Psychopathic individuals exhibit but do not avoid regret during counterfactual decision making

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Psychopathy is associated with persistent antisocial behavior and a striking lack of regret for the consequences of that behavior. Although explanatory models for psychopathy have largely focused on deficits in affective responsiveness, recent work indicates that aberrant value-based decision making may also play a role. On that basis, some have suggested that psychopathic individuals may be unable to effectively use prospective simulations to update action value estimates during cost–benefit decision making. However, the specific mechanisms linking valuation, affective deficits, and maladaptive decision making in psychopathy remain unclear. Using a counterfactual decision-making paradigm, we found that individuals who scored high on a measure of psychopathy were as or more likely than individuals low on psychopathy to report negative affect in response to regret-inducing counterfactual outcomes. However, despite exhibiting intact affective regret sensitivity, they did not use prospective regret signals to guide choice behavior. In turn, diminished behavioral regret sensitivity predicted a higher number of prior incarcerations, and moderated the relationship between psychopathy and incarceration history. These findings raise the possibility that maladaptive decision making in psychopathic individuals is not a consequence of their inability to generate or experience negative emotions. Rather, antisocial behavior in psychopathy may be driven by a deficit in the generation of forward models that integrate information about rules, costs, and goals with stimulus value representations to promote adaptive behavior.

psychopathy | counterfactual reasoning | affect | decision making | reward

The ability to establish, transmit, and enforce social norms is a signature of our species. Indeed, maintaining our uniquely high degree of stable, large-scale cooperation requires widespread norm compliance (1). However, although norm compliance is common, it is far from universal. Throughout history and across cultures, there have been those who would threaten social peace and community prosperity through their persistent violation of social norms. Psychopathic individuals, who exhibit a chronic and flagrant disregard for moral and legal norms, exemplify this type of person. Compared with nonpsychopathic individuals, they commit two to three times more violent and nonviolent crime and recidivate at a much higher rate (2). This persistent antisocial behavior comes at a high cost to society, with psychopathic individuals responsible for a disproportionate share of the estimated $2.34 trillion in annual costs associated with crime in the United States (3).

Psychopathy is defined by a combination of superficial charm, blunted empathy and punishment sensitivity, shallow emotional experiences, persistent antisocial behavior, and marked sensation seeking and impulsivity (2). Whereas many of the behavioral and lifestyle features of this disorder (e.g., sensation seeking, criminal offending) are shared with other antisocial subtypes, psychopathy is distinguished by the presence of deficits in emotional arousal, empathy, and affective responsiveness (2, 4). The behavioral manifestations of such deficits in psychopathic individuals are diverse, encompassing pathological lying, interpersonal manipulation, and the absence of guilt, remorse, and regret following decisions that cause harm to themselves or others. Such symptoms are considered by many to be defining features of the disorder (4); however, the cognitive and neurobiological mechanisms that produce them remain the subject of debate.

Dominant explanatory models of psychopathy attribute such symptoms to core deficits in emotion processing that prevent psychopathic individuals from generating negative affect responses to aversive stimuli, and that limit their capacity for empathic experience sharing with others (5). Consistent with this suggestion, psychopathic individuals show deficits in fear conditioning (6, 7), face emotion processing (8), and emotion-modulated startle (9). Additionally, psychopathic individuals show reduced functional and structural connectivity between amygdala and medial orbitofrontal cortex (mOFC) (10), accompanied by blunted corticolimbic engagement during moral decision making (11), aversive conditioning (6, 7), affective perspective taking (12), and in response to empathogenic (13) and facial emotion stimuli (14). Moreover, this association between corticolimbic dysfunction and psychopathy appears largely to be driven by interpersonal-affective symptoms rather than by antisocial-lifestyle features (13–15). Taken together, this work supports a model in which the affective deficits so central to psychopathy arise from dysfunction within brain networks that support the generation and evaluation of emotional states, and that link such states to social cues through associative mechanisms.

Although psychopathy research largely has focused on the basic social and affective processes detailed above, recent work highlights a potentially significant role for value-based decision making as

Significance

Psychopathic individuals display a chronic and flagrant disregard for social norms through their callous behavior and lack of regret for its consequences. Although psychopathy research largely attributes this to deficits in affective responsiveness, recent proposals suggest that value-based decision making may also contribute to the maladaptive behavior of psychopathic individuals. Using a counterfactual decision-making paradigm, we found that higher scores on psychopathy were associated with higher levels of retrospective regret. Despite this, however, individuals higher on psychopathy made riskier choices and were less influenced by prospective regret when making decisions. These findings support the idea that the maladaptive behavior of psychopathic individuals is related to deficits in domain-general cognitive processes, such as counterfactual decision making, rather than a primary affective deficit.

