (all p's > 0.73). This robust trial type effect whereby performance is worst on AY trials is consistent with a bias towards a proactive control mode, even in so-called "neutral" conditions, typically observed for healthy young adult populations (Gonthier et al., 2016). We did not observe a significant main effect of Affect condition ($F(2, 128) = 0.31$, $p = 0.74$, $\eta^2_p = 0.005$) or a significant Affect × trial type interaction ($F(6, 384) = 1.02$, $p = 0.41$, $\eta^2_p = 0.02$).

Proactive Behavioral Index

We then tested whether there was an effect of Affect condition on IES PBI. Results are shown in Fig. 3b. There was a marginally significant effect of Affect condition on

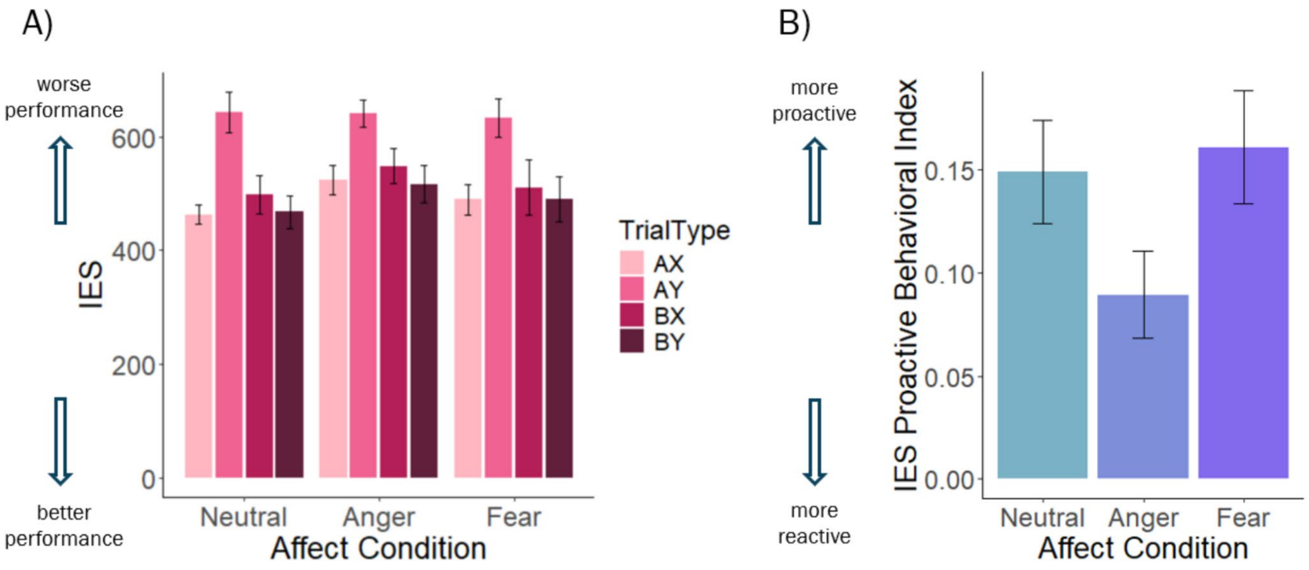

Fig. 3 A) Experiment 1: IES as a function of Trial Type (AX, AY, BX, BY) across the three Affect conditions. IES did not significantly differ by Affect condition. B) Experiment 1: PBI as a function of Affect condition. PBI was marginally greater in the Fear condition compared with the Anger condition but did not significantly differ from the Neutral condition.

IES PBI ($F(2, 128) = 2.49$, $p = 0.09$, $\eta^2_p = 0.04$). Follow-up comparisons revealed that PBI was marginally lower in the Anger condition ($M = 0.09$, $SD = 0.14$), than in the Fear condition ($M = 0.16$, $SD = 0.18$; $p = 0.096$, 95% CI [−0.15, 0.01]). No other comparisons were significant (p's > 0.21).

Punishment Phase: Is performance-contingent punishment associated with increased proactive control relative to noncontingent punishment? If so, is this effect amplified on threat trials?

To examine performance in the Punishment phase, we ran an ANOVA similar to that for the Affect phase, but with an additional factor for trial-level threat of shock (safe vs. threat) included in the model. We therefore examined the effects of Trial Type (AX, AY, BX, BY), Punishment condition (Contingent, Noncontingent), and trial-level Threat-of-Shock (safe, threat) on IES (results shown in Fig. 4a). The main effect of Trial Type was significant ($F(3, 303) = 110.42$, $p < 0.0001$, $\eta^2_p = 0.52$), with follow-up comparisons using the Tukey HSD test revealing that IES was larger on AY ($M = 785$, $SD = 615$) trials compared with AX ($M = 284$, $SD = 73$; $p < 0.0001$, 95% CI [423.17, 579.38]) trials, which in turn had larger IES than BY ($M = 199$, $SD = 80$; $p = 0.03$, 95% CI [7.47, 162.77]) and BX ($M = 193$, $SD = 100$; $p = 0.01$, 95% CI [13.26, 168.56]) trials. There was no significant main effect of Punishment condition ($F(1, 101) = 0.21$, $p = 0.65$, $\eta^2_p = 0.002$). The main effect of Threat-of-Shock was also not significant ($F(1, 101) = 0.16$, $p < 0.69$, $\eta^2_p = 0.002$). However, there was a significant interaction between Punishment condition and Trial Type ($F(3, 303) = 3.22$, $p = 0.02$, $\eta^2_p = 0.03$). Follow-up comparisons revealed that this was driven by AY trials, where larger IES in the Contingent versus Noncontingent condition was observed ($p = 0.007$, 95% CI [25.78, 286.33]), indicative of increased proactive control in the Contingent condition. No other interactions reached significance (Trial Type × Threat-of-Shock: $F(3, 303) = 1.86$, $p = 0.14$, $\eta^2_p = 0.02$; Punishment condition × Threat-of-Shock: $F(1, 101) = 0.15$, $p = 0.7$, $\eta^2_p = 0.002$; Trial Type × Threat-of-Shock × Punishment condition: $F(3, 303) = 0.16$, $p = 0.93$, $\eta^2_p = 0.002$).

Proactive Behavioral Index

We then tested whether Punishment condition and trial-level Threat-of-Shock significantly modulated the IES PBI. Results are shown in Fig. 4b. There was a significant main effect of Punishment condition ($F(1, 101) = 5.1$, $p = 0.03$, $\eta^2_p = 0.05$), such that PBI was greater in the Contingent condition ($M = 0.58$, $SD = 0.21$) than in the Noncontingent condition ($M = 0.5$, $SD = 0.21$). The main effect of Threat-of-Shock was also significant ($F(1, 101) = 12.98$, $p = 0.0005$, $\eta^2_p = 0.11$), such that PBI was greater on threat trials ($M = 0.57$, $SD = 0.21$) than on safe trials ($M = 0.51$, $SD = 0.22$). There was no significant interaction between Punishment condition and Threat-of-Shock ($F(1, 101) = 1.16$, $p = 0.28$, $\eta^2_p = 0.01$).

Punishment Avoidance Success

Participants in the Contingent punishment group avoided punishment on an average of 81% of threat trials (range 58–100%), by meeting the individualized response

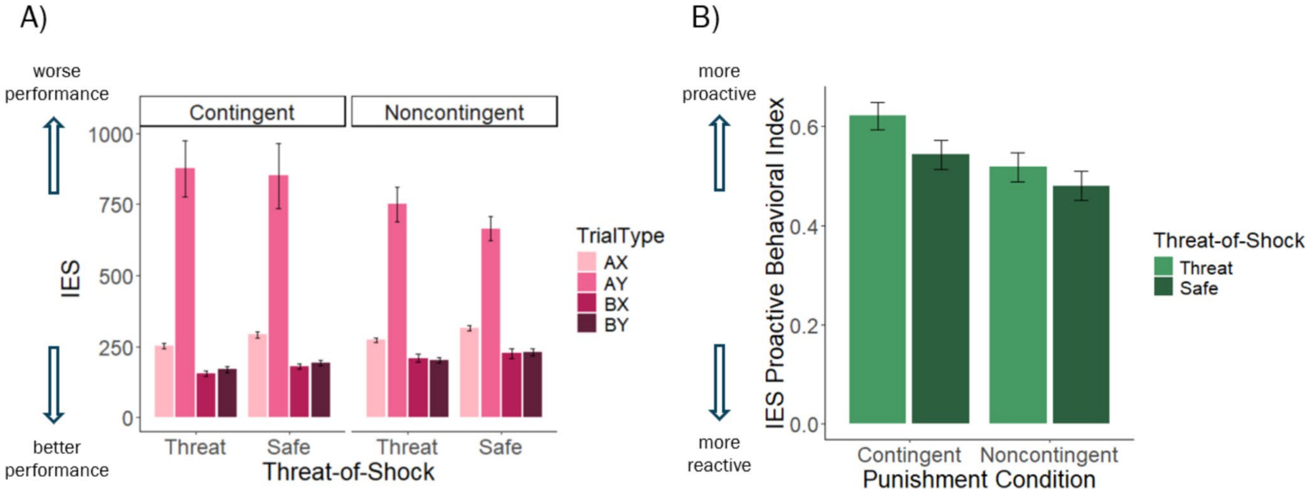

Fig. 4 A) Experiment 1: IES as a function of Trial Type (AX, AY, BX, BY) and Threat-of-Shock (threat, safe) across the two Punishment conditions. IES was heightened on AY trials in the Contingent condition relative to the Noncontingent condition. B) Experiment 1: IES PBI as a function of Punishment condition and Threat-of-Shock. PBI was higher in the Contingent condition than in the Noncontingent condition, and higher on threat trials compared with safe trials. The two effects did not interact.

deadline criteria. This resulted in participants in the Contingent group receiving an average of 15 pulses of electric shock across the two Punishment blocks. Participants in the Noncontingent group met the response deadline criteria at a similar rate, 80% of threat trials (range 22–98%), even though doing so did not allow for shock avoidance. On average, participants in both punishment conditions therefore met the response deadline criteria at rates much higher than the 30% rate that would be expected if performance was unchanged relative to the Affect phase. This suggests that participants were able to adaptively improve their performance under threat, regardless of whether receiving electric shock punishment was contingent on that performance.

Within-group Differences in Affect vs. Punishment Phase: Are sustained (block-level) performance-contingent and noncontingent punishment contexts associated with differences in proactive and reactive control, relative to each other and to performance under affect inductions?

Using a linear mixed-effects regression analysis, we examined whether IES was predicted by Trial Type (AX, AY, BX, BY), Phase (Affect, Punishment), and between-subject Group (Anger-Contingent, Anger-Noncontingent, Fear-Contingent, Fear-Noncontingent, Neutral-Contingent, Neutral-Noncontingent). Subject was included as a random intercept. The model including two-way interaction terms was a better fit than a model including main effects only ($\chi^2(23) = 130.42$, $p < 0.0001$), but adding the Trial Type × Phase × Group three-way interaction did not further improve model fit ($\chi^2(15) = 19.41$, $p = 0.2$) and was removed. Final model structure, using R notation, was thus as follows: *IES ~ Trial-Type + Phase + Group + Trial-Type:Phase + Trial-Type:Group + Phase:Group + (1|Subject).* We report key pairwise contrasts from this model; full statistics are reported in the supplementary material (Table S2).

We observed a significant effect of Trial-Type ($F(3,727.05) = 87.81$, $p < .001$) driven by higher IES, indicating worse performance, on AY trials relative to all other trial types (AY vs. AX: estimate = 299.6, $SE = 24.7$, $t = 12.14$, $p < .001$, AY vs. BX: estimate = 332.8, $SE = 24.7$, $t = 13.47$, $p < .001$, AY vs. BY: estimate = 343.3, $SE = 24.7$, $t = 13.91$, $p < .001$). We also observed a significant effect of Phase ($F(1,727.05) = 104.42$, $p < .001$), driven by higher IES, and thus worse performance, in the Affect versus Punishment phase (estimate = 178, $SE = 17.5$, $t = 10.22$, $p < .001$). These main effects were qualified by a significant Phase × Trial Type interaction ($F(3,727.05) = 33.14$, $p < 0.001$), such that the performance difference between AY trials and all other trial types were amplified in the Punishment vs. Affect phase (AY vs. AX: estimate = 308.7, $SE = 49.4$, $t = 6.25$, $p < .001$; AY vs. BX: estimate = 442.6, $SE = 49.4$, $t = 8.96$, $p < .001$; AY vs. BY: estimate = 407, $SE = 49.4$, $t = 8.24$, $p < .001$).

The between-subject groups did not significantly differ in overall IES ($F(5,101.82) = 1.77$, $p = 0.12$). In addition, the Trial Type × Group interaction was not significant ($F(15,727.05) = 1.38$, $p = 0.15$). However, there was a significant Phase × Group interaction ($F(5,727.05) = 3.58$, $p = 0.003$), such that IES differences between the Affect and Punishment phases were generally greater for the groups undergoing Noncontingent punishment versus those undergoing Contingent punishment. More specifically, after correcting for multiple comparisons, the Affect-Punishment phase difference in performance was significantly larger in the Fear-Noncontingent group relative to the Fear-Contingent group (estimate = 234.7, $SE = 60.4$, $t = 3.89$, $p = .002$), as well as in the Anger-Noncontingent group relative to the Fear-Contingent group (estimate = 183.1, $SE = 60.5$, $t = 3.03$, $p = .038$). Overall, while performance was better (i.e., lower IES) in the Punishment vs. Affect phase across all six groups, there was some suggestion that this difference was reduced in the Fear-Contingent condition relative to the contrast of both Fear and Anger groups receiving Noncontingent punishment. The lack of a significant three-way interaction suggests that all six groups further experienced a similar increase in proactive control in the Punishment phase relative to Affect phase.

Proactive Behavioral Index

Using a second linear mixed-effects regression analysis, we examined whether composite PBI scores (calculated from IES measures) was predicted by Phase (Affect, Punishment) and between-subject Group (Anger-Contingent, Anger-Noncontingent, Fear-Contingent, Fear-Noncontingent, Neutral-Contingent, Neutral-Noncontingent). Subject was again included as a random intercept. The model including the Phase × Group interaction did not provide a better fit than the model including fixed main effects alone ($\chi^2(5) = 2.55$, $p = 0.77$). Final model structure, using R notation, was thus as follows: *PBI ~ Phase + Group + (1|Subject).*

We observed a significant effect of Phase ($F(1,105.45) = 372.91$, $p < 0.0001$), such that PBI was heightened in the Punishment phase relative to the Affect phase (estimate = −.384, $SE = .02$, $t = -19.31$, $p < .001$). The main effect of Group was not significant ($F(5,101.35) = 1.7$, $p = 0.14$), suggesting that the six groups did not significantly differ in overall levels of proactive control. Further, the fact that adding the Phase × Group interaction term did not improve model fit suggests that higher levels of proactive control in the Punishment versus Affect phase were comparable across groups. PBI levels separated by Phase for each of the six groups are visualized in Fig. 5.

