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Abstract

Objective. Humans are often required to perform demanding cognitive and motor tasks under pressure. However, in such environments there is considerable inter-individual variability in the ability to successfully execute actions. Here, we consider how individual differences in self-reported sensitivity to punishment influence skilled motor performance under pressure and whether this relationship is moderated by the temporal detection of threat.

Method. Across two studies, one hundred and sixty UK participants (Study 1, n = 80, M_{Age} = 21.6, 52 Males; Study 2, n = 80, M_{Age} = 24.95, 45 Males) performed a precision-grip task and received either early or late warning of an upcoming stressful manipulation involving social evaluation and performance–dependent incentives.

Results. In both studies, we report an interaction where punishment sensitivity was adaptive for motor performance only when threats were detected early and there was opportunity to prepare for the upcoming stressor. Further, our results suggest that the benefits of punishment sensitivity are likely underpinned by the effective use of cognitive strategies.

Conclusion. Heightened sensitivity to punishment is adaptive for performance under pressure, provided threats are detected early and effective cognitive strategies are implemented.

Keywords: Reinforcement Sensitivity Theory, Defensive Distance, Threat Imminence, Anxiety, Performance

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In many domains, humans are required to execute skilled actions that contain consequences for success or failure; for example, consider an athlete performing in competition or a surgeon operating on a patient. In demanding situations, the effects of psychological stress on perceptual and behavioural processes are relatively well understood; for example, shifting attention to task-irrelevant threats (Eysenck, Derakshan, Santos, & Calvo, 2007; MacLeod & Mathews, 1988), consuming working memory (Beilock & Carr, 2005), and redirecting attention to explicit processes (Baumeister, 1984; Masters, 1992).

However, it is far less clear why individual differences occur in response to psychological stress. Notable attempts to consider the individual within the stress and performance literature have largely focused on the effect of personality-trait-like individual differences such as dispositional self-consciousness (Baumeister, 1984) and drive for self-enhancement (Wallace & Baumeister, 2002). However, recent research takes a more theoretically derived stance to understanding the impact of personality on motor performance by applying Reinforcement Sensitivity Theory (RST) to examine individual differences in stressful performance domains (e.g., Hardy, Bell, & Beattie, 2014). RST is a biologically-based theory of personality underpinned by neural circuits that mediate responses to reward, punishment and conflict resolution (Gray & McNaughton, 2000). One such individual difference is the sensitivity of the neural systems regulating defensive responses to threat. Importantly, although heightened sensitivity to threat is a significant risk factor for negative long-term health consequences (O'Donovan, Slavich, Epel, & Neylan, 2013) and psychopathology in adults (Johnson, Turner, & Iwata, 2003), heightened sensitivity to threat may actually be adaptive in some performance domains (e.g., Hardy et al., 2014). For example, across two independent samples of elite athletes, Hardy et al. observed a positive relationship between threat sensitivity (when combined with insensitivity to reward) and performance in stressful situations; to explain this somewhat counterintuitive benefit of threat sensitivity on performance, the authors also observed that threat sensitivity predicted earlier preparation for upcoming threats. In other words, threat sensitivity is potentially adaptive if it leads to the earlier implementation of effective coping strategies. To understand more clearly why threat sensitivity may facilitate earlier preparation, we illustrate the functional organisation of defensive systems with respect to two dimensions: direction and distance.

Defensive Direction

According to RST, two parallel defensive systems regulate responses to threats and are distinguished by defensive direction (McNaughton & Corr, 2004; Perkins & Corr, 2006). In the presence of highly aversive threats that necessitate avoidance, such as a person wielding a knife, the fight-flight-freeze system (FFFS) mediates defensive avoidance. However, not all threats need avoiding – either because the potential threat is ambiguous or the environment contains the concurrent potential for reward. In other words, it is sometimes desirable to approach potential threats if there is the chance of a significant payoff. For example, we may give a presentation to a room full of strangers because it offers the opportunity for social and financial rewards, despite the potential threat of public criticism or social rejection. In such mixed-incentive environments, the behavioural inhibition system (BIS; McNaughton & Corr, 2004) regulates defensive *approach*, prompting cautious behaviours and inhibiting on going responses (i.e., pausing to ruminate over the upcoming situation).

Defensive Distance

Defensive systems are hierarchically organised along a gradient of defensive distance whereby the specific physiological and behavioural response is determined by the perceived proximity of the threat (Blanchard, Hynd, Minke, Minemoto, & Blanchard, 2001; McNaughton & Corr, 2004; Perkins & Corr, 2006). This hierarchical organisation of defensive responses is highly adaptive because different brain regions can mediate either complex preparatory processes or reactive responses depending on what is most appropriate, given the proximity of threat (Mobbs, Hagan, Dalgleish, Silston, & Prevost, 2015).

The Benefit of Sensitivity to Punishment

Importantly, individuals differ in their perception of defensive distance to threat (Corr, 2013; McNaughton & Corr, 2004; Perkins, Cooper, Abdelall, Smillie, & Corr, 2010), hereafter referred to as *sensitivity to punishment*. At the same objective distance, an individual who is highly sensitive to punishment will perceive a threat as closer than someone less sensitive to punishment. Thus, if heightened sensitivity to punishment causes activation of the behavioural inhibition system to occur at an earlier stage (and prior to when a response is required), this may be adaptive for performance because it engages slow, preparatory processes that permit the simulation and imagination of future states to optimise future actions (Corr, 2011).

