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Change in motivational bias during treatment predicts outcome in anorexia nervosa

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Abstract

Objective: Reward and punishment sensitivity are known to be altered in anorexia nervosa (AN). Most research has examined these constructs separately although motivated behavior is influenced by considering both the potential for reward and risk of punishment. The present study sought to compare the relative balance of reward and punishment sensitivity in AN versus healthy controls (HCs) and examine whether motivational bias is associated with AN symptoms and treatment outcomes.

Methods: Adolescents and adults with AN ($n = 262$) in a partial hospitalization program completed the Eating Disorders Examination Questionnaire (EDE-Q), Behavioral Inhibition System/Behavioral Activation System (BIS/BAS) scales, and Sensitivity to Punishment/Sensitivity to Reward Questionnaire (SPSRQ) at admission and discharge. HCs (HC; $n = 90$) completed the BIS/BAS and SPSRQ. Motivational Bias Scores were calculated to reflect the dominance of reward versus punishment sensitivity.

Results: Individuals with AN demonstrated significantly greater bias toward punishment sensitivity than HC. In AN, a bias toward punishment was associated with higher EDE-Q Global score at admission. Change in motivational bias during treatment predicted EDE-Q Global scores, but not BMI, at discharge, with greater increases in reward sensitivity or greater decreases in punishment sensitivity during treatment predicting lower eating pathology. Similar findings were observed using the BIS/BAS and SPSRQ.

Discussion: Change in motivational bias during treatment is associated with improved outcomes in AN. However, it appears that much of the change in motivational bias can be attributed to changes in punishment sensitivity, rather than reward sensitivity. Future research should examine the mechanisms underlying punishment sensitivity decreases during treatment.

Public Significance: Sensitivity to reward and punishment may be important treatment targets for individuals with anorexia nervosa (AN). To date, most research has considered reward and punishment sensitivity separately, rather than examining their relationship to each other. We found that the balance of reward and punishment sensitivity (i.e.,

motivational bias) differs between healthy controls and those with AN and that this bias is associated with eating disorder symptoms and treatment outcome.

KEYWORDS
anorexia nervosa, motivation to approach, motivation to avoid, punishment sensitivity, reward sensitivity

1 | INTRODUCTION

Anorexia nervosa (AN) is a severe psychiatric illness characterized by dietary restriction, significant weight loss, and fear of weight gain. In addition to posing serious medical risk as malnutrition negatively impacts all major body systems (Gibson et al., 2020), AN is associated with significant worsening of multiple psychological symptoms (e.g., depression, anxiety, and obsessionality) and reduced quality of life (Pollice et al., 1997; van Hoeken & Hoek, 2020). A clear understanding of the factors that maintain AN behaviors (e.g., food restriction and excessive exercise) may illuminate useful targets for treatment and provide insight into the neurobiology underlying this disorder. Moreover, research is needed to understand how existing treatments influence putative maintenance factors and whether this contributes to change in eating disorder (ED) symptoms.

Human behavior is influenced by an individual's sensitivity to reward (i.e., responsivity to and/or approach toward positive consequences) and sensitivity to punishment (i.e., responsivity to and/or avoidance of aversive consequences) (Jonker et al., 2022). Individual differences in reward and punishment sensitivity can bias one toward greater approach motivation (i.e., driven by increased reward sensitivity) or greater avoidance motivation (i.e., driven by increased punishment sensitivity) (Tomer et al., 2014). A stable, extreme bias toward either approach or avoidance is thought to contribute to psychopathology, including externalizing behaviors such as substance use disorders or internalizing behaviors including anxiety and depression (Bijttebier et al., 2009). The biological underpinnings of reward and punishment sensitivity are thought to involve two motivational systems: the behavioral activation system (BAS), which activates behavior toward incentives, and the behavioral inhibition system (BIS), which guides behavior in response to aversive stimuli (Grays' Reinforcement Sensitivity Theory, Gray, 1981; Gray & McNaughton, 2000). Neuroimaging studies have established the association between approach/avoidance motivation and asymmetric activation of frontal brain regions, with greater left than right frontal activation linked to stronger approach motivation (higher BAS activity) and greater right than left frontal activation linked to stronger avoidance motivation (higher BIS activity) (Harmon-Jones et al., 2010; Murphy et al., 2003; Wager et al., 2003). More broadly, higher BAS (approach) has also been associated with increased ventral/dorsal striatum activation (Beaver et al., 2006; Hahn et al., 2009; Simon et al., 2010), whereas higher BIS (avoidance) is associated with insula and amygdala function (Kennis et al., 2013).

