Personality and Individual Differences 226 (2024) 112705

Contents lists available at ScienceDirect

Personality and Individual Differences

journal homepage: www.elsevier.com/locate/paid

Overburdening associations: The dependency of psychopathy-related acquisitional learning deficits on processing load☆

L.J. Gunschera[a,*], K. Dutton[b,c], E. Fox[b,c], A. Temple-McCune[b,1], R.A. Murphy[b]

[a] University of Cambridge, MRC Cognition and Brain Sciences Unit, United Kingdom
[b] University of Oxford, Department of Experimental Psychology, United Kingdom
[c] University of Adelaide, Department of Psychology, Australia

ARTICLE INFO

Keywords:
Psychopathy
Associative learning
Processing load
Attention

ABSTRACT

Psychopathic personality traits have been identified as an important predictor of associative learning capacity. Prior work has associated psychopathy with deficits when adapting learned associations in response to novel information. However, findings are inconsistent and are hypothesised to vary as a function of the processing load created by different experimental paradigms. We tested this hypothesis by examining the association between psychopathic traits and Stimulus-Response-Outcome contingency learning whilst manipulating contextual processing load. In experiments one and two, participants completed three versions of a configural object discrimination task that required participants to use increasingly multidimensional learning cues. Across both experiments, it was found that elevated levels of psychopathic traits were associated with a lesser capacity to form S-R-O associations in the bidimensional but not tridimensional versions of the learning task. This suggests psychopathy-related learning deficits may vary as a function of the processing load inherent to the bidimensional learning environment, rather than the type of learning taking place. This provides some of the first experimental evidence that psychopathic learning deficits are detectable during the acquisition phase of learning.

To adaptively interact with our environment, we must learn about action-outcome relationships and adapt our behaviour in response. This requires learning about associations between stimuli, responses, and outcomes (S-R-O), so that a desired outcome (e.g., reward or avoidance of punishment) can be pursued (Chatlosh et al., 1985). Beyond initial learning (hereafter termed *acquisition*), learned S-R-O relationships must be updated when the response-outcome contingency changes (hereafter termed *adaptation*) (Clark et al., 2004). Together, acquisition and adaption constitute *associative learning*, the fundamental process underpinning behavioural adaptation (Rushworth & Behrens, 2008), guiding responses to advantageous outcomes and optimizing performance in changing environments.

Associative learning capacity varies greatly between individuals (Murphy & Msetfi, 2014). A personality construct that may contribute to these differences is psychopathy (Budhani et al., 2006; Von Borries et al., 2010). Psychopathy entails a constellation of systematically co-varying personality traits reflecting disrupted interpersonal functioning (e.g., manipulativeness, grandiosity), affective deficits (e.g., fearlessness, callousness), erratic lifestyle (e.g., impulsivity, sensation seeking), and antisocial tendencies (e.g., persistent antisocial behaviour) (Blair, 2013; Patrick et al., 2009). Previous research indicates psychopathic traits to be dimensional (Dematteo et al., 2005; Guay et al., 2007), and to present across the general population (Benning et al., 2005). Examinations in the general population have relied on self-report measures of psychopathy, which have demonstrated good convergent and discriminant validity in clinical (Neal & Sellbom, 2012) and community samples (Mahmut et al., 2011). Assessing the psychopathic spectrum serves to strengthen the validity of etiological models beyond forensic contexts, as well as the more general impact of psychopathic traits on normative emotional and cognitive processing.

Psychopathic traits are associated with several differences in cognitive processes, including aberrant reinforcement learning (Mitchell

☆ For the purpose of open access, the author has applied a Creative Commons Attribution (CC BY) license to any Author Accepted Manuscript version arising from this submission. This work was funded by a small grant from The British Academy (SRG19R1\180820).

* Corresponding author at: University of Cambridge, 15 Chaucer Road, Cambridge, United Kingdom.
E-mail address: lg702@cam.ac.uk (L.J. Gunschera).

1 We would like to acknowledge our dear friend and colleague, Alexander Temple-McCune, who sadly passed away during the writing of this manuscript at the age of just 26. This work formed the basis of his unfinished DPhil (PhD) at the University of Oxford.

https://doi.org/10.1016/j.paid.2024.112705
Received 9 December 2023; Received in revised form 1 April 2024; Accepted 29 April 2024
Available online 6 May 2024

et al., 2006) and associative learning (Blair et al., 2004). Studies have suggested that psychopaths can acquire S-R-O relationships, but show context-specific deficits in monitoring and adapting to changing S-R-O contingencies (Budhani et al., 2006). Psychopathic subjects also demonstrate poor instrumental learning (Mitchell et al., 2006), make more errors on passive avoidance tasks, and are less able to engage in response reversal (Blair et al., 2004; Newman & Kosson, 1986; Newman & Schmitt, 1998). Overall, these results indicate that psychopathic deficits are specific to stimulus-reinforcement learning and the adaptation of S-R-O associations. However, studies reporting psychopathic subjects show deficits in both acquisition and adaptation (Borries et al., 2010) or no psychopathy-related deficits in associative learning (Gregory et al., 2015; Kiehl et al., 2000; Sadeh & Verona, 2008) indicate that psychopathy may not relate to associative learning differences. Possibly, inter-individual differences in reversal learning arise from differences in experimental design, such as the explicitness of participant instructions (Brazil et al., 2013). An explanation for these psychopathy-related learning deficits comes from attention-based models of psychopathy that postulate abnormalities in attention during information processing to cause a range of emotional and cognitive deficits (Baskin-Sommers et al., 2011; Baskin-Sommers & Brazil, 2022).

The Response Modulation Hypothesis (Gorenstein & Newman, 1980) first formulated top-down attention deficits implicated in psychopathy, suggesting that psychopaths struggle to reallocate attention towards non-dominant response sets. The Response Modulation Hypothesis inspired several iterations of attention-based theories, a more recent one of which is the Impaired Integration Theory (Hamilton et al., 2015). This theory suggests impairments in connectivity between discrete networks (i.e., default mode and salience network) resulting in an attentional bottleneck which confines the amount of information that can be simultaneously attended (Baskin-Sommers et al., 2011; Baskin-Sommers & Brazil, 2022; Sadeh & Verona, 2012). This renders individuals with elevated psychopathic traits less able to integrate multi-dimensional stimuli and leads to neglect of peripheral or contextual information (Baskin-Sommers et al., 2011; Hamilton & Newman, 2018). This difficulty in integration hinders the formation of some mental concepts and ultimately to the abnormal development of associative networks. Crucially, the Impaired Integration theory suggests that psychopathy-related deficits are relative to processing demand and manifest as a situationally specific pattern of impairment. Therefore, rather than conferring a global deficit, psychopathy may preserve processing capacity when stimuli are presented within participants' attentional bounds (Hoppenbrouwers et al., 2015; Hoppenbrouwers et al., 2016). Relativity has enabled the Impaired Integration theory to account for variability reported by different tasks in the presence or absence of the affective responding deficits prototypically associated with psychopathy (López et al., 2013; Munro et al., 2007). It is argued that the same relative processing challenges associated with psychopathy may similarly account for the variability within the psychopathy learning literature. Evidence suggests processing load influences the type of learning that occurs by altering the associability of S-R-O contingencies (Le Pelley et al., 2005; Le Pelley et al., 2011). Learning deficits associated with psychopathy may therefore be the product of reduced accompanying load reducing the associability of stimuli during learning and the intermittent observation of deficits as the result of variability in the processing load created by different experimental paradigms.

However, previous research in support of the Impaired Integration theory has been indirect and failed to examine the proposed mechanism, an impairment in information integration under processing load. Therefore, key predictions of the theory remain unsubstantiated by experimental evidence, with some research finding no support for the mechanism proposed by the Impaired Integration theory (Gunschera et al., 2023). Here, we set out to examine psychopathy-related learning deficits' dependency on perceptual load of the learning environment. If the Impaired Integration theory is correct in postulating that psychopathy-related differences in learning are driven by concurrent demands of learning cues on perceptual resources exceeding a limited attentional bottleneck, we should expect psychopathy-related deficits to be compounded by the fact that the same volume of information within the S-R-O must be processed over a shorter time.

Here, we tested these predictions in a lab-based experiment and a remote replication, assessing participants' levels of psychopathic personality traits alongside their performance on three configural object discrimination tasks, creating a low, medium, and high burden on perceptual load respectively. Based on the predictions of the Impaired Integration theory we postulated three hypotheses: Firstly, that across experiments participants would generally make less accurate predictive judgments on versions of the task that created greater perceptual load. Secondly, that this difference would be disproportionately greater for individuals with higher levels of psychopathic personality traits due to their reduced processing capacity. Therefore, we expected psychopathic traits to predict poorer learning with increasing perceptual load. Lastly, whilst the time participants took to progress through the task will not directly affect performance, we predicted longer reaction times and time spent observing feedback cues will reduce the strength of the relationship between psychopathic traits and learning during medium and high perceptual load.

1. Experiment 1

1.1. Methods

1.1.1. Transparency and openness

For both experiments, we report how we determined our sample size, all data exclusions, all manipulations, and all measures of the study. The data and analyses are openly available on OSF at https://osf.io/xgnwr/. The data was analysed using R, version 4.3.2 (R Core Team, 2023) and visualized using the package *ggplot2*, version 3.4.4 (Wickham et al., 2023). This study's design and its analysis were not pre-registered. The study was conducted in accordance with the standard set by the Declaration of Helsinki and approved by the local ethical committee of the University of Oxford (CUREC R60194/RE001).