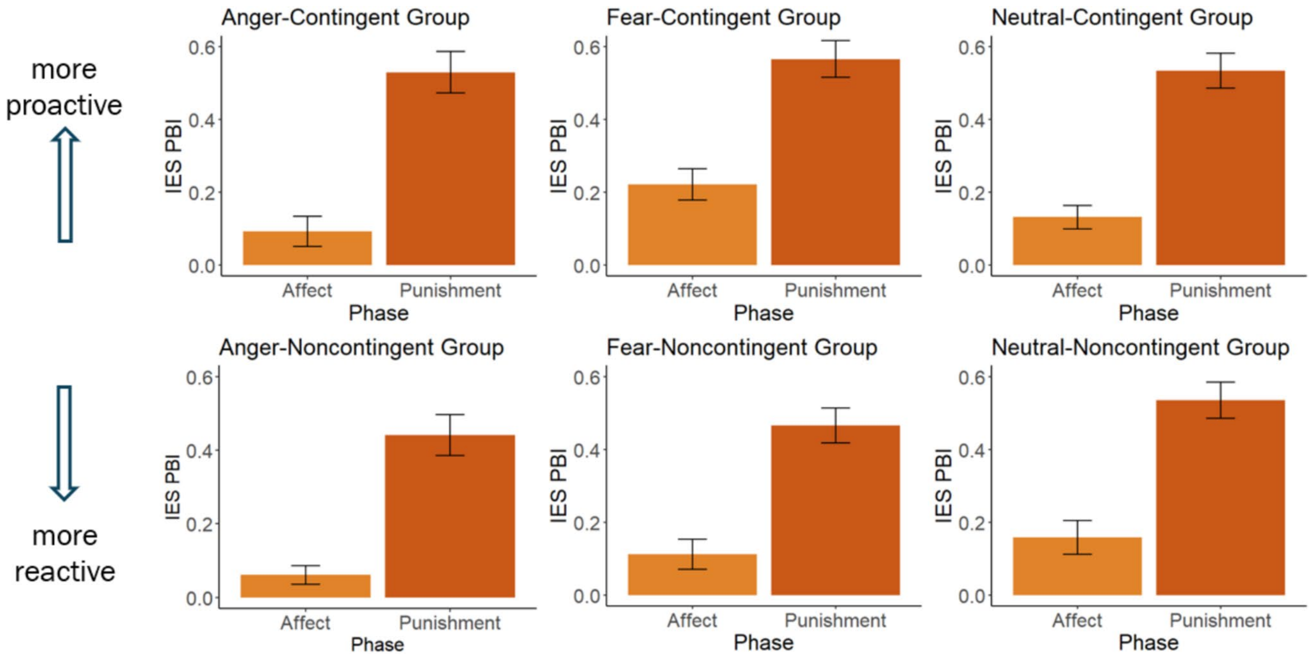

Fig. 5 Experiment 1: IES PBI as a function of Affect and Punishment condition for each of six between-subjects groups. Upward and downward arrows indicating greater proactive versus reactive control apply to each of the six plots. Across all six sub-conditions, proactive control was heightened in the Punishment phase relative to the Affect phase.

Experiment 1: Discussion

In Experiment 1, we investigated whether proactive and reactive control differed across image-based neutral and negative affect, performance-contingent punishment, and noncontingent punishment conditions. Our primary hypothesis was that negative affect, as induced by both the presentation of fear-based images and noncontingent punishment with electric shock, would be associated with increased reactive control relative to a neutral condition, while performance-contingent punishment would be associated with increased proactive control relative to all other conditions. We did not observe support for the first part of this hypothesis: reactive control did not significantly differ between fear-based and neutral images, and noncontingent punishment was associated with increased proactive, rather than reactive, control relative to both the neutral and negative affect image conditions. However, we did observe that, as predicted, performance-contingent punishment was associated with increased proactive control, as characterized by increases in both interference on AY trials and in the PBI composite measure, relative to the neutral, image-based negative affect, and noncontingent punishment conditions.

In testing the exploratory hypothesis that fear and anger-based negative affect inductions might differentially predict cognitive control outcomes, we observed marginally lower PBI in the Anger condition compared with the Fear condition. Although this effect did not reach significance, it was contrary to our exploratory hypothesis of potentially heightened proactive control in the Anger condition, given that anger is considered an approach-oriented emotion (Carver & Harmon-Jones, 2009). One limitation of the current study is that we did not obtain emotion ratings from participants for each stimulus image as an induction check. It is therefore possible that our Fear versus Anger manipulations had unintended effects on affect; anger in particular has been argued to be a complex emotion that might be challenging to induce using image stimuli (Gilam & Hendler, 2015; Thibodeau et al., 2008). Exploratory analyses of self-reported negative affect revealed that participants in the Anger condition reported greater negative affect that participants in the Neutral condition, while reported affect in the Fear condition did not significantly differ from reported affect in the other conditions. Therefore, our Fear manipulation may not have induced negative affect to the extent intended, while our Anger-related stimuli may have induced unintended negative emotions such as fear or disgust instead. In addition, it is possible that the images we used to induce Anger may have also differed from the Fear-inducing images in aspects other than emotion. Anger-inducing images may have had increased complexity (i.e., 9 of 10 Anger-inducing images depicted scenes, whereas 8 of 10 Fear-inducing stimuli depicted single objects or people) and increased social content (i.e., all 10 of the Anger-inducing stimuli included social content, whereas only 4 of 10 Fear-inducing stimuli included social content). It is possible that the Anger-inducing stimuli may have required more in-depth semantic interpretation due to the combination of these two features, which could potentially have interfered with proactive cognitive control processes. Finally, we note that post-hoc power analyses suggested that we were somewhat underpowered to detect a significant effect of Affect condition on PBI based on our observed effect size (power = 0.53, given alpha = 0.05, f = 0.20, N = 132). As such, the lack of significant differences in proactive versus reactive control between our Neutral Affect condition and our Fear and Anger conditions should be taken as tentative. Future work should recruit a more robust sample in order to detect potentially small effects of negative emotion manipulations. We will return to the implications of this marginal finding in the *General Discussion*.

Returning to our primary hypothesis, our observed association between performance-contingent primary punishment and increased proactive control was consistent with our predictions based on prior work utilizing threat of performance-contingent electric shock (Lindström et al., 2013). However, contrary to predictions, noncontingent punishment was associated with increased proactive control relative to the IAPs-induced neutral or negative affect conditions. One factor potentially contributing to this surprising finding is task order, as proactive control has been shown to increase with greater time on task (Fröber & Dreisbach, 2016; Hefer & Dreisbach, 2020) and the Punishment phase followed the Affect phase in the current study. However, exploratory analyses (reported in the supplementary materials) revealed that proactive control was still significantly higher in the Punishment relative to the Affect phase when block number was included as a predictor (i.e., helping control for time on task), suggesting that time-on-task effects were not likely to be solely responsible for observed differences by task phase.

Alternatively, there is a key methodological difference between Experiment 1 and previous literature reporting increased reactive control with negative affect (Yang et al., 2018), in that the threat cues in the Noncontingent condition in the current study were fully deterministic in predicting punishment, rather than probabilistic or uncertain. To investigate whether punishment uncertainty could account for our divergent findings, we conducted a second experiment modifying our Noncontingent condition such that trial-level threat was administered in a probabilistic (i.e., uncertain) fashion. In Experiment 2, we also aimed to systematically investigate the role of individual differences in trait anxiety and intolerance of uncertainty in shaping cognitive control under unpredictable, unavoidable threat of punishment. Finally, in Experiment 2, we counterbalanced task phase order, to more tightly control for the possibility that the phase-related differences in cognitive control observed in Experiment 1 were the product of time on task effects (Fröber & Dreisbach, 2016; Hefer & Dreisbach, 2020).

Experiment 2: Methods

In Experiment 2, we followed up on the results of Experiment 1 by investigating the effect of uncertain, noncontingent punishment, in combination with individual differences in trait anxiety and intolerance of uncertainty, in modulating cognitive control. Experiment 2 was also preregistered on the Open Science Framework (https://osf.io/fvkdy). Given the lack of significant differences observed between the neutral and negative affect image-inductions in Experiment 1, we chose to simplify the task design and omitted the Fear and Anger affective manipulations from Experiment 2. We also focused on introducing uncertainty to the noncontingent punishment condition, given that our performance-contingent punishment manipulation arguably included some level of inherent uncertainty (i.e., individuals are not fully certain whether their performance will be adequate to avoid the electric shock on a given trial). Therefore, all participants in Experiment 2 completed the AX-CPT under both an emotionally neutral baseline condition and a noncontingent punishment condition. The noncontingent punishment AX-CPT matched that in Experiment 1 with one key difference: instead of fully deterministic cues indicating whether electric shock would be received on a given trial, the cues indicating electric shock were probabilistic and only resulted in the receipt of electric shock a portion of the time. This allowed us to test the hypothesis that uncertain noncontingent punishment would be associated with increased reactive control relative to the within-subject neutral baseline condition in Experiment 2, as well as in comparison to the deterministic noncontingent punishment condition from Experiment 1 in a cross-experiment comparison (reported below).

Furthermore, to investigate the extent to which uncertainty might interact with trait individual differences to modulate cognitive control under noncontingent punishment conditions, we specifically recruited participants varying in trait anxiety. Compared with exploratory analyses of anxiety from Experiment 1 (reported in the supplementary materials), this allowed for a more targeted examination of whether individuals higher in trait anxiety and intolerance of uncertainty would display increased reactive control under threat of uncertain, noncontingent punishment.

Participants

We aimed to collect a sample of 52 participants, matched in trait anxiety levels to the Experiment 1 Contingent group with intact STAI-Trait data (more details on matched anxiety scores below). We further matched the number of times individuals received electric shocks, relative to their trait anxiety scores, across the punishment conditions in Experiments 1 and 2. In addition to matching our Experiment 1 sample in terms of trait anxiety distribution, we collected data from as many additional participants as possible during the participant recruitment period (i.e., until the end of the academic quarter, given recruitment of participants from an undergraduate subject pool). Our final sample consisted of 70 individuals, 51 of whom were matched on trait anxiety levels and number of electric shocks to Experiment 1 participants, and an additional 19 participants. Of participants in this final sample, 9 did not complete the Punishment condition due to technical issues with the electric shock device, leaving 61 with full data. The analyses reported below include only the 51 participants with full data who were matched to the Contingent group from Experiment 1, to facilitate comparison of the effects of predictable and uncertain punishment on cognitive control, with minimized differences in trait anxiety levels and frequency of electric shock. Analysis of task performance in the full collected sample can be found in the supplementary materials, and any divergences in the results between the full sample and the Experiment 1-matched subsample are briefly discussed in Experiment 2 *Discussion* below. To preview, results were generally consistent across the full sample versus the matched subsample. The only divergence was relatively small and occurred in the comparison of PBI scores between threat and safe trials within the Punishment phase, an effect which was found to be marginally significant with the matched subsample and nonsignificant with the full sample.

As in Experiment 1, participants were recruited via the University of Denver SONA participant pool and posted flyers. To meet inclusion criteria, all participants were fluent English speakers, had normal or corrected-to-normal vision, and no reported current psychological illness, history of neurological illness or injury, current psychotropic medication use, or pacemaker use. Data collection was completed between October 2023 and March 2024. Our final sample, including all 70 participants with at least partial usable data, had an age range of 18–31 years (M = 19.51, SD = 2.1), with an average of 13.6 years of education (SD = 1.57). Biological sex at birth was reported as 48 females and 22 males. Gender identification was reported as 44 women, 20 men, and 2 gender queer/gender nonconforming (three participants chose not to respond or to self-describe). Self-reported racial identity was 1.4% “American Indian”; 4.3% “Asian”; 4.3% “Black”; 1.4% “Central/South American”; 75.7% “White/Caucasian”; 5.7% selected more than one race; and 7.1% chose not to respond or to self-describe. Self-reported ethnicity was 17.1% “Hispanic or Latino/a” and 82.9% “NonHispanic or Latino/a.” Participants were compensated either $10/hour or with course credit for completing the study. The study protocol was approved by the University of Denver Institutional Review Board.

Potential participants were characterized as high- or low-anxiety based on whether their scores on the STAI-Trait scale fell above or below 40, which was the median STAI-Trait score for the Contingent group in Experiment 1. We therefore aimed to recruit 26 low-anxiety participants with scores < 40, and 26 high-anxiety participants with scores ≥ 40. The first half of our data collection resulted in unbalanced groups, with more high-anxiety individuals participating (i.e., individuals with STAI-trait scores ≥ 40). Given this, partway through data collection we added an online pre-screening survey before the in-person session to selectively recruit the remaining participants needed for the low-anxiety group. We recruited based on a median dividing value from Experiment 1 in order to examine the effects of uncertain punishment in Experiment 2 in a sample with a comparable range of trait anxiety levels.

Procedure

Participants provided informed consent upon arriving for the experiment. Initial self-report ratings of emotional valence and arousal were collected as a measure of current emotional state. Participants were then instructed on the AX-CPT paradigm and completed ten practice trials, performance on which were not analyzed. The practice trials were followed by another ten-trial mini-block, which was used to generate the individualized 30th percentile reaction time cutoff for use in the Punishment phase. Next, participants were asked to complete a series of individual differences questionnaires identical to those in Experiment 1 (i.e., demographics, BIS/BAS, IUS, and STAI measures). Participants were set up with electrodes on the nondominant hand to monitor SCL, and then they completed two task blocks each of the Baseline and Punishment phases of the AX-CPT. The two phases were completed in a counterbalanced order, such that half the participants completed the two Baseline task blocks first, followed by the two Punishment task blocks, while the other half of participants completed the two Punishment task blocks first, followed by the Baseline task blocks. The electric shock calibration protocol was completed immediately prior to the Punishment phase. Finally, participants completed a brief post-task survey and then were debriefed and compensated for their time.

The AX-CPT paradigm was identical to that of Experiment 1, apart from the punishment manipulation, detailed below. As in Experiment 1, SCL was monitored during each task block, and self-report ratings of emotional valence, arousal, motivation, effort, and threat ratings of the electric shock were collected after completion of the AX-CPT.

Baseline and Punishment Manipulations

In both the practice and reaction time cutoff mini-blocks, the pre-cue image displayed on each trial was an empty circle. During the neutral Baseline phase, the image of an empty circle again served as a pre-cue on each trial, for two task blocks of 80 trials each, with participants instructed that there was no possibility of receiving electric shocks. In the Punishment phase, all participants completed the noncontingent punishment AX-CPT.