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well (16). For example, psychopathic individuals exhibit heightened ventral striatal responses to reward (17), as well as increased striatal gray matter volume (18). These data, considered in light of the mOFC findings above, have led some to hypothesize that many of the most problematic behaviors in psychopathy result from a deficit in the ability to represent and integrate information about the costs and benefits of actions (16, 19). According to this view, psychopathy symptoms that are apparently affective in nature—such as the absence of guilt, remorse, and regret—may instead arise from dysfunction within domain-general valuation systems. The experience of regret—characteristically diminished or absent in psychopathic individuals—provides a particularly instructive example for considering how affective symptoms in psychopathy could arise from aberrant value-based decision making.

According to prominent accounts, psychopathic individuals "never look back with regret or forward with concern" (20). What is regret, precisely? Decision science situates regret in the context of counterfactual reasoning and offers a useful operationalization: an aversive emotional state that is elicited by a discrepancy in the outcome values of chosen vs. unchosen actions. Put simply, the experience of regret is triggered when an agent is informed that the outcome of their choice is worse than what they would have obtained had they chosen differently (21). A wealth of evidence suggests that people are generally regret-avoidant (22). When faced with a multioption choice problem, decision makers estimate the likelihood of experiencing regret for each option in the choice set and, all other things being equal, select the one with the lowest anticipated regret (23, 24). This process requires the ability to generate and compare outcome value representations for both chosen and unchosen actions; therefore, counterfactual reasoning is thought to be fundamental to regret-sensitive decision making (22). Before action selection, counterfactual processes generate a forward model of action–outcome relationships by prospectively simulating outcome values for each choice option. At feedback, retrospective counterfactual comparisons signal the difference between outcomes for the chosen vs. unchosen action; the aversive state of regret is triggered when the counterfactual outcome is better than the obtained outcome.

Notably, counterfactual thinking and regret engage strikingly similar neural circuitry (25, 26). The strongest overlap is in mOFC, a region where structural and functional alterations are consistently found in psychopathy. mOFC damage produces a syndrome that includes social and affective symptoms similar to those seen in psychopathy (27). Recent work suggests that the presence of such symptoms in mOFC patients may be due to lesion-induced alterations in the representation of information—including counterfactual signals—during value-based decision making (28–30). Together, these studies raise the possibility that diminished regret in psychopathy may result from a deficit in the ability to generate forward action–outcome models and/or perform retrospective counterfactual comparisons. To date, however, the use of counterfactual information during decision making in psychopathy remains unclear.

To examine the relationships between psychopathy, counterfactual decision making, and regret, we administered a counterfactual decision-making paradigm in a community-based sample that was significantly enriched for antisocial behavior. All participants received a clinical battery that assessed psychopathy and other antisocial trait subtypes. A marker of "real-world" antisocial behavior (prior incarcerations) was obtained for each participant. We measured affective responses to regret-inducing counterfactual outcomes, as well as behavioral sensitivity to prospective regret signals, which were tested for association with clinical and real-world indices of antisocial behavior.

Materials and Methods

Participants. Participants included 62 male adults (18–55) recruited through flyers soliciting risk-taking (e.g., crime, substance use, gambling, impulsive behavior, bullying) individuals in New Haven County, Connecticut, a high-crime region (see Table S1 for sample characteristics). Participants who performed below the fourth-grade level on a standardized measure of reading, had an IQ of <70, or met criteria for psychotic disorders were excluded (see *SI Materials and Methods* for detailed exclusion criteria). Participants earned $10/h (regardless of performance on the task) for their completion of the self-report measures and the experimental task. All participants provided written informed consent according to the procedures set forth by the Yale University Human Subjects Committee.

Measures.

Clinical assessment. We used the Self-Report Psychopathy-III (SRP-III) scale to measure psychopathy (31). Notably, the SRP-III is sensitive to aspects of behavior that are common to multiple antisocial subtypes (e.g., criminal behavior, sensation seeking, impulsivity) (32, 33). Therefore, to assess the degree to which psychopathy per se was associated with affective response modulo these general aspects, we used participants' scores on the Externalizing Spectrum Inventory-Brief (ESI-Brief) (34) as a covariate (see *SI Materials and Methods* for more information and Table S2 for zero-order correlations among assessments).