Notably, AN is thought to reflect dysregulation of these motivational systems, characterized by decreased approach motivation to rewarding outcomes and increased avoidance of aversive outcomes (Harrison et al., 2011; Kaye et al., 2013; Wierenga et al., 2014). For instance, studies using the BIS/BAS Questionnaire (Carver & White, 1994), a self-report measure designed to assess individual differences in the strength of the BAS (tendency to experience strong positive affect or behavioral approach in response to specific goal-oriented outcomes) and BIS (tendency to experience strong negative affect or behavioral inhibition in response to perceived threats), generally find increased BIS and decreased BAS in ED samples (Claes et al., 2006; Jonker et al., 2020; Harrison et al., 2010, 2011), consistent with other reports of decreased reward sensitivity (e.g., novelty seeking; Rybakowski et al., 2004) and elevated harm avoidance, intolerance of uncertainty, and anxiety (Glashouwer et al., 2014; Harrison et al., 2010, 2011; Jappe et al., 2011; Matton et al., 2013) in AN.

Neuroimaging studies assessing responsivity to rewarding outcomes such as pleasant taste and monetary gains also suggest deficits in basic reward processing and approach motivation in AN associated with decreased limbic-striatal reward response (Brooks et al., 2012; Fladung et al., 2013; Haynos et al., 2020; Kaye et al., 2020; Keating et al., 2012; Monteleone et al., 2017; O'Hara et al., 2015; Wierenga et al., 2014, 2015; Wu et al., 2016). While less is known about punishment systems at the neural level in AN, emerging evidence suggests altered frontal and striatal response to aversive outcomes such as unpleasant taste and monetary loss (Bernardoni et al., 2018; Bischoff-Grethe et al., 2013; Monteleone et al., 2017).

Though most prior research has examined reward and punishment sensitivity separately, decision-making is influenced by a consideration of both the potential for reward and risk of punishment (Verharen et al., 2020). Thus, it may be important not only to measure these constructs discretely but to evaluate their combined effect, a practice common in other fields such as computational psychiatry and neuropsychology (Dayan & Daw, 2008). For instance, the use of bias scores to examine individual-level cognitive asymmetries, derived from difference scores on individual tests (e.g., tests of verbal and visuospatial ability), has shown greater prognostic clinical utility than performance on individual tests (Houston et al., 2005; Jacobson et al., 2002, 2005). Similarly, motivational bias, reflecting the "relative dominance" of approach versus avoidance tendencies at the individual level has been evaluated using a difference score created by subtracting an individual's z-transformed BIS score from the z-transformed BAS score (Sutton & Davidson, 1997; Tomer et al., 2014). A positive value indicates relatively greater BAS activity. In healthy individuals, this bias score demonstrated better test–retest stability over a 5-month period than did individual BIS and BAS scores and was related to sensitivity to positive versus negative feedback in a learning

task. In separate studies it corresponded to prefrontal EEG asymmetry and asymmetry of frontal dopamine D2 receptor binding (Sutton & Davidson, 1997; Tomer et al., 2014), suggesting this self-report metric is conceptually similar to functional asymmetry associated with motivation bias, and may have greater clinical utility.

The present study sought to determine whether motivational bias as defined by the difference in BIS score and BAS Reward Responsiveness score differs significantly between healthy controls (HCs) and those with AN and whether bias scores are related to eating pathology at baseline and after treatment. We focused on BAS Reward Responsiveness since this scale is most aligned with the construct of reward sensitivity (Taubitz et al., 2015). To assess generalizability of this metric, we also calculated a Motivational Bias Score using the Sensitivity to Punishment Sensitivity to Reward Questionnaire (SPSRQ) (Cooper & Gomez, 2008), another commonly used self-report assessment that consists of questions related to both responsivity and approach/avoidance. Notably, whereas the BIS/BAS assesses sensitivity to general reward and punishment (e.g., "something I like"), the SPSRQ assesses sensitivity to specific rewarding and punishing cues (e.g., "obtaining money").