The noncontingent punishment condition was identical to that used in Experiment 1, with the key exception that the image cues indicating whether there was a threat of electric shock on a given trial were not 100% deterministic. Instead, the lightning bolt cue served as a probabilistic predictor of whether electric shock could be received on that trial. The probability that the lightning bolt cue would be followed by electric shock on a given punishment trial varied across participants, to match the number of shocks received between the current experiment and the Contingent condition in Experiment 1. Matching the number of shocks received was designed to facilitate cross-experiment comparisons (reported below) of the effect of performance contingency, while controlling for the total number of shocks received at the individual subject level. This resulted in the probability of electric shock receipt on Threat trials ranging from 0% to 42.5% across participants, with an average of 22%. Instead of a cloud image, the cue for safe trials in this experiment was replaced with a crossed out lightning bolt to signal the lack of threat. As in Experiment 1, the safe trials indicated with 100% certainty that there was no possibility of receiving electric shock on that trial. Once again, participants completed two task blocks in the Punishment phase, with 80 trials each.

Electric Shock Protocol, Skin Conductance Measure, and Questionnaires

The protocol for calibrating and administering electric shocks, the procedure for measuring SCL, and the procedure for questionnaire administration were all identical to those described for Experiment 1.

Post-Task Survey

At the very end of the experiment, just prior to debriefing and compensation, participants completed an additional brief post-task survey. Participants were asked to rate how threatening they found the electric shock, on a scale from 1 to 10. Additional questions inquired about the perceived frequency of threat of shock trials, and whether participants did anything differently on trials with the possibility of electric shock. If participants responded “yes” to this last question, they were asked to explain what they did differently in an open-ended response.

Data Analysis Plan

As in Experiment 1, the planned analyses were preregistered on the Open Science Framework (https://osf.io/fvkdy). Once again, in a departure from the preregistration, the results reported in the main manuscript use IES in place of reaction time and error rate. The full results with reaction times and error rates are reported in the supplementary materials. There were no major differences in results using IES compared with reaction times and error rates, but any small divergences are noted in our *General Discussion*. As in Experiment 1, analyses were carried out in R (version 4.2.2; R Core Team, 2022) using the tidyverse, psych, ggplot2, ez, lme4, lmerTest, effectsize, and afex packages.

Data Exclusions

Following the protocol established for Experiment 1, participants with accuracy scores below 50% for any task block, or with overall accuracy less than 3 standard deviations below the sample mean, were fully excluded from analysis. One participant was excluded on the basis of low accuracy using these criteria.

AX-CPT Outcome Measures

As in Experiment 1, IES and a composite measure of proactive control, PBI, were computed for use in analyses. Higher IES scores indicated worse performance, and more positive PBI measures indicated higher levels of proactive control (versus more negative PBI measures indicating higher levels of reactive control).

Punishment Phase: Is reactive control heightened on threat versus safe trials under uncertain noncontingent threat of punishment?

To examine task performance during the Punishment phase, we used a 4 (Trial Type: AX, AY, BX, BY) × 2 (Threat-of-Shock: safe, uncertain threat) repeated-measures ANOVA, with IES as the dependent measure. We also conducted a paired t-test to test for significant differences in PBI by Threat-of-Shock (uncertain threat, safe) in the Punishment phase.

Within-group differences in Baseline vs. Punishment Phase: Is the sustained effect of uncertain noncontingent punishment associated with increased reactive control relative to a neutral baseline condition?

To evaluate the sustained, block-level effect of threat on cognitive control, we analyzed differences between Baseline block trials and safe trials from the Punishment block using a 2 (Phase: Baseline, Punishment) × 4 (Trial Type: AX, AY, BX, BY) repeated-measures ANOVA, with IES as the dependent measure. We also performed a paired t-test to examine whether PBI differed between the Baseline phase and safe trials in the Punishment phase.

Punishment Phase – Individual Differences Effects: Do individuals higher in trait anxiety and intolerance of uncertainty display greater increases in reactive control on threat versus safe trials under uncertain punishment?

We investigated whether individual differences in trait anxiety and intolerance of uncertainty modulated cognitive control performance in the Punishment Phase. Scores on the STAI-Trait scale ranged from 22 to 72 (male $M = 39.53$ $SD = 10.86$; female $M = 43.11$, $SD = 12.24$). Scores on the IUS ranged from 37 to 125 (male $M = 61.07$, $SD = 20.51$; female $M = 66.91$, $SD = 22.14$). We note that these scores are slightly higher than average scores in published norms for young adults on the STAI-Trait scale and comparable young adult samples for the IUS.[2] However, given that no participants reported a current anxiety disorder diagnosis (given exclusion criteria during screening), we consider our sample to be in the subclinical range.

Given a strong correlation between trait anxiety and intolerance of uncertainty in our sample ($R = 0.74$, $p < 0.0001$), we performed a multivariate K-means cluster analysis to form two separate groups on the basis of both measures, following the procedure used by Wroblewski et al. (2022). This approach allowed us to characterize participants as either relatively high-scoring in both trait anxiety/intolerance of uncertainty (TA/IU), versus relatively low-scoring in both measures, maximizing the difference between clusters. The cluster analysis resulted in 29 participants characterized as low TA/IU (mean STAI-Trait score = 35.55, mean IUS score = 50.55) and 20 participants characterized as high TA/IU (mean STAI-Trait score = 51.05, mean IUS score = 86.55). The distribution of scores for each cluster are visualized in Fig. 6.

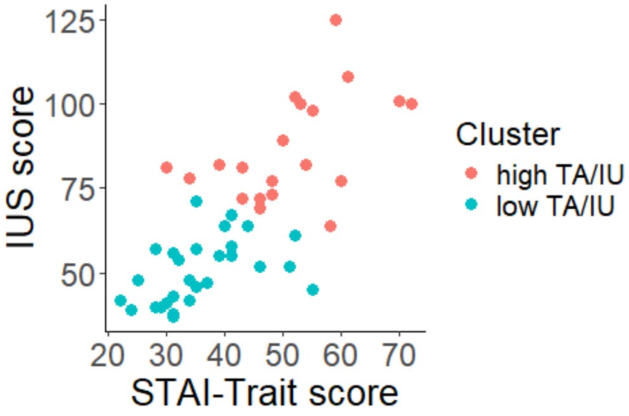

Fig. 6 Scatterplot depicting the results of the cluster analysis, assigning participants to one of two clusters of high or low trait anxiety and intolerance of uncertainty (TA/IU).

We then conducted a 2 (TA/IU Cluster: low-TA/IU, high-TA/IU) × 4 (Trial Type: AX, AY, BX, BY) × 2 (trial-level Threat-of-Shock: safe, uncertain threat) repeated-measures ANOVA, with IES as the dependent measure. We planned to conduct follow-up comparisons if any interaction terms proved significant.

Finally, we conducted a 2 (TA/IU Cluster: low-TA/IU, high-TA/IU) × 2 (trial-level Threat-of-Shock: safe, uncertain threat) repeated-measures ANOVA, with PBI as the dependent measure to examine whether proactive control in the Punishment phase differed by cluster.

Experiment 2: Results

Data Exclusions

No participant had accuracy below 50% on any task block. However, one participant was excluded from analyses due to overall task accuracy more than 3 standard deviations below the sample mean. A sample size of 50 remained for all matched-subsample analyses of task performance.

Punishment Phase: Is reactive control heightened on threat versus safe trials under uncertain noncontingent threat of punishment?

To examine performance in the Punishment phase, we used a 4 (Trial Type: AX, AY, BX, BY) × 2 (Threat-of-Shock: safe, uncertain threat) repeated-measures ANOVA, with IES examined as the dependent variable (results shown in Fig. 7). We additionally performed a paired t-test to compare IES PBI between uncertain threat and safe trials.

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[2] Published norms for the STAI-Trait scale: male young adults norm $M = 38.3$, $SD = 9.18$; female young adults norm $M = 40.4$, $SD = 10.15$ (Spielberger, 1985). Published norms are not available for the IUS. However, our sample average is consistent with other undergraduate young adult samples (Gerolimatos & Edelstein, 2012: $M = 63.55$, $SD = 22.06$; Kraemer et al., 2015: $M = 66.53$, $SD = 20.32$), although neither study screened for nor excluded participants with a diagnosed anxiety disorder. Another study found that participants meeting diagnostic criteria for Generalized Anxiety Disorder had scores comparable to our sample ($M = 66.30$, $SD = 20.39$), whereas a nonanxious control group had lower scores ($M = 45.15$, $SD = 12.80$) (Holaway et al., 2006). This suggests that our sample may have included undiagnosed participants in the clinical range for trait anxiety and intolerance of uncertainty, although the sample as a whole should not be interpreted as reflecting clinical levels of anxiety.

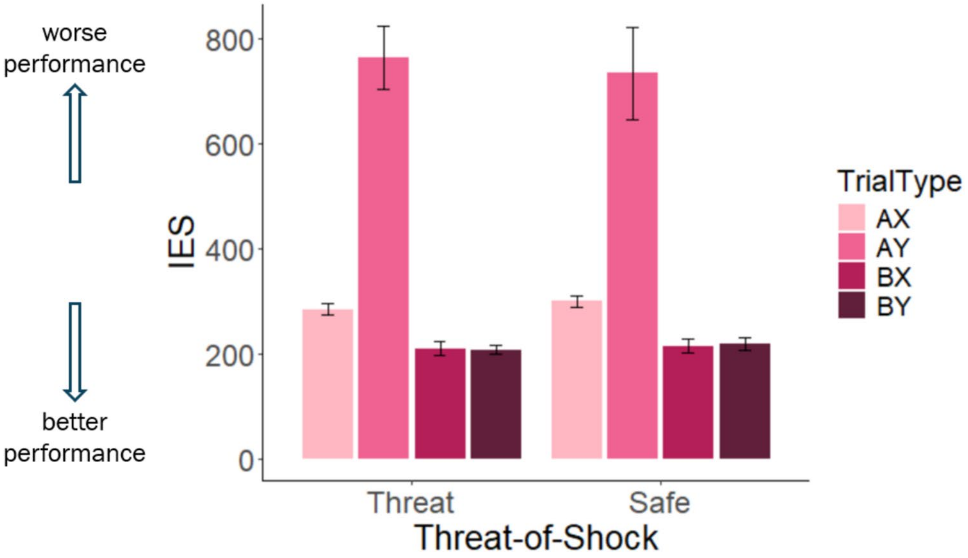

Fig. 7 Experiment 2: IES as a function of Trial Type and Threat-of-Shock in the Punishment phase. IES did not differ between threat and safe trials.

The main effect of trial type on IES was significant (*F(3, 147)* = 55.51, $p < 0.0001$, $\eta^2_p = 0.53$), with follow-up comparisons revealing that IES was significantly higher on AY trials ($M = 749$, $SD = 532$) than on the other three trial types (AX: $M = 293$, $SD = 71$, $p < 0.0001$, 95% CI [356.05, 556.7]; BY: $M = 214$, $SD = 72$, $p < 0.0001$, 95% CI [435.32, 635.97]; BX: $M = 213$, $SD = 95$, $p < 0.0001$, 95% CI [436.11, 636.75]). No other significant differences in IES measures by trial type were observed (all *p*'s > 0.16). We did not observe a significant main effect of Threat-of-Shock (*F(1, 49)* = 0.0003, $p = 0.99$, $\eta^2_p < 0.001$). There was no significant interaction between Threat-of-Shock and Trial Type (*F(3, 147)* = 0.28, $p = 0.84$, $\eta^2_p = 0.006$).

Finally, we conducted a paired t-test to examine whether IES PBI differed between threat and safe trials. IES PBI was marginally larger on threat trials compared with safe trials (*t(49)* = 1.77, $p = 0.08$, $d = 0.21$).

Punishment Avoidance Success

Participants successfully met the response deadline criteria on an average of 77% of threat trials (range 28–100%). Consistent with the findings in Experiment 1, this was much higher than the 30% avoidance rate that would be expected if performance was unchanged relative to the Baseline phase. We interpret this pattern as suggesting that participants were able to adaptively improve their performance in response to unpredictable, noncontingent threat of punishment.

Within-group differences in Baseline vs. Punishment Phase: Is the sustained effect of uncertain noncontingent punishment associated with increased reactive control relative to a neutral baseline condition?

To examine differences in task performance between the Baseline and Punishment phases we used a 4 (Trial Type: AX, AY, BX, BY) × 2 (Phase: Baseline, Punishment) repeated-measures ANOVA, with IES as the dependent measure (results shown in Fig. 8). We also performed a paired t-test to compare IES PBI between the Baseline and Punishment phases.

The main effect of Trial Type on IES was significant (*F(3, 150)* = 40.00, $p < 0.0001$, $\eta^2_p = 0.44$), with follow-up comparisons revealing that IES was larger on AY trials ($M = 674$, $SD = 471$) than on all other trial types (AX: $M = 348$, $SD = 112$, $p < 0.0001$, 95% CI [225.07, 425.61]; BX: $M = 294$, $SD = 229$, $p < 0.0001$, 95% CI [279.07, 479.62]; BY: $M = 271$, $SD = 147$, $p < 0.0001$, 95% CI [302.15, 502.69]). As in Experiment 1, this pattern of poorer performance on AY trials overall is consistent with typically observed findings that healthy young adults display a bias towards proactive control, even in "neutral" baseline conditions (Gonthier et al., 2016). We additionally observed a significant main effect of Phase (*F(1, 50)* = 4.65, $p = 0.04$, $\eta^2_p = 0.09$), such that IES was larger overall in the Baseline versus Punishment phase (Baseline: $M = 425$, $SD = 247$; Punishment: $M = 368$, $SD = 379$), reflecting improved task performance in the Punishment phase. Finally, there was a significant Phase × Trial Type interaction (*F(3, 150)* = 9.10, $p < 0.0001$,

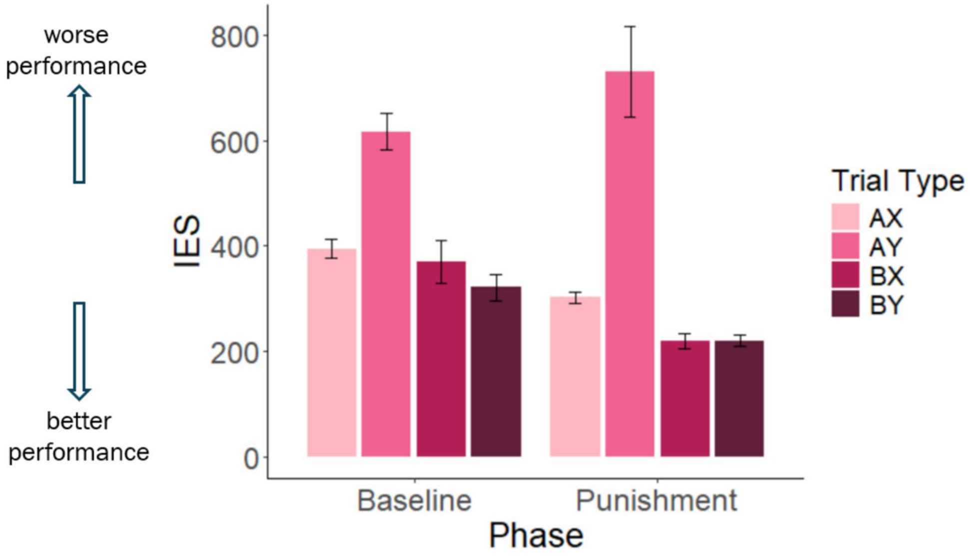

Fig. 8 Experiment 2: IES as a function of Trial Type and Phase. IES was larger overall in the Baseline phase. However, the effect of trial type (i.e., larger IES on AY trials) was heightened in the Punishment phase.