Criminal behavior. All participants were asked how many times they had been incarcerated. This self-report was confirmed using the State of Connecticut Department of Correction inmate database. Approximately 51% of the sample had been incarcerated at least once before participation.

Counterfactual gambling task. The present task was based on paradigms previously reported in the literature by Gillan et al. (35) and Camille et al. (23). The goal of the task was to earn as many points as possible. On each of 80 trials, participants had to choose between two wheels (gambles) that differed in expected value (Table S3). Each wheel offered two of the four possible outcomes: –210, –70, +70, and +210; respective probabilities were indicated by the proportion of the wheel occupied by a given outcome (0.25, 0.5, and 0.75). After a brief viewing period, participants selected one wheel via button press. On 50% of the trials, participants had the chance to change their mind and switch wheels before proceeding. Once the final selection was made, a red ball began to move within each wheel. After 1.5 s, the ball stopped on one of the sections of the selected wheel (the unselected wheel was occluded), indicating participants' obtained outcome for that trial. Participants then rated their affective response to that outcome using a rating bar that ranged from "Very Disappointed" (0) to "Neither Pleased Nor Disappointed" (50) "Very Pleased" (100) (Fig. 1). The outcome of the nonselected wheel was then revealed and participants made another affective rating. At the end of each trial, the participant's cumulative score was presented onscreen.

Data Analysis.

Affect ratings. Separate analyses were conducted for ratings obtained after partial and complete feedback using mixed-effects linear regression models in STATA 13. For rating 1 (partial feedback), obtained outcome (i.e., the outcome value of the participant's selection), chance counterfactual (i.e., the difference between the obtained outcome and what the participant could have obtained had the ball landed elsewhere within the chosen wheel), and SRP-III total score were included as continuous fixed-effect predictors; participant was modeled as a random effect. Interaction terms for SRP-III*chance counterfactual and SRP-III*obtained outcome were included in the same model, to examine the incremental effect of the counterfactual outcome over and above the obtained outcome. For rating 2 (complete feedback), obtained outcome, agent counterfactual (i.e., the difference between outcomes for the chosen vs. unchosen wheel), and SRP-III total score were included as continuous fixed-effect predictors; participant was modeled as a random effect. Interaction terms for SRP-III*agent counterfactual and SRP-III*obtained outcome were included in the same model, to examine the incremental effect of the counterfactual outcome over and above the obtained outcome. In keeping with prior work (26, 30, 35), we considered rating 1 and rating 2 to reflect reported disappointment and regret, respectively.

Decision making.

Choice models. We examined the effects of three trialwise parameters on decision making (i.e., wheel choice): expected value (e), anticipated disappointment (d), and prospective regret (r) (Fig. 1). These parameters represent prospective estimates of e, d, and r, which are used to generate action values for each wheel on each trial. Potential outcomes and associated probabilities were ascribed the following notation: x_1 and y_1 correspond to the possible outcomes of wheel 1 (W1), where $x_1 > y_1$. Similarly, x_2 and y_2 refer the two possible outcomes of wheel 2 (W2), with $x_2 > y_2$. p and 1 – p are the respective probabilities of earning x_1 and y_1 and likewise q and 1 – q are the respective probabilities associated with earning x_2 and y_2.

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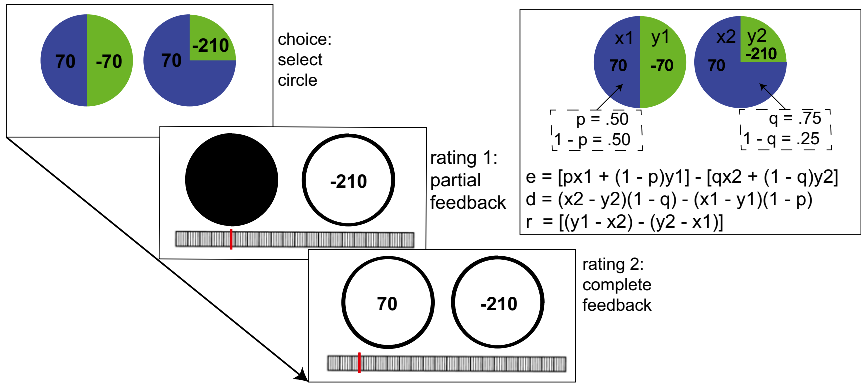

Fig. 1. Trial structure of task. Participants were presented two wheels (gambles) that differed with respect to the magnitudes and probabilities of outcomes, and asked to select one. After wheel choice, participants were shown how many points they won or lost and were asked to rate how pleased or disappointed they felt by that outcome (rating 1; partial feedback). Then, participants were shown how many points they could have won or lost if they had chosen differently (i.e., selected the other wheel) and were asked to rate how pleased or disappointed they felt knowing their outcomes compared with the other wheel (rating 2; complete feedback). The complete list of trials presented to participants is provided in Table S3. Equations represented here illustrate the mapping of these parameters onto information about each wheel provided to participants. d, Disappointment; e, expected value (EV); r, regret.