We hypothesized that individuals with AN would have a Motivational Bias Score weighted more heavily toward punishment sensitivity compared to HC and that this motivational bias would predict greater eating pathology. We also sought to understand whether a change in motivational bias over the course of treatment is associated with changes in eating pathology. Though reward and punishment sensitivity are conceptualized as trait-like characteristics that do not change substantially over time, recent studies show reductions in punishment sensitivity in patients with AN over the course of treatment (Harrison et al., 2016; Jonker et al., 2022). In contrast, existing research does not show significant changes in reward sensitivity during treatment (Harrison et al., 2016). If reward sensitivity remains constant, decreases in punishment sensitivity would result in a shift in motivational bias. However, previous research has not examined change in the relationship between punishment and reward sensitivity during treatment and its relationship to treatment outcome. We predicted that greater change in bias scores, with a shift away from greater punishment sensitivity, would predict fewer ED symptoms and increased weight at discharge. Importantly, we examined whether bias scores are robust to the measure used for their calculation (BIS/BAS and SPSRQ) and whether they provide value above and beyond examining reward or punishment sensitivity alone.

2 | METHODS

2.1 | Participants

Data from adolescents ($n = 145$) and adults ($n = 117$) with mixed AN ($N = 262$, 74% AN-R, 26% AN-BP, $M(SD)_{age} = 19.39(6.88)$ years, $M(SD)_{Admission\ BMI} = 17.82(1.75)$kg/m^2, $M(SD)_{Discharge\ BMI} = 20.31(2.11)$kg/m^2; see Table 1) who participated in a larger study examining naturalistic outcomes of an ED partial hospitalization program (PHP) and completed assessments at admission and discharge were included. AN data were collected between May 2016 and July 2021. Of note, an additional 106 individuals only completed admission assessments (see Supporting Information Methods). Adolescent HC ($n = 50$; $M(SD)_{age} = 16.14(1.25)$ years, $M(SD)_{BMI} = 20.78(1.97)$ kg/m^2) were recruited from the community as part of a larger study (R01MH113588) between July 2018 and November 2021. Adult HC ($n = 40$ $M(SD)_{age} = 20.10(3.45)$ years) were recruited from an undergraduate population at a local university between November 2021 and May 2022. These adult HC participants did not undergo diagnostic interviews to confirm the absence of an ED, but all had Eating Pathology Symptoms Inventory (EPSI) Body Dissatisfaction, Cognitive Restraint, Purging, Restricting, Binge Eating, and Exercise scores within 2 *SD*s of published norms for college students (Forbush et al., 2014). All study procedures were approved by the University of California, San Diego's Institutional Review Board (180055) and informed consent/assent was obtained prior to initiation of study procedures.

2.2 | Procedure

Criteria for admission to the PHP were consistent with the American Psychiatric Association's criteria guidelines for ED treatment (Yager

TABLE 1 Sample demographics.

	AN	HC
M (*SD*) or *n* (%)		
n	262	90
Female sex	252 (96.18%)	80 (88.89%)
Admission BMI (kg/m^2)	17.82 (1.75)	20.78 (1.96)[a]
Discharge BMI (kg/m^2)	20.31 (2.11)	-
Diagnosis		-
AN-R	195 (74.43%)	
AN-BP	67 (25.57%)	
Psychotropic medication	149 (56.87%)	-
Length of stay (days)	99.34 (42.94)	-
Race		
White	220 (83.97%)	61 (67.78%)
Asian	14 (5.34%)	17 (18.89%)
Black	0 (0.00%)	2 (2.22%)
Native Hawaiian/Pacific Islander	0 (0.00%)	0 (0.00%)
Native American/Alaska Native	2 (0.76%)	0 (0.00%)
Other or Multiracial	21 (8.02%)	10 (11.11%)
Not reported	5 (1.91%)	0 (0.00%)
Ethnicity		
Hispanic/Latino	33 (12.60%)	14 (15.56%)
Not Hispanic/Latino	228 (87.02%)	76 (84.44%)
Not reported	1 (0.38%)	0 (0.00%)

Note: Groups did not differ significantly on any demographic characteristics.
[a]BMI data were only available for the adolescent healthy control sample, and not the adult healthy control sample.

et al., 2014). For details regarding patient programming across the adult and adolescent programs, see Brown et al. (2018) and Reilly et al. (2020), respectively. Patients were given the option to participate in the study at admission. Interested individuals consented and completed self-report measures at admission (±14 days; $M(SD) = 4.64$ (3.33) days post-admission), 4 weeks into treatment, discharge (±14 days; $M(SD) = -1.58(4.86)$ days post discharge), and at several follow-up timepoints as part of the larger study.