$\eta^2_p = 0.15$). Follow-up comparisons revealed that IES differences between AY and the other three trial types, while significant in both phases, were greater in the Punishment phase (AY vs. AX: $p < 0.0001$, 95% CI [263.87, 592.97]; AY vs. BX: $p < 0.0001$, 95% CI [346.73, 675.84]; AY vs. BY: $p < 0.0001$, 95% CI [345.47, 674.58]) than in the Baseline phase (AY vs. AX: $p = 0.001$, 95% CI [57.70, 386.81]; AY vs. BX: $p = 0.0002$, 95% CI [82.86, 411.96]; AY vs. BY: $p < 0.0001$, 95% CI [130.26, 459.36]).

We conducted a paired *t*-test to examine whether PBI differed between the Baseline and Punishment phases. PBI was significantly greater in the Punishment phase than the Baseline phase ($t(50) = -4.09$, $p = 0.0002$, $d = -0.70$). Together, these analyses suggest improved performance and increased proactive control under uncertain punishment relative to baseline.

<u>Punishment Phase – Individual Differences Effects</u>: Do individuals higher in trait anxiety and intolerance of uncertainty display greater increases in reactive control on threat versus safe trials under uncertain punishment?

We then conducted a 2 (TA/IU Cluster: low-TA/IU, high-TA/IU) × 4 (Trial Type: AX, AY, BX, BY) × 2 (trial-level Threat-of-Shock: safe, uncertain threat) repeated-measures ANOVA, to examine whether IES differed by trait anxiety/intolerance of uncertainty cluster. We did not observe a significant main effect of cluster ($F(1, 46) = 0.91$, $p = 0.34$, $\eta^2_p = 0.02$). There was a significant main effect of Trial Type ($F(3, 138) = 52.92$, $p < 0.0001$, $\eta^2_p = 0.54$), with follow-up comparisons revealing that IES was larger on AY trials ($M = 749$, $SD = 532$) than on all other trial types (AX: $M = 293$, $SD = 71$, $p < 0.0001$, 95% CI [356.05, 556.70]; BY: $M = 214$, $SD = 72$, $p < 0.0001$, 95% CI [435.32, 635.97]; BX: $M = 213$, $SD = 95$, $p < 0.0001$, 95% CI [436.11, 636.75]). There was no significant effect of Threat-of-Shock ($F(1, 46) = 0.0004$, $p = 0.98$, $\eta^2_p = 0.0008$). Finally, none of the interaction terms reached significance (Cluster × Trial Type: $F(3, 138) = 0.60$, $p = 0.62$, $\eta^2_p = 0.01$; Cluster × Threat-of-Shock: $F(1, 46) = 1.04$, $p = 0.31$, $\eta^2_p = 0.02$; Trial Type × Threat-of-Shock: $F(3, 138) = 0.38$, $p = 0.77$, $\eta^2_p = 0.02$; Cluster × Trial Type × Threat-of-Shock: $F(3, 138) = 2.10$, $p = 0.10$, $\eta^2_p = 0.04$).

We additionally conducted a 2 (TA/IU Cluster: low-TA/IU, high-TA/IU) × 2 (trial-level Threat-of-Shock: safe, uncertain threat) repeated-measures ANOVA to examine whether PBI in the Punishment phase differed by trait anxiety/intolerance of uncertainty cluster. We did not observe a significant main effect of cluster ($F(1, 46) = 0.56$, $p = 0.46$, $\eta^2_p = 0.01$). There was a significant main effect of Threat-of-Shock ($F(1, 46) = 5.51$, $p = 0.02$, $\eta^2_p = 0.12$), such that PBI was higher on threat compared with safe trials. Finally, there was no significant interaction between cluster and Threat-of-Shock ($F(1, 46) = 2.16$, $p = 0.15$, $\eta^2_p = 0.04$).

Experiment 2: Discussion

In Experiment 2, we followed up on Experiment 1 by examining changes in cognitive control under unpredictable, noncontingent threat of punishment compared with a neutral baseline, as well as examining whether this effect was modulated by individual differences in trait anxiety and intolerance of uncertainty. We observed sustained, block-level increases in proactive control (as indexed by increased IES on AY trials and increased PBI) in the punishment phase relative to baseline phase, as well as trial-level, marginal increases in proactive control (measured with PBI) on trials with threat of uncertain, noncontingent punishment compared with safe trials. A post-hoc power analysis based on the observed effect size for the marginal effect of trial-level threat on PBI suggested that we were underpowered to detect a significant effect (power = 0.31, given two-tailed test, alpha = 0.05, $d = 0.21$, N = 50); caution should thus be taken in interpreting this marginal effect. Regardless, we observed a consistent pattern overall across both experiments, whereby threat of punishment was associated with increased proactive control, even when that threat was both uncertain and noncontingent, in contrast to prior observations in the literature (i.e., increased reactive control under threat of random punishment; Yang et al., 2018). As such, these findings suggest that punishment uncertainty may not account for diverging observations in our Experiment 1 noncontingent condition relative to findings reported by Yang et al. (2018). Instead, we speculate that other features of the task design, such as the inclusion of a speeded response deadline and the intensity of the electric shock, might account for our findings. These possibilities are addressed further in the *General Discussion* below.

In addition, we purposely counterbalanced condition order in Experiment 2, such that some participants completed the baseline phase first, whereas others completed the punishment phase first. Our results were consistent with Experiment 1, in that proactive control was heightened in the punishment phase even when phase order was counterbalanced. However, exploratory analyses (reported in the Supplementary materials) in which we examined the difference between the Baseline and Punishment phases separately for each counterbalance order revealed that some order effects may have been present as well. While both counterbalance groups displayed increased proactive control (i.e., elevated AY interference) in the Punishment phase, this difference was larger for participants that completed the Baseline phase first. For participants that completed the Punishment phase first, there appeared to be a potential "carry-over" effect of the threat of shock, such that heightened levels of proactive control were observed in the subsequent neutral baseline condition. Given that AY interference was consistently elevated in the Punishment phase compared with the Baseline phase, across orders, we suggest that some carry-over may have occurred but that the effects of noncontingent punishment on proactive control are not solely attributable to time-on-task/order effects. The consequences of employing task designs with static versus counterbalanced order when investigating the effect of noncontingent punishment is explored further below in the *General Discussion*.

Finally, in Experiment 2, individual differences in trait anxiety and intolerance of uncertainty were not significantly associated with differences in overall task performance or the use of proactive control under uncertain punishment. We therefore did not find support for our second hypothesis—that individuals higher in trait anxiety might display increased reactive control on threat trials, although we express caution in interpreting this null finding, especially given that we did not observe an overall increase in reactive control with uncertain threat as originally predicted. Additional exploratory analyses examining individual-level variability in physiological response to uncertain threat suggested both that trait anxiety might be positively associated with threat-induced arousal and that threat-induced arousal might be positively associated with proactive control and overall performance, but these did not translate to a significant relationship between trait anxiety and task performance. These analyses are reported in the supplement and discussed further in the *General Discussion*.

Cross-Experiment Comparisons

We capitalized on the matched samples between the Contingent group from Experiment 1 and the sample from Experiment 2 to directly examine whether performance differed among the punishment phases for each of our three between-subject punishment conditions (Experiment 1 Contingent Punishment, Experiment 1 Noncontingent Punishment, Experiment 2 Unpredictable Punishment). In Experiment 1, the Contingent and Noncontingent groups differed on multiple dimensions, including the number of electric shocks received during the task and outcome certainty on each trial. In contrast, both the Contingent condition from Experiment 1 and the unpredictable punishment condition in Experiment 2 had uncertain outcomes in terms of shock receipt on a trial-by-trial basis, as well as matched numbers of shocks received. Therefore, we aimed to isolate the dimensions of punishment contingency and outcome predictability and investigate whether one or both dimensions contributed to differences in proactive control across punishment conditions. Both contingency and predictability were examined in the same model to test for each predictor while controlling for the potential influence of the other.

Data Analysis Plan

We used two linear mixed-effects regression models, implemented using the *lmer* command in the *lmerTest* R package (Kuznetsova et al., 2017), to investigate the extent to which contingency and predictability dimensions of punishment predicted IES and PBI outcome measures. No model comparison procedure was conducted for these analyses, given our predefined aim of examining whether contingency and predictability modulated the effect of punishment on proactive control. The fixed effect of Contingency was contrast-coded as +1 for the Experiment 1 Contingent group and −1 for both the Experiment 1 Noncontingent group and the Experiment 2 Unpredictable group. The fixed effect of Predictability was contrast-coded as +1 for the Experiment 1 Noncontingent group and −1 for both the Experiment 1 Contingent group and the Experiment 2 Unpredictable group. We again assessed the significance of each fixed effect using Type III F-tests with Satterthwaite's approximation for degrees of freedom, and followed up significant effects using estimated marginal means and pairwise contrasts between factor levels, computed with the *emmeans* R package. We again adjusted our pairwise contrasts for multiple comparisons in emmeans using the Tukey HSD procedure for main effects and the Šidák method for interaction effects.

In our first model, we examined whether Contingency and Predictability, each in two- and three-way interaction with Trial Type (AX, AY, BX, BY) and Threat-of-Shock (safe, threat), predicted IES. In our second model, we examined whether Contingency and Predictability, each in interaction with Threat-of-Shock, predicted PBI. Subject was included as a random intercept in both models. We attempted to add Experiment as an additional random intercept, but discarded this due to singularity (model overfitting) concerns.

Cross-Experiment Comparisons: Results

To examine whether the dimensions of Contingency and Predictability, which varied across the three punishment conditions employed in our two experiments, predicted overall task performance and proactive control, we conducted two regression analyses. Key findings are reported below with full analysis statistics available in the Supplementary materials (Table S3 for IES model, Table S4 for PBI model). Performance for the three punishment conditions are visualized in Fig. 9a for IES and Fig. 9b for PBI.

IES Analysis: Does task performance vary with performance-contingency and predictability in punishment?

We first examined whether Contingency and Predictability, each in interaction with Trial Type (AX, AY, BX, BY) and Threat-of-Shock (safe, threat), predicted IES. Subject was included as a random intercept. R notation for this model was thus as follows: *IES ~ Contingency + Predictability + Trial-Type + Threat-of-Shock + Contingency:Trial-Type + Contingency:Threat-of-Shock + Predictability:Trial-Type + Predictability:Threat-of-Shock + Trial-Type:Threat-of-Shock + Contingency:Trial-Type:Threat-of-Shock + Predictability:Trial-Type:Threat-of-Shock + (1|Subject).*

When testing for potential effects of Contingency on performance measured using IES, we did not observe a significant main effect of Contingency (F(1,154.26) = 0.41, p = 0.52), but did observe a significant Contingency × Trial Type interaction (F(3,1074.98) = 3.00, p = 0.03), such that IES was significantly heightened on AY versus BX trials in the Contingent condition relative to the two noncontingent conditions (estimate = 155.8, SE = 58.7, t = 2.66, p = 0.047) and marginally heightened on AY versus BY trials (estimate = 143.1, SE = 58.7, t = 2.44, p = 0.086). Contingency did not significantly interact with Threat-of-Shock (F(1,1075.00) = 0.18, p = 0.68). No significant Contingency × Trial Type × Threat-of-Shock interaction was observed (F(3,1075.00) = 0.02, p = 0.997).

When testing for potential effects of Predictability on performance measured using IES, we did not observe a significant main effect of Predictability (F(1,154.26) = 0.11, p = 0.74) or any significant interactions between Predictability and other predictors of interest: (Predictability x Trial-Type: F(3,1074.98) = 0.29, p = 0.83; Predictability x Threat-of-Shock: F(1,1074.99) = 0.00, p = 0.998; Predictability x Trial-Type x Threat-of-Shock: F(3,1074.98) = 0.21, p = 0.89).

Does proactive control vary with performance-contingency and predictability in punishment?

We then examined whether Contingency and Predictability, each in interaction with Threat-of-Shock (safe, threat), predicted PBI. Subject was included as a random intercept. R notation for this model was as follows: *PBI ~ Contingency + Predictability + Threat-of-Shock + Contingency:Threat-of-Shock + Predictability:Threat-of-Shock + (1|Subject).*

When testing for potential effects of Contingency on proactive control measured using PBI, we observed a significant main effect of Contingency (F(1,153.01) = 4.01, p = 0.047), such that PBI was heightened in the Contingent condition relative to the two noncontingent conditions (estimate = −0.08, SE = 0.04, t = −2.00, p = 0.047). Contingency did not significantly interact with Threat-of-Shock (F(1,150.54) = 1.32, p = 0.25).

When testing for potential effects of Predictability on proactive control measured using PBI, we did not observe a significant main effect of Predictability (F(1,153.01) = 0.01, p = 0.90) or a significant interaction between Predictability and Threat-of-Shock (F(1,150.49) = 0.004, p = 0.95).