The expected value (e) associated with choice of W1 was modeled by subtracting the expected value of W2 from that of W1, using Eq. **1**. When e is positive, value-maximizing participants should select W1:

$$e = EV_{W1} - EV_{W2} = [px_1 + (1-p)y_1] - [qx_2 + (1-q)y_2]. \quad [1]$$

The anticipated disappointment (d) parameter takes into account both the probability of realizing the worst possible outcome, and the difference between the worst and best possible outcomes for that same wheel. The anticipated disappointment estimate for W1 is subtracted from that of W2, as detailed in Eq. **2**. When d is positive, disappointment-avoiding participants should choose W1:

$$d = (x_2 - y_2)(1-q) - (x_1 - y_1)(1-p). \quad [2]$$

The prospective regret (r) calculation (Eq. **3**) considers the size of the difference between the lowest and the highest outcomes across both wheels. This is grounded in the assumption that the magnitude of the difference between the obtained outcome and what could have been obtained had one chosen the other wheel determines the magnitude of reported regret/relief. Thus, regret-avoidant participants should choose the wheel that minimizes this difference, that is, W1 when r is positive and W2 when r is negative:

$$r = [(y_1 - x_2) - (y_2 - x_1)]. \quad [3]$$

Based on these three parameters, individual trial-by-trial estimates were calculated for the probability of choosing wheel 1 ($Pw1_{it}$), where t denotes trial number and i denotes individual participant: $P(\text{Wheel } 1_{it}) = 1 - P(\text{Wheel } 2_{it}) = F(e_{it}, d_{it}, r_{it})$. F is the inverse logit function, $F(\theta) = e^{\theta}(1 + e^{\theta})$ and θ is the logit predicted by the individual values of e, d, and r in the logistic regression.

Individual difference analyses. We constructed several mixed-effects logistic regression models to estimate the main effects of e, d, and r on wheel choice [Choice ~ e + d + r + (1|Participant)] as well their interactions with psychopathy [Choice ~ e + d + r + SRP-III + SRP-III:e + SRP-III:d + SRP-III:r + (1|Participant)]. In these models, choice was a binary outcome variable (coded 1 for wheel 1 and 0 for wheel 2), SRP-III total score and each decision-making parameter (e, d, r) were considered as continuous fixed-effect predictors, and participant was treated as a random effect. Additional models presented in *SI Results* tested for symptom domain selectivity (e.g., externalizing vs. psychopathy; fearless dominance vs. impulsive-antisociality) and controlled for variation in age, education, IQ, substance abuse history, trait anxiety, and race/ethnicity.

Real-world behavior. To determine whether variability in behavioral regret sensitivity predicted real-world choice behavior, we first obtained subjectwise estimates of the strength of association between r and choice behavior (i.e., unstandardized regression coefficients for r, from the main effect model described above). Next, we similarly calculated individual estimates of the strength of association between affective ratings and the chance/agent counterfactual magnitude for each trial. These values were entered into a negative binomial regression as a predictor of the number of prior incarcerations. SRP-III score and SRP-III*rating interaction terms were also included in the model.

Results

Affect Models.

Partial feedback. Consistent with previous research, we found a significant main effect for obtained outcome [B = 0.083, SE = 0.004, 95% confidence interval (CI) = 0.077–0.090, $z = 23.77$, $P < 0.001$] on affective response, such that higher outcome values were associated with more positive affective ratings, and lower outcomes were associated with more negative affective (disappointment) ratings. Chance counterfactual also had a significant main effect on affective ratings (B = 0.015, SE = 0.002, 95% CI = 0.012–0.019, $z = 8.11$, $P < 0.001$), with more positive affect reported when the difference between obtained and counterfactual outcomes was positive and more negative affect reported when the difference was negative. There was no main effect of SRP-III on rating 1 ($P = 0.98$). The interaction between obtained outcome and SRP-III was significant (B = 0.007, SE = 0.002, 95% CI = 0.003–0.01, $z = 3.90$, $P < 0.001$), with higher psychopathy scores predicting stronger negative and stronger positive affective responses to negative and positive obtained outcomes, respectively. However, we did not observe significant interactions between SRP-III and chance counterfactual ($P = 0.359$) (Fig. 2 *A* and *C*), showing that psychopathy did not modulate affective responses to disappointment-inducing outcomes. After controlling for variation in externalizing, psychopathy did not significantly modulate the effect of either obtained outcome or chance counterfactual on reported affect (obtained outcome: $P = 0.294$; chance counterfactual: $P = 0.522$; *SI Results*).

