Supporting Information

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SI Materials and Methods

Participants. A prescreen phone interview and in-person assessment materials were used to exclude individuals who had performed below the fourth-grade level on a standardized measure of reading (Wide Range Achievement Test-III); who scored below 70 on a brief measure of IQ (Shipley); who had diagnoses of schizophrenia, bipolar disorder, or psychosis, not otherwise specified (Structured Clinical Interview for DSM Disorders); or who had a history of medical problems (e.g., uncorrectable auditory or visual deficits; head injury with loss of consciousness greater than 30 min) that may impact their comprehension of the materials or performance on the task.

Measures.

Self-Report Psychopathy-III (31). The Self-Report Psychopathy-III (SRP-III) is a 64-item self-report questionnaire that is intended to measure features (e.g., criminal tendencies, erratic lifestyle, interpersonal manipulation, and callous affect) of psychopathy similar to those assessed by the Psychopathy Checklist-Revised (48). Items are scored on a 5-point Likert scale ranging from 1 (disagree strongly) to 5 (agree strongly). In the present study, the SRP-III displayed good internal consistency (Cronbach's $\alpha = 0.910$).

Externalizing Spectrum Inventory-Brief (34). 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). To assess the degree to which the construct of psychopathy per se was associated with affective and behavioral regret sensitivity modulo these general aspects, we used participants' score on the Externalizing Spectrum Inventory-Brief (ESI-Brief) to control for variation in trait externalizing. Externalizing can be considered a superordinate taxon encompassing poor response inhibition, threat hypersensitivity, and heightened negative affect, and is markedly elevated in antisocial and substance use syndromes. Of note, although externalizing and psychopathy produce similar behavioral manifestations (e.g., crime), they are characterized by unique neurocognitive profiles and distinct etiopathophysiological mechanisms. We therefore used the ESI as a phenotype control variable to assess whether any association to SRP scores was driven by psychopathy-specific variance as opposed to the more general aspects of antisocial behavior linked to externalizing.

The ESI-Brief is a 100-item self-report questionnaire that assesses a range of behavioral and personality characteristics associated with the externalizing spectrum of psychopathology. The items consist of statements regarding specific behaviors and qualities, and participants are asked to choose the response that best describes them on a 4-point Likert scale: True (1), Mostly True (2), Mostly False (3), or False (4). Before scoring, the appropriate items were reverse coded. Total scores range from 100 to 400, with higher scores corresponding to higher levels of externalizing. For the present sample, the internal consistency (Cronbach's α) was 0.981.

SI Results

Behavioral and Affective Regret Sensitivity. In line with previous research (35), behavioral regret sensitivity (operationalized as the strength of the relationship between prospective regret and choice behavior) was not significantly correlated with affective regret sensitivity (operationalized as the strength of the relationship between the magnitude of the agent counterfactual and the magnitude of reported affective response) ($P = 0.716$). Likewise, behavioral regret sensitivity was not significantly correlated with affective disappointment sensitivity (i.e., strength of relationship between chance counterfactual and affective response; $P = 0.434$), or with affective outcome sensitivity (i.e., strength of relationship between obtained outcome and reported affect) for either partial ($P = 0.160$) or complete ($P = 0.450$) feedback trials.

Task Effects: Change of Mind by Opting to Switch. As noted in *Materials and Methods*, participants had the opportunity to change their minds and switch their wheel selections on 50% of trials. This opportunity to switch wheels previously was shown to intensify the regret sensitivity among healthy participants (23), but not among individuals with psychopathology, such as obsessive–compulsive disorder (35), suggesting healthy participants were more sensitive to the emotional impact of personal responsibility. Follow-up analyses were conducted to examine the relationship between psychopathy and the opportunity to change one's mind on affective responses.

The majority of individuals did not switch wheels (M = 3.23; SD = 3.15 of 40 trials). However, the total number of wheel switches did correlate with SRP-III score [$r_{(60)} = 0.30$, $P = 0.019$], such that a higher level of SRP-III was associated with more wheel switches. Consistent with Gillan et al. (35), the change-of-mind opportunity did not exacerbate emotional responses to obtained outcomes ($P = 0.779$) or to the regret/relief (agent counterfactual) ($P = 0.525$). Additionally, no two-way interactions with SRP-III ($P = 0.883$) and obtained outcome or regret/relief ($P = 0.814$) were observed.

