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The Benefit of Punishment Sensitivity On Motor Performance Under Pressure

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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, $n = 80$, $M_{\text{Age}} = 21.6$, 52 Males; Study 2, $n = 80$, $M_{\text{Age}} = 24.95$, 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

1   The Benefit of Punishment Sensitivity On Motor Performance Under Pressure

2   In many domains, humans are required to execute skilled actions that contain

3   consequences for success or failure; for example, consider an athlete performing in competition

4   or a surgeon operating on a patient. In demanding situations, the effects of psychological stress

5   on perceptual and behavioural processes are relatively well understood; for example, shifting

6   attention to task-irrelevant threats (Eysenck, Derakshan, Santos, & Calvo, 2007; MacLeod &

7   Mathews, 1988), consuming working memory (Beilock & Carr, 2005), and redirecting attention

8   to explicit processes (Baumeister, 1984; Masters, 1992).

9   However, it is far less clear why individual differences occur in response to psychological

10   stress. Notable attempts to consider the individual within the stress and performance literature

11   have largely focused on the effect of personality-trait-like individual differences such as

12   dispositional self-consciousness (Baumeister, 1984) and drive for self-enhancement (Wallace &

13   Baumeister, 2002). However, recent research takes a more theoretically derived stance to

14   understanding the impact of personality on motor performance by applying Reinforcement

15   Sensitivity Theory (RST) to examine individual differences in stressful performance domains

16   (e.g., Hardy, Bell, & Beattie, 2014). RST is a biologically-based theory of personality

17   underpinned by neural circuits that mediate responses to reward, punishment and conflict

18   resolution (Gray & McNaughton, 2000). One such individual difference is the sensitivity of the

19   neural systems regulating defensive responses to threat. Importantly, although heightened

20   sensitivity to threat is a significant risk factor for negative long-term health consequences

21   (O'Donovan, Slavich, Epel, & Neylan, 2013) and psychopathology in adults (Johnson, Turner, &

22   Iwata, 2003), heightened sensitivity to threat may actually be adaptive in some performance

23   domains (e.g., Hardy et al., 2014). For example, across two independent samples of elite athletes,

1   Hardy et al. observed a positive relationship between threat sensitivity (when combined with

2   insensitivity to reward) and performance in stressful situations; to explain this somewhat

3   counterintuitive benefit of threat sensitivity on performance, the authors also observed that threat

4   sensitivity predicted earlier preparation for upcoming threats. In other words, threat sensitivity is

5   potentially adaptive if it leads to the earlier implementation of effective coping strategies. To

6   understand more clearly why threat sensitivity may facilitate earlier preparation, we illustrate the

7   functional organisation of defensive systems with respect to two dimensions: direction and

8   distance.

9   **Defensive Direction**

10   According to RST, two parallel defensive systems regulate responses to threats and are

11   distinguished by defensive direction (McNaughton & Corr, 2004; Perkins & Corr, 2006). In the

12   presence of highly aversive threats that necessitate avoidance, such as a person wielding a knife,

13   the fight-flight-freeze system (FFFS) mediates defensive avoidance. However, not all threats

14   need avoiding – either because the potential threat is ambiguous or the environment contains the

15   concurrent potential for reward. In other words, it is sometimes desirable to approach potential

16   threats if there is the chance of a significant payoff. For example, we may give a presentation to a

17   room full of strangers because it offers the opportunity for social and financial rewards, despite

18   the potential threat of public criticism or social rejection. In such mixed-incentive environments,

19   the behavioural inhibition system (BIS; McNaughton & Corr, 2004) regulates defensive

20   *approach*, prompting cautious behaviours and inhibiting on going responses (i.e., pausing to

21   ruminate over the upcoming situation).

1   **Defensive Distance**

2   Defensive systems are hierarchically organised along a gradient of defensive distance

3   whereby the specific physiological and behavioural response is determined by the perceived

4   proximity of the threat (Blanchard, Hynd, Minke, Minemoto, & Blanchard, 2001; McNaughton

5   & Corr, 2004; Perkins & Corr, 2006). This hierarchical organisation of defensive responses is

6   highly adaptive because different brain regions can mediate either complex preparatory

7   processes or reactive responses depending on what is most appropriate, given the proximity of

8   threat (Mobbs, Hagan, Dalgleish, Silston, & Prevost, 2015).

9   **The Benefit of Sensitivity to Punishment**

10   Importantly, individuals differ in their perception of defensive distance to threat (Corr,

11   2013; McNaughton & Corr, 2004; Perkins, Cooper, Abdelall, Smillie, & Corr, 2010), hereafter

12   referred to as *sensitivity to punishment*. At the same objective distance, an individual who is

13   highly sensitive to punishment will perceive a threat as closer than someone less sensitive to

14   punishment. Thus, if heightened sensitivity to punishment causes activation of the behavioural

15   inhibition system to occur at an earlier stage (and prior to when a response is required), this may

16   be adaptive for performance because it engages slow, preparatory processes that permit the

17   simulation and imagination of future states to optimise future actions (Corr, 2011).

18   Empirical evidence for the adaptive benefit of punishment sensitivity largely comes from

19   research in low-to-moderate stress environments, where extended rumination is proposed to

20   facilitate performance (see Perkins & Corr, 2014). For example, Perkins & Corr, (2005)

21   demonstrated that anxiety proneness (i.e., a highly reactive BIS) was a positive predictor of

22   performance in financial managers, albeit only in those who were also highly intelligent (as

23   cognitive ability may aid effective interpretation of feedback and improve decision-making

1   processes). Yet research in more hazardous environments (e.g., the military and adventure

2   sports) has offered mixed evidence in support for the benefit of punishment sensitivity, with

3   studies showing a negative effect of trait anxiety (Leikas, Mäkinen, Lönnqvist, & Verkasalo,

4   2009; Perkins, Kemp, & Corr, 2007) and positive effects of state anxiety on performance (Hardy

5   & Hutchinson, 2007).