1.1.2. Participants

One hundred and ten participants ($N = 110$; female = 74; Mean age = 23.38, Range: 18–63) were recruited via the online Oxford participant recruitment scheme (general population) and the research participation scheme (Undergraduate Students). An a priori power analysis in G*power (Faul et al., 2007) indicated a sample of 89 participants to be suitable for detecting even a small effect ($f^2 = 0.15$) at 0.95 statistical power for a linear multiple regression.

1.1.3. Design

Participants experienced the experiment as a fully-within-subjects design. Each participant would first complete a self-report questionnaire assessment of psychopathic traits and then complete several control tasks before moving on to the configuration discrimination tasks. Each participant completed three versions of the configuration discrimination task in a repeated measures format.

1.1.4. Assessment of psychopathic traits

Psychopathic personality traits were assessed using the Psychopathic Personality Inventory (PPI-R) (Lilienfeld & Andrews, 1996; Lilienfeld & Widows, 2005), a self-report questionnaire designed to measure psychopathic traits in the absence of the antisocial behaviour facet of the construct, and applicable for use within non-offender populations. The PPI-R consists of 154 statements to which participants must indicate the extent to which they are a true or false description of themselves using a four-point Likert scale (e.g., 'It bothers me a lot when I see someone crying'; false, mostly false, mostly true, true). The PPI-R captures dimensional variations of psychopathic traits capture dimensional variations of psychopathic traits and a mounting body of evidence suggests that psychopathy is a dimensional trait (Benning et al., 2005; Edens et al., 2006). To draw the distinction to psychopathy as a clinical disorder we refer to the measurement of psychopathy in the general population as ‘psychopathic traits’. Assessing the psychopathic spectrum serves to strengthen the validity of etiological models beyond forensic contexts, as well as the more general impact of psychopathic traits on normative emotional and cognitive processing. Factor analyses have determined that items on the PPI-R weigh onto two core underlying factors, Fearless Dominance (FD), and Self-Centred Impulsivity (SCI). The FD dimension has demonstrated the most robust associations with the cognitive and affective processing deficits prototypical of the psychopathic syndrome, including impaired response modulation (Gorenstein & Newman, 1980), the modulation of affective processing by attention (Newman et al., 2010), reinforcement learning (Mitchell et al., 2006), and crucially associative learning (Blair et al., 2004; Borries et al., 2010; Budhani et al., 2006; Mitchell et al., 2002; Newman & Kosson, 1986). Given our study's interest in learning processes, we will base our interpretations based on outcomes on the FD subscale.

1.1.5. Control tasks

The working memory capacity facet of IQ (Lezak, 1995) and local-global processing bias (referred to as *attentional scope*) (McDonald et al., 1997) was controlled for using participants' performance on a forward and backward visual digit span (Wechsler, 1949) and a Navon task (Navon, 1977) respectively. Digit Span was measured as the average maximum length of numeric sequence accurately recalled between the forward and backward versions of the task. During the Navon task participants were asked to identify global or local elements of a letter stimuli, which was used to infer global and local processing respectively. The differences in response times between incongruent (smaller and larger letters are always distinct) global and local trials were used to generate an attentional scope score.

1.1.6. Configuration discrimination tasks

The amount of perceptual load inherent to each version of the task was manipulated by varying the number of dimensions of the stimuli that needed to be simultaneously attended to in order to successfully solve the predictive judgments (see Table A1). The stimuli used in each task had three components, one of two possible black shapes, one of two possible background colours (red, yellow) and one of two possible background orientations.

In the low perceptual load, unidimensional version, only one element of the configural stimuli was predictive of the outcome. For example, a positive outcome may be predicted by the presence of one black shape within the configural stimuli whereas a negative outcome could be predicted by the presence of the other black shape. In this example, all other dimensions of the configural stimuli (background colour and angle of background gradient) are irrelevant to the predictive judgement. In the medium load, bidimensional version, two elements of the configural stimuli would predict the outcome. For example, a positive outcome may be predicted both by a configuration that included one of the black shapes with one of the background colours and by a configuration that included the other back shape and the other background colour. In the high load, tridimensional version, all three elements of the stimuli were needed to predict the outcome. Fig. 1B contains examples of the stimuli used and the task relevant dimensions.

1.1.6.1. Materials. All experimental stimuli were programmed and presented using MATLAB (*MATLAB Version 2016b*, 2016) and the Psychophysics Toolbox extensions (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). Stimuli consisted of three distinct dimensions; a shape (an abstract black shape presented in the foreground), a colour (a background colour), and an angled linear grating in the background. Eight different stimuli combinations were used in each of the discrimination tasks. Three sets of stimuli were created, using different shapes, colours

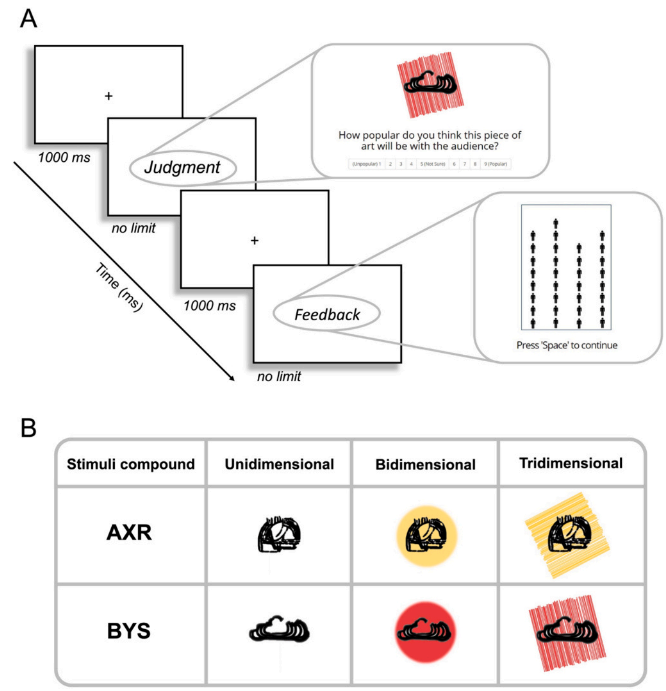

Fig. 1. Experimental sequence and stimuli examples.
Note. A: At the beginning of each trial, a fixation cross would appear for 1000 milliseconds. One of the stimuli would then be shown and participants would be required to make a predictive popularity judgement for an imagined audience before continuing the trial. A second fixation cross would then appear for 1000 ms. Feedback was then presented in the form of a picture of a room containing the number of people who liked the piece of art. This allowed the participants to determine whether their judgement was correct or not. Participants then had to press the ‘space’ bar on their keyboard to continue to the next trial. B: Compound stimuli made from one of two variants of three dimensions: a black shape (A/B), a background colour (X/Y), and a background orientation (R/S). Based on whether the task was the unidimensional, bidimensional, or tridimensional version participants would need to attend one, two, or three dimensions of the stimuli respectively to solve the predictive judgement. Stimulus sets used for each task were counterbalanced between participants.

and angles such that participants had a distinct set of stimuli for each of the discrimination tasks. The three colour (RGB) pairs were yellow (249, 220, 109) versus red (210, 75, 77), pink (229, 78, 187) versus peach (247, 223, 226), and blue (157, 228, 226) versus green (145, 222, 93). The line grating angles were 26° versus 103°, 51° versus 129°, and 77° versus 154° (for examples, see Fig. 1B). The choice of which stimuli set was used with each discrimination task was counterbalanced between participants.

1.1.6.2. Procedure. Upon the start of the discrimination task, participants were given instructions, completed a practice trial, and were invited to ask any questions to ensure understanding of the task. Thereafter, participants were tasked with viewing the works and then attempting to predict the outcome or ‘popularity’ of each piece. Participants were informed that the task would be divided into three blocks in which they would be presented with three entirely independent sets of art. In each block, participants would complete one of the three versions of the configuration discrimination task using one of the three stimuli sets (counterbalanced). Each of the stimuli sets contained eight configural stimuli, four of which were popular (+outcome), and four of which were unpopular (−outcome). For each discrimination task, each of the eight stimuli combinations was displayed 12 times, for a total of 96 trials per task, and 288 trials over the full course of the experiment. Between each task, participants were given the opportunity to rest, reminded that the artwork they would see in the following task was independent, and prompted the task instructions.

On each trial, participants were presented with one of the eight possible stimuli combinations for that task's set and were asked to predict the popularity (outcome) of the piece. Predictive judgments were made using a 9-point Likert scale (1 = 'unpopular', through 5 = 'unsure', to 9 'popular'), provided using a keyboard button press. The sequence of events during a trial and their timing is shown in Fig. 1A. After providing a response the participants were shown a visual depiction of the outcome paired with that particular stimulus. This remained on the screen until participants pressed a button in order to move on to the next stimuli. Feedback was partially probabilistic to preserve participants' engagement with the task throughout the trials (Byrom & Murphy, 2016). When a stimulus was popular, the feedback displayed a room containing the audience members who enjoyed the piece of art that was either 70 %, 80 %, or 90 % full. When the stimulus was partnered with an unpopular outcome, participants were given feedback in the form of a picture of a room that was either 10 %, 20 %, or 30 % full. In addition to participants' responses to any given trial, the time they took to make their predictive judgement (reaction time; RT) and the duration of time they spent viewing the feedback cue before electing to move on to the next trial (time on feedback; ToF) were also recorded.