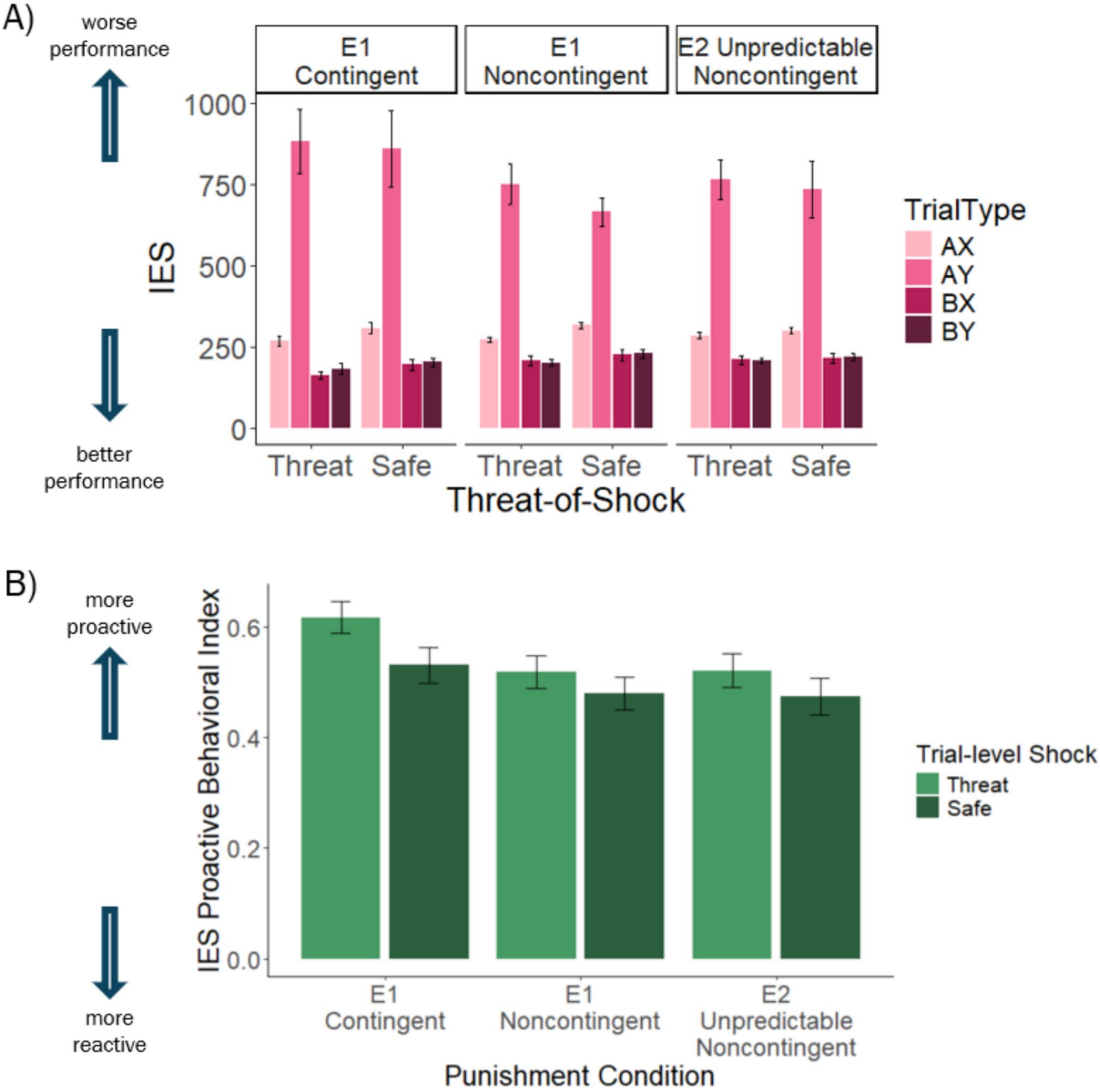

Fig. 9 A) Cross-experiment comparison of IES as a function of Trial Type, Punishment condition, and Threat-of-Shock. For regression analyses, Contingency was contrast coded to compare the Experiment 1 Contingent group to the two noncontingent conditions (Experiment 1 Noncontingent group and Experiment 2 Unpredictable group). Predictability was contrast coded to compare the Experiment 1 Noncontingent group to the two unpredictable conditions (Experiment 1 Contingent group and Experiment 2 Unpredictable group). B) Cross-experiment comparison of IES PBI as a function of Punishment condition and Threat-of-Shock. For regression analyses, Contingency was contrast coded to compare the Experiment 1 Contingent group to the two noncontingent conditions (Experiment 1 Noncontingent group and Experiment 2 Unpredictable group). Predictability was contrast coded to compare the Experiment 1 Noncontingent group to the two unpredictable conditions (Experiment 1 Contingent group and Experiment 2 Unpredictable group).

Cross-Experiment Comparisons: Discussion

We leveraged data from both experiments to further explore potential modulation of cognitive control by punishment contingency and uncertainty in two cross-experiment analyses examining the role of the Contingency and Predictability dimensions in shaping punishment-motivated cognitive control performance. We observed that performance-contingency predicted increased proactive control, as indexed by heightened IES on AY trials as well as by increased PBI, dovetailing with our findings from Experiment 1. In contrast, punishment uncertainty did not significantly predict cognitive control outcomes, providing further support for our interpretation of the Experiment 2 results. This pattern also suggests that the observation of increased proactive control in the performance-contingent compared with noncontingent punishment conditions in Experiment 1 is likely attributable to differences in punishment contingency between the two conditions, as opposed to differences in punishment predictability.

General Discussion

Across two experiments, we examined how negative affect (as induced via negatively valenced images and noncontingent punishment) and performance-contingent punishment motivation influenced the balance of proactive and reactive cognitive control in the AX-CPT. In Experiment 1, modeled after Fröber and Dreisbach (2014), we compared cognitive control performance between an initial Affect phase, in which IAPS images were deployed to induced either Fear, Anger, or Neutral affect, and a Punishment phase, in which participants were faced with the prospect of electric shock, which either could be avoided with fast and accurate performance (Contingent condition) or could not be avoided (Noncontingent condition). In Experiment 2, we examined whether the Experiment 1 results replicated when electric shock punishments were both noncontingent *and* uncertain, and whether cognitive control under uncertain threat varied with individual variability in trait anxiety and intolerance of uncertainty. Across both experiments, we observed that the threat of punishment was associated with increased proactive control relative to either an affectively neutral baseline or negative affect manipulation, regardless of punishment contingency or uncertainty. This shift towards proactive control under threat of punishment was accompanied by an overall improvement in performance, as evidenced by decreased IES in the punishment phases, and higher punishment avoidance rates than would have been expected had performance been maintained at baseline levels. In addition, performance-contingency further modulated the increase in proactive control under punishment, such that proactive control was higher when shock receipt was performance-contingent and thus avoidable, compared with when shock receipt was unavoidable. This suggests that the motivation to avoid punishment may facilitate proactive control to a greater extent than the negative affect associated with noncontingent punishment alone. In contrast, outcome uncertainty did not appear to significantly influence proactive control in the context of a noncontingent punishment manipulation. In Experiment 1, our exploratory comparison of fear and anger image-based affect inductions revealed only trend-level differences in proactive control between conditions, with marginally heightened proactive control when participants were presented with fear-inducing compared with anger-inducing images. Finally, in Experiment 2, individual differences in trait anxiety and intolerance of uncertainty did not significantly modulate cognitive control performance.

Our observation that the threat of performance-contingent punishment via electric shock was associated with increased proactive control presents an important step towards a fuller characterization of punishment effects on cognitive control and helps address discrepancies in the existing literature (i.e., between Lindström et al., 2013 and Ličen et al., 2016). It is notable that our findings are consistent with those of Lindström et al. (2013), who observed an association between performance-contingent punishment, administered using electric shock, and increased proactive control. Limited studies have employed such primary performance-contingent punishments in the cognitive control literature, and to our knowledge, the Lindström et al. findings have not been broadly incorporated into accounts of punishment-related changes in proactive and reactive control (Ličen et al., 2016). Instead, prior work with the AX-CPT paradigm has largely focused on the use of monetary loss as a performance-contingent punishment (Ličen et al., 2016), and on observations of reduced proactive control, accompanied by increases in reactive control, in association with primary noncontingent threat and negative affect (Yang et al., 2018; Husa et al., 2022). Our current observations of increased proactive control with performance-contingent punishment relative to experimentally matched noncontingent conditions suggest that punishment motivation might facilitate increased proactive control beyond the influence of associated negative affect. In addition, we observed heightened proactive control on threat compared with safe trials in Experiment 1, suggesting that increased proactive control in association with punishment threat may arise transiently (i.e., trial-by-trial) as well as on a sustained basis. Together, these observations provide, to our knowledge, the first evidence to-date that primary, performance-contingent punishments can facilitate increased proactive control in the AX-CPT, and thus can potentially operate similarly to rewards. Indeed, our results are directionally similar to observations by Fröber & Dreisbach (2014) and Chiew & Braver (2014), in which performance-contingent reward incentives were associated with greater proactive control relative to noncontingent reward and positive affect manipulations. While we did not include a direct comparison between reward and punishment incentives, our results, along with prior literature, suggest that the presence of either a positive or negative performance-contingent motivator might facilitate increases in proactive control relative to positive or negative affect inductions in this task context. Interestingly, our observation of similar effects of reward and punishment incentives on the

AX-CPT contrasts with recent work (Leng et al., 2021) that has identified differences in cognitive control with monetary reward and loss. Specifically, Leng et al. used drift-diffusion modeling to provide evidence that rewards might promote response speeding and increased drift rate, versus loss promoting increased response caution. However, that study did not distinguish between proactive and reactive control or use primary punishments; in turn, our study did not apply modeling approaches to isolate potential differences in performance parameters that Leng et al. may have been able to uncover. Given these differences, it remains an open question whether task context, punishment type, or both can help determine whether punishments and rewards have similar or different effects on cognitive control. In addition, future work should directly compare effects of more diverse categories of rewards and punishments on cognitive control in the AX-CPT, to explore the possibility that primary punishments may be directionally similar to rewards (i.e., associated with increasing proactive control), but might differ in magnitude (Carsten et al., 2021), or in other performance metrics such as response speed (Carsten et al., 2019).

Despite the intriguing alignment between the current study results and prior work employing performance-contingent threat of electric shock (Lindström et al., 2013), our findings contrast with prior observations of increased reactive control in association with noncontingent threat of electric shock (Yang et al., 2018). One possibility accounting for discrepant findings between the current and prior work is that time-on-task effects may have promoted increased proactive control in the Punishment phase in Experiment 1, given that this phase always followed the Affect phase and proactive control has been shown to increase with longer time on task (Fröber & Dreisbach, 2016; Hefer & Dreisbach, 2020). However, control analyses including task block number as a covariate revealed that the significant difference in proactive control observed between phases persisted when accounting for time-on-task (reported in the supplementary materials). Although task block number was correlated with task phase (with blocks 1 and 2 comprising the Affect phase, and blocks 3 and 4 comprising the Punishment phase), limiting our ability to fully account for time-on-task effects, the results of our control analyses suggest that the increase in proactive control across task phases (i.e., from Affect to Punishment) is substantially greater than the increase in proactive control with time-on-task (i.e., from the first to second task block within each phase). In addition, in Experiment 2 we counterbalanced the order of the baseline and punishment phases to address this limitation from Experiment 1; even when counterbalanced, we continued to observe increased proactive control under threat of punishment relative to a neutral baseline. Exploratory analyses (reported in the supplementary material) revealed some evidence of potential carry-over effects of the punishment manipulation when participants in Experiment 2 completed that condition prior to the neutral baseline condition, resulting in reduced differences in proactive control between task phases. Importantly, however, while the magnitude of the difference in proactive control between the baseline and punishment conditions was reduced for participants in this order condition, the direction of this effect remained the same, with greater proactive control under punishment. Therefore, while there are tradeoffs to using a static order (as in Experiment 1) versus a counterbalanced order (as in Experiment 2), with static order reducing potential carry-over of the electric shock manipulation and counterbalancing helping to account for time-on-task effects, the parallel findings across our two experiments suggest that observed effects are likely related to the punishment manipulations and not solely artifacts of task order. To further clarify the effects of punishment manipulations, time-on-task and carry-over confounds might be reduced in future work by employing experimental designs in which punishment, affect, and neutral task phases are compared either between-subjects or within-subjects across multiple experimental sessions.

Furthermore, in considering our results regarding noncontingent punishment, our Experiment 2 findings suggest that proactive control may be enhanced by noncontingent threat of punishment even when it is unpredictable, suggesting that outcome uncertainty is unlikely to account for differences between our Experiment 1 noncontingent results and prior work (Yang et al., 2018). This conclusion was further supported by our cross-experiment comparisons testing for predictability effects. As observed in Experiment 1, proactive control increased in the punishment phase, relative to a neutral baseline, in Experiment 2. Additionally, in both experiments, proactive control increased with trial-level threat (although note that this increase was marginal in Experiment 2 and was no longer significant when the full Experiment 2 sample was utilized; see supplementary materials). While this effect is therefore interpreted with caution, our observed pattern of enhanced proactive control under the threat of unpredictable, noncontingent punishment appears to be at odds with Yang et al.'s observation of increased reactive control under a similar threat manipulation. We explore several potential contributors to our divergent findings.

First, our noncontingent punishment conditions in both experiments utilized individualized response deadlines, in order to provide a comparison to the Experiment 1 Contingent condition that better isolated the effect of performance contingency. However, response deadlines were not present either in the neutral and IAPS-induced Fear and Anger comparison conditions in the current study, nor in most prior studies employing noncontingent threat (Husa et al., 2022; Yang et al., 2018). While success at beating the response deadline was not tied to shock receipt in the noncontingent conditions, participants may have found the response deadline and subsequent feedback (Correct, Incorrect, Too Slow) motivating on their own (Devine et al., 2024), resulting in modulation of cognitive control performance. Indeed, previous work has demonstrated that response deadlines, even in the absence of motivational incentives, can facilitate increases in proactive control relative to a baseline condition (Ličen et al., 2016). Thus, participants in the current study may have been motivated to beat the response deadline, potentially by intrinsic motivation sparked by the challenge to improve performance (Ryan & Deci, 2000), or by extrinsic motivation to comply with experimenter instructions, which may have been further reinforced by feedback provided after each trial (Ličen et al., 2016). Either way, it is possible that motivation to beat the response deadline may have outweighed a potential increase in reactive control driven by punishment threat, resulting in a net shift towards proactive control. However, our data from both experiments argue against threat-related increases in reactive control altogether; threat trials were associated with increased proactive control relative to safe trials, despite both trial types employing a response deadline. While this comparison was only marginally significant in Experiment 2, at the very least, we did not observe evidence that threat trials were significantly associated with enhanced reactive control, as might be expected to emerge in this comparison if threat of noncontingent punishment had an effect counter to that of the response deadline. Regardless, future work should compare threat of noncontingent primary punishment to neutral and negatively valenced image-based inductions while controlling for the presence or absence of a response deadline, to better isolate whether differences in proactive control may be driven by the threat of noncontingent electric shock.