Although individuals higher on SRP-III were not differentially emotionally affected by the opportunity to change their minds, they did display greater wheel switching on trials that allowed choice switches. It may be that individuals higher on psychopathy reacted more to the information presented in the moment. Although speculative, this is consistent with attention-based models of psychopathy that suggest psychopathic individuals fail to integrate contextual information and react strongly to goal-relevant information in the moment (45). In the counterfactual paradigm, the pattern of points within wheels and across trials provided context for choices. This information requires parallel integration of information, a process that is deficient in psychopathic individuals. Instead, individuals high on psychopathic traits may have seen the opportunity to switch wheels as relevant to their ultimate goal of earning more points, without consideration of other previously presented information.

Individual Difference Analyses: Symptom Domain Selectivity.

Affective and regret sensitivity in psychopathy vs. externalizing. Two antisocial subtypes, individuals with psychopathy and externalizing traits, are associated with significantly higher rates of antisocial activity and substance abuse than other individuals. Although individuals with psychopathy and those with externalizing traits have similar phenotypic expressions, including violent behavior, impulsivity, and substance abuse, they are associated with distinct psychobiological dysfunctions. We next examined subtype-specific associations to affective and behavioral regret sensitivity.

To assess the degree to which psychopathy was associated with affective responses (i.e., retrospective regret) controlling for other antisocial traits (i.e., externalizing), we used participants' score on the ESI-Brief to construct a model that simultaneously considered affective rating-by-psychopathy and affect rating-by-externalizing interactions. For partial feedback ratings, psychopathy did not significantly modulate the effect of obtained outcome or chance counterfactual on reported affect after controlling for r-by-externalizing interactions (obtain outcome: $P = 0.294$; chance counterfactual: $P = 0.522$). However, we did observe

a significant interaction between obtained outcome and externalizing (B = 0.0001, SE = 0.021, 95% CI = 0.0000025–0.0003, z = 1.99, $P < 0.047$), such that individuals with higher ESI-Brief scores reported more negative affect in response to negative outcomes.

For complete feedback, psychopathy significantly moderated the impact of obtained outcome on affective ratings (B = −0.006, SE = 0.002, 95% CI = −0.0101 to −0.0017, z = −2.76, P = 0.006), with less negative affect reported in response to the most negative outcomes for individuals with high vs. low SRP-III scores, and no difference in reported affect for positive outcomes. After controlling for variation in externalizing, psychopathy did not significantly moderate the relationship between agent counterfactual and affective ratings (P = 0.101). By contrast, a significant interaction was observed for externalizing and agent counterfactual (B = 0.0001, SE = 0.00004, 95% CI = 0.0003–0.0002, z = 2.67, P = 0.008); individuals exhibiting high vs. low levels of externalizing reported increased negative affect to the most negative counterfactuals. However, externalizing did not significantly moderate the effect of obtained outcome on affective ratings (P = 0.124). On the whole, these findings suggest that externalizing-specific variance moderates the degree of reported negative affect when an individual learns that the outcome of their choice is much worse than it would have been had they chosen differently. Importantly, although psychopathy-specific variance predicted weaker affective responses to negative obtained outcomes, it was not associated with differential affective regret sensitivity.

To determine the selectivity of diminished prospective regret sensitivity for psychopathy, we constructed a model that simultaneously considered decision variable-by-psychopathy and decision variable-by-externalizing interactions. We observed a significant r-by-psychopathy interaction even after controlling for variation in externalizing (B = −0.0004, SE = 0.0002, 95% CI = −0.0007 to −0.0001, z = −2.91, P = 0.004); however, the r-by-externalizing interaction was not significant (P = 0.16). Together, these results confirmed that psychopathy is associated with decreased behavioral regret sensitivity, even after adjusting for variation in aspects of antisocial behavior that may be present in, but not specific to, psychopathy.