6   These mixed effects may be better understood when one considers additional factors that

7   influence the punishment sensitivity – performance relationship. Two aspects in particular may

8   determine whether punishment sensitivity is adaptive for performance: the time available to

9   engage defensive responses and the possession of effective modulatory processes, or coping

10   strategies. If heightened sensitivity to punishment is adaptive because it leads to the earlier

11   engagement of preparatory responses, individuals may only benefit in environments where it is

12   possible to explicitly detect an upcoming threat and engage in early preparatory responses.

13   However, time alone may be insufficient to facilitate performance unless individuals also possess

14   effective cognitive strategies that can be implemented prior to performance (Hardy et al. 2014).

15   Interestingly, indirect evidence in a more applied setting has shown that individuals who

16   underwent a training program designed to sensitise them to threat whilst developing strategies to

17   deal with the threats performed better in pressure situations (Bell, Hardy, & Beattie, 2013). In the

18   absence of such strategies, individuals may experience prolonged activation of defensive systems

19   and anxious states that persist during performance situations.

20   **Present Research**

21   Although recent research (i.e., Hardy et al., 2014) offers an important advancement to the

22   stress and performance literature by establishing a positive relationship between punishment

23   sensitivity and motor performance; there are important limitations to current understanding.

1   Notably, the role of proximity to the threat (i.e., when one is aware and prepares for an upcoming

2   threat) is yet to be experimentally tested. Establishing the influence of threat proximity is vital

3   for two reasons; to increase our understanding of the factors influencing human performance

4   under pressure; and for the development of effective interventions to ameliorate the potentially

5   destructive effects of pressure on performance.

6   Here, we examine the effect of punishment sensitivity on skilled performance in a mixed-

7   incentive environment and test whether the punishment sensitivity – performance relationship is

8   dependent on when threats are detected. We examined this in a between-subjects design by

9   manipulating when participants were made aware of an upcoming psychological stressor that

10   involved both monetary incentives and social evaluation. In the distal threat condition,

11   participants had time to prepare and engage coping strategies whereas this was not possible for

12   the participants in the proximal threat condition. Further, to examine the modulatory effect of

13   top-down, cognitive processes, participants completed the task after being trained (Study 1) or

14   untrained (Study 2) on the implementation of effective coping strategies. We assessed

15   performance using a precision grip task whilst recording changes in state anxiety (Studies 1 and

16   2) and effort (Study 2) through self-report and psychophysiological markers (Study 2).

17   We predicted that punishment sensitivity would benefit performance when threats were

18   detected early and there was opportunity to engage in cognitive processes that reappraise threat

19   and regulate arousal. In contrast, we predicted that punishment sensitivity would be detrimental

20   for performance when threats were detected late and there was no opportunity to engage

21   defensive strategies prior to encountering the threatening performance environment. Because our

22   experimental manipulation was designed to examine the effect of punishment sensitivity on

23   behaviour, we anticipated that these effects would be independent of reward sensitivity,

1   however, to confirm this we also examined whether reward sensitivity moderated the effects of

2   punishment sensitivity on performance.

3   **Study 1: Method**

4   **Participants**

5   Power analysis (G*Power; Faul, Erdfelder, Lang, & Buchner, 2007) indicated 77

6   participants were required to provide sufficient power (.80) to detect a small-to-medium effect

7   (i.e., a Cohen's f^2 of 0.15) for the interaction between punishment sensitivity and threat

8   preparation condition. Consequently, we recruited 80 healthy, right-handed, participants from a

9   university campus (52 men, 28 women, $M_{age} = 21.6$ years, $SD = 5.31$ years). We obtained

10   institutional ethical approval for the research and written informed consent from all participants.

11   Three participants in the proximal threat condition reported awareness of the experimental

12   manipulation prior to the start of the experiment and were consequently excluded from further

13   analyses.

14   **Experimental Design**

15   Participants sat in front of a 19in LCD monitor (60Hz) that displayed visual feedback of

16   the target and cursor (Figure 1A). Participants sat in front of the display and held the grip force

17   transducer (MLT004/ST, ADInstruments) in the palm of their dominant hand. We amplified the

18   analog force output using a PowerLab (16/35, ADInstruments) data acquisition device and force

19   data was translated into position data of the cursor on the monitor screen; we utilised a one-to-

20   one mapping between force (Nm) and cursor position (mm). Position data was filtered using a

21   second order, dual-pass Butterworth filter with a low pass cut-off frequency of 16 Hz and were

22   processed offline in custom written software (LabVIEW, National Instruments; MATLAB,

23   MathWorks).

1   **Procedure**

2   We used a multifactorial design with a between-subjects manipulation of threat detection

3   (distal, proximal) and within-subjects factors of psychological stress (baseline, preparation and

4   stress). Participants were randomly assigned to either a distal or proximal threat detection

5   condition prior to attending the session. We informed participants that the purpose of the

6   research was to examine the effects of personality and performance strategies on motor

7   performance and they would receive £5 (~$6) for their participation, regardless of performance;

8   these instructions ensured that participants were unlikely to anticipate or detect the true nature of

9   the experiment.

10   During each trial, participants controlled a blue horizontal cursor (length 12cm and width

11   0.2cm) along the vertical axis by means of a force grip transducer. We instructed participants to

12   maintain the cursor within a 12cm × 0.4cm red target box (Figure 1A) and that task performance

13   was dependent on their ability to react quickly and move as fast and as accurately as possible to

14   each target. The location of the target box varied along the vertical axis and corresponded to

15   force amplitude. To standardise the physical demands of the task, we scaled all target forces

16   relative to each participant's maximal voluntary contraction (MVC), which was assessed prior to

17   the experimental trials.

18   INSERT_FIGURE1

19   **Trials and targets.** Participants completed 30 trials of the precision grip task over three

20   separate blocks (see Figure 1D-E); blocks one and two contained 12 trials, whereas block 3

21   contained six trials. Each trial lasted 30s and included 12 targets presented at intervals along the

22   vertical axis (2%, 4%, 6%, 8%, 10% and 12% MVC; see figure 1B). Targets were presented

23   twice at each interval in a pseudorandom, counterbalanced order. Thus, the first two blocks each

1   contained a total of 144 targets and block three contained 72 targets. Each target was presented

2   for a duration of 2.25s – 2.75s; this inter trial variation acted as a variable fore period, preventing

3   anticipatory movements.