A second potential factor contributing to differences between the results of the current study and Yang et al. (2018), is that, despite experimenter instructions, it is possible that some Experiment 2 participants may have incorrectly believed that shock receipt was contingent on performance. This could have promoted use of proactive control under punishment threat. Indeed, four participants spontaneously reported in response to an open-ended question in our post-task survey that they suspected contingency was present on the threat trials. Removing these participants from analyses did not significantly change results (reported in Supplementary materials). However, it is possible that additional participants may have had a similar experience without reporting it. It is thus possible that when unpredictable threat was combined with the motivation to beat a response deadline, participants may have suspected that punishment receipt was contingent on performance and were therefore motivated to increase proactive control. Future work investigating noncontingent threat of punishment should include a direct post-task question to participants about whether or not they believed punishment receipt was contingent on performance to address this possibility.

A final possibility that could account for differences in cognitive control under threat in the current study, compared with Yang et al. (2018), relates to differences in the electric stimulation threat used across studies. The subjective level of the individually calibrated stimulation intensity was arguably higher in the study by Yang et al. (who calibrated to a level that was subjectively rated as "painful, but tolerable," while in the current study we calibrated the stimulation level to be subjectively rated as "uncomfortable, but not painful"). In addition, the number of shocks administered per task block was much lower in Yang et al. (8 shocks across 5 task blocks in Yang et al., 2018; versus an average of 17.6 shocks across two task blocks in Experiment 2 of the current study). Therefore, it is possible that stimulation intensity, stimulation frequency, or the combination of the two could have led to different effects on cognitive control in the current study compared with Yang et al. (2018). Namely, the more frequent stimulation in the current study could have promoted habituation to shock; combined with the less intense calibration criteria, our shock manipulation may have been experienced as less threatening than that used by Yang and colleagues. The differences in findings across studies suggest that it is therefore possible that at mild-to-moderate levels, unavoidable punishment promotes proactive control; at high-intensity levels, it might promote reactive control instead. Consistent with this possibility, exploratory analyses examining individual differences in participant-reported threat perceptions revealed that higher perceived threat was associated with reduced proactive control across participants in our Experiment 1 Noncontingent condition (reported in supplementary materials). This account also aligns with theoretical frameworks suggesting that high-intensity threat stimuli may be associated with greater competition for cognitive resources (Pessoa, 2009), which may make it more difficult for participants to engage in proactive control. Future work investigating this possibility would be valuable in establishing when aversive contexts might facilitate one mode of control versus the other.

In the current study, we observed that increases in proactive control under punishment were generally accompanied by an overall improvement in task performance, as indexed with IES measures. This finding aligns with observations of improved performance when monetary reward and loss incentives were bundled together (Ličen et al., 2016) but contrasts with other work that demonstrates that punishment threat improved performance only for certain trial types or under certain conditions (Lindström et al., 2013; Yang et al., 2018). Alongside the overall improvements in performance with incentive observed in terms of the IES measures, it is possible that punishment threat, particularly in combination with the speeded response deadline, led participants to adopt a speed-accuracy trade-off in which faster responding was prioritized at the cost of increased error rates. We conducted follow-up analyses with error rate and reaction time outcomes to test for this possibility (reported in the supplement). While speed-accuracy trade-offs did emerge in some cases (e.g., in Experiment 1, participants in the Contingent condition had shorter reaction times but higher error rates relative to participants in the Noncontingent condition), they did not negate our primary findings regarding shifts in proactive control (see supplementary materials). Future work should employ further efforts to investigate or intentionally control for potential speed-accuracy trade-offs under threat of punishment by employing measures, such as the Balanced Integration Score (BIS; Liesefeld & Janczyk, 2019; 2023). In the current study, we chose to use IES over BIS as a combined measure of reaction time and accuracy given our use of the AX-CPT and interest in proactive control and related statistical concerns about calculating and interpreting the composite PBI measure (i.e., the standardized difference between AY and BX performance in the AX-CPT) from BIS. Specifically, IES measures can be calculated separately using error rate and RT per condition, while BIS is a relative measure, with performance in each condition calculated relative to all other conditions and trial types. As such, calculating PBI from BIS measures arguably would involve calculating a relative measure from another relative measure, potentially inflating reliability concerns associated with the use of difference scores (Zorowitz & Niv, 2023).

In contrast to our observation of increased proactive control and improved performance under threat, we did not find strong evidence that cognitive control significantly differed between our three IAPS-induced Affect conditions in Experiment 1. While we observed a marginal effect whereby proactive control was heightened in the Fear condition relative to the Affect condition, contrary to hypotheses, neither negative affect condition significantly differed from our neutral comparison condition. Our comparison may have been limited by the use of IAPS images to induce negative affect, and by the difficulty of inducing more complex emotions, such as anger with visual stimuli. In addition, we did not obtain individualized emotion ratings from participants for each stimulus item, limiting our ability to verify that fear and anger were successfully induced by our manipulations in the present study. Therefore, the extent to which our Anger manipulation actually resulted in participants feeling angry, versus eliciting a more complicated mix of emotions, is unclear. Future research employing a stronger and more tightly controlled manipulation of anger versus fear will be important for a more thorough investigation of how discrete negative emotions may differentially impact cognitive control outcomes. Despite these limitations, our findings are consistent with the interpretation discussed above; that, contrary to our predictions, motivational valence may not always be a primary driver of the modulation of proactive and reactive control. Instead, we speculate that the trend towards decreased proactive control in the Anger versus Fear conditions might potentially be attributed to increased semantic processing associated with the stimuli presented in the Anger condition, which were more likely to include depictions of complex scenes and social stimuli. We speculate that images presented in the Anger condition may therefore have presented a greater task distraction for some participants, as semantic processing of the scenes may have depleted cognitive resources necessary for proactive control.

In addition to the group-level effects discussed so far, we investigated whether individual variability in trait anxiety and intolerance of uncertainty modulated cognitive control under threat of punishment. Exploratory analyses in our Experiment 1 data suggest that individuals higher in trait anxiety and intolerance of uncertainty displayed reduced proactive control specifically on threat trials (reported in supplementary materials). This finding is consistent with hypotheses that individuals high in trait anxiety may engage in less proactive control under threat, as anxiety over the impending threat competes with task demands for cognitive resources. However, when we deliberately recruited a sample varying in trait anxiety for Experiment 2, we did not observe significant differences in proactive control under threat as a function of trait anxiety and intolerance of uncertainty. Future work could help to discern whether the lack of an observed relationship between trait anxiety and cognitive control performance in our Experiment 2 sample is better attributed to the context of uncertain punishment, or to sample size-related power limitations.

While collected as an exploratory measure, our analyses of physiological arousal (indexed using SCL and reported in supplementary materials) suggest a potential link between threat-related differences in arousal and proactive control across both experiments. In Experiment 1, we observed greater punishment-related increases in arousal when punishment was performance-contingent compared with when it was noncontingent, suggesting that relatively elevated motivation to avoid punishment may have been accompanied by heightened arousal. This pattern is consistent with prior observations of increased arousal under contingent versus noncontingent punishment (Manohar et al., 2017). Furthermore, individual differences in arousal predicted performance outcomes in the Experiment 1 Noncontingent condition, as participants with greater punishment-related increases in arousal also displayed reduced proactive control and increased error rates in the Punishment phase. Unexpectedly, we observed an opposite relationship in Experiment 2; individuals who displayed greater arousal under unpredictable, noncontingent threat displayed increased proactive control, and improved overall performance. These results raise the intriguing possibility that while punishment uncertainty did not appear to modulate group-level differences in proactive control, uncertainty might interact with physiological arousal responses to differentially shape cognitive control outcomes across individuals. In the Experiment 1 Noncontingent condition, in which punishment receipt was fully predictable and unavoidable, heightened arousal responses may have harmed performance, as participants' responses to threat competed for cognitive resources with performance demands. In contrast, in Experiment 2, in which punishment receipt was unavoidable but also unpredictable, greater arousal may have facilitated improved performance as the threat of electric shock may have been perceived as more distant, and therefore less distracting. These interpretations remain tentative and speculative given the present data but suggest that the relationship between arousal and controlled performance under threat may vary with contextual factors, warranting additional follow-up.

Interestingly, individual differences in trait anxiety and intolerance of uncertainty were inconsistently related to differences in physiological arousal as well as cognitive performance. In Experiment 1, individual differences in trait anxiety and intolerance of uncertainty were negatively associated with proactive control but were not significantly related to differences in physiological arousal. However, in Experiment 2, individual differences in trait anxiety and intolerance of uncertainty were not significantly related to cognitive control outcomes but positively related to punishment-related increases in SCL. It is possible that these inconsistent results across our two experiments may reflect limitations in sample size or anxiety range, given that a clinical anxiety diagnosis served as exclusion criteria. While the exploratory and inconsistent nature of these analyses makes it difficult to draw definitive conclusions about the relationships between trait anxiety/intolerance of uncertainty, physical arousal responses to threat, and cognitive control performance, our results suggest that further investigating these relationships may prove informative in advancing understanding of individual variability in cognitive responses to threat.

Altogether, the results of the current study suggest that punishment incentives, both performance-contingent and noncontingent, can facilitate increases in proactive control in the AX-CPT. This novel finding raises the possibility that performance-contingent punishment motivation may drive increases in proactive control in a similar manner to rewards (Fröber & Dreisbach, 2014; Chiew & Braver, 2014), although the extent to which the magnitude of this effect might be comparable remains an open question. In our noncontingent punishment conditions, where avoiding punishments was not possible, a more complex relationship between affect and cognitive control emerged. Our results, in combination with prior work, suggest that when threats are experienced as less intense, cognitive control performance, including proactive control, may benefit. When threats increase in intensity, or when participants experience high levels of anxiety, performance may instead be harmed and shift into a reactive control mode as threat stimuli compete for limited cognitive resources (Yang et al., 2018; Husa et al., 2022). Our exploratory findings suggest that physiological arousal responses to threat may reflect this inverted-U relationship between noncontingent threat and cognitive control outcomes. This interpretation is consistent with broader accounts, suggesting that emotional arousal, rather than emotional valence, may tend to drive affective influences on cognitive control (Demanet et al., 2011). Overall, the results of the current study raise many intriguing questions, including the role of task parameters in shaping the motivation-cognitive control relationship, and the underlying neural mechanisms supporting this relationship. We explore these questions below in considering directions for future research.

Limitations and future directions

As noted above in our discussion of several aspects of our findings, several limitations of the current study should be considered and will be important to address in future research. These included the use of static and counter-balanced task orders, the possibility that participants incorrectly believed that the electric shocks were performance-contingent in Experiment 2, and the potential that our image-based affect conditions may not have sufficiently induced fear and anger. In addition, we identified important directions for future work, including a direct comparison between reward and punishment incentives, testing for the potential role of threat intensity in shaping cognitive control outcomes, and investigating individual differences in trait anxiety and physiological arousal responses to threat in larger and more diverse samples.

Additionally, our design to compare performance-contingent and noncontingent punishment led to an imbalance in the number of threat versus safe trials. Specifically, we aimed to match the number of electric shocks received across conditions, minimizing differences in shock habituation; as such, our task design consisted of a greater number of threat-possible trials in the performance-contingent relative to noncontingent conditions. This design decision was motivated by our anticipation that shock punishment receipt might be a higher-intensity affective experience than shock punishment anticipation (as suggested by neuroimaging studies of pain anticipation versus receipt; Wager et al., 2011; 2013). However, it is possible that this imbalance may have contributed to a heightened perception of threat in the performance-contingent condition, as suggested by self-report ratings across the two punishment conditions in

Experiment 1 (reported in supplementary materials). Interestingly, other self-reported aspects of affective experience, including arousal, negative affect, effort, and motivation, did not significantly differ between the contingent and noncontingent conditions, suggesting that the two conditions may have only differed in the specific aspect of affective experience related to threat perception. Furthermore, it is unclear whether the difference in threat perception between conditions was driven by the percentage of threat versus safe trials or another factor that differed between conditions, such as punishment contingency or number of shocks received. Future work should address these open questions by matching the percentile of threat and safety trials across conditions, as well as investigating whether shifts in proactive control are modulated differently by the distinct processes of punishment anticipation and punishment receipt, carefully considering matching of one task parameter versus another across conditions.

Relatedly, an important direction for future research will be to disentangle the effects of various task design and incentive features in shaping cognitive control outcomes under threat of punishment and to help account for divergent findings in the literature. For instance, the use of different punishment types (such as monetary loss versus electric shocks) may help account for diverging findings between the current study and Ličen et al. (2016). While an initial comparison of findings across studies suggests that primary and secondary punishments may differentially influence cognitive control, further investigation is needed. Another task feature that may have influenced results was the design of the Experiment 1 Affect phase. Given our theoretical motivation to investigate effects under separate Fear and Anger inductions as well as a Neutral induction, our experimental design was constructed to allow for relatively equal samples across these three Affect conditions. However, this approach may be argued to lead to an imbalance whereby ~2/3 of our sample completed a negative affect induction, versus ~1/3 completed a neutral affect induction, prior to the Punishment phase. While our Experiment 1 analyses (see *Within-group Differences in Affect vs. Punishment Phase*) did not suggest that increases in proactive control in the Punishment phase differed by preceding Affect phase, it is possible that the relative imbalance between negatively and neutrally valenced affect inductions in Experiment 1's design may have influenced observed differences across conditions. Future work may benefit from addressing such imbalances and employing alternative designs.

Additionally, some studies (such as Ličen et al., 2016) bundled reward and punishment incentives together, limiting interpretation of separate valence effects. This might be important to investigate more given that reward and punishment incentives may interact when both are present, as suggested in more recent work (Yee et al., 2016; 2021). An intriguing question for future work is whether differing effects across incentive types result from differences in motivational or affective intensity, or from differences in the neural systems underlying the processing of different incentive types (Delgado et al., 2011). Furthermore, the criteria for determining reward receipt or punishment avoidance can vary across studies and versions of cognitive control tasks, such that sometimes only accuracy is rewarded or punished, and other times participants are required to respond quickly as well, as in the current study. Response deadlines during task performance may be motivating on their own (Devine et al., 2024; Dambacher et al., 2011) and might be linked with either positive or negative affective responses depending on the difficulty of successfully meeting the response deadline, which could vary at the individual or task level. Future work could manipulate the presence versus absence of a response time deadline for punishment avoidance to investigate additional motivational and affective influences related to the presence of the deadline and to help clarify when performance-contingent punishment motivation might increase performance speed (as in the current study) versus increasing response caution (Carsten et al., 2019; Leng et al., 2021). Finally, the current study only manipulated uncertainty for the noncontingent threat conditions, given that performance-contingent outcomes arguably include some level of inherent uncertainty (i.e., participants are not fully certain of whether they will meet the response deadline or not on a given trial). However, future work could investigate the effects of additional degrees of uncertainty in performance-contingent punishment on cognitive control performance; for example, by varying the utility of threat and safety cues. Considering other dimensions of potential uncertainty in punishment threat and receipt in future work will be important for advancing a scientific understanding of how punishment influences performance in daily life. Such investigations of uncertainty and cognitive performance might be further informed by incorporating individual differences in trait anxiety and related psychological constructs (Mushtaq et al., 2011).