Regret sensitivity in fearless dominance and impulsive antisociality. Given the specific association with psychopathy and prospective regret sensitivity, as a convergent test of selectivity, we also examined trait-specific associations with this measure. Prior work using the Psychopathic Personality Inventory has identified two underlying factors: "fearless dominance" (FD) that is thought to preferentially index the interpersonal-affective facets of psychopathy, and "impulsive antisociality" (IA) is linked to substance abuse, aggression, impulsivity, and criminality (49). Using the Multidimensional Personality Questionnaire-Brief Form (50), FD and IA subscales (which were a derivative of the Psychopathic Personality Inventory) were calculated as linear combinations of specific standardized (i.e., z-scored) primary trait scales. Specifically, FD was calculated as (0.34 × zSocial Potency) + (−0.42 × zStress Reaction) + (−0.21 × zHarm Avoidance). IA was calculated as (0.16 × zAggression) + (0.31 × zAlienation) + (−0.13 × zTraditionalism) + (−0.29 × zControl) + (−0.15 × zSocial Closeness). Statistical analyses included decision variable-by-FD and decision variable-by-IA interactions as predictors of choice behavior. Results confirmed that lower behavioral regret sensitivity was specific to FD (r-by-FD interaction: B = −0.002, SE = 0.0003, 95% CI = −0.0026 to −0.0015, z = −7.83, $P < 0.001$; P = 0.449 for r-by-IA interaction).

In addition, this analysis revealed significant interactions between FD and both expected value and disappointment sensitivity (e-by-FD: B = 0.004, SE = 0.0009, 95% CI = 0.0023 to −0.0059, z = 4.65, $P < 0.001$; d-by-FD: B = 0.004, SE = 0.0009, 95% CI = 0.0023 to −0.0059, z = 4.65). The e-by-FD interaction is especially noteworthy, as it shows that individuals who score higher on this trait behave as rational utility maximizers. In other words, their choices are strictly yoked to the difference in expected value between the two wheels. If one considers prospective regret information as signaling an action cost, the observed pattern of behavior suggests that this cost signal is not able to appropriately modulate the representation of action values during decision making.

Individual Difference Analyses: Covariates. For all analyses, several covariates were considered. Specifically, we examined age, IQ, education, substance abuse history, trait anxiety, and race/ethnicity as covariates. Each of these covariates was selected based on previous research that documented associations between these variables and counterfactual decision making, psychopathy, and/or criminal behavior. For example, impulsive-antisocial behavior tends to decrease with age (51); differences related to IQ/education indirectly relate to decision making and antisocial behavior; prolonged substance abuse can impact decision making and also has shared variance with psychopathic traits and criminal behavior (52); anxiety has been linked to differences in counterfactual decision making, as well as distinct etiological manifestations of psychopathy [e.g., primary and secondary psychopathy (53)]; and, finally, some previous work has shown specific racial/ethnic differences in cognitive mechanisms in psychopathy (54). Inclusion of these covariates did not alter any of the reported affect, decision-making, or real-world behavior (prior incarceration) results (i.e., psychopathy-related effects remained significant).

SI Discussion

Power. Although the current sample size is comparable to or larger than those of other studies examining individual differences in counterfactual decision making (23, 35, 44), there is increasing recognition that compelling statistical inference requires explicit consideration of power. Power analyses indicated that the current sample size provided sufficient power (i.e., >80%) for all models, at an average of 97%, to detect a moderate effect size (d = 0.50 with a two-tailed α of 0.05).