Complete feedback. At the complete feedback stage, participants were shown what they would have obtained had they chosen a different wheel. In line with prior work, there were main effects of obtained outcome (B = 0.013, SE = 0.003, 95% CI = 0.008–0.018, $z = 4.71$, $P < 0.001$), with larger loss and larger gain outcomes predicting stronger negative and stronger positive affective responses, respectively. Additionally, there was a main effect of agent counterfactual (B = 0.041, SE = 0.002, 95% CI = 0.037–0.004, $z = 22.35$, $P < 0.001$) on affect ratings, with larger negative values (indicating better outcomes for the unchosen wheel) and larger positive outcomes (indicating better outcomes for the chosen wheel) predicting stronger negative and positive affective responses, respectively. The main effect of SRP-III was not significant ($P = 0.215$); however, we did observe significant interactions between SRP-III and both obtained outcome (B = –0.004, SE = 0.001, 95% CI = –0.006 to –0.0008, $z = -2.51$, $P < 0.012$) and agent counterfactual (B = 0.005, SE = 0.0009, 95% CI = 0.0034–0.0070, $z = 5.62$, $P < 0.001$) (Fig. 2 *B* and *D*). These results show that higher SRP-III scores predicted lower reported negative affect in response to negative obtained outcomes, and exaggerated

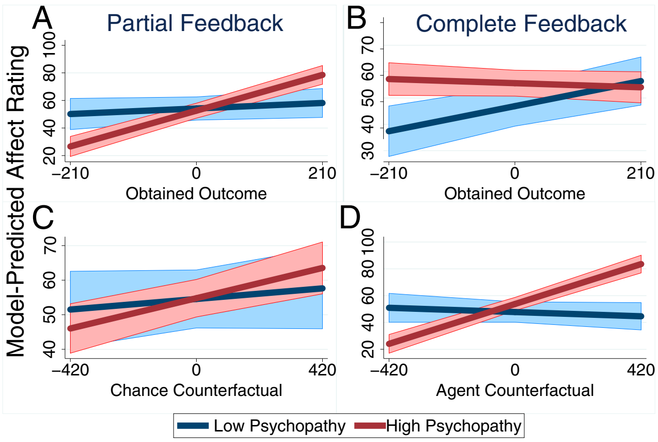

Fig. 2. Affective ratings for partial and complete feedback. During partial feedback, individuals high on psychopathy reported more extreme affective responses to the values of what they won or lost (*A*), but not to chance counterfactual information (*C*). During complete feedback, the affective ratings for high psychopathy individuals were less influenced by obtained outcome (*B*), but more influenced by agent counterfactual values (*D*). Together, these show that psychopathy is associated with typical, or perhaps even enhanced, emotional responses to regret. Shading around lines represents 95% CI for point estimates.

negative and positive affective responses to negative and positive counterfactual feedback (i.e., more reported regret/relief). After controlling for variation in externalizing, the SRP-III*obtained outcome interaction remained significant ($P = 0.006$); however, the SRP-III*agent counterfactual interaction did not ($P = 0.101$), indicating that, although psychopathy-specific variance predicted weaker affective responses to negative outcomes, it was not associated with differential affective regret sensitivity (*SI Results*).

Decision-Making Models.

Main effects of decision variables e, d, and r. There was a significant main effect for e, whereby all participants showed a tendency to choose wheels based on anticipated economic utility (B = 0.012, SE = 0.001, 95% CI = 0.010 to –0.014, $z = 12.51$, $P < 0.001$). The main effect of r was also significant (B = 0.004, SE = 0.0003, 95% CI = 0.004–0.005, $z = 15.01$, $P < 0.001$). However, the main effect of d was not significant (B = 0.0008, SE = 0.0004, 95% CI = –0.00001–0.002, $z = 1.93$, $P = 0.054$). These results are largely consistent with prior work showing that individuals make choices to minimize the likelihood of experiencing regret (21, 24).