It will be important for future work to examine threat-related effects on performance in cognitive control paradigms other than the AX-CPT. In the AX-CPT paradigm, proactive control has been argued as the default (and perhaps most optimal) mode for healthy young adults (Gonthier et al., 2016). This paradigm has been used to demonstrate a shift towards proactive control with reward incentives (Chiew & Braver, 2013). However, in other task contexts where reactive control may be more adaptive, rewards have been found to facilitate increases in reactive control instead (Boehler et al., 2014; Magis-Weinberg et al., 2019). Such findings have been argued to suggest that rewards may flexibly optimize the control mode for a given task, rather than influencing control in a "one size fits all" fashion (i.e., universally increasing proactive control; Chiew, 2021). The question of whether primary punishment incentives can operate in a similar manner to flexibly promote *either* proactive or reactive control, depending on task context, is an open question that will be important for future research to address.

Finally, this research could be extended to examine the neural mechanisms underlying punishment influences on cognitive control. This might be particularly important given our intriguing observation of increased proactive control under performance-contingent punishment. Reward prospect-related increases in proactive control have been proposed to result from increased mesolimbic dopamine activity and subsequent dopamine binding at D1 prefrontal cortex receptors (Cools, 2016). Given our observations of punishment-related increases in proactive control, a key question for future research is whether a similar dopaminergic mechanism underlies the effects of primary punishment incentives on cognitive control, or whether reward and punishment motivation are associated with distinct neural mechanisms that may both facilitate increases in proactive control behavior. While evidence for the link between reward motivation and dopamine system activity is more extensive, dopamine has also been implicated in signaling the motivational salience of threat of punishment (Bromberg-Martin et al., 2010) and in supporting the successful avoidance of aversive outcomes (Lloyd & Dayan, 2016; Menegas et al., 2018). However, the underlying mechanisms supporting cognitive control under threat of punishment may also be more complex, with additional neurotransmitter systems, including serotonin (Yee et al., 2022), implicated in punishment processing. Interactions between multiple, interacting neurotransmitter systems and their effects on cognition are beginning to be mapped out (Cools et al., 2011) and may be important for gaining a comprehensive understanding of adaptive performance.

Relatedly, our exploratory findings raise intriguing questions for future research regarding the role of emotional arousal and its underlying neurobiology in the modulation of cognitive control under threat of punishment. The locus-coeruleus norepinephrine (LC-NE) system, responsible for regulating arousal levels, is implicated in successful cognitive control performance (Grueschow et al., 2020), along with the dopamine system (Köhler et al., 2016). It is currently an open question how the functioning of these two neuromodulator systems may interact to shape cognitive control outcomes under the threat of punishment. The use of arousal measures with increased temporal precision, such as pupil dilation, may prove beneficial in further exploring the relationship between the LC-NE system and cognitive control under threat, as variation in both tonic and phasic LC-NE activity could be examined in relation to cognitive control performance across task conditions and between individuals.

Conclusion

We demonstrated novel evidence that primary performance-contingent punishment and noncontingent threat can facilitate increased proactive control in the AX-CPT. In addition, proactive control increases were greater when punishment was performance-contingent, suggesting that the motivation to avoid punishment may promote proactive control increases beyond the effect of negative affect alone. This result presents the preliminary suggestion that performance-contingent primary punishments and rewards may modulate proactive control in a similar manner, distinguishable from the effects of negative or positive affect alone (i.e., in the relative absence of incentive motivation). Finally, our findings with noncontingent threat and our exploratory investigation of individual differences in trait anxiety/intolerance of uncertainty and physiological arousal suggest that in the absence of performance contingency, contextual factors, such as uncertainty and threat intensity, may play an important role in shaping cognitive control outcomes under punishment. While many open questions remain regarding contextual and individual difference influences on cognitive control under threat, our results provide an important step towards elucidating how negative affect and the motivation to avoid punishment may adaptively modulate cognitive control.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.3758/s13415-026-01421-5.

Acknowledgments This work is supported by an American Psychological Association of Graduate Students/Psi Chi Junior Scientist Fellowship to R.E.B. and a University of Denver Partners in Scholarship award to C.A.S.

Funding This work was supported by an American Psychological Association of Graduate Students/Psi Chi Junior Scientist Fellowship to R.E.B. and a University of Denver Partners in Scholarship award to C.A.S.

Data availability Data are available at https://osf.io/u2vzq/.

Code availability Analysis code will be made available at https://osf.io/u2vzq/ by the time of publication.

Declarations

Ethics approval Approval was obtained from the University of Denver Institutional Review Board. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication Not applicable.

Open Practices statement Both Experiment 1 (https://osf.io/kjmqg) and Experiment 2 (https://osf.io/fvkdy) were preregistered on the Open Science Framework. Data are available at https://osf.io/u2vzq/. Analysis code will be made available at https://osf.io/u2vzq/ by the time of publication.

Conflicts of interest/Competing interests The authors have no conflicts of interest to disclose.

References

Barke, A., Stahl, J., & Kröner-Herwig, B. (2012). Identifying a subset of fear-evoking pictures from the IAPS on the basis of dimensional and categorical ratings for a German sample. *Journal of Behavior Therapy and Experimental Psychiatry, 43*(1), 565–572. https://doi.org/10.1016/j.jbtep.2011.07.006

Beck, S. M., Locke, H. S., Savine, A. C., Jimura, K., & Braver, T. S. (2010). Primary and secondary rewards differentially modulate neural activity dynamics during working memory. *PLoS ONE, 5*(2), Article e9251. https://doi.org/10.1371/journal.pone.0009251

Berridge, K. C., Robinson, T. E., & Aldridge, J. W. (2009). Dissecting components of reward: 'Liking,' 'wanting,' and learning. *Current Opinion in Pharmacology, 9*(1), 65–73. https://doi.org/10.1016/j.coph.2008.12.014

Bland, A. R., & Schaefer, A. (2012). Different Varieties of Uncertainty in Human Decision-Making. *Frontiers in Neuroscience*, *6*. https://doi.org/10.3389/fnins.2012.00085

Boehler, C. N., Schevernels, H., Hopf, J.-M., Stoppel, C. M., & Krebs, R. M. (2014). Reward prospect rapidly speeds up response inhibition via reactive control. *Cognitive, Affective & Behavioral Neuroscience, 14*(2), 593–609. https://doi.org/10.3758/s13415-014-0251-5

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9

Braem, S., Duthoo, W., & Notebaert, W. (2013). Punishment sensitivity predicts the impact of punishment on cognitive control. *PLoS ONE, 8*(9), Article e74106. https://doi.org/10.1371/journal.pone.0074106

Braem, S., King, J. A., Korb, F. M., Krebs, R. M., Notebaert, W., & Egner, T. (2013). Affective modulation of cognitive control is determined by performance-contingency and mediated by ventromedial prefrontal and cingulate cortex. *Journal of Neuroscience, 33*(43), 16961–16970. https://doi.org/10.1523/JNEUROSCI.1208-13.2013

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16*(2), 106–113. https://doi.org/10.1016/j.tics.2011.12.010

Braver, T. S., Paxton, J. L., Locke, H. S., & Barch, D. M. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. *Proceedings of the National Academy of Sciences, 106*(18), 7351–7356. https://doi.org/10.1073/pnas.0808187106

Bromberg-Martin, E. S., Matsumoto, M., & Hikosaka, O. (2010). Dopamine in motivational control: Rewarding, aversive, and alerting. *Neuron, 68*(5), 815–834. https://doi.org/10.1016/j.neuron.2010.11.022

Bruyer, R., & Brysbaert, M. (2011). Combining speed and accuracy in cognitive psychology: Is the inverse efficiency score (IES) a better dependent variable than the mean reaction time (RT) and the percentage of errors (PE)? *Psychologica Belgica, 51*(1), Article 1. https://doi.org/10.5334/pb-51-1-5

Bugg, J. M., & Crump, M. J. C. (2012). In support of a distinction between voluntary and stimulus-driven control: A review of the literature on proportion congruent effects. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00367

Buhr, K., & Dugas, M. J. (2002). The intolerance of uncertainty scale: Psychometric properties of the English version. *Behaviour Research and Therapy, 40*(8), 931–945. https://doi.org/10.1016/S0005-7967(01)00092-4

Cacioppo, J. T., & Berntson, G. G. (1994). Relationship between attitudes and evaluative space: A critical review, with emphasis on the separability of positive and negative substrates. *Psychological Bulletin, 115*(3), 401–423. https://doi.org/10.1037/0033-2909.115.3.401

Carleton, R. N. (2014). The intolerance of uncertainty construct in the context of anxiety disorders: Theoretical and practical perspectives. *Expert Review of Neurotherapeutics*. https://doi.org/10.1586/ern.12.82

Carsten, T., Hoofs, V., Boehler, C. N., & Krebs, R. M. (2019). Are losses more effective than rewards in improving performance in a cognitive task? *Motivation Science, 5*(3), 257–268. https://doi.org/10.1037/mot0000117

Carsten, T., Kostandyan, M., Boehler, C. N., & Krebs, R. M. (2021). Comparing the motivational value of rewards and losses in an EEG-pupillometry study. *European Journal of Neuroscience, 53*(6), 1822–1838. https://doi.org/10.1111/ejn.15064

Carter, R. M., MacInnes, J. J., Huettel, S. A., & Adcock, R. A. (2009). Activation in the VTA and nucleus accumbens increases in anticipation of both gains and losses. *Frontiers in Behavioral Neuroscience*. https://doi.org/10.3389/neuro.08.021.2009

Carver, C. S. (2006). Approach, avoidance, and the self-regulation of affect and action. *Motivation and Emotion, 30*(2), 105–110. https://doi.org/10.1007/s11031-006-9044-7

Carver, C. S., & Harmon-Jones, E. (2009). Anger is an approach-related affect: Evidence and implications. *Psychological Bulletin, 135*(2), 183–204. https://doi.org/10.1037/a0013965

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology, 67*(2), 319–333. https://doi.org/10.1037/0022-3514.67.2.319

Chaillou, A.-C., Giersch, A., Hoonakker, M., Capa, R. L., Doignon-Camus, N., Pham, B.-T., & Bonnefond, A. (2018). Evidence of impaired proactive control under positive affect. *Neuropsychologia, 114*, 110–117. https://doi.org/10.1016/j.neuropsychologia.2018.04.021

Chatham, C. H., Frank, M. J., & Munakata, Y. (2009). Pupillometric and behavioral markers of a developmental shift in the temporal dynamics of cognitive control. *Proceedings of the National Academy of Sciences, 106*(14), 5529–5533. https://doi.org/10.1073/pnas.0810002106

Chiew, K. S. (2021). Revisiting positive affect and reward influences on cognitive control. *Current Opinion in Behavioral Sciences, 39*, 27–33. https://doi.org/10.1016/j.cobeha.2020.11.010

Chiew, K. S., & Braver, T. S. (2011). Positive Affect Versus Reward: Emotional and Motivational Influences on Cognitive Control. *Frontiers in Psychology*, *2*. https://doi.org/10.3389/fpsyg.2011.00279

Chiew, K. S., & Braver, T. S. (2013). Temporal Dynamics of Motivation-Cognitive Control Interactions Revealed by High-Resolution Pupillometry. *Frontiers in Psychology*, *4*. https://doi.org/10.3389/fpsyg.2013.00015

Chiew, K. S., & Braver, T. S. (2014). Dissociable influences of reward motivation and positive emotion on cognitive control. *Cognitive, Affective, & Behavioral Neuroscience, 14*(2), 509–529. https://doi.org/10.3758/s13415-014-0280-0

Chiew, K. S., & Braver, T. S. (2016). Reward favors the prepared: Incentive and task-informative cues interact to enhance attentional control. Journal of Experimental Psychology: *Human Perception and Performance, 42*(1), 52–66. https://doi.org/10.1037/xhp0000129

Cools, R. (2016). The costs and benefits of brain dopamine for cognitive control. *Wiley Interdisciplinary Reviews. Cognitive Science, 7*(5), 317–329. https://doi.org/10.1002/wcs.1401

Cools, R., Nakamura, K., & Daw, N. D. (2011). Serotonin and dopamine: Unifying affective, activational, and decision functions. *Neuropsychopharmacology, 36*(1), 98–113. https://doi.org/10.1038/npp.2010.121

Cooper, J. (2019). In search of the motivation for dissonance reduction: The drive to lessen aversive consequences. *Cognitive dissonance: Reexamining a pivotal theory in psychology* (2nd ed, pp. 175–193). American Psychological Association. https://doi.org/10.1037/0000135-009

Dambacher, M., Hübner, R., & Schlösser, J. (2011). Monetary Incentives in Speeded Perceptual Decision: Effects of Penalizing Errors Versus Slow Responses. *Frontiers in Psychology*, *2*. https://doi.org/10.3389/fpsyg.2011.00248

Delgado, M., Jou, R., & Phelps, E. (2011). Neural systems underlying aversive conditioning in humans with primary and secondary reinforcers. *Frontiers in Neuroscience*. https://doi.org/10.3389/fnins.2011.00071

Delgado, M. R., Nearing, K. I., LeDoux, J. E., & Phelps, E. A. (2008). Neural circuitry underlying the regulation of conditioned fear and its relation to extinction. *Neuron, 59*(5), 829–838. https://doi.org/10.1016/j.neuron.2008.06.029

Demanet, J., Liefooghe, B., & Verbruggen, F. (2011). Valence, Arousal, and Cognitive Control: A Voluntary Task-Switching Study. *Frontiers in Psychology*, *2*. https://doi.org/10.3389/fpsyg.2011.00336

Devine, S., Roy, M., Beierholm, U., & Otto, A. R. (2024). Proximity to rewards modulates parameters of effortful control exertion. *Journal of Experimental Psychology. General, 153*(5), 1257–1267. https://doi.org/10.1037/xge0001561

Dreisbach, G., & Fröber, K. (2019). On how to be flexible (or not): Modulation of the stability-flexibility balance. *Current Directions in Psychological Science, 28*(1), 3–9. https://doi.org/10.1177/0963721418800030

Fales, C. L., Barch, D. M., Burgess, G. C., Schaefer, A., Mennin, D. S., Gray, J. R., & Braver, T. S. (2008). Anxiety and cognitive efficiency: Differential modulation of transient and sustained neural activity during a working memory task. *Cognitive, Affective & Behavioral Neuroscience, 8*(3), 239–253. https://doi.org/10.3758/CABN.8.3.239