Discussion of Hughes et al. (44). It is useful to discuss the relationship between the findings reported here and those reported in a prior study by Hughes et al. (44). Briefly, the authors observed that affective (but not behavioral) regret sensitivity was lower in a group of 60 incarcerated offenders compared with 20 healthy volunteers, and reported weak evidence of an association between impulsive-antisocial (but not psychopathic) traits and behavioral regret sensitivity. This is in contrast to the present finding that lower behavioral regret sensitivity is specifically lower in psychopathic (but not impulsive-antisocial) individuals. There are several methodological differences between the two studies that account for the seemingly discrepant findings. First, the Hughes et al. primary comparison involved a contrast between 60 incarcerated offenders and 20 undergraduate controls. Despite demographic differences between these samples, they failed to consistently control for the potentially confounding effects of age, socioeconomic status, environmental exposures, substance abuse, education, ethnicity, and psychiatric illness. Post hoc analyses found a weak association between impulsive-antisocial traits and behavioral regret sensitivity. However, these analyses should be interpreted with caution given the authors' design and analysis choices. In particular, Hughes et al. used only 16 trials in their experimental design, compared with 80 in the current study [n.b. of the nine extant studies using the Camille et al. counterfactual paradigm (23), the median number of trials is 80; range: 60–192]. Furthermore, in their analyses of affective regret sensitivity, as few as 0 trials were included in their statistical model for some participants. Finally, Hughes et al. used mixed-effect linear/probit regression models with separate trialwise regret, disappointment, and expected value predictors. In all of the previous research that used this task, panel logit or linear mixed models were used to estimate how strongly participants relied on

prospective regret, disappointment, and expected value signals. Critically, given how the regret, disappointment, and expected value predictors are constructed, each of these shares some variance with the other. Appropriate statistical modeling requires that all three of these predictors be included in the same model; likewise, any examination of individual differences requires that the model include all three predictors and an additional three terms representing interactions between these predictors and some group or individual difference variable (e.g., psychopathy). For example, the inference that impulsive-antisocial traits affected the use of prospective regret signals in Hughes et al. (44) was derived from a model that included only regret and regret X impulsive-antisocial trait predictors. This is important because—given the covariance between regret, disappointment, and expected value predictors—it is impossible to know whether this effect is specific to the regret variable or is driven by disappointment or expected value. Considering the present data, the interaction between psychopathy and expected value is significant when we use a model that only includes expected value, psychopathy, and expected value X psychopathy predictors. However, this effect disappears when we model the data appropriately, showing that this apparent effect was actually driven by variance held in common with the other parameters (e.g., disappointment, regret). The modeling approach used by Hughes et al. (44) limits the inferential power of their findings and makes it challenging to compare the results of that study to the findings reported here. Overall, it is really difficult to compare the findings from the study by Hughes et al. (44) to the findings from the present study because their design and analytic choices preclude the possibility of examining the relationship between counterfactual decision making, psychopathy, and regret (prospective and retrospective).

Table S1. Sample characteristics

Characteristic	*N*	Min	Max	M	SD
Age	62	19	55	38.65	11.34
Sex (male)	62				
Race					
White	23				
Black	35				
Biracial	4				
Highest level of education		2	8	3.94	1.36
1. Grade 6 and below	0				
2. Grade 7–12	6				
3. Graduated high school or equivalent	18				
4. Some college	27				
5. Graduated 2-y college	2				
6. Graduated 4-y college	5				
7. Some graduate/professional school	2				
8. Completed graduate/professional school	2				
Annual Income		1	5	1.81	1.32
1. $0–$15,000	38				
2. $15,001–$30,000	13				
3. $30,001–$45,000	3				
4. $55,001–$60,000	1				
5. $60,001+	7				
Employment status		1	6	2.68	1.38
1. Full time	15				
2. Part time	9				
3. Unemployed	30				
4. Retired	0				
5. Disability	4				
6. Full-time student	4				
Number of arrests		0	40	4.19	6.61
0	16				
1–5	31				
6–10	9				
11+	6				
Number of incarcerations		0	11	0.94	1.71
0	30				
1–5	30				
6–10	1				
11+	1				
IQ	62	85	125	106.85	10.80
SRP-III total	62	100	236	163.35	28.83

Table S2. Zero-order correlations among task variables, key individual difference variables, and covariates