Decision Variable-by-Psychopathy interactions. The results described above indicate that trial-by-trial variation in choice behavior is driven, in part, by trialwise variation in the magnitude of prospective regret signals. However, this linkage was significantly weaker in individuals with higher SRP-III scores (B = –0.0005, SE = 0.0001, 95% CI = –0.0008 to –0.0002, $z = -3.71$, $P < 0.001$; Fig. 3*A*), suggesting that, although the magnitude of anticipated regret drives choice at low levels of psychopathy, this relationship becomes uncoupled as psychopathy severity increases. In other words, participants with higher SRP-III scores appeared relatively insensitive to the prospect of regret during value-based decision making, despite the fact that they reported typical negative affective responses to regret-inducing outcomes. The relationship between SRP-III and prospective regret sensitivity remained significant after controlling for variation in externalizing ($P = 0.016$; *SI Results*), indicating that psychopathy is associated with decreased behavioral regret sensitivity even after adjusting for variation in nonspecific aspects of antisocial behavior.

The interaction between d and SRP-III was also significant, albeit weaker in magnitude (B = –0.0005, SE = 0.0002, 95% CI = –0.0009 to –0.0003, $-z = 2.39$, $P = 0.017$; Fig. 3*C*). We did not observe a main effect of SRP-III on choice behavior ($P = 0.143$), nor was the interaction between SRP-III and e ($P = 0.118$; Fig. 3*B*) significant. SRP-III scores did not significantly predict the total number of points won at the end of the task ($P = 0.834$). These findings, considered together with the affective rating data above, show that individuals scoring higher on a measure of psychopathy exhibited typical (or perhaps even more extreme) negative emotional responses to regret-inducing outcomes, yet their ability to use prospective regret signals to guide choice behavior appeared relatively compromised. This pattern of results suggests that psychopathy is associated with a selective deficit in the ability to use forward action–outcome models to guide action selection; retrospective counterfactual evaluation, on the other hand, appears to be preserved.

Real-world behavior. Lower behavioral regret sensitivity predicted a greater number of prior incarcerations (B = –65.48, SE = 26.64, 95% CI = –117.69 to –13.27, $z = -2.46$, $P = 0.014$). Behavioral regret sensitivity remained a significant negative predictor of number of prior incarcerations, even after controlling for affective outcome sensitivity, affective regret sensitivity, and affective disappointment sensitivity ($P = 0.04$). Although these results show that behavioral regret sensitivity selectively predicts incarceration, the relevance of psychopathy to that relationship remained unclear. To confirm a direct link between psychopathy, behavioral regret sensitivity, and real-world decision making, we modeled the effect of interactions between SRP-III score and behavioral regret sensitivity, affective regret sensitivity, affective outcome sensitivity, and affective disappointment sensitivity on number of prior incarcerations. The psychopathy-by-behavioral regret sensitivity interaction was the only significant predictor of incarceration in this model (B = –22.94, SE = 11.06, 95% CI = –44.62124 to –1.259966, $z = -2.07$, $P = 0.038$) (Fig. 4). This result shows that the highest risk for incarceration results from a combination of high SRP-III scores and low behavioral regret sensitivity. Psychopathy was not associated with the number of prior incarcerations at higher levels of behavioral regret sensitivity, suggesting that higher behavioral regret sensitivity mitigated the impact of SRP-III score on incarceration.

Discussion

Psychopathic individuals display a striking lack of remorse and regret when faced with the profoundly adverse consequences of their frequent and flagrant norm violations. Some influential theories suggest that this is due to an inability to generate aversive emotional responses to negative outcomes. The current data suggest that an alternative viewpoint merits consideration. Using a counterfactual decision-making paradigm, we found that psychopathy was not associated with blunted emotional responses to retrospective regret signals. Individuals with high SRP-III scores reported significant negative affect when informed that they could have received a better outcome had they chosen a foregone option. By contrast, psychopathy did affect the degree to which prospective regret signals were used to guide choice behavior. These signals were largely ignored in individuals who scored high on SRP-III, whose decisions were driven primarily by the expected value of each option irrespective of the