Empirical evidence for the adaptive benefit of punishment sensitivity largely comes from research in low-to-moderate stress environments, where extended rumination is proposed to facilitate performance (see Perkins & Corr, 2014). For example, Perkins & Corr, (2005) demonstrated that anxiety proneness (i.e., a highly reactive BIS) was a positive predictor of performance in financial managers, albeit only in those who were also highly intelligent (as cognitive ability may aid effective interpretation of feedback and improve decision-making processes). Yet research in more hazardous environments (e.g., the military and adventure sports) has offered mixed evidence in support for the benefit of punishment sensitivity, with studies showing a negative effect of trait anxiety (Leikas, Mäkinen, Lönnqvist, & Verkasalo, 2009; Perkins, Kemp, & Corr, 2007) and positive effects of state anxiety on performance (Hardy & Hutchinson, 2007).

These mixed effects may be better understood when one considers additional factors that influence the punishment sensitivity – performance relationship. Two aspects in particular may determine whether punishment sensitivity is adaptive for performance: the time available to engage defensive responses and the possession of effective modulatory processes, or coping strategies. If heightened sensitivity to punishment is adaptive because it leads to the earlier engagement of preparatory responses, individuals may only benefit in environments where it is possible to explicitly detect an upcoming threat and engage in early preparatory responses. However, time alone may be insufficient to facilitate performance unless individuals also possess effective cognitive strategies that can be implemented prior to performance (Hardy et al. 2014). Interestingly, indirect evidence in a more applied setting has shown that individuals who underwent a training program designed to sensitise them to threat whilst developing strategies to deal with the threats performed better in pressure situations (Bell, Hardy, & Beattie, 2013). In the absence of such strategies, individuals may experience prolonged activation of defensive systems and anxious states that persist during performance situations.

Present Research

Although recent research (i.e., Hardy et al., 2014) offers an important advancement to the stress and performance literature by establishing a positive relationship between punishment sensitivity and motor performance; there are important limitations to current understanding.

Notably, the role of proximity to the threat (i.e., when one is aware and prepares for an upcoming threat) is yet to be experimentally tested. Establishing the influence of threat proximity is vital for two reasons; to increase our understanding of the factors influencing human performance under pressure; and for the development of effective interventions to ameliorate the potentially destructive effects of pressure on performance.

Here, we examine the effect of punishment sensitivity on skilled performance in a mixed-incentive environment and test whether the punishment sensitivity – performance relationship is dependent on when threats are detected. We examined this in a between-subjects design by manipulating when participants were made aware of an upcoming psychological stressor that involved both monetary incentives and social evaluation. In the distal threat condition, participants had time to prepare and engage coping strategies whereas this was not possible for the participants in the proximal threat condition. Further, to examine the modulatory effect of top-down, cognitive processes, participants completed the task after being trained (Study 1) or untrained (Study 2) on the implementation of effective coping strategies. We assessed performance using a precision grip task whilst recording changes in state anxiety (Studies 1 and 2) and effort (Study 2) through self-report and psychophysiological markers (Study 2).

We predicted that punishment sensitivity would benefit performance when threats were detected early and there was opportunity to engage in cognitive processes that reappraise threat and regulate arousal. In contrast, we predicted that punishment sensitivity would be detrimental for performance when threats were detected late and there was no opportunity to engage defensive strategies prior to encountering the threatening performance environment. Because our experimental manipulation was designed to examine the effect of punishment sensitivity on behaviour, we anticipated that these effects would be independent of reward sensitivity, however, to confirm this we also examined whether reward sensitivity moderated the effects of punishment sensitivity on performance.

Study 1: Method

Participants

Power analysis (G*Power; Faul, Erdfelder, Lang, & Buchner, 2007) indicated 77 participants were required to provide sufficient power (.80) to detect a small-to-medium effect (i.e., a Cohen's f^2 of 0.15) for the interaction between punishment sensitivity and threat preparation condition. Consequently, we recruited 80 healthy, right-handed, participants from a university campus (52 men, 28 women, M_{age} = 21.6 years, *SD* = 5.31 years). We obtained institutional ethical approval for the research and written informed consent from all participants. Three participants in the proximal threat condition reported awareness of the experimental manipulation prior to the start of the experiment and were consequently excluded from further analyses.

Experimental Design

Participants sat in front of a 19in LCD monitor (60Hz) that displayed visual feedback of the target and cursor (Figure 1A). Participants sat in front of the display and held the grip force transducer (MLT004/ST, ADInstruments) in the palm of their dominant hand. We amplified the analog force output using a PowerLab (16/35, ADInstruments) data acquisition device and force data was translated into position data of the cursor on the monitor screen; we utilised a one-to-one mapping between force (Nm) and cursor position (mm). Position data was filtered using a second order, dual-pass Butterworth filter with a low pass cut-off frequency of 16 Hz and were processed offline in custom written software (LabVIEW, National Instruments; MATLAB, MathWorks).

Procedure

We used a multifactorial design with a between-subjects manipulation of threat detection (distal, proximal) and within-subjects factors of psychological stress (baseline, preparation and stress). Participants were randomly assigned to either a distal or proximal threat detection condition prior to attending the session. We informed participants that the purpose of the research was to examine the effects of personality and performance strategies on motor performance and they would receive £5 (~$6) for their participation, regardless of performance; these instructions ensured that participants were unlikely to anticipate or detect the true nature of the experiment.

During each trial, participants controlled a blue horizontal cursor (length 12cm and width 0.2cm) along the vertical axis by means of a force grip transducer. We instructed participants to maintain the cursor within a 12cm × 0.4cm red target box (Figure 1A) and that task performance was dependent on their ability to react quickly and move as fast and as accurately as possible to each target. The location of the target box varied along the vertical axis and corresponded to force amplitude. To standardise the physical demands of the task, we scaled all target forces relative to each participant's maximal voluntary contraction (MVC), which was assessed prior to the experimental trials.