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Choice	1	0.073**	0.006	0.384**	0.323**	−0.131**	0.032*	0.008	−0.026	0.082**	−0.025	0.071**	−0.017	0.005
2. Rating 1 (partial)		1	0.535**	0.137**	−.065**	−0.077**	0.002	−0.025	−0.051**	0.065**	0.015	0.056**	−0.031*	−0.069**
3. Rating 2 (complete)			1	0.016	−0.059**	−0.007	0.040**	0	0.009	0.034**	−0.014	0.048**	−0.025	−0.047**
4. Regret (R)				1	0.331**	−.607**	0	0	0	0	0	0	0	0
5. Expected value (E)					1	0.159**	0	0	0	0	0	0	0	0
6. Disappointment (D)						1	0	0	0	0	0	0	0	0
7. SRP-III total score							1	0.750**	−0.140**	0.082**	−0.393**	0.333*	0.214**	0.224
8. ESI total score								1	−0.024	0.041**	−0.288**	0.203**	0.382**	0.146**
9. Age									1	−0.008	−0.051**	−0.043**	−0.175**	−0.050**
10. Education, y										1	−0.143**	0.513**	−0.158**	0.166**
11. Race/ethnicity											1	−0.244**	−0.097**	−0.044**
12. IQ (Shipley)												1	−0.476**	0.264**
13. Trait anxiety (STAI)													1	0.298**
14. Substance use, y														1

Note: Race/ethnicity was recoded into a dichotomous variable with White (1) and Non-White (0). *$P < 0.05$, **$P < 0.01$.

Table S3. List of trials

	Wheel 1					Wheel 2				
Trial	x_1	p	y_1	1 − p	Outcome	x_2	q	y_2	1 − q	Outcome
1	210	0.50	−70	0.50	210	70	0.75	−70	0.25	−70
2	−70	0.75	−210	0.25	−210	210	0.25	−210	0.75	−210
3	70	0.75	−210	0.25	70	210	0.25	−70	0.75	−70
4	70	0.50	−70	0.50	70	210	0.50	−210	0.50	210
5	210	0.25	−70	0.75	−70	210	0.50	−210	0.50	−210
6	70	0.50	−210	0.50	70	70	0.25	−70	0.75	−70
7	70	0.75	−70	0.25	70	210	0.50	−70	0.50	210
8	70	0.50	−70	0.50	−70	210	0.50	−210	0.50	210
9	210	0.25	70	0.75	210	210	0.50	−70	0.50	−70
10	210	0.50	70	0.50	210	210	0.75	−210	0.25	210
11	70	0.75	−210	0.25	70	210	0.50	−210	0.50	−210
12	70	0.75	−210	0.25	70	210	0.50	−210	0.50	−210
13	210	0.25	−70	0.75	210	70	0.50	−70	0.50	−70
14	70	0.75	−70	0.25	−70	210	0.25	70	0.75	70
15	−70	0.50	−210	0.50	−210	210	0.25	−210	0.75	210
16	210	0.25	70	0.75	210	210	0.50	−70	0.50	210
17	210	0.25	−210	0.75	210	−70	0.75	−210	0.25	−70
18	−70	0.50	−210	0.50	−210	70	0.25	−210	0.75	70
19	−70	0.50	−210	0.50	−210	70	0.25	−210	0.75	−210
20	70	0.75	−210	0.25	−210	210	0.25	70	0.75	210
21	−70	0.75	−210	0.25	−70	210	0.25	−210	0.75	−210
22	210	0.50	70	0.50	70	210	0.75	−210	0.25	210
23	70	0.50	−210	0.50	−210	70	0.25	−70	0.75	−70
24	70	0.50	−70	0.50	70	70	0.75	−210	0.25	−210
25	70	0.75	−70	0.25	70	70	0.75	−70	0.25	−70
26	210	0.50	−210	0.50	−210	210	0.25	−210	0.75	210
27	210	0.25	−70	0.75	−70	70	0.50	−70	0.50	70
28	70	0.50	−70	0.50	70	70	0.75	−210	0.25	70
29	210	0.25	70	0.75	70	210	0.75	−210	0.25	210
30	210	0.50	70	0.50	210	210	0.75	−70	0.25	210
31	70	0.75	−210	0.25	70	210	0.25	−70	0.75	−70
32	70	0.50	−70	0.50	70	210	0.25	−70	0.75	−70
33	210	0.75	−210	0.25	210	70	0.25	−210	0.75	−210
34	210	0.50	70	0.50	70	210	0.75	−70	0.25	−70
35	70	0.75	−210	0.25	70	210	0.25	−70	0.75	−70
36	70	0.75	−70	0.25	70	210	0.50	−210	0.50	−210
37	70	0.50	−210	0.50	−210	70	0.25	−70	0.75	70
38	−70	0.50	−210	0.50	−70	210	0.25	−210	0.75	−210
39	70	0.75	−70	0.25	70	210	0.25	−70	0.75	−70
40	70	0.25	−210	0.75	−210	−70	0.50	−210	0.50	−70
41	70	0.50	−70	0.50	70	70	0.75	−210	0.25	−210
42	70	0.50	−70	0.50	−70	210	0.25	−70	0.75	−70
43	210	0.50	−210	0.50	210	210	0.25	−210	0.75	−210
44	210	0.25	−70	0.75	−70	210	0.50	−210	0.50	210
45	70	0.75	−70	0.25	70	210	0.50	−70	0.50	−70
46	210	0.25	−210	0.75	210	70	0.50	−210	0.50	−210
47	210	0.25	−210	0.75	−210	70	0.50	−210	0.50	70
48	−70	0.75	−210	0.25	−70	210	0.50	−210	0.50	210
49	−70	0.50	−210	0.50	−70	70	0.25	−210	0.75	−210
50	210	0.50	70	0.50	70	210	0.75	−70	0.25	−70
51	210	0.50	70	0.50	210	210	0.75	−70	0.25	−70
52	210	0.50	−210	0.50	−210	210	0.25	−70	0.75	−70
53	210	0.50	−210	0.50	210	70	0.25	−210	0.75	−210
54	70	0.75	−70	0.25	70	210	0.50	−70	0.50	210
55	210	0.25	70	0.75	70	210	0.50	−70	0.50	210
56	210	0.50	−70	0.50	−70	210	0.75	−210	0.25	210
57	70	0.75	−210	0.25	70	210	0.25	−70	0.75	−70
58	−70	0.75	−210	0.25	−70	210	0.25	−210	0.75	−210
59	70	0.50	−70	0.50	−70	70	0.75	−210	0.25	70
60	70	0.75	−210	0.25	70	70	0.25	−70	0.75	−70
61	210	0.25	−210	0.75	−210	−70	0.50	−210	0.50	−70