1.2. Results

The distribution of the Fearless Dominance psychopathic personality trait elevation scores ($M = 76.79$; $SE = 1.54$) was normative both in terms of skew (−0.137; $SE = 0.230$), and kurtosis (0.006; $SE = 0.457$). A Shapiro-Wilk test failed to detect a statistically significant departure from normality, $W(109) = 0.993, p = .875$. To better visualise variations in task performance along the psychopathic spectrum, a quartile split was conducted on Fearless Dominance Psychopathy scores to provide dichotomous groups of high (Range: 89–115; $n = 28$) and low (Range: 29–66; $n = 28$) on FD psychopathic traits. The quartile split was performed purely for illustrative purposes and does not factor into any of the experimental analyses (see Fig. 2). Descriptive statistics for the high psychopathy group, the low psychopathy group and the total sample are provided in Table B1. Cronbach's alpha showed that the PPI-R had acceptable reliability, both for the FD ($\alpha = 0.9$) and SCI subfactors ($\alpha = 0.91$), along with the Total PPI-R Score ($\alpha = 0.94$).

An alpha level of 0.05 was used throughout the analyses. We applied Bonferroni corrections for all post-hoc pairwise comparisons to examine the difference in discrimination accuracy between tasks. The results are presented with this correction applied. All analyses are based on standardised data with a mean of zero and a standard deviation of one. Discrimination scores were calculated as the sum of predictions in response to outcome stimuli minus the sum of predictions in response to stimuli without outcome. A one-way ANOVA revealed a statistically significant difference in participants' discrimination scores between the three tasks ($F(2, 327) = 222.888, p < .001$). Post Hoc analysis revealed that this difference was detectable between both the Unidimensional and bidimensional tasks ($p < .001$), unidimensional and tridimensional tasks ($p < .001$), and the unidimensional and tridimensional tasks ($p < .001$). Means and standard errors are reported in Table B1.

Discrimination between stimuli improved across training in all three task versions but this performance appeared related to individual differences in psychopathy. As shown in Fig. 2, highly psychopathic individuals perform marginally better than the low psychopathy group when discriminating between stimuli configurations in the unidimensional task and marginally poorer during the bidimensional task. These observations were verified through linear regression.

1.2.1. Regression analyses

Three multiple hierarchical regressions were used to explore psychopathy-related differences in the strength of object discrimination between the configuration discrimination tasks. In the first, baseline differences in associative learning capacity were assessed using participants' unidimensional discrimination task performance as the dependent variable. The second and third examined the effect of additional perceptual load on learning relative to baseline capacity by utilising performance on the bidimensional and tridimensional tasks respectively as outcome measures.

Two further multiple hierarchical regressions were then used to explore whether psychopathy was related to participants' RT to learning cues and ToF on outcome, and feedback cues. In each analysis, variables were included in two stages. Firstly, variables extraneous to our hypothesis were controlled for by modelling the collective influence of sex, age, working memory capacity, task order, set order, and attentional scope on the outcome measures. In the following regressions, unidimensional task performance also was included as an index measure of associative learning to control for baseline differences in capacity. Psychopathy-related effects were then assessed by examining whether

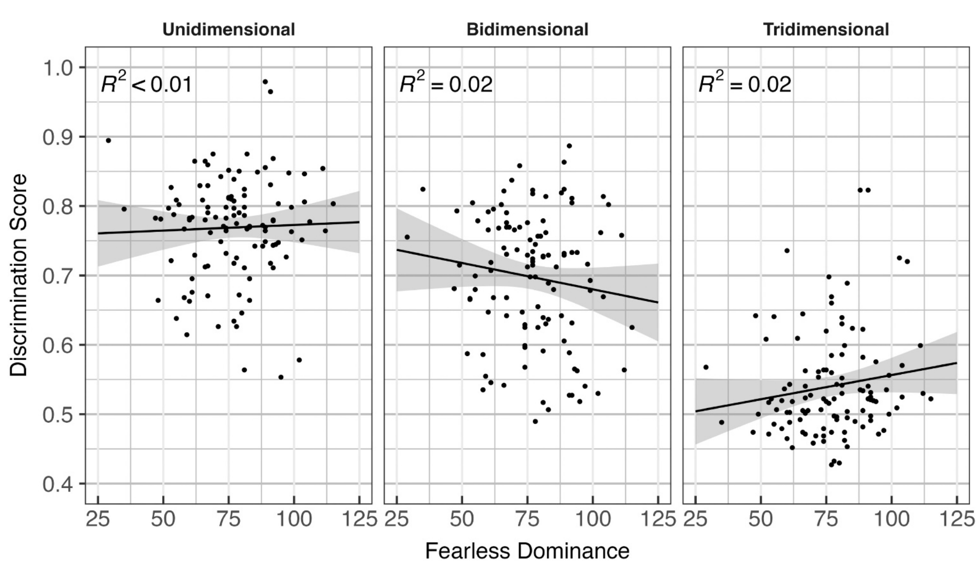

Fig. 2. *Discrimination task performance as a function of psychopathic traits.*
Note. Discrimination scores were computed by subtracting the number of incorrect responses from the number of correct responses on the configuration discrimination task.

the subsequent inclusion of the FD, SCI, or Total PPI psychopathic personality trait dimensions separately amounted to a statistically significantly increased the amount of variance accounted for by the model.

1.2.1.1. Unidimensional discrimination. In the first regression, the initial model of the influence of sex, age, WMC, task order, set order, and attentional scope did not have a statistically significant influence on discrimination scores in the unidimensional task (All p's $\geq$ 0.200). Including FD (t(102) = 0.574, p = .567), SCI (t(102) = −0.888, p = .377), or Total Psychopathy (t(102) = −0.356, p = .723) dimensions did not explain a statistically significantly greater amount of variance, suggesting that that baseline associative learning capacity varies irrespective of accompanying levels of psychopathic personality traits.

1.2.1.2. Bidimensional discrimination. In the second regression, it was found that a model including the control variables of age, working memory capacity, task order, set order, attentional scope, and baseline associative learning capacity (indexed by unidimensional task performance), explained a statistically significant portion of the variance in bidimensional discrimination scores (R^2 = 0.280, F(7, 102) = 5.669, p < .01). This was largely driven by baseline differences in associative learning capacity (β = 0.405 (SE = 0.085), 95 % CI [0.237, 0.572], t(102) = 4.738, p < .001), and by a moderate sex influence wherein female participants tended to perform marginally better on the bidimensional task than males (β = 0.390 (SE = 0.185), 95 % CI [0.029, 0.752], t(102) = 2.115, p = .037).

Both the FD dimension of psychopathy (R^2 change = 0.029, β = −0.179 (SE = 0.086), 95 % CI [−0.348, −0.010], t(101) = −2.074, p = .041) as well as total psychopathy scores (R^2 change = 0.036, β = −0.204 (SE = 0.088), 95 % CI [−0.377, −0.030], t(101) = −2.303, p = .023) accounted for a statistically significant increase in explained variance once included in the model. The influence of the SCI dimension was non-significant (p = .148). Of note, neither the influence of FD (p = .488) nor total psychopathy scores (p = .223) remained significant once included within the model simultaneously, suggesting that the FD component comprising total psychopathy was a driving influence behind the significant variance in bidimensional discrimination scores explained by psychopathy total scores. The directionality of this effect indicates that with increasing psychopathic personality traits performance tended to decline under medium load.

1.2.1.3. Tridimensional discrimination. In the control model of the third regression, neither age, working memory capacity, task order, set order, attentional scope nor baseline associative learning had a statistically significant influence on the tridimensional discrimination tasks (all p's $\geq$ 0.110). However, a statistically significant sex-based effect on performance was observed wherein male participants tended to perform poorer on the task than their female counterparts (β = 0.644 (SE = 0.199), 95 % CI [0.254, 1.035], t(101) = 3.233, p = .002). Contrasting our expectations, neither the FD psychopathy dimension (p = .312), SCI dimension (p = .111), nor total psychopathy (p = .416) accounted for a statistically significant increase in the amount of variance explained.

1.2.2. Moderation analyses

To test the hypothesis that RT and ToF moderate the relationship between psychopathy and performance on the different versions of the configuration discrimination task we conducted a series of six moderation analyses using hierarchical multiple regressions. Two analyses were conducted for the unidimensional, bidimensional, and tridimensional discrimination tasks, one that examined the moderating influence of RT and the other of ToF. In each, an interaction term was created between the FD dimension of psychopathy and either RT or ToF, using centred variables to avoid the problems incurred by increased multicollinearity (Aiken et al., 1991). These interaction terms were then included within a regression model that included both the control variables and the FD dimension of psychopathy.