4   **Performance feedback.** Participants received feedback at the end of each trial based on

5   their mean absolute error, where error was sampled every 20ms and defined as the distance (in %

6   MVC) between the outer edge of the target box and the centre of the cursor (Figure 1A).

7   Feedback was normalised ((1 / mean absolute error) $\times$ 100) to produce a score between 0 and

8   100; however, because large momentary errors could strongly bias the normalised feedback these

9   scores were not included in the main analysis.

10   **Cognitive strategies.** Because the potential benefits of punishment sensitivity may

11   depend on the ability to implement cognitive strategies (e.g., Bell et al., 2013; Hardy et al.,

12   2014), we explicitly trained participants to use coping strategies. Participants read a script with

13   instructions for the implementation of three psychological skills that are successfully used by

14   performers to facilitate good performance: imagery, muscle relaxation and cue words (see Hardy,

15   Roberts, Thomas, & Murphy, 2010). Because the coping strategies were designed to support

16   performance, we instructed participants to use the strategy (or combination of strategies) that

17   they thought would best facilitate performance.

18   **Practice.** We familiarised participants with the task and gave them 12 practice trials, this

19   number was chosen based on pilot testing indicating it was sufficient to obtain a plateau in

20   performance.

21   **Block 1: baseline performance.** To measure baseline performance, participants

22   completed 12 trials whilst instructed to perform at their best and focus on reacting as quickly and

23   as accurately as possible to each target.

1   **Block 2: threat detection.** Immediately after block one, we informed participants in the

2   distal threat condition that the purpose of the experiment was to examine their performance

3   under pressure (Figure 1D). We fully disclosed the anxiety manipulation and told them that they

4   would now have an opportunity to prepare for the upcoming stressor. In contrast, we told

5   participants in the proximal threat condition to continue performing as well as they could. Both

6   groups then completed a further 12 trials (Figure 1E).

7   **Block 3: psychological stress.** After block two, we informed participants in the proximal

8   threat condition that the purpose of the experiment was to examine their performance under

9   psychological stress. Participants then performed six trials with monetary, competitive and

10   evaluative incentives and consequences for performance; this multifaceted approach has been

11   successfully used to elicit performance anxiety (e.g., Baumeister & Showers, 1986). Participants

12   began block three with £5, the amount they were initially promised for taking part. They gained

13   £1 for successful trials and lost £1 for unsuccessful trials. Trial success was determined by

14   average error and participants were set a target score for each trial. Based on pilot testing, the

15   target score was calculated as 0.675×1 *SD* above mean baseline performance as this reflected a

16   difficulty level that was challenging yet achievable. Thus, regardless of individual ability, target

17   difficulty was matched across participants. We manipulated social and evaluative threats by

18   informing participants that their performance would be ranked on a leader board with the names

19   of the best and worst five performers being emailed to all participants after completion of the

20   research. To increase evaluative pressure, we positioned a video camera next to the monitor. We

21   instructed participants that the purpose of the recording was to allow the experimenter to

22   examine the behaviour of the five individuals who performed the worst to identify reasons why

23   they might have choked under pressure.

1   **Debrief.** After completing the final block of trials, we fully debriefed participants,

2   explained the true purpose of the experiment, and compensated them. Participants received a

3   maximum pay out of £11 (if successful on all 6 stress trials), however, participants who lost

4   money in the stress condition due to poor performance were still compensated with £5 and

5   thanked for their participation.

6   **Measures[1]**

7   **Sensitivity to punishment**. We derived the primary measure of punishment sensitivity using

8   Corr's (2001) transformations of the Eysenck Personality Questionnaire - Revised Short version

9   (EPQR-S; Eysenck, Eysenck, & Barrett, 1985); a well-validated and frequently used measure

10   assessing extraversion (12 items), neuroticism (12 items) and psychoticism (12 items). These

11   factors were transformed to reflect an underlying component of punishment sensitivity, an

12   approach that has been used in the absence of alternative measures that directly assess

13   punishment sensitivity (Hardy et al., 2014; Kambouropoulos & Staiger, 2004). Specifically,

14   punishment sensitivity was calculated through the following transformation: $(12 -$ Extraversion$)$

15   $+ (2 \times$ Neuroticism$) -$ Psychoticism. Although well-validated alternative self-report measures of

16   punishment (and reward) sensitivity are also available (e.g., BIS/BAS; Carver & White, 1994 &

17   SPSRQ; (Torrubia, Avila, Molt, & Caseras, 2001) they are somewhat limited by content validity

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[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.

1   and their conflation of the BIS and FFFS (McNaughton & Corr, 2004). Consequently, we used

2   the EPQ-transformations in order to be consistent with recent research examining the effects of

3   punishment sensitivity on performance (e.g., Hardy et al., 2014). However, in recognition that

4   our primary measure of punishment sensitivity did not distinguish between the BIS and FFFS

5   (McNaughton & Corr, 2004), we also included a secondary self-report measure of punishment

6   sensitivity that directly examined the unique sensitivities of the BIS (23 items; $M = 51.27$, $SD =$

7   11.52) and FFFS (13 items; $M = 20.71$, $SD = 5.72$) using scales from the Reinforcement

8   Sensitivity Theory Personality Questionnaire (RST-PQ; Corr & Cooper, 2016).

9   **Anxiety.** To examine the efficacy of our stress manipulation, and individual differences

10   in the response to the manipulation, we assessed cognitive anxiety prior to each block via the

11   worry scale from the mental readiness form (MRF-3; Krane, 1994). The MRF measures

12   cognitive anxiety with a single item "My thoughts are" with the anchors *calm* (1) and *worried*

13   (11).