2.3 | Measures

2.3.1 | Diagnostic interviews

Diagnoses were established using semi-structured interviews administered by trained bachelor's-level research assistants and doctoral-level trainees. Adult participants completed the Structured Clinical Interview for DSM-5 (SCID-5; (First, 2014)) or the MINI Neuropsychiatric Interview 7.0 (Sheehan et al., 1998), while adolescent participants completed the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Aged Children (K-SADS; Kaufman et al., 1997) or the MINI-KID (Sheehan et al., 2010). Assessors were extensively trained in diagnostic interviews and received supervision from two licensed clinical psychologists with expertise in diagnostic interviewing. Assessors were observed regularly and attended weekly diagnostic consensus meetings and individual assessment consultation as needed.

2.3.2 | Anthropometrics

Height and weight were measured to calculate body mass index (BMI).

2.3.3 | Eating Disorder Examination Questionnaire

The 28-item Eating Disorder Examination Questionnaire (EDE-Q; Fairburn & Beglin, 2008) was used to measure eating pathology at admission and discharge. The EDE-Q is scored using a 7-point (0–6) scale, with greater scores indicating greater severity. The current study used the Global score, which is calculated by computing the mean of all four subscale scores (dietary restraint, shape concerns, eating concerns, and weight concerns). The Global score had excellent internal consistency in our sample at admission ($\alpha = .92$) and discharge ($\alpha = .92$).

2.3.4 | Behavioral Inhibition System/Behavioral Activation System (BIS/BAS) Scales

The 24-item BIS/BAS (Carver & White, 1994) scales were used to measure reward and punishment sensitivity. The BIS/BAS is scored using a 4-point scale ranging from 1 (very true for me) to 4 (very false for me). Responses were reverse scored (with the exception of items 2 and 22), such that higher scores indicate greater reward or punishment sensitivity. This measure generates four subscales: one BIS subscale which measures negative affect and tendency to avoid perceived threats (punishment sensitivity) and three BAS subscales assessing three domains of positive affect and tendency to approach goal-directed outcomes (reward sensitivity): Reward Responsiveness, Drive, and Fun-seeking. The current study used scores on the BIS and BAS Reward Responsiveness subscales to index punishment and reward sensitivity. The BAS Reward Responsiveness subscale is purported to be a purer measure of the behavioral approach system than the other BAS subscales, which measure persistence in pursuing goals (BAS Drive) and desire for novel, spontaneous rewards and thought to reflect impulsivity (Fun-Seeking). BIS and BAS Reward Responsiveness subscales showed adequate internal consistency in our sample at admission ($\alpha = .70–.76$) and discharge ($\alpha = .73–.76$).

2.3.5 | Sensitivity to Punishment/Sensitivity to Reward Questionnaire

The Sensitivity to Reward and Sensitivity to Punishment subscales of the 24-item shortened Sensitivity to Punishment/Sensitivity to Reward Questionnaire (SPSRQ; Cooper & Gomez, 2008) were used as an alternative measure of reward and punishment sensitivity. Each item is answered as either "yes" (1) or "no" (0) and items within each subscale are summed to create a total subscale score. SPSRQ subscales (Sensitivity to Reward [SR] and Sensitivity to Punishment [SP]) showed adequate to good internal consistency in our sample at admission ($\alpha = .66–.86$) and discharge ($\alpha = .72–.84$). For participants who received the full-length version of the SPSRQ, we calculated short-form scores.

2.4 | Statistical analysis

Analyses were conducted in SPSS 28.0. To compute a Motivational Bias Score, we first scaled "reward" and "punishment" scores on the BIS/BAS and SPSRQ, since the range of possible scores on the reward and punishment subscales of both measures differs (i.e., scores on the BAS-Reward Responsiveness subscale can range from 5 to 20, while BIS subscale scores can range from 7 to 28; scores on the SPSRQ-SR subscale range from 0 to 10, while scores on the SP subscale range from 0 to 14). Both measures had punishment subscales with more items, so we divided total punishment score by the number of items in the subscale, and then multiplied this value by the number of items in the reward subscale of the measure to scale scores. Then, to derive Motivational Bias Scores, we subtracted punishment sensitivity scaled scores from reward sensitivity scores, similar to prior studies (Sutton & Davidson, 1997; Tomer et al., 2014), but using calibrated scores rather than z-scores given that z-scores are dependent on the normative sample used. Thus, positive bias scores reflect higher reward sensitivity than punishment sensitivity and negative bias scores reflect higher punishment sensitivity than reward sensitivity. Participants with a bias score of zero have balanced reward and punishment sensitivity. We calculated bias scores separately for the BIS/BAS and for the SPSRQ. To compute change in bias score

from admission to discharge, we subtracted baseline bias scores from discharge bias scores. Participants with positive change scores decreased in punishment sensitivity or increased in reward sensitivity from baseline to discharge, while participants with negative change scores increased in punishment sensitivity or decreased in reward sensitivity from baseline to discharge.