INSERT_FIGURE1

Trials and targets. Participants completed 30 trials of the precision grip task over three separate blocks (see Figure 1D-E); blocks one and two contained 12 trials, whereas block 3 contained six trials. Each trial lasted 30s and included 12 targets presented at intervals along the vertical axis (2%, 4%, 6%, 8%, 10% and 12% MVC; see figure 1B). Targets were presented twice at each interval in a pseudorandom, counterbalanced order. Thus, the first two blocks each contained a total of 144 targets and block three contained 72 targets. Each target was presented for a duration of 2.25s – 2.75s; this inter trial variation acted as a variable fore period, preventing anticipatory movements.

Performance feedback. Participants received feedback at the end of each trial based on their mean absolute error, where error was sampled every 20ms and defined as the distance (in % MVC) between the outer edge of the target box and the centre of the cursor (Figure 1A). Feedback was normalised ((1 / mean absolute error) × 100) to produce a score between 0 and 100; however, because large momentary errors could strongly bias the normalised feedback these scores were not included in the main analysis.

Cognitive strategies. Because the potential benefits of punishment sensitivity may depend on the ability to implement cognitive strategies (e.g., Bell et al., 2013; Hardy et al., 2014), we explicitly trained participants to use coping strategies. Participants read a script with instructions for the implementation of three psychological skills that are successfully used by performers to facilitate good performance: imagery, muscle relaxation and cue words (see Hardy, Roberts, Thomas, & Murphy, 2010). Because the coping strategies were designed to support performance, we instructed participants to use the strategy (or combination of strategies) that they thought would best facilitate performance.

Practice. We familiarised participants with the task and gave them 12 practice trials, this number was chosen based on pilot testing indicating it was sufficient to obtain a plateau in performance.

Block 1: baseline performance. To measure baseline performance, participants completed 12 trials whilst instructed to perform at their best and focus on reacting as quickly and as accurately as possible to each target.

Block 2: threat detection. Immediately after block one, we informed participants in the distal threat condition that the purpose of the experiment was to examine their performance under pressure (Figure 1D). We fully disclosed the anxiety manipulation and told them that they would now have an opportunity to prepare for the upcoming stressor. In contrast, we told participants in the proximal threat condition to continue performing as well as they could. Both groups then completed a further 12 trials (Figure 1E).

Block 3: psychological stress. After block two, we informed participants in the proximal threat condition that the purpose of the experiment was to examine their performance under psychological stress. Participants then performed six trials with monetary, competitive and evaluative incentives and consequences for performance; this multifaceted approach has been successfully used to elicit performance anxiety (e.g., Baumeister & Showers, 1986). Participants began block three with £5, the amount they were initially promised for taking part. They gained £1 for successful trials and lost £1 for unsuccessful trials. Trial success was determined by average error and participants were set a target score for each trial. Based on pilot testing, the target score was calculated as 0.675 × 1 *SD* above mean baseline performance as this reflected a difficulty level that was challenging yet achievable. Thus, regardless of individual ability, target difficulty was matched across participants. We manipulated social and evaluative threats by informing participants that their performance would be ranked on a leader board with the names of the best and worst five performers being emailed to all participants after completion of the research. To increase evaluative pressure, we positioned a video camera next to the monitor. We instructed participants that the purpose of the recording was to allow the experimenter to examine the behaviour of the five individuals who performed the worst to identify reasons why they might have choked under pressure.

Debrief. After completing the final block of trials, we fully debriefed participants, explained the true purpose of the experiment, and compensated them. Participants received a maximum pay out of £11 (if successful on all 6 stress trials), however, participants who lost money in the stress condition due to poor performance were still compensated with £5 and thanked for their participation.

Measures[1]

Sensitivity to punishment. We derived the primary measure of punishment sensitivity using Corr's (2001) transformations of the Eysenck Personality Questionnaire - Revised Short version (EPQR-S; Eysenck, Eysenck, & Barrett, 1985); a well-validated and frequently used measure assessing extraversion (12 items), neuroticism (12 items) and psychoticism (12 items). These factors were transformed to reflect an underlying component of punishment sensitivity, an approach that has been used in the absence of alternative measures that directly assess punishment sensitivity (Hardy et al., 2014; Kambouropoulos & Staiger, 2004). Specifically, punishment sensitivity was calculated through the following transformation: (12 − Extraversion) + (2 × Neuroticism) – Psychoticism. Although well-validated alternative self-report measures of punishment (and reward) sensitivity are also available (e.g., BIS/BAS; Carver & White, 1994 & SPSRQ; (Torrubia, Avila, Molt, & Caseras, 2001) they are somewhat limited by content validity

[1] Additional measures: at the start of the experiment, participants also completed measures assessing (grandiose and vulnerable) narcissistic traits. Prior to the stress block, participants completed single-item measures assessing both their perceived probability of success and their desire to succeed on the pressure trials. These measures addressed a separate research question and are not further reported in the current analysis.

and their conflation of the BIS and FFFS (McNaughton & Corr, 2004). Consequently, we used the EPQ-transformations in order to be consistent with recent research examining the effects of punishment sensitivity on performance (e.g., Hardy et al., 2014). However, in recognition that our primary measure of punishment sensitivity did not distinguish between the BIS and FFFS (McNaughton & Corr, 2004), we also included a secondary self-report measure of punishment sensitivity that directly examined the unique sensitivities of the BIS (23 items; $M = 51.27$, $SD = 11.52$) and FFFS (13 items; $M = 20.71$, $SD = 5.72$) using scales from the Reinforcement Sensitivity Theory Personality Questionnaire (RST-PQ; Corr & Cooper, 2016).