14   **Awareness.** It was important that participants in the proximal condition were naïve to the

15   experimental manipulations prior to the explicit instructions. To confirm this, we asked

16   participants at the end of the experiment: 'At the start of the experiment, please indicate how

17   aware you were that the experiment would test your ability to perform under pressure?' We

18   assessed awareness on a scale of 1 (*not at all*) to 11 (*greatly*).

19   **Performance.** To quantify performance during the precision grip task, we examined

20   three components of movement that were critical for performance: reaction time, movement

21   time, and initial movement accuracy (Mosconi et al., 2015). We calculated reaction time (RT) as

22   the time between the presentation of a new target stimulus and movement onset. We determined

23   movement onset for each target by working back from peak velocity to locate the first point in

1   which velocity increased above 0 mm/s for a target at a higher force, or decreased below 0 mm/s

2   for a target at a lower force (Figure 1C). Similarly, we calculated the end of the movement by

3   working forward from peak velocity to the point in which the velocity fell below 0 mm/s.

4   Movement time (MT) was then defined as the time between movement onset and movement end.

5   We defined initial movement accuracy (ACC) as the distance between the cursor and target at

6   movement end. To standardise accuracy across all targets we calculated the percentage

7   movement error, relative to the required distance to the target. Therefore, if the force at

8   movement onset (MO) was 2% MVC, the movement end (ME) was 10% MVC, but the target

9   (T) was 8% MVC, the initial movement accuracy score would be (+) 33.3%, ((ME-T)/(T-MO)).

10   Initial movement accuracy scores for each block were calculated as the mean of absolute

11   accuracy across all sub trials. We excluded targets from analysis where participants moved in the

12   wrong direction or reacted faster than 60ms (this accounted for 4.3% of all trials). We excluded

13   force movements to the first target on each trial, because they had highly variable start locations

14   that were uncharacteristic of all other target movements.

15   **Data Reduction**

16   We used moderated hierarchical regression to examine the interactive effects of

17   punishment sensitivity and threat proximity on performance. As is recommended practice for

18   moderated hierarchical regression (Jaccard & Turrisi, 2003), we created a single value for each

19   dependent variable by calculating improvement scores (stress − baseline) for RT, MT and ACC.

20   To assess overall performance change whilst accounting for any potential performance trade offs

21   we standardised the change scores for RT, MT and ACC and then summed them to create a

22   single composite measure of performance improvement (ΔPerformance) for each participant

23   (e.g., Wallace & Baumeister, 2002). To aid illustration of the effects, ΔPerformance was

1   reversed so that a positive value indicated performance improvement and a negative value

2   indicated a performance decrease.

3   **Study 1: Results**

4   **Preliminary Analysis.**

5   There were no between-group differences in sex, punishment sensitivity scores or

6   baseline performance of participants in the distal and proximal conditions (all *p*'s > .1); see Table

7   1 for correlations and descriptive statistics. Importantly, all participants in the proximal threat

8   condition reported being unaware of the anxiety manipulation (*M* = 1.380, Range 1-3).

9   INSERT_TABLE1

10   **Efficacy of the psychological stressor manipulation.** Repeated-measures ANOVA,

11   using the greenhouse-geisser epsilon, revealed a significant block × threat preparation interaction

12   to predict cognitive anxiety ($F(1.60,119.64) = 4.683$, $p = .017$, $\eta_p^2 = .059$). Participants in the

13   proximal condition experienced significantly higher anxiety in the stress block (*M* = 4.62, *SD* =

14   2.29) compared to either the baseline (*M* = 2.89, *SD* = 1.49) or preparation block (*M* = 3.11, *SD*

15   = 1.77); ($F(1.46,72) = 18.16$, $p = < .001$, $\eta_p^2 = .34$). In contrast, participants in the distal

16   condition reported lower anxiety during the baseline (*M* = 2.88, *SD* = 1.51) block and higher

17   anxiety only in both the preparation block (*M* = 4.00, *SD* = 1.75) and stress block (*M* = 4.40, *SD*

18   = 2.26); ($F(1.43,78) = 22.69$, $p = < .001$, $\eta_p^2 = .37$).

19   **Performance.** Repeated-measures ANOVA revealed no block × threat preparation

20   interaction to predict RT, MT and ACC (all *p*-values > .22). There was a significant main effect

21   of block on RT ($F(2,150) = 143.852$, $p < .001$, $\eta_p^2 = .657$) and ACC ($F(2,150) = 15.245$, $p <$

22   $.001$, $\eta_p^2 = .169$), yet no effect of block on MT; ($F(1.78,133.44) = 1.862$, $p = .164$, $\eta_p^2 = .024$).

1   Follow up tests confirmed that participants in both conditions reacted quicker and more

2   accurately in the psychological stress condition

3   **Punishment sensitivity and anxiety.** Moderated regression analyses were performed

4   using PROCESS (Hayes, 2013) for SPSS with bias-corrected confidence intervals (CI's)

5   generated from 5000 bootstraps; all CI's are reported at the 95% level and alpha was set at .05

6   for all analyses. Predictors were mean-centred prior to analysis, and variables in regression

7   models satisfied homoscedasticity and normality of residuals assumptions. Threat preparation

8   condition was coded 0 (distal) and 1 (proximal). Estimates of (conditional) main effects for each

9   variable are calculated based on setting all other variables to their sample mean. Regression

10   analysis revealed no interaction between punishment sensitivity and threat preparation condition

11   to predict the change in anxiety from the baseline to stress blocks (β = -.007, p = .914, 95% CI [-

12   0.131, 0.117]). Examining main effects, threat preparation condition (distal vs. proximal) had no

13   effect on Δanxiety (β = -.067, p = .900, 95% CI [-1.121, 0.986]) whereas punishment sensitivity

14   predicted a significant increase in anxiety (β = .090, p = .005, 95% CI [0.028, 0.151]).