Fröber, K., & Dreisbach, G. (2014). The differential influences of positive affect, random reward, and performance-contingent reward on cognitive control. *Cognitive, Affective & Behavioral Neuroscience, 14*(2), 530–547. https://doi.org/10.3758/s13415-014-0259-x

Fröber, K., & Dreisbach, G. (2016). How performance (non)contingent reward modulates cognitive control. *Acta Psychologica, 168*, 65–77. https://doi.org/10.1016/j.actpsy.2016.04.008

Gerolimatos, L. A., & Edelstein, B. A. (2012). Predictors of health anxiety among older and young adults. *International Psychogeriatrics, 24*(12), 1998–2008. https://doi.org/10.1017/S1041610212001329

Gilam, G., & Hendler, T. (2015). Deconstructing Anger in the Human Brain. In M. Wöhr & S. Krach (Eds.), *Social Behavior from Rodents to Humans* (Vol. 30, pp. 257–273). Springer International Publishing. https://doi.org/10.1007/7854_2015_408

Gonthier, C., Macnamara, B. N., Chow, M., Conway, A. R. A., & Braver, T. S. (2016). Inducing Proactive Control Shifts in the AX-CPT. *Frontiers in Psychology*, *7*. https://www.frontiersin.org/articles/https://doi.org/10.3389/fpsyg.2016.01822

Goschke, T., & Bolte, A. (2014). Emotional modulation of control dilemmas: The role of positive affect, reward, and dopamine in cognitive stability and flexibility. *Neuropsychologia, 62*, 403–423. https://doi.org/10.1016/j.neuropsychologia.2014.07.015

Grueschow, M., Kleim, B., & Ruff, C. C. (2020). Role of the locus coeruleus arousal system in cognitive control. *Journal of Neuroendocrinology, 32*(12), Article e12890. https://doi.org/10.1111/jne.12890

Grupe, D. W., & Nitschke, J. B. (2013). Uncertainty and anticipation in anxiety: An integrated neurobiological and psychological perspective. *Nature Reviews Neuroscience, 14*(7), Article 7. https://doi.org/10.1038/nrn3524

Han, S., Lerner, J. S., & Keltner, D. (2007). Feelings and consumer decision making: The appraisal-tendency framework. *Journal of Consumer Psychology, 17*(3), 158–168. https://doi.org/10.1016/S1057-7408(07)70023-2

Harmon-Jones, E., & Sigelman, J. (2001). State anger and prefrontal brain activity: Evidence that insult-related relative left-prefrontal activation is associated with experienced anger and aggression. *Journal of Personality and Social Psychology, 80*(5), 797–803. https://doi.org/10.1037/0022-3514.80.5.797

Hefer, C., & Dreisbach, G. (2016). The motivational modulation of proactive control in a modified version of the AX-continuous performance task: Evidence from cue-based and prime-based preparation. *Motivation Science, 2*(2), 116–134. https://doi.org/10.1037/mot0000034

Hefer, C., & Dreisbach, G. (2020). The volatile nature of positive affect effects: Opposite effects of positive affect and time on task on proactive control. *Psychological Research, 84*(3), 774–783. https://doi.org/10.1007/s00426-018-1086-4

Holaway, R. M., Heimberg, R. G., & Coles, M. E. (2006). A comparison of intolerance of uncertainty in analogue obsessive-compulsive disorder and generalized anxiety disorder. *Journal of Anxiety Disorders, 20*(2), 158–174. https://doi.org/10.1016/j.janxdis.2005.01.002

Hur, J., Smith, J. F., DeYoung, K. A., Anderson, A. S., Kuang, J., Kim, H. C., Tillman, R. M., Kuhn, M., Fox, A. S., & Shackman, A. J. (2020). Anxiety and the neurobiology of temporally uncertain threat anticipation. *The Journal of Neuroscience, 40*(41), 7949–7964. https://doi.org/10.1523/JNEUROSCI.0704-20.2020

Husa, R. A., Buchanan, T. W., & Kirchhoff, B. A. (2022). Subjective stress and proactive and reactive cognitive control strategies. *European Journal of Neuroscience, 55*, 2558–2570. https://doi.org/10.1111/ejn.15214

Jimura, K., Locke, H. S., & Braver, T. S. (2010). Prefrontal cortex mediation of cognitive enhancement in rewarding motivational contexts. *Proceedings of the National Academy of Sciences, 107*(19), 8871–8876. https://doi.org/10.1073/pnas.1002007107

Köhler, S., Bär, K.-J., & Wagner, G. (2016). Differential involvement of brainstem noradrenergic and midbrain dopaminergic nuclei in cognitive control. *Human Brain Mapping, 37*(6), 2305–2318. https://doi.org/10.1002/hbm.23173

Kraemer, K. M., McLeish, A. C., & O'Bryan, E. M. (2015). The role of intolerance of uncertainty in terms of alcohol use motives among college students. *Addictive Behaviors, 42*, 162–166. https://doi.org/10.1016/j.addbeh.2014.11.033

Krebs, R. M., Boehler, C. N., & Woldorff, M. G. (2010). The influence of reward associations on conflict processing in the Stroop task. *Cognition, 117*(3), 341–347. https://doi.org/10.1016/j.cognition.2010.08.018

Krug, M. K., & Braver, T. S. (2014). Motivation and cognitive control: Going beyond monetary incentives. *The psychological science of money* (pp. 137–162). Springer New York. https://doi.org/10.1007/978-1-4939-0959-9_7

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal* *of Statistical Software, 82*, 1–26. https://doi.org/10.18637/jss.v082.i13

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). International Affective Picture System (IAPS): Technical Manual and Affective Ratings. *NIMH Center for the Study of Emotion and Attention, 1*(39–58), 3.

Leng, X., Yee, D., Ritz, H., & Shenhav, A. (2021). Dissociable influences of reward and punishment on adaptive cognitive control. *PLoS Computational Biology, 17*(12), Article e1009737. https://doi.org/10.1371/journal.pcbi.1009737

Lenth R, Piaskowski J (2025). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 2.0.1, https://rvlenth.github.io/emmeans/.

Ličen, M., Hartmann, F., Repovš, G., & Slapničar, S. (2016). The Impact of Social Pressure and Monetary Incentive on Cognitive Control. *Frontiers in Psychology*, *7*. https://www.frontiersin.org/articles/https://doi.org/10.3389/fpsyg.2016.00093

Liesefeld, H. R., & Janczyk, M. (2019). Combining speed and accuracy to control for speed-accuracy trade-offs(?). *Behavior Research Methods, 51*(1), 40–60. https://doi.org/10.3758/s13428-018-1076-x

Liesefeld, H. R., & Janczyk, M. (2023). Same same but different: Subtle but consequential differences between two measures to linearly integrate speed and accuracy (LISAS vs. BIS). *Behavior Research Methods, 55*(3), 1175–1192. https://doi.org/10.3758/s13428-022-01843-2

Lindström, B. R., Mattsson-Mårn, I. B., Golkar, A., & Olsson, A. (2013). In your face: Risk of punishment enhances cognitive control and error-related activity in the corrugator supercilii muscle. *PLoS ONE, 8*(6), Article e65692. https://doi.org/10.1371/journal.pone.0065692

Lloyd, K., & Dayan, P. (2016). Safety out of control: Dopamine and defence. *Behavioral and Brain Functions, 12*(1), Article 15. https://doi.org/10.1186/s12993-016-0099-7

Locke, H. S., & Braver, T. S. (2008). Motivational influences on cognitive control: Behavior, brain activation, and individual differences. *Cognitive, Affective & Behavioral Neuroscience, 8*(1), 99–112. https://doi.org/10.3758/CABN.8.1.99

Magis-Weinberg, L., Custers, R., & Dumontheil, I. (2019). Rewards enhance proactive and reactive control in adolescence and adulthood. *Social Cognitive and Affective Neuroscience, 14*(11), 1219–1232. https://doi.org/10.1093/scan/nsz093

Mäki-Marttunen, V., Hagen, T., & Espeseth, T. (2019). Proactive and reactive modes of cognitive control can operate independently and simultaneously. *Acta Psychologica, 199*, Article 102891. https://doi.org/10.1016/j.actpsy.2019.102891

Manohar, S. G., Finzi, R. D., Drew, D., & Husain, M. (2017). Distinct motivational effects of contingent and noncontingent rewards. *Psychological Science, 28*(7), 1016–1026. https://doi.org/10.1177/0956797617693326

Menegas, W., Akiti, K., Amo, R., Uchida, N., & Watabe-Uchida, M. (2018). Dopamine neurons projecting to the posterior striatum reinforce avoidance of threatening stimuli. *Nature Neuroscience, 21*(10), 1421–1430. https://doi.org/10.1038/s41593-018-0222-1

Meteyard, L., & Davies, R. A. I. (2020). Best practice guidance for linear mixed-effects models in psychological science. *Journal of Memory and Language, 112*, Article 104092. https://doi.org/10.1016/j.jml.2020.104092

Murty, V. P., LaBar, K. S., Hamilton, D. A., & Adcock, R. A. (2011). Is all motivation good for learning? Dissociable influences of approach and avoidance motivation in declarative memory. *Learning & Memory, 18*(11), 712–717. https://doi.org/10.1101/lm.023549.111

Murty, V. P., LaBar, K. S., & Adcock, R. A. (2016). Distinct medial temporal networks encode surprise during motivation by reward versus punishment. *Neurobiology of Learning and Memory, 134*, 55–64. https://doi.org/10.1016/j.nlm.2016.01.018

Mushtaq, F., Bland, A., & Schaefer, A. (2011). Uncertainty and Cognitive Control. *Frontiers in Psychology*, *2*. https://www.frontiersin.org/articles/https://doi.org/10.3389/fpsyg.2011.00249

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences, 13*(4), 160–166. https://doi.org/10.1016/j.tics.2009.01.006

Prével, A., Hoofs, V., & Krebs, R. M. (2021). Effect of noninstructed instrumental contingency of monetary reward and positive affect in a cognitive control task. *Royal Society Open Science, 8*(8), Article 202002. https://doi.org/10.1098/rsos.202002

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Richmond, L., Redick, T. S., & Braver, T. S. (2015). Remembering to prepare: The benefits (and costs) of high working memory capacity. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 41*(6), 1764–1777. https://doi.org/10.1037/xlm0000122

Roseman, I. J. (2008). Motivations and emotivations: Approach, avoidance, and other tendencies in motivated and emotional behavior. *Handbook of Approach and Avoidance Motivation* (pp. 343–366). Psychology Press.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55*(1), 68–78. https://doi.org/10.1037/0003-066X.55.1.68

Shenhav, A. (2024). The affective gradient hypothesis: An affect-centered account of motivated behavior. *Trends in Cognitive Sciences, 28*(12), 1089–1104. https://doi.org/10.1016/j.tics.2024.08.003

Spielberger, C. D. (1983). State-trait anxiety inventory for adults. https://psycnet.apa.org/doi/https://doi.org/10.1037/t06496-000

Strang, N. M., & Pollak, S. D. (2014). Developmental continuity in reward-related enhancement of cognitive control. *Developmental Cognitive Neuroscience, 10*, 34–43. https://doi.org/10.1016/j.dcn.2014.07.005

Thibodeau, R., Jorgensen, R. S., & Jonovich, S. J. (2008). Anger elicitation using affective pictures: An individual differences approach. *Journal of Individual Differences, 29*(2), 80–89. https://doi.org/10.1027/1614-0001.29.2.80

Wager, T. D., Atlas, L. Y., Leotti, L. A., & Rilling, J. K. (2011). Predicting individual differences in placebo analgesia: Contributions of brain activity during anticipation and pain experience. *Journal of Neuroscience, 31*(2), 439–452. https://doi.org/10.1523/JNEUROSCI.3420-10.2011

Wager, T. D., Atlas, L. Y., Lindquist, M. A., Roy, M., Woo, C.-W., & Kross, E. (2013). An fMRI-based neurologic signature of physical pain. *The New England Journal of Medicine, 368*(15), 1388–1397. https://doi.org/10.1056/NEJMoa1204471

Wroblewski, A., Hollandt, M., Yang, Y., Ridderbusch, I. C., Pietzner, A., Szeska, C., Lotze, M., Wittchen, H.-U., Heinig, I., Pittig, A., Arolt, V., Koelkebeck, K., Rothkopf, C. A., Adolph, D., Margraf, J., Lueken, U., Pauli, P., Herrmann, M. J., Winkler, M. H., & Richter, J. (2022). Sometimes i feel the fear of uncertainty: How intolerance of uncertainty and trait anxiety impact fear acquisition, extinction and the return of fear. *International Journal of Psychophysiology, 181*, 125–140. https://doi.org/10.1016/j.ijpsycho.2022.09.001

Wu, T., Chen, C., Spagna, A., Wu, X., Mackie, M.-A., Russell-Giller, S., Xu, P., Luo, Y., Liu, X., Hof, P. R., & Fan, J. (2020). The functional anatomy of cognitive control: A domain-general brain network for uncertainty processing. *Journal of Comparative Neurology, 528*(8), 1265–1292. https://doi.org/10.1002/cne.24804

Yang, Y., Miskovich, T. A., & Larson, C. L. (2018). State Anxiety Impairs Proactive but Enhances Reactive Control. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2018.02570

Yang, Q., Si, S., & Pourtois, G. (2023). Parsing the contributions of negative affect vs. aversive motivation to cognitive control: An experimental investigation. *Frontiers in Behavioral Neuroscience, 17*, Article 1209824. https://doi.org/10.3389/fnbeh.2023.1209824

Yee, D. M., Crawford, J. L., Lamichhane, B., & Braver, T. S. (2021). Dorsal anterior cingulate cortex encodes the integrated incentive motivational value of cognitive task performance. *Journal of Neuroscience, 41*(16), 3707–3720. https://doi.org/10.1523/JNEUROSCI.2550-20.2021

Yee, D. M., Krug, M. K., Allen, A. Z., & Braver, T. S. (2016). Humans Integrate Monetary and Liquid Incentives to Motivate Cognitive Task Performance. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.02037

Yee, D. M., Leng, X., Shenhav, A., & Braver, T. S. (2022). Aversive motivation and cognitive control. *Neuroscience and Biobehavioral Reviews, 133*, Article 104493. https://doi.org/10.1016/j.neubiorev.2021.12.016

Zorowitz, S., & Niv, Y. (2023). Improving the reliability of cognitive task measures: A narrative review. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 8*(8), 789–797. https://doi.org/10.1016/j.bpsc.2023.02.004