Anxiety. To examine the efficacy of our stress manipulation, and individual differences in the response to the manipulation, we assessed cognitive anxiety prior to each block via the worry scale from the mental readiness form (MRF-3; Krane, 1994). The MRF measures cognitive anxiety with a single item “My thoughts are” with the anchors *calm* (1) and *worried* (11).

Awareness. It was important that participants in the proximal condition were naïve to the experimental manipulations prior to the explicit instructions. To confirm this, we asked participants at the end of the experiment: ‘At the start of the experiment, please indicate how aware you were that the experiment would test your ability to perform under pressure?’ We assessed awareness on a scale of 1 (*not at all*) to 11 (*greatly*).

Performance. To quantify performance during the precision grip task, we examined three components of movement that were critical for performance: reaction time, movement time, and initial movement accuracy (Mosconi et al., 2015). We calculated reaction time (RT) as the time between the presentation of a new target stimulus and movement onset. We determined movement onset for each target by working back from peak velocity to locate the first point in which velocity increased above 0 mm/s for a target at a higher force, or decreased below 0 mm/s for a target at a lower force (Figure 1C). Similarly, we calculated the end of the movement by working forward from peak velocity to the point in which the velocity fell below 0 mm/s. Movement time (MT) was then defined as the time between movement onset and movement end. We defined initial movement accuracy (ACC) as the distance between the cursor and target at movement end. To standardise accuracy across all targets we calculated the percentage movement error, relative to the required distance to the target. Therefore, if the force at movement onset (MO) was 2% MVC, the movement end (ME) was 10% MVC, but the target (T) was 8% MVC, the initial movement accuracy score would be (+) 33.3%, ((ME-T)/(T-MO)). Initial movement accuracy scores for each block were calculated as the mean of absolute accuracy across all sub trials. We excluded targets from analysis where participants moved in the wrong direction or reacted faster than 60ms (this accounted for 4.3% of all trials). We excluded force movements to the first target on each trial, because they had highly variable start locations that were uncharacteristic of all other target movements.

Data Reduction

We used moderated hierarchical regression to examine the interactive effects of punishment sensitivity and threat proximity on performance. As is recommended practice for moderated hierarchical regression (Jaccard & Turrisi, 2003), we created a single value for each dependent variable by calculating improvement scores (stress – baseline) for RT, MT and ACC. To assess overall performance change whilst accounting for any potential performance trade offs we standardised the change scores for RT, MT and ACC and then summed them to create a single composite measure of performance improvement (ΔPerformance) for each participant (e.g., Wallace & Baumeister, 2002). To aid illustration of the effects, ΔPerformance was reversed so that a positive value indicated performance improvement and a negative value indicated a performance decrease.

Study 1: Results

Preliminary Analysis.

There were no between-group differences in sex, punishment sensitivity scores or baseline performance of participants in the distal and proximal conditions (all *p'*s > .1); see Table 1 for correlations and descriptive statistics. Importantly, all participants in the proximal threat condition reported being unaware of the anxiety manipulation (*M* = 1.380, Range 1-3).

INSERT_TABLE1

Efficacy of the psychological stressor manipulation. Repeated-measures ANOVA, using the greenhouse-geisser epsilon, revealed a significant block × threat preparation interaction to predict cognitive anxiety ($F(1.60,119.64) = 4.683$, $p = .017$, $\eta_p^2 = .059$). Participants in the proximal condition experienced significantly higher anxiety in the stress block (*M* = 4.62, *SD* = 2.29) compared to either the baseline (*M* = 2.89, *SD* = 1.49) or preparation block (*M* = 3.11, *SD* = 1.77); ($F(1.46,72) = 18.16$, $p = < .001$, $\eta_p^2 = .34$). In contrast, participants in the distal condition reported lower anxiety during the baseline (*M* = 2.88, *SD* = 1.51) block and higher anxiety only in both the preparation block (*M* = 4.00, *SD* = 1.75) and stress block (*M* = 4.40, *SD* = 2.26); ($F(1.43,78) = 22.69$, $p = < .001$, $\eta_p^2 = .37$).

Performance. Repeated-measures ANOVA revealed no block × threat preparation interaction to predict RT, MT and ACC (all *p*-values > .22). There was a significant main effect of block on RT (F $(2,150) = 143.852$, $p < .001$, $\eta_p^2 = .657$) and ACC ($F(2,150) = 15.245$, $p < .001$, $\eta_p^2 = .169$), yet no effect of block on MT; ($F(1.78,133.44) = 1.862$, $p = .164$, $\eta_p^2 = .024$).

Follow up tests confirmed that participants in both conditions reacted quicker and more accurately in the psychological stress condition

Punishment sensitivity and anxiety. Moderated regression analyses were performed using PROCESS (Hayes, 2013) for SPSS with bias-corrected confidence intervals (CI's) generated from 5000 bootstraps; all CI's are reported at the 95% level and alpha was set at .05 for all analyses. Predictors were mean-centred prior to analysis, and variables in regression models satisfied homoscedasticity and normality of residuals assumptions. Threat preparation condition was coded 0 (distal) and 1 (proximal). Estimates of (conditional) main effects for each variable are calculated based on setting all other variables to their sample mean. Regression analysis revealed no interaction between punishment sensitivity and threat preparation condition to predict the change in anxiety from the baseline to stress blocks (β = -.007, p = .914, 95% CI [-0.131, 0.117]). Examining main effects, threat preparation condition (distal vs. proximal) had no effect on Δanxiety (β = -.067, p = .900, 95% CI [-1.121, 0.986]) whereas punishment sensitivity predicted a significant increase in anxiety (β = .090, p = .005, 95% CI [0.028, 0.151]).