15   **Main Analysis**

16   **Punishment sensitivity and performance.** A moderated hierarchical regression model

17   examining the effect of sensitivity to punishment on ΔPerformance, revealed no main effect of

18   either the threat preparation condition, (β = -.123, p = .687, 95% CI [-0.729, 0.482]) or

19   punishment sensitivity (β = .002, p = .914, CI [-0.034, 0.037]). However, of greater interest, was

20   the significant punishment sensitivity $\times$ condition interaction explaining 5.47% of the variance in

21   performance improvement, $\Delta F(1, 73)$ = 4.24, ΔR^2 = .055, β = -.074, p = .043, 95% CI [-0.145, -

22   0.002]. Simple slopes analysis revealed a positive relationship between punishment sensitivity

23   and performance improvement in the distal threat preparation condition β = 0.037, $t(73)$ = 1.621,

1   *p* =.109, 95% CI [-0.009, 0.083], and a negative relationship in the proximal (no preparation)

2   condition, *β* = -0.036, *t*(73) = -1.328 *p* =.188, 95% CI [-0.091, 0.018], (Figure 2).

3   Replacing punishment sensitivity with scores from the measure of BIS sensitivity

4   replicated the findings above. The main effects of both BIS (*β* = .009, *p* = .514, 95% CI [-0.018,

5   0.035]) and threat preparation (*β* = -.195, *p* = .522, 95% CI [-0.800, 0.410]) to predict

6   ΔPerformance were not significant, but there was a significant BIS × threat preparation

7   interaction *ΔF*(1, 71) = 4.849, *ΔR²* = .063, *β* = -.059, *p* = .031, 95% CI [-0.112, -0.006]. The

8   simple slopes analysis indicated a significant positive relationship between BIS and

9   ΔPerformance in the distal threat condition *β* = 0.038, *t*(71) = 2.116, *p* =.038, 95% CI [0.002,

10   0.073], and no relationship in the proximal threat condition *β* = -0.021, *t*(71) = -1.059, *p* =.293,

11   95% CI [-0.061, 0.019,]. In contrast, FFFS sensitivity did not interact with threat preparation to

12   predict performance, ΔF(1, 71) = 1.145, *ΔR²* = .016, *β* = -.058, *p* = .288, 95% CI [-0.166, -

13   0.050]. The main effects of FFFS (*β* = .021, *p* = .452, 95% CI [-0.034, 0.075]) and threat

14   preparation (*β* = -.176, *p* = .570, 95% CI [-0.791, 0.439]) were also not statistically significant.

15   INSERT_FIGURE2

16   Because previous research has shown that punishment sensitivity may only benefit

17   performance when people are also insensitive to reward (e.g., Hardy et al. 2014), we ran a further

18   analysis testing a three-way (reward sensitivity[21] × punishment sensitivity × threat preparation)

19   interaction to predict performance. This three way interaction was not statistically significant

20   (*ΔF*(1, 69) = 0.941, *β* =.007, *ΔR²* = .012, *p* = .335) and reward sensitivity did not have a

21   (conditional) main effect of on performance (*β* = .015, *p* = .621, 95% CI [-0.044, 0.073]).

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[2] We calculated a measure of reward sensitivity using transformations of the EPQ scores

(Corr, 2001); (2 × Extraversion) + Neuroticism - Psychoticism.

1   Importantly, the punishment sensitivity × threat preparation interaction remained a significant

2   predictor of performance improvement ($p = .048$), even after controlling for the effect of reward

3   sensitivity.

4   **Study 1: Discussion**

5   We provide evidence that sensitivity to punishment can benefit motor performance when

6   threats are detected early and there is time to prepare. One reason for the positive relationship

7   between punishment sensitivity and performance following distal threats is that time facilitates

8   the effective implementation of cognitive strategies (e.g., reappraisal, imagery, etc.) to down-

9   regulate anxiety and/or improve preparation (Bell et al., 2013; Hardy et al., 2014). However,

10   because all participants were explicitly trained to implement cognitive strategies, it is unclear

11   whether the punishment sensitivity – performance relationship is contingent on the possession of

12   these additional cognitive strategies. Thus in Study 2 we investigated whether punishment

13   sensitivity might still have beneficial effects on performance, independent of cognitive strategies

14   **Study 2**

15   In Study 2, we replicated the experimental design and analysis from Study 1 with one key

16   exception; participants were not trained on the implementation of cognitive strategies. Thus, if

17   cognitive strategies were necessary for the benefits of punishment sensitivity in the distal threat

18   condition, punishment sensitivity would unlikely benefit distal threat performance in Study 2. To

19   better understand the effect of individual differences in punishment sensitivity on the overall

20   response to threat (and not just performance), we used self-report and objective (i.e.,

21   cardiovascular) measures of anxiety and effort, two factors that are intimately linked to

22   performance (Eysenck & Calvo, 1992). To this extent, although punishment sensitivity may

1   benefit performance, this may come at the cost of a significant increase in effort, thereby

2   reducing efficiency.

3   **Study 2: Methods**

4   **Participants**

5   Eighty healthy, right-handed participants completed the experiment. Three participants

6   were excluded from the proximal threat group due to prior awareness of the experimental

7   manipulation, leaving a final sample of 77 (45 men, 32 women, M_{age} = 24.95 years, SD = 6.47

8   years). Participants were asked to refrain from exercising (4hrs) and consuming alcohol (12hrs)

9   or caffeine (3hrs) prior to testing. Due to issues with the recording equipment, data from an

10 additional three participants are not included in the analysis of cardiovascular measures.

11 **Procedure**

12   In Study 2 we did not provide coping strategies and instructed participants that the

13 purpose of the experiment was to examine the relationship between their personality,

14 physiological responses, and performance. Unless stated, all experimental procedures, measures

15 and analyses were the same as in Study 1.

1   **Measures**[3]

2   **Punishment sensitivity.** We measured punishment sensitivity using the same

3   transformations from the EPQR-S (Eysenck et al., 1985); to reduce participant burden, the

4   secondary measures of BIS and FFFS were not assessed.

5   **Self-report effort and anxiety.** We assessed cognitive anxiety prior to each block via the

6   mental readiness form (MRF-3; Krane, 1994; see Study 1). Mental effort was assessed

7   immediately after each block using Zijlstra's (1993) Rating Scale for Mental Effort (RSME)

8   where participants rated the level of mental effort expended by intersecting a (150mm) vertical

9   scale ranging from 0-150 with anchors *no effort at all* (3) and *extreme effort* (114).