1.2.2.1. Reaction time. The main effect of reaction times was significant in the unidimensional (β = −0.290 (SE = 0.104), 95 % CI [−0.494, −0.086], t(101) = −2.786, p = .006) and tridimensional (β = 0.339 (SE = 0.090), 95 % CI [0.163, 0.516], t(101) = 3.770, p < .001) discrimination tasks but remained non-significant in the biconditional task (p = .918). Contrary to our initial hypothesis, including an interaction term between RT and FD psychopathic traits failed to provide a statically significant increase in the volume of variance accounted for by the models of unidimensional (p = .214), bidimensional (p = .194), or tridimensional (p = .998) configuration discrimination task performance.

1.2.2.2. Time on feedback. The main effect of time on feedback was non-significant for the unidimensional (p = .095), bidimensional (p = .092), and tridimensional (p = .421) discrimination tasks. Conflicting with our hypotheses, including an interaction term between ToF and FD psychopathic traits failed to provide a statically significant increase in the volume of variance accounted for by the models of unidimensional (p = .469), bidimensional (p = .168), or tridimensional (p = .629) configuration discrimination task performance.

1.3. Discussion (Experiment 1)

The results of Experiment 1 indicate that psychopathic personality traits selectively impact configuration discrimination. As expected, perceptual load impaired acquisitional learning as indicated by the low discrimination scores in the bidimensional and tridimensional tasks relative to those of the unidimensional task. However, the magnitude of this decline in performance was amplified by the presence of psychopathy, as participants who reported more elevated levels of psychopathic personality traits had statistically significantly poorer discrimination scores on the bidimensional discrimination task. Importantly, this effect was demonstrated after controlling for baseline differences in associative learning capacity as indexed by performance on the unidimensional task, which when analysed directly was not significantly affected by individual levels of psychopathy. This indicates that this finding cannot be explained through differences in simple associative learning alone and suggests that the psychopathy-related effects on learning within the task pertained specifically to configural object discriminations.

However, the present results are subject to several limitations that advise us to be cautious when interpreting these findings. First, our results only provide partial support for the predictions of the Impaired Integration theory, and the load-dependency of performance was not observed on the triconditional task. One interpretation of these findings is that the interruptive effect of load on psychopathy-related learning is non-linear. Rather than ever greater load causing ever greater impairments, elevated levels of psychopathic personality traits may instead lower an individual's threshold at which load begins to impede acquisitional learning. If the load were to increase beyond this, it would eventually exceed the high thresholds of individuals with shallower levels of psychopathic traits at which point their ability to form S-R-O associations would similarly begin to decline. Crucially, this creates a window of load at which psychopathy becomes a relevant influence on learning, a point at which load is overburdening individuals higher on psychopathic traits relative to individuals lower on psychopathic traits. Any increase in load beyond this point marginalises individual differences as greater proportions of psychopathic and non-psychopathic individuals alike are beyond their processing limitations. In the unidimensional and tridimensional tasks, participants' tolerance for load was either similarly fallen short of or exceeded, irrespective of accompanying levels of psychopathic personality traits. This is however based on the unfounded assumption that the scale to which load tolerance is exceeded has no bearing on performance. We should therefore consider alternative explanations such as methodological error. One such possibility is that existing psychopathy-related differences in tridimensional task performance are masked by a floor effect which raises the possibility that individual differences in ability were masked by universally low performance. Across the sample, configuration discrimination scores in the tridimensional condition were poorer than expected based on the results of previous studies (Byrom & Murphy, 2016) and close to chance ($M = 0.54$; $SD = 0.01$). We set out to further examine this possibility in a follow-up study.

2. Experiment 2

Although we did observe psychopathy-related differences in accuracy as a function of perceptual load, these differences were limited to the biconditional task. To examine the robustness of these findings and whether our results in the tridimensional task were driven by a flooring effect, we performed the second experiment with modifications to increase participant accuracy across the tasks. Our hypothesis was based on the results of the first experiment: firstly, participants would collectively make less accurate predictive judgments during versions of the tasks that created greater perceptual load; Secondly, the size of this difference would vary as a function of psychopathic traits; and thirdly, that temporal factors would not affect the strength of the relationship between psychopathy and learning under load. We also tested the exploratory hypothesis that the psychopathy-related learning deficits demonstrated in Experiment 1 would be observable in an online testing environment.

2.1. Methods

2.1.1. Participants

Two hundred and one participants ($N = 201$; female = 117; Mean age = 31.00, Range: 18–64) were recruited using Prolific (www.prolific.com). Once recruited, participants were provided with a link that directed them to Gorilla Experiment Builder (www.gorilla.sc) (Anwyl-Irvine et al., 2019), which was used to create and host the study. An a priori power analysis in G*power (Faul et al., 2007) indicated a sample of 199 participants to be suitable for detecting even a small effect ($f^2 = 0.04$) at 80 % statistical power for a linear multiple regression with one predictor. Our minimum effect size of interest was based on the relationship between psychopathy and performance observed in the bidirectional configuration discrimination task. The study was conducted in accordance with the standard set by the Declaration of Helsinki and approved by the local ethical committee of the University of Oxford (CUREC R60194/RE001).

2.1.2. Procedure

The protocol used in Experiment 2 was based on our previous experiment and was structured in a fully within subjects design. Once participants followed the experiment link provided by the recruitment platform, they were presented with a consent checkbox and asked to provide basic demographic information. The procedure and tasks matched that of Experiment 1 with several strategic exceptions aimed at facilitating online data collection. Firstly, a short form of the psychopathy assessment tool was used; secondly, the Navon task was dropped from the testing battery; lastly, the instructions for the configuration discrimination task were made more explicit. This change to the instructions was made to compensate for the fact that an experimenter would not be present to explain the task to participants in person and to increase the accuracy of participants in order to reduce the likelihood of encountering a floor effect, as was speculated in Experiment 1. In Experiment 1, participants were given no direction towards the stimuli or their multiple dimensions and were left to discover and learn the S-R-O relationships independently. In Experiment 2, the instructions highlighted that the number of relevant dimensions may change as they progress through the task. This was done by including an additional instruction panel, which was again done under the guise of a fictitious art gallery as in the previous experiment: "[Between the tasks] the audience may change their mind and focus on different features or combinations of features when deciding whether or not they like a piece of art".

2.1.3. Assessment of psychopathic traits

Psychopathy was assessed using the short form of the PPI-R (PPI-R: SF) (Lilienfeld & Hess, 2001). The PPI-R:SF is comprised of 56 items and considered particularly useful in multi-measure batteries for its brevity yet similar psychometric validity when compared with the full-length version (Kastner et al., 2012). Items within the questionnaire make up the same 8 subscales and weigh on to the same underlying factor structure as the full-length PPI-R (Kastner et al., 2012; Smith et al., 2011). As with the PPI-R, scores on the PPI-R:SF have a strong relationship with the PCL-R total score and have been validated in both forensic and community samples (Tonnaer et al., 2013).

2.1.4. Inclusion criteria

To maintain the fidelity of responses, compliance checks were inserted into the PPI-R:SF questionnaire and configuration discrimination task. In the questionnaire, this took the form of statements directing participants to select a particular response option (e.g., "This is a compliance check. Select 'True' to this statement"). In the configuration discrimination task, this took the form of images of text that instructed participants to provide a particular response (e.g., "This is a compliance check. Rate this image as 8"). Participants who failed these checks were removed from the study and new participants sampled until 201 complete responses had been selected ($N = 9$). Additionally, participants were advised that the testing session should take no longer than one hour. If the duration of the testing session exceeded 75 min participants were removed from the study ($N = 22$).

2.2. Results

The distribution of the Fearless Dominance psychopathic personality trait elevation scores ($M = 25.194$; $SE = 9.157$) was significantly normative in terms of skew (0.009; $SE = 0.172$) and kurtosis (−0.299; $SE = 0.341$), and a Shapiro-Wilk test did not detect a significant departure from normality, $W(201) = 0.995$, $p = .744$. To better visualise variations in task performance along the psychopathic spectrum, we split the Fearless Dominance psychopathy scores into dichotomous groups of high (Range: 31–52; $n = 50$) and low (Range: 2–19; $n = 51$) Fearless Dominance. Descriptive statistics for the high psychopathic trais group, the low psychopathic traits group and the total sample are provided in Table B2. Cronbach's alpha showed that the PPI-R had acceptable reliability, both for the FD ($\alpha = 0.9$) and SCI sub factors ($\alpha = 0.91$), along with the Total PPI Score ($\alpha = 0.94$).