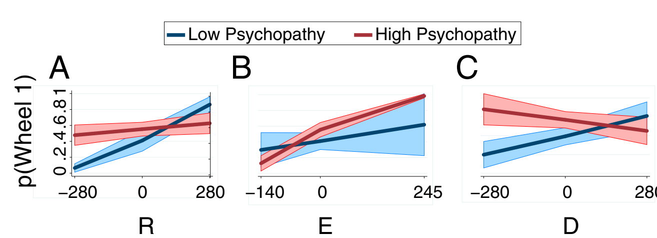

Fig. 3. Behavioral sensitivity to regret, expected value, and disappointment. Panels illustrate the logit model-predicted probability of choosing wheel 1 at varying levels of prospective regret (*A*), expected value (*B*), and disappointment (*C*), for high (red line)- and low (blue line)-psychopathy individuals. Shading around lines represent 95% CI for point estimates. Choice behavior in individuals higher on psychopathy were less affected by prospective regret (*A*) and disappointment (*C*) signals.

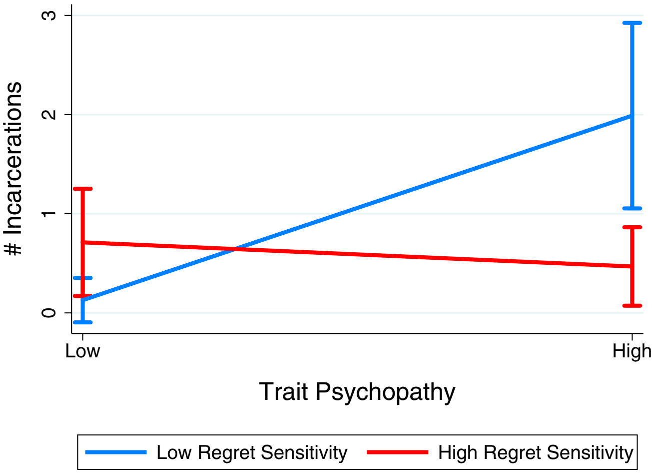

Fig. 4. Behavioral regret sensitivity moderates the relationship between psychopathy and number of prior incarcerations. Individuals with a combination of high SRP-III scores and low behavioral regret sensitivity reported more prior incarcerations, compared with individuals with high SRP-III scores and high behavioral regret sensitivity. For display, SRP-III and behavioral regret sensitivity values were separately split into two groups, based on median values. Error bars indicate 95% CIs. Although not used for inference, the 2 × 2 group factor interaction is also significant ($P < 0.01$).

potential for postdecision regret. Moreover, behavioral regret sensitivity predicted participants' incarceration histories, a real-world marker of maladaptive decision making, and moderated the impact of psychopathy on criminal behavior. On the whole, these findings raise the intriguing possibility that maladaptive decision making in psychopathy is not the result of a basic emotion deficit, but may instead arise from a problem with generating forward models that estimate values for a range of potential actions by simulating likely outcomes associated with their execution, or in using such models to guide online action selection.

The finding that behavioral regret sensitivity is reduced in psychopathic individuals is especially interesting given that psychopathy is associated with structural and functional deficits in brain circuitry important for counterfactual decision making. Several lesion studies have shown that patients with mOFC damage exhibit behavioral regret insensitivity (25, 30), and functional imaging findings confirm that mOFC activity predicts regret-avoidant decision making (24). Likewise, electrophysiological data indicate that mOFC neurons maintain a representation of the reward value of unchosen options following action selection (36)—consistent with mOFC's suggested role in prospectively mapping action options to outcome values (37)—and that mOFC counterfactual value signals are transmitted to other regions more directly involved in action selection (e.g., dorsolateral prefrontal cortex, medial caudate) (36, 37). With regard to psychopathy, structural imaging studies have found reduced surface area, cortical thickness, and gray matter volume within OFC (38). Accordingly, psychopathic individuals exhibit blunted OFC activation during reward learning, empathy, and emotion appraisal paradigms (12, 13, 15), and show reduced functional and structural connectivity between OFC and subcortical zones (e.g., amygdala and striatum) (10, 39). Taken together, findings from these parallel literatures suggest that diminished behavioral regret sensitivity may be a consequence of OFC dysfunction or, more likely, dysconnectivity in psychopathic individuals.