Main Analysis

Punishment sensitivity and performance. A moderated hierarchical regression model examining the effect of sensitivity to punishment on ΔPerformance, revealed no main effect of either the threat preparation condition, (β = -.123, p = .687, 95% CI [-0.729, 0.482]) or punishment sensitivity (β = .002, p = .914, CI [-0.034, 0.037]). However, of greater interest, was the significant punishment sensitivity × condition interaction explaining 5.47% of the variance in performance improvement, $\Delta F(1, 73) = 4.24$, $\Delta R^2 = .055$, β = -.074, p = .043, 95% CI [-0.145, -0.002]. Simple slopes analysis revealed a positive relationship between punishment sensitivity and performance improvement in the distal threat preparation condition β = 0.037, $t(73) = 1.621$,

p =.109, 95% CI [-0.009, 0.083], and a negative relationship in the proximal (no preparation) condition, β = -0.036, t(73) = -1.328 p =.188, 95% CI [-0.091, 0.018], (Figure 2).

Replacing punishment sensitivity with scores from the measure of BIS sensitivity replicated the findings above. The main effects of both BIS (β = .009, p = .514, 95% CI [-0.018, 0.035]) and threat preparation (β = -.195, p = .522, 95% CI [-0.800, 0.410]) to predict ΔPerformance were not significant, but there was a significant BIS × threat preparation interaction $\Delta F(1, 71) = 4.849$, $\Delta R^2 = .063$, β = -.059, p = .031, 95% CI [-0.112, -0.006]. The simple slopes analysis indicated a significant positive relationship between BIS and ΔPerformance in the distal threat condition β = 0.038, t(71) = 2.116, p =.038, 95% CI [0.002, 0.073], and no relationship in the proximal threat condition β = -0.021, t(71) = -1.059, p =.293, 95% CI [-0.061, 0.019,]. In contrast, FFFS sensitivity did not interact with threat preparation to predict performance, $\Delta F(1, 71) = 1.145$, $\Delta R^2 = .016$, β = -.058, p = .288, 95% CI [-0.166, -0.050]. The main effects of FFFS (β = .021, p = .452, 95% CI [-0.034, 0.075]) and threat preparation (β = -.176, p = .570, 95% CI [-0.791, 0.439]) were also not statistically significant.

INSERT_FIGURE2

Because previous research has shown that punishment sensitivity may only benefit performance when people are also insensitive to reward (e.g., Hardy et al. 2014), we ran a further analysis testing a three-way (reward sensitivity[21] × punishment sensitivity × threat preparation) interaction to predict performance. This three way interaction was not statistically significant (ΔF(1, 69) = 0.941, β =.007, ΔR^2 = .012, p = .335) and reward sensitivity did not have a (conditional) main effect of on performance (β = .015, p = .621, 95% CI [-0.044, 0.073]).

[2] We calculated a measure of reward sensitivity using transformations of the EPQ scores (Corr, 2001); (2 × Extraversion) + Neuroticism - Psychoticism.

Importantly, the punishment sensitivity × threat preparation interaction remained a significant predictor of performance improvement (*p* = .048), even after controlling for the effect of reward sensitivity.

Study 1: Discussion

We provide evidence that sensitivity to punishment can benefit motor performance when threats are detected early and there is time to prepare. One reason for the positive relationship between punishment sensitivity and performance following distal threats is that time facilitates the effective implementation of cognitive strategies (e.g., reappraisal, imagery, etc.) to down-regulate anxiety and/or improve preparation (Bell et al., 2013; Hardy et al., 2014). However, because all participants were explicitly trained to implement cognitive strategies, it is unclear whether the punishment sensitivity – performance relationship is contingent on the possession of these additional cognitive strategies. Thus in Study 2 we investigated whether punishment sensitivity might still have beneficial effects on performance, independent of cognitive strategies

Study 2

In Study 2, we replicated the experimental design and analysis from Study 1 with one key exception; participants were not trained on the implementation of cognitive strategies. Thus, if cognitive strategies were necessary for the benefits of punishment sensitivity in the distal threat condition, punishment sensitivity would unlikely benefit distal threat performance in Study 2. To better understand the effect of individual differences in punishment sensitivity on the overall response to threat (and not just performance), we used self-report and objective (i.e., cardiovascular) measures of anxiety and effort, two factors that are intimately linked to performance (Eysenck & Calvo, 1992). To this extent, although punishment sensitivity may benefit performance, this may come at the cost of a significant increase in effort, thereby reducing efficiency.

Study 2: Methods

Participants

Eighty healthy, right-handed participants completed the experiment. Three participants were excluded from the proximal threat group due to prior awareness of the experimental manipulation, leaving a final sample of 77 (45 men, 32 women, M_{age} = 24.95 years, *SD* = 6.47 years). Participants were asked to refrain from exercising (4hrs) and consuming alcohol (12hrs) or caffeine (3hrs) prior to testing. Due to issues with the recording equipment, data from an additional three participants are not included in the analysis of cardiovascular measures.

Procedure

In Study 2 we did not provide coping strategies and instructed participants that the purpose of the experiment was to examine the relationship between their personality, physiological responses, and performance. Unless stated, all experimental procedures, measures and analyses were the same as in Study 1.

Measures[3]

Punishment sensitivity. We measured punishment sensitivity using the same transformations from the EPQR-S (Eysenck et al., 1985); to reduce participant burden, the secondary measures of BIS and FFFS were not assessed.