Data were examined and conformed to assumptions of normality. To test cross-sectional hypotheses, independent samples *t*-tests were used to compare differences between reward sensitivity, punishment sensitivity, and bias scores in individuals with AN versus HC at baseline, using both the BIS/BAS and SPSRQ. In individuals with AN, linear regressions were used to examine the relationship between bias scores and eating pathology/BMI at admission, controlling for age. To test longitudinal hypotheses, separate linear regressions were used to examine the relationship between admission bias scores and change in eating pathology/BMI at discharge (controlling for age, length of stay, and admission eating pathology/BMI), and change in bias scores and change in eating pathology/BMI at discharge (controlling for age, length of stay, admission eating pathology/BMI, and admission bias score) (Fisher, 2003; Schlegl et al., 2016). Regressions were repeated with reward sensitivity and punishment sensitivity to examine whether bias scores provided added predictive value over reward or punishment sensitivity alone. Sensitivity analyses examined the impact of medication use, BMI, age, AN subtype, and weight status at admission on our findings, and examined whether individuals who did not complete measures at discharge differed significantly from those who did. Lastly, to better understand change in BIS/BAS and SPSRQ, we examined item-level changes from admission to discharge using paired *t*-tests. For regression analyses, Bonferroni correction was used to determine a family-wise *p*-value of .006 for the 2 bias motivation predictors (admission, change), 2 clinical measures (EDE-Q, BMI) across 2 measures (BIS/BAS, SPSRQ).

3 | RESULTS

3.1 | Reward sensitivity, punishment sensitivity, and motivational bias in AN at admission versus HC

See Table S1 for correlations between variables of interest. BAS-Reward Responsiveness scores were higher in HC relative to AN, and

TABLE 2 AN and HC scores on measures.

	HC	AN-admission	AN-discharge	AN-change	HC versus AN-admission (*t*, *d*)	HC versus AN-discharge (*t*, *d*)	AN-admission versus AN-discharge (*t*, *d*)
EDE-Q Global	-	3.67 (1.49)	2.18 (1.47)	−1.50 (1.50)	-	-	16.10, 1.00*
BAS-Reward	17.54 (1.86)	16.40 (2.54)	16.22 (2.62)	−0.18 (2.37)	6.00, 1.01*	4.41, 0.58*	1.23, 0.08
BIS-Punish	21.00 (3.62)	24.34 (2.99)	23.69 (3.47)	−0.65 (2.80)	14.33, 2.12*	6.27, 0.76*	3.73, 0.23*
BIS/BAS Bias Score	2.54 (2.91)	−0.98 (3.20)	−0.70 (3.49)	0.28 (3.05)	9.23, 1.13*	7.91, 1.01*	1.50, 0.09
SPSRQ Short-SR	4.79 (2.33)	4.65 (2.33)	4.70 (2.53)	0.05 (1.82)	0.49, 0.06	0.30, 0.04	0.44, 0.03
SPSRQ Short-SP	6.19 (3.97)	9.71 (3.51)	9.09 (3.78)	−0.63 (2.89)	7.47, 0.97*	6.20, 0.75*	3.50, 0.22*
SPSRQ Bias Score	0.37 (4.04)	−2.29 (3.56)	−1.79 (3.81)	0.50 (2.64)	5.54, 0.72*	4.57, 0.55*	3.04, 0.19*

Abbreviations: BAS, Behavioral Activation Scale; BIS, Behavioral Inhibition Scale; EDE-Q, Eating Disorder Examination-Questionnaire; SP, Sensitivity to Punishment; SPSRQ, Sensitivity to Punishment/Sensitivity to Reward Questionnaire; SR, Sensitivity to Reward.
*$p < .05$.