Although the link between OFC function and behavioral regret sensitivity is relatively uncontroversial, less is known about the specific mechanisms that support this link. mOFC (particularly areas 10r and 10m) is one component of a distributed network that supports the construction of self-relevant mental simulations. mOFC activation is consistently seen across otherwise disparate tasks—such as prospection, autobiographical episodic recall, and theory of mind—that require a mental model of hypothetical actions, states, or outcomes (40–42). The use of such models to represent actions, states, and outcomes is a hallmark of "model-based" decision systems. Whereas "model-free" valuation relies on the directly experienced outcomes of an agent's actions, model-based valuation uses prospective simulation to integrate counterfactual reward information into stimulus/action value representations. Recent work suggests that connectivity between mOFC and striatum may be important for the model-based updating of action–value associations via counterfactual outcome simulation. Although mOFC has been shown to represent counterfactual outcome values (36), striatal signals encode action values that are directly used to guide action selection (37). Recent work by Kishida et al. (43) shows that striatal dopamine transients reflect the integration of reward prediction error and counterfactual prediction error signals. Together, these data raise the possibility that model-based value information represented in prefrontal cortex may shape choice behavior, in part, by directly modulating subcortical action value signals (i.e., "model-based modulation").

The current study provides evidence that model-based modulation is disrupted in psychopathy. Participants with higher scores on a measure of psychopathy showed typical levels of negative emotion in response to regret-inducing feedback (i.e., intact retrospective counterfactual simulation), but appeared unable to use counterfactual value representations to guide choice behavior (i.e., impaired prospective counterfactual simulation). One might expect that a model-based decision-making deficit per se would disrupt both processes, as is evident in OFC lesion patients (30). Instead, psychopathy-related differences were evident only when counterfactual information was required for action selection. Notably, such differences were selective for psychopathy, rather than more general aspects of antisocial behavior. This finding would appear to be at odds with the only other study to examine counterfactual decision making in an antisocial population, which reported a weak association between behavioral regret sensitivity and impulsive-antisocial traits (44). The discrepant findings highlight the utility of phenotype selectivity analyses for neural and behavioral studies of psychopathy (see *SI Discussion* for a detailed discussion of this issue).

These findings are particularly interesting given that psychopathy is associated with aberrant selective attention. A putative early "attentional bottleneck" leads to enhanced allocation of resources to information that is consistent with an individual's current, goal-directed focus; however, this comes at the expense of processing information that may be highly salient, yet peripheral to that goal set (45). Here, participants were explicitly instructed to maximize the number of points won. This instruction could have generated an inflexible attentional focus on reward magnitude, producing the relative overweighting of expected value and underweighting of anticipated regret that we observed in individuals with high levels of trait psychopathy. This hypothesis is consistent with the known importance of attention processes for input selection during value-based decision making (46), and with work showing decreased regret sensitivity and diminished counterfactual elaboration in individuals with poor attentional flexibility (47). Future work should test the hypothesis that aberrant model-based value modulation in psychopathy arises from a primary deficit in the allocation of goal-directed attention.

Several methodological and conceptual limitations should be noted. First, although we used a targeted recruitment approach in a high-crime community to ensure a distribution of psychopathic traits (Table S1), the rates of psychopathy (e.g., 1% in the general population vs. 15–25% in prisons) and the measures used to assess these traits (e.g., questionnaire vs. Psychopathy Checklist interview) are different in forensic populations (48). Future studies should examine counterfactual decision-making processes in incarcerated offenders to confirm the generalizability of these findings to the full range of psychopathy severity. Finally, we used an economic decision-making paradigm to operationalize regret sensitivity. Although this conceptualization of regret has compelling support from both experimental psychology and behavioral economics, one might entertain an objection based on the distinction between regret and remorse. The former describes a negative emotion elicited by knowledge of a rejected alternative's outcome for oneself; the latter entails an aversive state induced by information that a foregone alternative would have produced a better outcome for another. Clinical characterizations suggest that psychopathic individuals demonstrate impairments in both regret and remorse. Future work using novel tasks that consider counterfactual decision making in the context of dyadic interactions will be useful for clarifying the relationship between remorse sensitivity and psychopathy, and in particular, to determine the degree to which regret and remorse sensitivity exert independent and interactive effects on real-world behavior in psychopathic individuals.

In sum, the present study identifies a specific deficit in the ability of individuals with psychopathic traits to integrate prospective counterfactual signals into decision making. By contrast, their ability to perform retrospective counterfactual comparisons appears to be preserved, as evidenced by their self-reported negative affect when faced with regret-inducing counterfactual information. The current data provide additional support for the idea that maladaptive behavior in psychopathy may result from deficits in domain-general cognitive processes, such as counterfactual representation, rather than a primary emotion deficit. Specifying the mechanisms that account for the striking disconnect between affective experience and decision making observed here will be crucial for advancing our understanding of the cognitive and neurobiological roots of psychopathy.

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