Table S3. Cont.

	Wheel 1					Wheel 2				
Trial	x_1	p	y_1	1 − p	Outcome	x_2	q	y_2	1 − q	Outcome
62	210	0.75	−210	0.25	−210	210	0.25	70	0.75	210
63	210	0.50	70	0.50	210	210	0.75	−210	0.25	−210
64	210	0.25	−210	0.75	210	210	0.25	−210	0.75	−210
65	70	0.50	−210	0.50	70	70	0.25	−70	0.75	−70
66	210	0.25	70	0.75	70	210	0.75	−210	0.25	210
67	70	0.75	−70	0.25	−70	210	0.50	−70	0.50	−70
68	210	0.25	−210	0.75	210	70	0.75	−70	0.25	−70
69	210	0.50	70	0.50	210	210	0.50	−210	0.50	−210
70	210	0.25	70	0.75	210	210	0.50	−70	0.50	210
71	70	0.25	−210	0.75	70	70	0.50	−210	0.50	−210
72	−70	0.50	−210	0.50	−210	210	0.25	−210	0.75	−210
73	70	0.50	−70	0.50	70	210	0.75	−210	0.25	−210
74	210	0.25	−70	0.75	−70	210	0.50	−210	0.50	210
75	70	0.75	−210	0.25	−210	210	0.50	−210	0.50	210
76	210	0.50	70	0.50	70	210	0.75	−210	0.25	210
77	210	0.25	70	0.75	70	210	0.75	−210	0.25	210
78	210	0.75	−210	0.25	−210	210	0.50	−70	0.50	210
79	210	0.50	−210	0.50	−210	210	0.75	−210	0.25	210
80	70	0.50	−70	0.50	−70	210	0.50	−210	0.50	−210