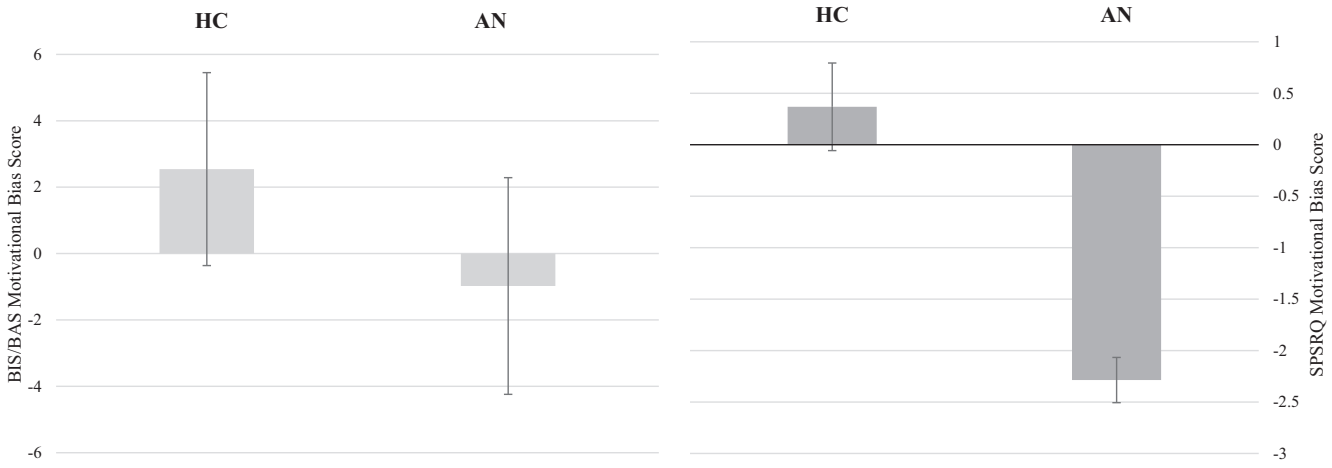

FIGURE 1 Differences in the balance of reward and punishment sensitivity between AN and HC. Positive bias scores reflect a tendency toward greater reward sensitivity, while negative bias scores reflect a tendency toward greater punishment sensitivity.

BIS scores were higher in AN relative to HC (Table 2). SPSRQ sensitivity to reward scores did not differ between AN and HC, whereas SPSRQ sensitivity to punishment scores were higher in AN relative to HC.

Bias scores calculated from the BIS/BAS differed between HC and AN at admission, such that individuals with AN had scores weighted more heavily toward punishment than HC (see Figure 1). Similarly, bias scores calculated from the SPSRQ were also

TABLE 3 Regression analysis exploring associations between Motivational Bias Score and ED symptoms.

	Adjusted R^2	*B*	*SE*	*β*	*t*	*p*
Outcome variable: Admit EDE-Q Global						
Full model: $F(2, 259) = 9.64$, $p < .001$	0.06					
Constant		3.60	0.27		13.45	<.001
Age		<−0.01	0.01	−.01	−0.19	.85
BIS/BAS Motivational Bias Score		−0.12	0.03	−.26	−4.39	<.001
Outcome variable: Discharge EDE-Q Global						
Full model: $F(4, 257) = 20.16$, $p < .001$	0.23					
Constant		0.74	0.33		2.23	.03
Age		−0.02	0.01	−.07	−1.23	.22
Length of stay		<0.01	<0.01	−.01	−0.09	.93
Admit EDE-Q Global		0.47	0.06	.48	8.41	<.001
BIS/BAS Motivational Bias Score		−0.01	0.03	−.02	−0.39	.70
Outcome Variable: Discharge EDE-Q Global						
Full model: $F(5, 256) = 24.92$, $p < .001$	0.31					
Constant		0.68	0.31		2.18	<.01
Age		−0.01	0.01	−.03	−0.48	.63
Length of stay		<−0.01	<0.01	−.03	−0.63	.53
Admit EDE-Q Global		0.46	0.05	.47	8.75	<.001
Admit Bias Score		−0.07	0.03	−.15	−2.54	.01
Change in BIS/BAS Motivational Bias Score		−0.16	0.03	−.33	−5.80	<.001
Outcome variable: Admit EDE-Q Global						
Full model: $F(2, 259) = 9.92$, $p < .001$	0.06					
Constant		3.35	0.28		12.11	<.001
Age		<0.01	0.01	.02	−0.28	.78
SPSRQ Motivational Bias Score		−0.11	0.03	−.27	−4.46	<.001
Outcome variable: Discharge EDE-Q Global						
Full model: $F(4, 257) = 20.30$, $p < .001$	0.23					
Constant		0.72	0.33		2.18	.03
Age		−0.01	0.01	−.07	−1.17	.25
Length of stay		<−0.01	<0.01	−.01	−0.11	.91
Admit EDE-Q Global		0.47	0.06	.47	8.32	<.001
SPSRQ Motivational Bias Score		−0.02	0.02	−.04	−0.76	.45
Outcome variable: Discharge EDE-Q Global						
Full model: $F(5, 256) = 18.39$, $p < .001$	0.25					
Constant		0.73	0.32		2.24	.03
Age		−0.01	0.01	−.04	−0.69	.49
Length of stay		<−0.01	<0.01	−.03	−0.51	.61
Admit EDE-Q Global		0.45	0.06	.46	8.19	<.001
Admit Bias Score		−0.04	0.02	−.09	−1.61	.11
Change in SPSRQ Motivational Bias Score		−0.09	0.03	−.17	−2.90	.004