An alpha level of 0.05 was used throughout the analyses, with a Bonferroni correction to control for multiple comparisons. All analyses are based on standardised data with a mean of zero and a standard deviation of one. Across all 12 blocks positive outcome trials were more positive for outcome (popular) trials than no outcome (unpopular) trials indicating that participants were successfully able to utilise feedback cues to guide performance. This observation was confirmed by a one-way ANOVA which revealed a statistically significant difference in participants' discrimination scores between the three tasks, $F(2, 600) = 32.59$, $p < .001$. Post hoc analyses revealed that this difference was detectable between both the unidimensional and bidimensional tasks ($t(200) = 3.766$, $p < .001$), unidimensional and tridimensional tasks ($t(200) = -6.712$, $p < .001$), and the unidimensional and tridimensional tasks ($t(200) = -9.819$, $p < .001$). However, the directionality of the difference between the unidimensional and bidimensional tasks was inverse to our expectations as participants were more accurate on the bidimensional task than the unidimensional task (see Fig. 3). Moreover, Fig. 3 shows that individuals high on the FD dimension perform

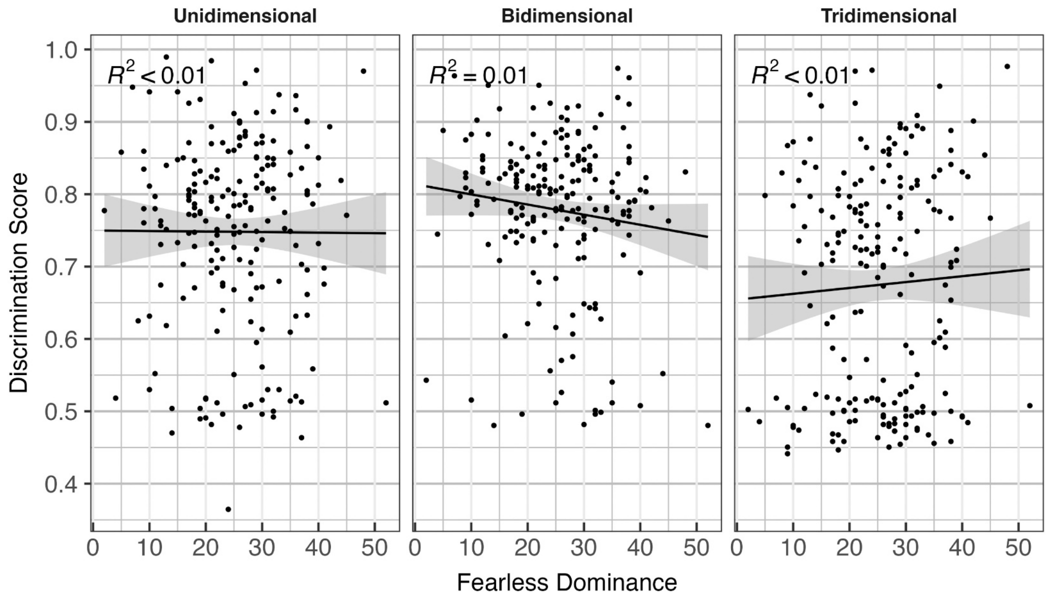

Fig. 3. *Discrimination task performance as a function of psychopathic traits.*
Note. Discrimination scores were computed by subtracting the number of incorrect responses from the number of correct responses on the configuration discrimination task.

marginally poorer during the bidimensional task.

2.2.1. Regression analyses

The analysis approach matched that of Experiment 1 and three multiple hierarchical regressions were performed to assess whether performance of the three different versions of the configuration discrimination task varied as a function of individual levels of psychopathic traits.

2.2.1.1. Unidimensional discrimination. In the unidimensional task null model, neither age ($t(200) = 0.822$, $p = .412$), WMC ($t(200) = 0.024$, $p = .981$), task order ($t(200) = -1.192$, $p = .235$), or set order ($t(200) = 0.759$, $p = .451$) influenced task performance. However, sex was identified as a statistically significant predictor as female participants tended to perform poorer than males ($\beta = -0.407$ ($SE = 0.146$), 95 % CI [−0.692, −0.121], $t(200) = -2.795$, $p = .006$). Including the FD dimension of psychopathy in the model did not account for a statistically significant increase in the explained variance (R^2 *Change* $= \mathbf{0.004}$, $F(1,194) = 0.75$, $p = .387$). This was also true for the SCI dimension (R^2 *Change* $= \mathbf{0.001}$, $F(1,194) = 0.25$, $p = .617$) as well as total psychopathy (R^2 *Change* $= \mathbf{0.001}$, $F(1,194) = 0.19$, $p = .666$).

2.2.1.2. Bidimensional discrimination. In the bidimensional task null model, it was found that sex ($t(200) = -0.998$, $p = .319$), age ($t(200) = 0.226$, $p = .822$), WMC ($t(200) = -0.08$, $p = .937$), task order ($t(200) = 0.618$, $p = .537$), and set order ($t(200) = -0.721$, $p = .472$) had no influence on task performance. However, baseline associative learning capacity as indexed by participant performance on the unidimensional task was identified as a statistically significant predictor of bidimensional discrimination ($\beta = 0.547$ ($SE = 0.061$), 95 % CI [0.428, 0.666], $t(200) = 9.012$, $p < .001$). After controlling for these variables, including the FD dimension of psychopathy in the model accounted for a statistically significant increase in the explained variance (R^2 *Change* $= 0.018$, $\beta = -0.142$ ($SE = 0.061$), 95 % CI [−0.262, −0.021], $F(1,193) = 5.334$, $p = .022$). This replicates our findings from Experiment 1 associating the FD dimension of psychopathy with differential performances during configural learning. However, the SCI dimension ($t(200) = 0.515$, $p = .607$) as well as total psychopathy scores ($t(200) = -1.125$, $p = .262$) were not significantly related to accuracy during the task.

2.2.1.3. Tridimensional discrimination. In the tridimensional task null model, it was found that neither WMC ($t(194) = 1.426$, $p = .156$), task order ($t(194) = -0.896$, $p = .371$), or set order ($t(194) = -0.960$, $p = .338$) influenced task performance. However, sex ($B = -0.046$ ($SE = 0.020$), 95 % CI [−0.085, −0.007], $\beta = -0.148$, $t(194) = -2.261$, $p = .025$), and age ($B = -0.002$ ($SE = 0.001$), 95 % CI [−0.004, 0], $\beta = -0.14$, $t(194) = -2.174$, $p = .031$) were identified as statistically significant predictors. Participants who were female and younger tended to perform better than participants who were male and older. As in the bidimensional analysis, baseline associative learning capacity as indexed by unidimensional task performance was also identified as a significant predictor of tridimensional configuration discrimination ($\beta = 0.395$ ($SE = 0.064$), 95 % CI [0.269, 0.521], $t(194) = 6.155$, $p < .001$). After controlling for these variables, including psychopathic traits in the model did not account for a statistically significant increase in the explained variance. This was true for both the FD ($t(193) = 0.141$, $p = .888$) and SCI ($t(193) = 0.636$, $p = .526$) dimensions as well as total psychopathy score ($t(193) = -0.135$, $p = .892$), suggesting that psychopathic traits were unrelated to performance in the hardest version of the configuration discrimination task.

2.2.2. Moderation analyses

To test the hypothesis that RT and ToF moderate the relationship between psychopathic traits and performance on the different versions of the configuration discrimination task, we conducted six hierarchical multiple regressions, matching the analysis procedure of Experiment 1. No direct relationships were identified between psychopathic traits and psychopathic trait subscales and response time and time on feedback (all p's ≥ 0.280). Additional regression analyses showed no relationship between response times and performance on the unidimensional ($p = .797$), bidimensional ($p = .579$), and tridimensional task ($p = .164$). In contrast, time on feedback was associated with performance on the unidimensional ($\beta = -0.183$ ($SE = 0.070$), 95 % CI [−0.321, −0.046], $t(193) = -2.613$, $p = .010$), but remained non-significant in the bidimensional ($p = .169$) and tridimensional task ($p = .471$). Including an interaction term between both response time or time on feedback and fearless dominance psychopathic traits failed to provide significant increases in variance accounted for (all p's ≥ 0.077). Additional exploratory analyses focused on sample differences are reported in Appendix C.

3. General discussion

Across two experiments we have provided novel experimental evidence that acquisitional learning deficits associated with psychopathy vary as a function of processing load. Across both experiments, psychopathic traits were associated with impaired configural learning in the bidimensional object discrimination task. This was relative to baseline acquisitional learning as indexed by performance on the unidimensional version of the task, indicating that this difference cannot be explained by underlying differences in simple associative learning capacity. The bidimensional task required participants to form S-R-O associations with multidimensional stimuli. They were therefore required to divide their attention across multiple sources of information to process the different dimensions of the learning cues simultaneously, increasing the volume of sensory information and by extension increasing perceptual load during learning. In contrast to the IES, object discrimination varying as a function of psychopathic traits demonstrates that psychopathy-related deficits are observable during the acquisition stage of learning. The situational specificity of these deficits to more cognitively demanding versions of the task suggests that these deficits were moderated by the contextual properties of the learning environment and the amount of perceptual load generated by each task. This is consistent with the postulations of the Impaired Integration theory, that psychopathic learning deficits stem from a limited pool of processing resources which prohibit the formation and use of S-R-O associations to guide behaviour. By extension, this supports an interpretation of heterogeneity within the psychopathy learning literature where variability in reported findings is the product of differing amounts of processing load created by different learning paradigms. Moreover, by demonstrating these effects across two studies we highlight the reliability and replicability of the influence of processing load on psychopathy-related deficits in acquisitional learning across lab-based and online experimental contexts. Additionally, our exploratory analysis has demonstrated that the change in testing conditions does not affect the strength of this effect. This provides support for the viability of online-based research methods when investigating psychopathy-related learning deficits and that the results of such investigations are generalisable to lab-based work.