10   **Cognitive strategies.** Although participants were not explicitly given coping strategies, it

11   was possible that they might still possess and implement existing learned strategies. To assess

12   usage and efficacy of cognitive strategies during the experiment, we retrospectively asked

13   participants to report any strategies they had used to support their performance during the

14   experiment. Coping use was coded 1 for participants who reported using at least one strategy and

15   0 for participants who reported no strategy use. To quantify the perceived benefit, or

16   effectiveness, of these strategies, participants who reported coping use were asked to indicate

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[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.

1   'How much did the strategy benefit your performance'. Responses were anchored from 1 (*not at*

2   *all*) to 11 (*greatly*).

3   **Physiological responses.** We recorded cardiovascular responses using electrodes placed

4   on the right clavicle (positive), lower left rib (negative) and left clavicle (earth). The signal was

5   amplified through a PowerLab Data Acquisistion Device and digitally filtered with a 50Hz high

6   pass and 0.3Hz low pass using LabChart 7 software (AD Instruments, Dunedin). The square root

7   of the mean of the sum of squared successive differences in cardiac interbeat intervals (r-MSSD)

8   and the standard deviation of R-wave-to-R-wave intervals (SDNN) were computed as measures

9   of heart rate variability. R-MSSD is a time domain surrogate of the frequency domain based high

10 (0.15–0.40 Hz) spectral power band, which reflects parasympathetic nervous system activity and

11 decreases are indicative of heightened cognitive anxiety. SDNN is a time domain index of heart

12 rate variability that closely reflects activity in the frequency domain-based low (0.04–0.15 Hz)

13 spectral power band, and is influenced by both sympathetic and parasympathetic inputs;

14 decreases in SDNN reflect an increase in effort. To ensure we could compare equivalent

15 cardiovascular responses across blocks, we analysed responses during only the first 180s of each

16 block.

17 **Study 2: Results**

18 **Preliminary Analysis**

19   There were no between-group differences in sex, baseline self-report measures (anxiety,

20 effort, and mental effort), physiological response or performance variables (all $ps > .2$; see Table

21 2 for correlations and descriptive statistics). Participants in the distal threat group ($M = 23.15$, *SD*

22 $= 5.27$) were, on average, younger than the participants in the proximal threat group ($M = 26.89$,

23 $SD = 7.13$); $t(75) = 2.632$, $p = .010$.

1   INSERT_TABLE2

2   **Efficacy of the Psychological Stressor Manipulation**

3   **Self-reported anxiety and effort.** Repeated-measures ANOVA revealed a significant

4   block × threat preparation interaction on cognitive anxiety ($F(2,146) = 9.642$, $p < .001$, $\eta_p^2 =$

5   .117). Follow up tests indicated that participants in the distal condition experienced significantly

6   higher anxiety in both the stress block ($M = 4.46$, $SD = 1.74$) and preparation block ($M = 4.13$,

7   $SD = 1.74$) compared to the baseline block ($M = 2.95$, $SD = 1.37$). In contrast, participants in the

8   proximal condition experienced significantly higher anxiety in the stress block ($M = 4.22$, $SD =$

9   2.19) compared to both the baseline ($M = 3.08$, $SD = 1.67$) and preparation block ($M = 3.33$, SD

10 $= 1.58$) The block × threat preparation interaction was not significant for effort ($F (2, 150) =$

11 0.985, $p = .376$, $\eta_p^2 = .01$). However, there was a main effect of block ($F (2, 150) = 47.626$, $p <$

12 .001, $\eta_p^2 = .39$) such that participants in both conditions exerted considerably greater effort in the

13 stress block ($M = 83.87$, $SD = 2.25$) compared to the preparation ($M = 81.20$, $SD = 2.45$) and

14 baseline blocks ($M = 95.30$, $SD = 2.54$).

15   **Punishment sensitivity and anxiety.** A moderated hierarchical regression analysis

16 revealed no main effect of either punishment sensitivity ($\beta = -.009$, $p = .727$, 95% CI [-0.057,

17 0.040]) or threat preparation condition ($\beta = -.445$, $p = .238$, 95% CI [-1.190, 0.301]) to predict a

18 change in cognitive anxiety from the baseline to stress block. There was a significant punishment

19 sensitivity × threat preparation interaction, $\Delta F(1, 73) = 5.688$, $\Delta R^2 = .051$, $\beta = -.098$, $p = .049$,

20 95% CI [-0.196, -0.000]; however, simple slopes analyses revealed that punishment sensitivity

21 was unrelated to anxiety in the distal threat condition ($p = .241$) and had a non-significant

22 (negative) relationship with anxiety in the proximal threat condition ($p = .109$).

1   The effect of punishment sensitivity on self-reported anxiety was complemented by

2   equivalent changes in our physiological measure of anxiety, r-MSSD. The main effect of

3   punishment sensitivity (β = .117, p = .530, 95% CI [-0.252, 0.486]) and threat preparation

4   condition (β = 1.615, p = .576, 95% CI [-4.116, 7.347]) to predict r-MSSD was not significant.

5   However, the punishment sensitivity × threat preparation interaction accounted for 14.67% of the

6   variance in r-MSSD, $\Delta F(1, 70)$ = 12.122, β = 1.296, p < .001, 95% CI [0.554, 2.039].

7   Punishment sensitivity led to a significant reduction of r-MSSD (reflecting increased anxiety) in

8   the distal threat condition (β = -0.496, $t(70)$ = -2.005, p =.049, 95% CI [-0.990, -0.003]) and a

9   significant increase (reflecting lower anxiety) in the proximal threat condition (β = 0.800, $t(70)$ =

10   2.877, p =.005, 95% CI [0.245, 1.355]).