Self-report effort and anxiety. We assessed cognitive anxiety prior to each block via the mental readiness form (MRF-3; Krane, 1994; see Study 1). Mental effort was assessed immediately after each block using Zijlstra's (1993) Rating Scale for Mental Effort (RSME) where participants rated the level of mental effort expended by intersecting a (150mm) vertical scale ranging from 0-150 with anchors *no effort at all* (3) and *extreme effort* (114).

Cognitive strategies. Although participants were not explicitly given coping strategies, it was possible that they might still possess and implement existing learned strategies. To assess usage and efficacy of cognitive strategies during the experiment, we retrospectively asked participants to report any strategies they had used to support their performance during the experiment. Coping use was coded 1 for participants who reported using at least one strategy and 0 for participants who reported no strategy use. To quantify the perceived benefit, or effectiveness, of these strategies, participants who reported coping use were asked to indicate

[3] Additional measures: participants also completed scales assessing (grandiose and vulnerable) narcissistic traits. Prior to the stress block, participants (*n* = 73) completed single-item measures assessing their gain focus and loss focus for the upcoming stress block (i.e., regulatory focus), and their perception of the resources they possess and the demands required of the task (i.e., challenge versus threat appraisal; *n* = 77). These measures addressed a separate research question and are not further reported in the current analysis.

'How much did the strategy benefit your performance'. Responses were anchored from 1 (*not at all*) to 11 (*greatly*).

Physiological responses. We recorded cardiovascular responses using electrodes placed on the right clavicle (positive), lower left rib (negative) and left clavicle (earth). The signal was amplified through a PowerLab Data Acquisistion Device and digitally filtered with a 50Hz high pass and 0.3Hz low pass using LabChart 7 software (AD Instruments, Dunedin). The square root of the mean of the sum of squared successive differences in cardiac interbeat intervals (r-MSSD) and the standard deviation of R-wave-to-R-wave intervals (SDNN) were computed as measures of heart rate variability. R-MSSD is a time domain surrogate of the frequency domain based high (0.15–0.40 Hz) spectral power band, which reflects parasympathetic nervous system activity and decreases are indicative of heightened cognitive anxiety. SDNN is a time domain index of heart rate variability that closely reflects activity in the frequency domain-based low (0.04–0.15 Hz) spectral power band, and is influenced by both sympathetic and parasympathetic inputs; decreases in SDNN reflect an increase in effort. To ensure we could compare equivalent cardiovascular responses across blocks, we analysed responses during only the first 180s of each block.

Study 2: Results

Preliminary Analysis

There were no between-group differences in sex, baseline self-report measures (anxiety, effort, and mental effort), physiological response or performance variables (all *p*s > .2; see Table 2 for correlations and descriptive statistics). Participants in the distal threat group (M = 23.15, SD = 5.27) were, on average, younger than the participants in the proximal threat group (M = 26.89, SD = 7.13); $t(75) = 2.632$, $p = .010$).

INSERT_TABLE2

Efficacy of the Psychological Stressor Manipulation

Self-reported anxiety and effort. Repeated-measures ANOVA revealed a significant block × threat preparation interaction on cognitive anxiety ($F(2,146) = 9.642$, $p < .001$, $\eta_p^2 = .117$). Follow up tests indicated that participants in the distal condition experienced significantly higher anxiety in both the stress block ($M = 4.46$, $SD = 1.74$) and preparation block ($M = 4.13$, $SD = 1.74$) compared to the baseline block ($M = 2.95$, $SD = 1.37$). In contrast, participants in the proximal condition experienced significantly higher anxiety in the stress block ($M = 4.22$, $SD = 2.19$) compared to both the baseline ($M = 3.08$, $SD = 1.67$) and preparation block ($M = 3.33$, $SD = 1.58$) The block × threat preparation interaction was not significant for effort ($F\ (2, 150) = 0.985$, $p = .376$, $\eta_p^2 = .01$). However, there was a main effect of block ($F\ (2, 150) = 47.626$, $p < .001$, $\eta_p^2 = .39$) such that participants in both conditions exerted considerably greater effort in the stress block ($M = 83.87$, $SD = 2.25$) compared to the preparation ($M = 81.20$, $SD = 2.45$) and baseline blocks ($M = 95.30$, $SD = 2.54$).

Punishment sensitivity and anxiety. A moderated hierarchical regression analysis revealed no main effect of either punishment sensitivity ($\beta = -.009$, $p = .727$, 95% CI [-0.057, 0.040]) or threat preparation condition ($\beta = -.445$, $p = .238$, 95% CI [-1.190, 0.301]) to predict a change in cognitive anxiety from the baseline to stress block. There was a significant punishment sensitivity × threat preparation interaction, $\Delta F(1, 73) = 5.688$, $\Delta R^2 = .051$, $\beta = -.098$, $p = .049$, 95% CI [-0.196, -0.000]; however, simple slopes analyses revealed that punishment sensitivity was unrelated to anxiety in the distal threat condition ($p = .241$) and had a non-significant (negative) relationship with anxiety in the proximal threat condition ($p = .109$).

The effect of punishment sensitivity on self-reported anxiety was complemented by equivalent changes in our physiological measure of anxiety, r-MSSD. The main effect of punishment sensitivity (β = .117, p = .530, 95% CI [-0.252, 0.486]) and threat preparation condition (β = 1.615, p = .576, 95% CI [-4.116, 7.347]) to predict r-MSSD was not significant. However, the punishment sensitivity × threat preparation interaction accounted for 14.67% of the variance in r-MSSD, $\Delta F(1, 70) = 12.122$, β = 1.296, p < .001, 95% CI [0.554, 2.039]. Punishment sensitivity led to a significant reduction of r-MSSD (reflecting increased anxiety) in the distal threat condition (β = -0.496, $t(70) = -2.005$, p =.049, 95% CI [-0.990, -0.003]) and a significant increase (reflecting lower anxiety) in the proximal threat condition (β = 0.800, $t(70) =$ 2.877, p =.005, 95% CI [0.245, 1.355]).