Our work provides a compelling explanation for the observed heterogeneity in the psychopathy learning literature, which has been inconsistent in demonstrating deficits in acquisitional and adaptational learning. Our findings implicate perceptual load as a determinant of psychopathy-related learning. The results are compelling as they have been demonstrated using a paradigm that holds constant other factors that may influence the associability of stimuli. For example, whilst many paradigms used by previous studies have used equally balanced outcome stimuli (Brazil et al., 2013; He et al., 2011; Kiehl et al., 2000) others have not and instead had a disproportionate number of trials associated with one particular outcome (Newman et al., 1990). This imbalance affects the associability between the stimuli contingencies as greater attention is allocated towards stimuli that appear more frequently (Mackintosh & Holgate, 1968). Thus, more attention is required to respond or withhold a response in the opposing direction (Kiehl et al., 2000), making errors more likely for highly psychopathic individuals with limited attentional capacity (Wolf et al., 2012). Moreover, many paradigms have used probabilistic contingency structures wherein a response to stimuli is only associated with a greater likelihood of an outcome in a particular direction. Psychopaths are sensitive to such changes in contingency probability, which can impact the success of reinforcement learning (Von Borries et al., 2010). Here, a quasi-probabilistic structure was used for the purpose of preserving task novelty, avoiding issues associated with probabilistic feedback. Nonetheless, contingencies remained deterministic as outcomes varied between binary feedback, 'Popular' or 'Unpopular'. Therefore, participants remained able to determine the correct response outcomes. Taken together, these characteristics of the present paradigm strengthen claims that resulting findings are the consequence of the processing requirement of the learning environment, as opposed to confounding factors affecting the associability of stimuli.

Demonstrating that psychopathic traits affects the success of acquisitional learning and that this influence was specific to conditions where task processing demands were greater challenges the assumptions of explanatory models of psychopathy that do not account for the situational specificity of these effects. The Impaired Integration theory may better account for this pattern of results, suggesting that an attentional bottleneck confines the amount of information that can be simultaneously attended. This results in the incomplete or superficial processing of attentionally demanding sensory information that exceeds this lower capacity for processing, making it more challenging to associate this information with prior knowledge and experience. Although we found no underlying psychopathy-related differences in simple learning during the unidimensional task, increasing the complexity of the learning cues caused a disproportionately greater decline in learning by highly psychopathic individuals relative to those with shallow levels of psychopathic traits. This provides novel experimental evidence in partial support of the Impaired Integration theory generated by directly testing its underlying assumptions in the context of learning and demonstrating that these deficits are detectable during the acquisition phase of learning.

However, our results were not entirely aligned with the predictions of the Impaired Integration theory. Specifically, we found no psychopathy-based difference in performance during the tridimensional task across the two experiments. This version was the most multidimensional version of the task and required attention to be divided across the most loci of information, thereby placing the greatest load on the availability of processing resources. We might therefore have expected this task to reveal the greatest psychopathy-related differences if attentional constraints were underpinning the learning deficits. However, this lack of linearity in the relationship between psychopathic traits and processing load might be accounted for a methodological issue with tasks that rely on processing load that was described by Reed et al. (1985) in the context of reversal learning. Participants were presented with a dual task paradigm that simultaneously required them to respond to a tone whilst engaging in an essay writing task. The researchers varied the complexity of the essay writing task whilst processing load was operationalised as participants' reaction times to the tone. As expected, easy versions of the essay task created a low load that increased with increasing task difficulty. However, when the primary task increased in difficulty beyond a certain point the load returned to low, reflecting a cognitive disengagement of the learner with the task. Whilst accuracy in the tridimensional task was further from chance in Experiment 2 than Experiment 1, the relative difficulty of this version of the task may still have caused participants to disengage from the task and reduced the overall processing load experienced. This highlights the need for psychopathic learning research to not only consider the complexity of experimental paradigms but also the prior capacity of the learners on tasks to match stimuli dimensionality or instructional material to the expected level of difficulty. Moreover, the findings may be explained by a motivational difference resulting from individuals high on psychopathic traits being prone to boredom and more sensitive to rewards (Blais et al., 2023). The bidimensional task may not have been stimulating enough to engage individuals high on psychopathic traits. Although one would expect this effect to result in psychopathy-related performance differences in both the unidimensional and bidimensional task, future research may examine the extent to which the observed findings can be explained by boredom sensitivity. In addition to successfully reproducing acquisitional learning deficits associated with psychopathic traits and highlighting why they may arise as a function of processing load, Experiment 2 provides insight into how learning was impaired. Prior work has suggested that whilst psychopathic participants may initially learn more poorly, their performance recovers if given sufficient training and exposure to feedback. However, the analysis of Experiment 2 revealed that deficits were still observable when selectively considering the final quarter of trials indicating that, rather than slower learning, the deficits may be the result of poor overall acquisitional learning capacity. This suggests that the properties of the learning environment may create more stable patterns of impairments and that presenting two information streams during learning may result in a less recoverable decline in performance for individuals high on psychopathic traits.

It is important to acknowledge the limitations of the current study. Foremost amongst these is that these findings apply only to acquisitional learning making the most promising direction for future research the examination of whether the influence of bidimensional processing load on psychopathy-related learning generalises to adaptational learning. This is crucial not just for the purpose of assessing the generalisability of our observed effects but because the major point of variability within the psychopathy learning literature has been within reversal learning paradigms. Therefore, whilst the results of the current study can inform explanatory models that offer explanations for this heterogeneity, we cannot specifically apply these findings to reversal learning without further evidence. However, whilst this evidence may bolster model-based explanations of heterogeneity of findings in the psychopathic learning literature, such as that provided by the Impaired Integration theory, reversal learning paradigms are the setting for the greatest amount of interstudy variability. Demonstrating that adaptational learning with psychopathic traits is similarly affected by perceptual load would provide compelling evidence that the difference in load between experimental paradigms was the uncontrolled extraneous factor determining when and where psychopathy-related learning deficits would manifest.

4. Conclusion

In summary, we have demonstrated that psychopathic personality traits are associated with a reduced capacity to acquire S-R-O associations within multidimensional learning environments. Moreover, we have demonstrated the reliability and generalisability of these effects by replicating our finding in an online testing environment. We found evidence to suggest that these deficits are the product of a reduced capacity to learn rather than a slower rate of learning. The added attentional requirement of multidimensional learning suggests that learning deficits associated with psychopathy may be determined by processing load, in part supporting models such as the Impaired Integration theory that centralise the role of processing bottlenecks in psychopathy. These findings suggest that variations in experimental paradigms used in different studies may explain the heterogeneity in the psychopathy learning literature and pave the way for future work that could test for the same involvement of perceptual load during reversal learning.

CRediT authorship contribution statement

L.J. Gunschera: Data curation, Formal analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. **K. Dutton:** Conceptualization, Methodology, Supervision, Writing – review & editing. **E. Fox:** Conceptualization, Funding acquisition, Methodology, Resources, Supervision, Writing – review & editing. **A. Temple-McCune:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Software, Writing – original draft. **R.A. Murphy:** Conceptualization, Funding acquisition, Investigation, Methodology, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

None.

Data availability

The data of both experiments and the corresponding analysis code are available at https://osf.io/xgnwr/.

Appendix A

Table A1
Three versions of the configuration discrimination task.

Stimuli compound	Paired outcome		
	Unidimensional	Bidimensional	Tridimensional
AXR	+	+	+
BXR	−	−	−
AYR	+	−	−
BYR	−	+	+
AXS	+	+	−
BXS	−	−	+
AYS	+	−	+
BYS	−	+	−

Note. Each version of the task used the same stimulus configurations. The compound stimulus is defined by three dimensions, shape (A/B), background colour (X/Y), and background orientation (R/S). The presence (popular) or absence (unpopular) of a positive outcome is denoted by + or – respectively.

Appendix B. Descriptive statistics

Table B1
Descriptive statistics of Experiment 1 split by psychopathy scores.

	Psychopathic traits group		
	1st quartile	4th quartile	Total sample
	M (*SE*)	*M* (*SE*)	*M* (*SE*)
PPI1 (fearless dominance)	56.25 (1.65)	97.26 (1.88)	76.79 (1.54)
PPI2 (self-centred impulsivity)	72.50 (4.40)	76.72 (5.82)	83.36 (2.49)
PPI total	149.00 (5.24)	187.64 (7.53)	184.97 (3.74)
Digit span	7.09 (0.21)	6.90 (0.25)	7.05 (0.12)

(*continued on next page*)

Table B1 (*continued*)

	Psychopathic traits group		
	1st quartile	4th quartile	Total sample
	M (*SE*)	*M* (*SE*)	*M* (*SE*)
Attentional scope	0.02 (0.01)	0.03 (0.01)	0.02 (0.01)
Unidimensional discrimination score	0.76 (0.01)	0.78 (0.01)	0.77 (0.01)
Bidimensional discrimination score	0.70 (0.02)	0.68 (0.02)	0.70 (0.01)
Tridimensional discrimination score	0.53 (0.01)	0.56 (0.02)	0.54 (0.01)
Unidimensional reaction time (s)	1.67 (0.14)	1.75 (0.19)	1.64 (0.07)
Bidimensional reaction time (s)	1.72 (0.09)	1.92 (0.15)	1.81 (0.06)
Tridimensional reaction time (s)	2.06 (0.13)	2.22 (0.19)	2.02 (0.08)
Unidimensional time on feedback (s)	0.62 (0.04)	0.64 (0.06)	0.62 (0.02)
Bidimensional time on feedback (s)	0.60 (0.37)	0.67 (0.06)	0.62 (0.02)
Tridimensional time on feedback (s)	0.70 (0.04)	0.69 (0.04)	0.68 (0.02)
N	28	27	110

Note. M and SE represent mean and standard error, respectively. N represents the number of participants.