11   **Punishment sensitivity and effort.** Moderated hierarchical regression analysis revealed

12   no main effect of punishment sensitivity (β = -.088, p = .693, 95% CI [-0.528, 0.352]) and threat

13   preparation condition (β = -2.729, p = .423, 95% CI [-9.482, 4.023]) to predict changes in self-

14   reported mental effort (baseline – stress). Further, the punishment sensitivity × threat preparation

15   interaction was not significant, $\Delta F(1, 73)$ = 0.059, ΔR^2 = .001, β = -.107, p = .809, 95% CI [-

16   0.989, 0.775]. Similarly, the main effect of punishment sensitivity (β = 0.259, p = .280, 95% CI

17   [-0.215, 0.733]) and threat preparation condition (β = -0.531, p = .886, 95% CI [-6.826, 7.889])

18   to predict SDNN (a physiological indicator of mental effort) was not significant. However, the

19   threat preparation x punishment sensitivity interaction was significant $\Delta F(1, 70)$ = 5.278, β =

20   1.098, p = .025, 95% CI [0.145, 2.051]; punishment sensitivity was unrelated to SDNN in the

21   distal threat preparation condition (β = -0.260, $t(70)$ = -0.819, p =.416, 95% CI [-0.894, 0.373])

22   but predicted a significant increase (reflecting a reduction in effort) in the proximal threat

23   condition (β = 0.838, $t(70)$ = -2.346, p =.022, 95% CI [0.126, 1.550]).

1   **Main Analysis**

2   **Punishment sensitivity and performance.** Examining the effect of punishment

3   sensitivity and ΔPerformance, we performed a moderated hierarchical regression testing the

4   main and interactive effects of punishment sensitivity and threat preparation; changes in self-

5   reported and physiological measures of anxiety and effort were entered as covariates. This

6   revealed no main effect of either the threat preparation condition or punishment sensitivity on

7   ΔPerformance. However, replicating the results of Study 1, the punishment sensitivity × threat

8   preparation interaction was significant and explained 8.46% of the variance in ΔPerformance,

9    $\Delta F(1, 65) = 6.582$, $\beta = -.119$, $p = .013$, 95% CI [-0.211, -0.026]; Figure 3 displays the nature of

10   the interaction. The effects of the physiological measures of change in anxiety ($\beta = -.005$, $p =$

11   .748, 95% CI [-0.036, 0.026]) and effort ($\beta = .011$, $p = .355$, 95% CI [-0.013, 0.035]) on

12   performance were not significant; however, there was a significant effect of self-reported effort

13   leading to performance improvement ($\beta = .023$, $p = .047$, 95% CI [-0.003, 0.046]) and a marginal

14   effect of cognitive anxiety leading to performance impairment ($\beta = -.188$, $p = .080$, 95% CI [-

15   0.400, 0.023]). Simple slopes analysis revealed a positive relationship between punishment

16   sensitivity and performance improvement in the distal threat condition $\beta = 0.065$, $t(65) = 2.257$, p

17   $= .027$, 95% CI [0.008, 0.123,] and a non significant (negative) relationship in the proximal

18   threat condition, $\beta = -0.054$, $t(65) = -1.589$ $p = .117$, 95% CI [-0.121, 0.014]. Notably, the

19   punishment sensitivity × threat preparation interaction remained significant when all covariates

20   were removed from the model, $\Delta F(1, 73) = 3.992$, $\beta = -.103$, $p = .020$, 95% CI [-0.188, -0.017].

21   INSERT_FIGURE3

22   **Coping strategies.** One interpretation of the punishment sensitivity and performance

23   results just presented is that the beneficial effects of punishment sensitivity appear to be

1   independent of coping strategies. However, an alternative possibility is that participants already

2   possessed effective coping strategies that they were able to implement. Indeed, when we asked

3   participants whether they used strategies to support their performance, a significant proportion

4   (56/77) of participants reported using at least one cognitive strategy, $\chi^2\,(1) = 15.909$, $p < .001$.

5   Strategy use was equivalent for participants in the distal ($N = 28$) and proximal ($N = 28$) threat

6   conditions, $\chi^2\,(1) = 0.312$, $p = .576$. We next asked whether sensitivity to punishment would

7   predict greater use of coping strategies; a logistic regression model with punishment sensitivity

8   as a predictor indicated a trend for punishment sensitivity to predict greater coping use

9   (Nagalkerke's $R^2 = 0.67$, $p = .064$).

10   More relevant than usage, perhaps, is whether the coping strategies were beneficial for

11   performance. Analyzing the data from the 56 participants who used coping strategies, a

12   moderated hierarchical regression revealed a main effect of punishment sensitivity on coping

13   benefit, ($\beta = .084$, $p = .011$, 95% CI [0.020, 0.148]); in other words, the more sensitive an

14   individual was to punishment, the more they reported benefitting from the use of coping

15   strategies. However, coping benefit was unrelated to whether participants were in the proximal

16   or distal condition ($p = .793$) and there was no interaction between threat preparation condition

17   and punishment sensitivity ($p = .715$).

18   We then examined if the effectiveness of coping strategies could explain the benefits of

19   punishment sensitivity on performance. In other words, the performance improvements in

20   individuals who are highly sensitive to punishment could be a result of the efficacy of their

21   coping strategy. We used a conditional indirect effects analysis (PROCESS, Model 7) to

22   examine whether coping efficacy mediated the relationship between punishment sensitivity and

23   performance in the proximal and distal conditions. There was a significant indirect effect in the

1   distal threat condition (β = .017, 95% CI [0.002, 0.048]) but not in the proximal condition (β =

2   .023, 95% CI [-0.004, 0.076]). This result indicates that coping effectiveness accounted for the

3   beneficial effects of punishment sensitivity when the threat was distal and there was time to

4   prepare.

5   **General Discussion**

6   We examined the relationship between individual differences in sensitivity to punishment

7   and the execution of skilled motor actions in a mixed-incentive environment (i.e., involving both

8   potential rewards and punishments). Activation of the behavioural inhibition system during a

9   task (i.e., state anxiety) is typically associated with impairments to either the effectiveness or

10   efficiency of task performance (Eysenck et al., 2007). However, here we considered whether

11   individual differences in the sensitivity of defensive system could influence performance,

12   depending on whether threats are detected early or late.