Punishment sensitivity and effort. Moderated hierarchical regression analysis revealed no main effect of punishment sensitivity (β = -.088, p = .693, 95% CI [-0.528, 0.352]) and threat preparation condition (β = -2.729, p = .423, 95% CI [-9.482, 4.023]) to predict changes in self-reported mental effort (baseline – stress). Further, the punishment sensitivity × threat preparation interaction was not significant, $\Delta F(1, 73) = 0.059$, $\Delta R^2 = .001$, β = -.107, p = .809, 95% CI [-0.989, 0.775]. Similarly, the main effect of punishment sensitivity (β = 0.259, p = .280, 95% CI [-0.215, 0.733]) and threat preparation condition (β = -0.531, p = .886, 95% CI [-6.826, 7.889]) to predict SDNN (a physiological indicator of mental effort) was not significant. However, the threat preparation x punishment sensitivity interaction was significant $\Delta F(1, 70) = 5.278$, β = 1.098, p = .025, 95% CI [0.145, 2.051]; punishment sensitivity was unrelated to SDNN in the distal threat preparation condition (β = -0.260, $t(70) = -0.819$, p =.416, 95% CI [-0.894, 0.373]) but predicted a significant increase (reflecting a reduction in effort) in the proximal threat condition (β = 0.838, $t(70) = -2.346$, p =.022, 95% CI [0.126, 1.550]).

Main Analysis

Punishment sensitivity and performance. Examining the effect of punishment sensitivity and ΔPerformance, we performed a moderated hierarchical regression testing the main and interactive effects of punishment sensitivity and threat preparation; changes in self-reported and physiological measures of anxiety and effort were entered as covariates. This revealed no main effect of either the threat preparation condition or punishment sensitivity on ΔPerformance. However, replicating the results of Study 1, the punishment sensitivity × threat preparation interaction was significant and explained 8.46% of the variance in ΔPerformance, $\Delta F(1, 65) = 6.582$, $\beta = -.119$, $p = .013$, 95% CI [-0.211, -0.026]; Figure 3 displays the nature of the interaction. The effects of the physiological measures of change in anxiety ($\beta = -.005$, $p = .748$, 95% CI [-0.036, 0.026]) and effort ($\beta = .011$, $p = .355$, 95% CI [-0.013, 0.035]) on performance were not significant; however, there was a significant effect of self-reported effort leading to performance improvement ($\beta = .023$, $p = .047$, 95% CI [-0.003, 0.046]) and a marginal effect of cognitive anxiety leading to performance impairment ($\beta = -.188$, $p = .080$, 95% CI [-0.400, 0.023]). Simple slopes analysis revealed a positive relationship between punishment sensitivity and performance improvement in the distal threat condition $\beta = 0.065$, $t(65) = 2.257$, $p = .027$, 95% CI [0.008, 0.123,] and a non significant (negative) relationship in the proximal threat condition, $\beta = -0.054$, $t(65) = -1.589$ $p = .117$, 95% CI [-0.121, 0.014]. Notably, the punishment sensitivity × threat preparation interaction remained significant when all covariates were removed from the model, $\Delta F(1, 73) = 3.992$, $\beta = -.103$, $p = .020$, 95% CI [-0.188, -0.017].

INSERT_FIGURE3

Coping strategies. One interpretation of the punishment sensitivity and performance results just presented is that the beneficial effects of punishment sensitivity appear to be independent of coping strategies. However, an alternative possibility is that participants already possessed effective coping strategies that they were able to implement. Indeed, when we asked participants whether they used strategies to support their performance, a significant proportion (56/77) of participants reported using at least one cognitive strategy, $\chi^2(1) = 15.909$, $p < .001$. Strategy use was equivalent for participants in the distal ($N = 28$) and proximal ($N = 28$) threat conditions, $\chi^2(1) = 0.312$, $p = .576$. We next asked whether sensitivity to punishment would predict greater use of coping strategies; a logistic regression model with punishment sensitivity as a predictor indicated a trend for punishment sensitivity to predict greater coping use (Nagalkerke's $R^2 = 0.67$, $p = .064$).

More relevant than usage, perhaps, is whether the coping strategies were beneficial for performance. Analyzing the data from the 56 participants who used coping strategies, a moderated hierarchical regression revealed a main effect of punishment sensitivity on coping benefit, ($\beta = .084$, $p = .011$, 95% CI [0.020, 0.148]); in other words, the more sensitive an individual was to punishment, the more they reported benefitting from the use of coping strategies. However, coping benefit was unrelated to whether participants were in the proximal or distal condition ($p = .793$) and there was no interaction between threat preparation condition and punishment sensitivity ($p = .715$).

We then examined if the effectiveness of coping strategies could explain the benefits of punishment sensitivity on performance. In other words, the performance improvements in individuals who are highly sensitive to punishment could be a result of the efficacy of their coping strategy. We used a conditional indirect effects analysis (PROCESS, Model 7) to examine whether coping efficacy mediated the relationship between punishment sensitivity and performance in the proximal and distal conditions. There was a significant indirect effect in the distal threat condition (β = .017, 95% CI [0.002, 0.048]) but not in the proximal condition (β = .023, 95% CI [-0.004, 0.076]). This result indicates that coping effectiveness accounted for the beneficial effects of punishment sensitivity when the threat was distal and there was time to prepare.