Table B2
Descriptive statistics of Experiment 2 split by psychopathic traits scores.

Variables	1st quartile	4th quartile	Total sample
	M (*SE*)	*M* (*SE*)	*M* (*SE*)
PPI1 (fearless dominance)	13.55 (0.59)	36.84 (0.61)	25.19 (0.65)
PPI2 (self-centred impulsivity)	22.45 (1.27)	25.32 (1.36)	25.42 (0.69)
PPI-R: SF total	43.39 (1.61)	69.52 (1.59)	58.25 (1.04)
Digit span	6.56 (0.27)	7.01 (0.25)	6.55 (0.12)
Unidimensional discrimination score	0.76 (0.02)	0.75 (0.02)	0.75 (0.01)
Bidimensional discrimination score	0.79 (0.01)	0.76 (0.02)	0.78 (0.01)
Tridimensional discrimination score	0.67 (0.02)	0.68 (0.02)	0.68 (0.01)
Unidimensional reaction time (s)	2.20 (0.11)	2.15 (0.13)	2.25 (0.06)
Bidimensional reaction time (s)	2.18 (0.13)	2.12 (0.12)	2.34 (0.12)
Tridimensional reaction time (s)	2.32 (0.13)	2.47 (0.19)	2.30 (0.07)
Unidimensional time on feedback (s)	0.89 (0.07)	0.72 (0.05)	0.88 (0.06)
Bidimensional time on feedback (s)	1.03 (0.12)	0.78 (0.06)	1.04 (0.12)
Tridimensional time on feedback (s)	0.93 (0.10)	0.89 (0.07)	0.94 (0.07)
N	51	50	201

Note. M and SE represent mean and standard error, respectively. N represents the number of participants.

Appendix C. Exploratory analysis

Sample influence on psychopathy and learning

The accuracy of participants on the three versions of the configuration discrimination tasks in Experiment 2 was higher than in Experiment 1, suggesting our manipulation was successful in increasing discrimination scores. This addresses prior concerns of potential flooring effects, yet bidimensional task performance on Experiment 2 was no longer statistically significantly different from performance on the unidimensional task. This is likely driven by the change in instruction providing a non-uniform facilitation of learning across the task types. When comparing performance in each of the tasks between the two experiments we can see that the size of the difference in accuracy is greatest in the tridimensional task and decreases through the bidimensional task to be smallest in the unidimensional task. This is concerning especially in light of insightful work by Brazil and colleagues (2013) who demonstrated that reversal learning errors associated with psychopathy were moderated by the overtness of task demands. This is problematic for the generalisability of findings between the two experiments as it raises the possibility that the relationship between psychopathy and task performance may also have been affected by the manipulation and therefore differ between our experiments.

We tested for this possibility in a follow-up analysis in which we combined the datasets generated by both experiments ($N = 311$) and conducted a moderation analysis using hierarchic multiple regression, modelling the influence originating sample on the relationship between psychopathic traits and discrimination scores in bidimensional configuration discrimination task. Predictors were entered into the model in three stages. Firstly, as a control model consisting of age, sex, WMC, task order, set order, baseline associative learning capacity as indexed by scores on the unidimensional discrimination task, and the direct influence of the original sample. Secondly, the direct influence of psychopathic traits. And lastly, the interaction term between psychopathic traits and sample.

From the control model it was found that across both samples only unidimensional task performance ($B = 0.466$ ($SE = 0.044$), 95 % CI [0.379, 0.554], $\beta = 0.489$, $t(303) = 10.5$, $p < .001$) had a statistically significant impact on bidimensional discrimination scores (all others p's > 0.95). Including psychopathic traits in the model revealed that overall, the direct influence of psychopathic traits was also statistically significant (R^2 Change $= 0.019$, $B = -0.001$ ($SE < 0.001$), 95 % CI [-0.002, 0.000], $\beta = -0.268$, $t(302) = -3.02$, $p = .003$). However, including the interaction term had no significant impact ($p = .944$), suggesting that the relationship between psychopathic traits and disproportionately poorer configural learning in the bidimensional task was robust across samples.

Slower learning rates or reduced learning capacity

A second question raised by the data is whether psychopathy-related differences in configural learning are the product of slower learning rates or restricted acquisitional learning capacity. A notable feature of these tasks is that they consisted of far fewer trials than the current study resulting in participants failing to reach a clear asymptotic performance. In contrast, the number of trials in the tasks of the current study allowed participants to reliably reach asymptotic learning. Crucially, if psychopathy-related effects are observable during the later stages of each task, once asymptotic learning has been reached it would suggest that these deficits constitute a difference in the capacity to acquire learned associations. If not, it suggests that acquisitional learning capacity is preserved the results are the product of slower learning rates. We tested this in a follow-up analysis by repeating our analysis of the bidimensional task in Experiment 1 using only trials from the last quarter of each task, i.e., the 3 final presentations of the 8 stimuli. As in the main analysis, variables were entered into a hierarchic multiple regression in two stages. Firstly, as a control model that included sex, age, WMC, task order, set order, and baseline learning capacity as indexed by performance on the unidimensional task. And secondly, psychopathy as indexed by the FD dimension of the PPI-R.

When analysing performance during the final three training blocks of the bidimensional discrimination task it was found that neither sex, age, WMC, task order, nor set order influenced task performance (all p's ≥ 0.26). However, baseline associative learning capacity was again identified as a statistically significant, directionally positive, predictor of bidimensional discrimination ($B = 0.439$ ($SE = 0.052$), 95 % CI [0.33, 0.54], $\beta = 0.523$, $t(195) = 8.48$, $p < .000$). After controlling for these factors, including psychopathic traits within the model accounted for a statistically significant increase in the explained variance (R^2 Change $= 0.015$, $B = -0.002$ ($SE = 0.001$), 95 % CI [−0.003, 0.000], $\beta = -0.126$, $t(194) = -2.02$, $p = .045$). This demonstrates that the results of our initial analysis persist even when selectively considering trials that were presented after participants had reached asymptote configuration discrimination. This suggests that psychopathy-related acquisitional learning deficits may not just be the product of slower learning alone and that if sufficiently burdened with bidimensional processing load, may fail to reach a comparable level of learning even with sufficient training.

Appendix D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.paid.2024.112705.

References

Aiken, L. S., West, S. G., & Reno, R. R. (1991). *Multiple regression: Testing and interpreting interactions*. Newbury Park, CA: Sage Publications.

Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., & Evershed, J. K. (2019). *Gorilla in our midst: An online behavioral experiment builder. 52* pp. 388–407).

Baskin-Sommers, A. R., & Brazil, I. A. (2022). The importance of an exaggerated attention bottleneck for understanding psychopathy. *Trends in Cognitive Sciences*. https://doi.org/10.1016/j.tics.2022.01.001

Baskin-Sommers, A. R., Curtin, J. J., & Newman, J. P. (2011). Specifying the attentional selection that moderates the fearlessness of psychopathic offenders. *Psychological Science, 22*, 226–234.

Benning, S. D., Patrick, C. J., Blonigen, D. M., Hicks, B. M., & Iacono, W. G. (2005). Estimating facets of psychopathy from normal personality traits: A step toward community epidemiological investigations. *Assessment, 12*, 3–18.

Blair, R. J. R. (2013). Psychopathy: Cognitive and neural dysfunction. *Dialogues in Clinical Neuroscience, 15*, 181–190.

Blair, R. J. R., et al. (2004). Passive avoidance learning in individuals with psychopathy: Modulation by reward but not by punishment. *Personality and Individual Differences, 37*, 1179–1192.

Blais, J., Fazaa, G. R., & Mungall, L. R. (2023). A pre-registered examination of the relationship between psychopathy, boredom-proneness, and university-level cheating. *Psychological Reports, 00332941231184385*. https://doi.org/10.1177/00332941231184385

Borries, A. K. L. V., et al. (2010). Neural correlates of error-related learning deficits in individuals with psychopathy. *Psychological Medicine, 40*, 1559–1568.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*, 433–436.

Brazil, I. A., et al. (2013). Reversal deficits in individuals with psychopathy in explicit but not implicit learning conditions. *Journal of Psychiatry & Neuroscience, 38*, E13–E20.

Budhani, S., Richell, R. A., & Blair, R. J. R. (2006). Impaired reversal but intact acquisition: Probabilistic response reversal deficits in adult individuals with psychopathy. *Journal of Abnormal Psychology, 115*, 552–558.

Byrom, N. C., & Murphy, R. A. (2016). Individual difference in configural associative learning. *Journal of Experimental Psychology: Animal Learning and Cognition, 42*, 325–335.

Chatlosh, D. L., Neunaber, D. J., & Wasserman, E. A. (1985). Response-outcome contingency: Behavioral and judgmental effects of appetitive and aversive outcomes with college students. *Learning and Motivation, 16*, 1–34.

Clark, L., Cools, R., & Robbins, T. W. (2004). The neuropsychology of ventral prefrontal cortex: Decision-making and reversal learning. *Brain and Cognition, 55*, 41–53.