13   Across two studies, our behavioural results clearly show that heightened sensitivity to

14   threat was adaptive for motor performance when threats were detected early (distally) and there

15   was time to prepare for a threat. In contrast, punishment sensitivity was largely unrelated to

16   performance when threats were detected proximally, and participants lacked the time to prepare.

17   Notably, in Study 1 the interaction effects were consistent across two distinct psychometric

18   scales assessing sensitivity to punishment, suggesting that the effects are unlikely to be an

19   artefact of the particular measure used. Further, we show that the benefits of heightened

20   punishment sensitivity appear to be conditional on the implementation of effective cognitive

21   strategies.

22   The motor performance improvements associated with heightened sensitivity to

23   punishment are consistent with an emerging literature that highlights the adaptive function of the

1   defensive approach system in environments where rumination and preparation may benefit

2   performance (Hardy et al., 2014; Perkins & Corr, 2014). We suggest that heightened sensitivity

3   to threat benefits performance by increasing the engagement of these defensive processes, prior

4   to performance. Specifically, punishment sensitivity may enhance both the conscious simulation

5   of motor movements and imagination of future states (Suddendorf & Corballis, 2007). These

6   processes may serve a function in both reducing the novelty, or surprise, of the upcoming

7   psychological stressor and improving motor planning.

8   An important caveat to the engagement of conscious processes (i.e., rumination and

9   simulation) is that they may be ineffective if they are negatively biased and increase aversion to

10   the threat. To this effect, our results in Study 2 underscore the importance of possessing effective

11   cognitive strategies to process potential threats. Even when participants were untrained on

12   strategies, they reported implementing strategies, and interestingly, punishment sensitivity

13   predicted both greater usage and greater efficacy of coping strategies. Given that coping efficacy

14   mediated the relationship between punishment sensitivity and motor performance only when

15   there was time to prepare, it appears likely that punishment sensitivity benefits performance

16   through the earlier implementation of coping strategies (cf. Hardy et al., 2014). However, it is

17   also possible that punishment sensitivity has a direct effect on the qualitative components of

18   coping use; for example, individuals who are highly sensitive to threats may be better equipped

19   to cope with anxiety because they regularly encounter anxious states during goal pursuit and

20   have developed effective strategies or automated responses that inoculate against the debilitative

21   effects of anxiety and facilitate goal-directed approach (Epstein, 1989; Eysenck et al., 2007).

22   In addition to the influence of explicit coping strategies, the distal detection of threat may

23   have also benefitted performance through its influence on the interpretation of anxiety. Perceived

1   control is a regulatory dimension that may affect whether individuals appraise anxiety as

2   facilitative or debilitative (Carver & Scheier, 1988; Cheng & Hardy, 2016; Hardy & Hutchinson,

3   2007). Importantly, the interpretation of anxiety as adaptive can lead to greater investment of

4   effort and an improvement in performance, whereas a negative appraisal of anxiety can lead to

5   disengagement (Eysenck, 1992). Although we did not assess perceived control in our studies, it

6   is plausible that participants in the distal threat condition would perceive greater control

7   (compared to the proximal condition) and therefore interpret anxiety as facilitative and

8   consequently they invest greater effort in their performance. Our psychophysiological (and self-

9   report) measures in Study 2 support the idea that punishment sensitivity increased the investment

10   of effort in the distal threat condition as a result of increased efficacy and control, whereas it lead

11   to a withdrawal of effort in the proximal threat condition.

12   A significant strength of our study is the novel consideration of the interplay between the

13   sensitivity of the human defence system, threat proximity and cognitive strategies. Indeed,

14   cognitive appraisals are likely to significantly shape the relationship between threat sensitivity

15   and behaviour and we suggest that future research would benefit from considering the interplay

16   between higher-order and lower-level processes. For example, a more nuanced understanding of

17   an individual's response to threat can be gained by considering their intrinsic valuation of

18   rewards and threats (Hall, Chong, McNaughton, & Corr, 2011) and cognitive appraisal of the

19   demands of psychological stressors and the resources to cope.

20   Although we were able to reliably replicate the key interaction effects (punishment

21   sensitivity by threat preparation) across two studies, future research may wish to consider using

22   larger, more highly powered samples. Further, despite merit in the experimental design used

23   here, we concede that laboratory tasks are limited in their capacity to generate psychological

1   stress. Whilst our anxiety manipulations successfully increased cognitive and physiological

2   anxiety, the effect is probably small relative to the anxiety experienced in situations with greater

3   personal significance, such as delivering a speech to a large audience. The intensity of threat is

4   pertinent because the benefits of punishment sensitivity may only be relevant in moderately

5   threatening situations. In environments containing intense threats, heightened punishment

6   sensitivity may impair performance (Perkins et al., 2007) because there is a limit to the utility of

7   cognitive strategies in down regulating anxiety and coping with threats (e.g., Eysenck et al.,

8   2007). However, given that the benefits of heightened punishment sensitivity have been observed

9   in elite level sport (Hardy et al., 2014) it appears that the potential benefits should extend to

10   environments that contain a reasonably high level of pressure.

11   **Conclusion**

12   Multiple theories are proposed to account for the effects of anxiety on performance

13   (Baumeister, 1984; Eysenck & Calvo, 1992; Eysenck et al., 2007; Masters, 1992). However, a

14   notable component that is absent from current approaches is a theoretically grounded explanation

15   of individual differences in the positive versus negative effects of anxiety upon performance.

16   Here, we present evidence that punishment sensitivity is an adaptive personality trait when

17   threats are detected early and there is opportunity to implement effective coping strategies that

18   facilitate performance. These results stress the importance of considering the effect of

19   psychological stress on performance by integrating evidence from contemporary ecological (e.g.,

20   Mobbs et al., 2015) and neuropsychological (McNaughton & Corr, 2004) models of defensive

21   systems that underpin anxiety to gain a more comprehensive understanding of how humans

22   perform under pressure.

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