General Discussion

We examined the relationship between individual differences in sensitivity to punishment and the execution of skilled motor actions in a mixed-incentive environment (i.e., involving both potential rewards and punishments). Activation of the behavioural inhibition system during a task (i.e., state anxiety) is typically associated with impairments to either the effectiveness or efficiency of task performance (Eysenck et al., 2007). However, here we considered whether individual differences in the sensitivity of defensive system could influence performance, depending on whether threats are detected early or late.

Across two studies, our behavioural results clearly show that heightened sensitivity to threat was adaptive for motor performance when threats were detected early (distally) and there was time to prepare for a threat. In contrast, punishment sensitivity was largely unrelated to performance when threats were detected proximally, and participants lacked the time to prepare. Notably, in Study 1 the interaction effects were consistent across two distinct psychometric scales assessing sensitivity to punishment, suggesting that the effects are unlikely to be an artefact of the particular measure used. Further, we show that the benefits of heightened punishment sensitivity appear to be conditional on the implementation of effective cognitive strategies.

The motor performance improvements associated with heightened sensitivity to punishment are consistent with an emerging literature that highlights the adaptive function of the defensive approach system in environments where rumination and preparation may benefit performance (Hardy et al., 2014; Perkins & Corr, 2014). We suggest that heightened sensitivity to threat benefits performance by increasing the engagement of these defensive processes, prior to performance. Specifically, punishment sensitivity may enhance both the conscious simulation of motor movements and imagination of future states (Suddendorf & Corballis, 2007). These processes may serve a function in both reducing the novelty, or surprise, of the upcoming psychological stressor and improving motor planning.

An important caveat to the engagement of conscious processes (i.e., rumination and simulation) is that they may be ineffective if they are negatively biased and increase aversion to the threat. To this effect, our results in Study 2 underscore the importance of possessing effective cognitive strategies to process potential threats. Even when participants were untrained on strategies, they reported implementing strategies, and interestingly, punishment sensitivity predicted both greater usage and greater efficacy of coping strategies. Given that coping efficacy mediated the relationship between punishment sensitivity and motor performance only when there was time to prepare, it appears likely that punishment sensitivity benefits performance through the earlier implementation of coping strategies (cf. Hardy et al., 2014). However, it is also possible that punishment sensitivity has a direct effect on the qualitative components of coping use; for example, individuals who are highly sensitive to threats may be better equipped to cope with anxiety because they regularly encounter anxious states during goal pursuit and have developed effective strategies or automated responses that inoculate against the debilitative effects of anxiety and facilitate goal-directed approach (Epstein, 1989; Eysenck et al., 2007).

In addition to the influence of explicit coping strategies, the distal detection of threat may have also benefitted performance through its influence on the interpretation of anxiety. Perceived control is a regulatory dimension that may affect whether individuals appraise anxiety as facilitative or debilitative (Carver & Scheier, 1988; Cheng & Hardy, 2016; Hardy & Hutchinson, 2007). Importantly, the interpretation of anxiety as adaptive can lead to greater investment of effort and an improvement in performance, whereas a negative appraisal of anxiety can lead to disengagement (Eysenck, 1992). Although we did not assess perceived control in our studies, it is plausible that participants in the distal threat condition would perceive greater control (compared to the proximal condition) and therefore interpret anxiety as facilitative and consequently they invest greater effort in their performance. Our psychophysiological (and self-report) measures in Study 2 support the idea that punishment sensitivity increased the investment of effort in the distal threat condition as a result of increased efficacy and control, whereas it lead to a withdrawal of effort in the proximal threat condition.

A significant strength of our study is the novel consideration of the interplay between the sensitivity of the human defence system, threat proximity and cognitive strategies. Indeed, cognitive appraisals are likely to significantly shape the relationship between threat sensitivity and behaviour and we suggest that future research would benefit from considering the interplay between higher-order and lower-level processes. For example, a more nuanced understanding of an individual’s response to threat can be gained by considering their intrinsic valuation of rewards and threats (Hall, Chong, McNaughton, & Corr, 2011) and cognitive appraisal of the demands of psychological stressors and the resources to cope.

Although we were able to reliably replicate the key interaction effects (punishment sensitivity by threat preparation) across two studies, future research may wish to consider using larger, more highly powered samples. Further, despite merit in the experimental design used here, we concede that laboratory tasks are limited in their capacity to generate psychological stress. Whilst our anxiety manipulations successfully increased cognitive and physiological anxiety, the effect is probably small relative to the anxiety experienced in situations with greater personal significance, such as delivering a speech to a large audience. The intensity of threat is pertinent because the benefits of punishment sensitivity may only be relevant in moderately threatening situations. In environments containing intense threats, heightened punishment sensitivity may impair performance (Perkins et al., 2007) because there is a limit to the utility of cognitive strategies in down regulating anxiety and coping with threats (e.g., Eysenck et al., 2007). However, given that the benefits of heightened punishment sensitivity have been observed in elite level sport (Hardy et al., 2014) it appears that the potential benefits should extend to environments that contain a reasonably high level of pressure.

Conclusion

Multiple theories are proposed to account for the effects of anxiety on performance (Baumeister, 1984; Eysenck & Calvo, 1992; Eysenck et al., 2007; Masters, 1992). However, a notable component that is absent from current approaches is a theoretically grounded explanation of individual differences in the positive versus negative effects of anxiety upon performance. Here, we present evidence that punishment sensitivity is an adaptive personality trait when threats are detected early and there is opportunity to implement effective coping strategies that facilitate performance. These results stress the importance of considering the effect of psychological stress on performance by integrating evidence from contemporary ecological (e.g., Mobbs et al., 2015) and neuropsychological (McNaughton & Corr, 2004) models of defensive systems that underpin anxiety to gain a more comprehensive understanding of how humans perform under pressure.

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