Dematteo, D., Heilbrun, K., & Marczyk, G. (2005). Psychopathy, risk of violence, and protective factors in a noninstitutionalized and noncriminal sample. *International Journal of Forensic Mental Health, 4*, 147–157.

Edens, J. F., Marcus, D. K., Lilienfeld, S. O., & Poythress, N. G. (2006). Psychopathic, not psychopath: Taxometric evidence for the dimensional structure of psychopathy. *Journal of Abnormal Psychology, 115*, 131–144.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175–191.

Gorenstein, E. E., & Newman, J. P. (1980). Disinhibitory psychopathology: A new perspective and a model for research. *Psychological Review, 87*, 301–315.

Gregory, S., et al. (2015). Punishment and psychopathy: A case-control functional MRI investigation of reinforcement learning in violent antisocial personality disordered men. *Lancet Psychiatry, 2*, 153–160.

Guay, J. P., Ruscio, J., Knight, R. A., & Hare, R. D. (2007). A taxometric analysis of the latent structure of psychopathy: Evidence for dimensionality. *Journal of Abnormal Psychology, 116*, 701–716.

Gunschera, L. J., et al. (2023). No impaired integration in psychopathy: Evidence from an illusory conjunction paradigm. *Personality Disorders, Theory, Research, and Treatment*. https://doi.org/10.1037/per0000619

Hamilton, R. K. B., Hiatt Racer, K., & Newman, J. P. (2015). Impaired integration in psychopathy: A unified theory of psychopathic dysfunction. *Psychological Review, 122*, 770–791.

Hamilton, R. K. B., & Newman, J. P. (2018). Information processing capacity in psychopathy: Effects of anomalous attention. *Personality Disorders, Theory, Research, and Treatment, 9*, 182–187.

He, J. B., Liu, C. J., Guo, Y. Y., & Zhao, L. (2011). Deficits in early-stage face perception in excessive internet users. *Cyberpsychology, Behavior and Social Networking, 14*, 303–308.

Hoppenbrouwers, S. S., Van der Stigchel, S., Sergiou, C. S., & Theeuwes, J. (2016). Top-down attention and selection history in psychopathy: Evidence from a community sample. *Journal of Abnormal Psychology, 125*, 1–7.

Hoppenbrouwers, S. S., Van der Stigchel, S., Slotboom, J., Dalmaijer, E. S., & Theeuwes, J. (2015). Disentangling attentional deficits in psychopathy using visual search: Failures in the use of contextual information. *Personality and Individual Differences, 86*, 132–138.

Kastner, R. M., Sellbom, M., & Lilienfeld, S. O. (2012). A comparison of the psychometric properties of the psychopathic personality inventory full-length and short-form versions. *Psychological Assessment, 24*, 261–267. Preprint at https://doi.org/10.1037/a0025832.

Kiehl, K. A., Smith, A. M., Hare, R. D., & Liddle, P. F. (2000). An event-related potential investigation of response inhibition in schizophrenia and psychopathy. *Biological Psychiatry, 48*, 210–221.

Kleiner, M., et al. (2007). *What's new in Psychtoolbox-3? Cognitive and computational psychophysics*.

Le Pelley, M. E., Beesley, T., & Griffiths, O. (2011). Overt attention and predictiveness in human contingency learning. *Journal of Experimental Psychology. Animal Behavior Processes, 37*, 220–229.

Le Pelley, M. E., Oakeshott, S. M., & McLaren, I. P. L. (2005). Blocking and unblocking in human causal learning. *Journal of Experimental Psychology. Animal Behavior Processes, 31*, 56–70.

Lezak, M. D. (1995). Neuropsychological assessment, 3rd ed.. In *Neuropsychological assessment* (3rd ed.). New York, NY, US: Oxford University Press.

Lilienfeld, S. O., & Andrews, B. P. (1996). Development and preliminary validation of a self-report measure of psychopathic personality traits in noncriminal populations. *Journal of Personality Assessment, 66*, 488–524.

Lilienfeld, S. O., & Hess, T. H. (2001). Psychopathic personality traits and somatization: Sex differences and the mediating role of negative emotionality. *Journal of Psychopathology and Behavioral Assessment, 23*, 11–24.

Lilienfeld, S. O., & Widows, M. R. (2005). *Psychopathic personality inventory-revised: Professional manual*. Lutz, FL: Psychological Assessment Resources.

López, R., Poy, R., Patrick, C. J., & Moltó, J. (2013). Deficient fear conditioning and self-reported psychopathy: The role of fearless dominance. *Psychophysiology, 50*, 210–218.

Mackintosh, N. J., & Holgate, V. (1968). Effects of inconsistent reinforcement on reversal and nonreversal shifts. *Journal of Experimental Psychology, 76*, 154–159.

Mahmut, M. K., Menictas, C., Stevenson, R. J., & Homewood, J. (2011). Validating the factor structure of the self-report psychopathy scale in a community sample. *Psychological Assessment, 23*, 670–678.

MATLAB Version 2016b.(2016). Preprint at.

McDonald, R. J., et al. (1997). Systematic comparison of the effects of hippocampal and fornix-fimbria lesions on acquisition of three configural discriminations. *Hippocampus, 7*, 371–388.

Mitchell, D. G. V., Colledge, E., Leonard, A., & Blair, R. J. R. (2002). Risky decisions and response reversal: Is there evidence of orbitofrontal cortex dysfunction in psychopathic individuals? *Neuropsychologia, 40*, 2013–2022.

Mitchell, D. G. V., et al. (2006). Instrumental learning and relearning in individuals with psychopathy and in patients with lesions involving the amygdala or orbitofrontal cortex. *Neuropsychology, 20*, 280–289.

Munro, G. E. S., et al. (2007). Response inhibition in psychopathy: The frontal N2 and P3. *Neuroscience Letters, 418*, 149–153.

Murphy, R. A., & Msetfi, R. M. (2014). Individual differences in associative learning. *Frontiers in Psychology, 5*.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology, 9*, 353–383.

Neal, T. M. S., & Sellbom, M. (2012). Examining the factor structure of the Hare Self-Report Psychopathy Scale. *Journal of Personality Assessment, 94*, 244–253. Preprint at https://doi.org/10.1080/00223891.2011.648294.

Newman, J. P., Curtin, J. J., Bertsch, J. D., & Baskin-Sommers, A. R. (2010). Attention moderates the fearlessness of psychopathic offenders. *Biological Psychiatry, 67*, 66–70.

Newman, J. P., & Kosson, D. S. (1986). Passive avoidance learning in psychopathic and nonpsychopathic offenders. *Journal of Abnormal Psychology, 95*, 252–256.

Newman, J. P., Patterson, C. M., Howland, E. W., & Nichols, S. L. (1990). Passive avoidance in psychopaths: The effects of reward. *Personality and Individual Differences, 11*, 1101–1114.

Newman, J. P., & Schmitt, W. A. (1998). Passive avoidance in psychopathic offenders: A replication and extension. *Journal of Abnormal Psychology, 107*, 527–532.

Patrick, C. J., Fowles, D. C., & Krueger, R. F. (2009). Triarchic conceptualization of psychopathy: Developmental origins of disinhibition, boldness, and meanness. *Development and Psychopathology, 21*, 913–938.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*, 437–442.

R Core Team. (2023). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Reed, S. K., Dempster, A., & Ettinger, M. (1985). Usefulness of analogous solutions for solving algebra word problems. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 11*, 106–125.

Rushworth, M. F. S., & Behrens, T. E. J. (2008). Choice, uncertainty and value in prefrontal and cingulate cortex. *Nature Neuroscience, 11*, 389–397.

Sadeh, N., & Verona, E. (2008). Psychopathic personality traits associated with abnormal selective attention and impaired cognitive control. *Neuropsychology, 22*, 669–680.

Sadeh, N., & Verona, E. (2012). Visual complexity attenuates emotional processing in psychopathy: Implications for fear-potentiated startle deficits. *Cognitive, Affective, & Behavioral Neuroscience, 12*, 346–360.

Smith, S. T., Edens, J. F., & Vaughn, M. G. (2011). Assessing the external correlates of alternative factor models of the psychopathic personality inventory–short form across three samples. *Journal of Personality Assessment, 93*, 244–256.

Tonnaer, F., Cima, M., Sijtsma, K., Uzieblo, K., & Lilienfeld, S. O. (2013). Screening for psychopathy: Validation of the psychopathic personality inventory-short form with reference scores. *Journal of Psychopathology and Behavioral Assessment, 35*, 153–161.

Von Borries, A. K. L., et al. (2010). Neural correlates of error-related learning deficits in individuals with psychopathy. *Psychological Medicine, 40*, 1559–1568.

Wechsler, D. (1949). *Wechsler intelligence scale for children; manual. Wechsler intelligence scale for children; manual*. Oxford, England: The Psychological Corp.

Wickham, H., et al. (2023). *ggplot2: Create elegant data visualisations using the grammar of graphics*.

Wolf, R. C., Warren, C. M., Carpenter, R. W., Zeier, J. D., & Newman, J. P. (2012). Reduced susceptibility to the attentional blink in psychopathic offenders: Implications for the attention bottleneck hypothesis. *Neuropsychology, 26*, 102–109.