Abbreviations: B, unstandardized beta; *SE*, standard error; *β*, standardized beta.

significantly lower in AN at admission compared to HC. See Table 2 for comparisons between HC and AN at discharge. Notably, SPSRQ ($r = -.13$, $p = .21$) and BIS/BAS bias scores ($r = -.12$, $p = .28$) were not associated with age in the HC sample or the AN sample ($r = -.05$–$.06$, $p = .38$–$.42$).

3.2 | Relationship between motivational bias and ED severity at admission

Controlling for age, regression analyses indicated that BIS/BAS bias score was associated with admit EDE-Q Global score, such that a

TABLE 4 Regression analysis exploring associations between motivational bias score and BMI.

	Adjusted R^2	*B*	*SE*	*β*	*t*	*p*
Outcome variable: Admit BMI						
Full model: $F(2, 259) = 0.54$, $p = .58$	−0.004					
Constant		17.53	0.33		53.83	<.001
Age		0.02	0.02	.06	1.00	.32
BIS/BAS Motivational Bias Score		0.01	0.03	.02	0.36	0.72
Outcome variable: Discharge BMI						
Full model: $F(4, 256) = 50.13$, $p < .001$	0.44					
Constant		8.47	0.91		9.36	<.001
Age		−0.02	0.01	−.08	−1.59	.11
Length of stay		0.01	<0.01	.32	6.64	<.001
Admit BMI		0.62	0.05	.60	12.74	<.001
BIS/BAS Motivational Bias Score		0.04	0.03	.08	1.59	.11
Outcome variable: Discharge BMI						
Full model: $F(5, 255) = 40.43$, $p < .001$	0.43					
Constant		8.54	0.91		9.42	<.001
Age		−0.02	0.01	−.09	−1.74	.08
Length of stay		0.01	<0.01	.33	6.72	<.001
Admit BMI		0.62	0.05	.60	12.68	<.001
Admit Bias Score		0.06	0.03	.10	1.91	.06
BIS/BAS change in Motivational Bias Score		0.04	0.03	.06	1.16	.25
Outcome variable: Admit BMI						
Full model: $F(2, 259) = 0.48$, $p = .62$	−0.004					
Constant		17.52	0.34		52.03	<.001
Age		0.02	0.02	.06	0.98	.33
SPSRQ Motivational Bias Score		<−0.01	0.03	<−.01	−0.05	.96
Outcome variable: Discharge BMI						
Full model: $F(4, 256) = 49.01$, $p < .001$	0.43					
Constant		8.43	0.91		9.25	<.001
Age		−0.02	0.01	−.08	−1.65	.10
Length of stay		0.01	<0.01	.32	6.54	<.001
Admit BMI		0.62	0.05	.60	12.71	<.001
SPSRQ Motivational Bias Score		<−0.01	0.02	<−.01	0.03	.98
Outcome variable: Discharge BMI						
Full model: $F(5, 255) = 39.57$, $p < .001$	0.43					
Constant		8.56	0.92		9.33	<.001
Age		−0.02	0.01	−.09	−1.82	.07
Length of stay		0.01	<0.01	.33	6.65	<.001
Admit BMI		0.61	0.05	.59	12.51	<.001
Admit Bias Score		0.01	0.03	.02	0.32	.75
Change in SPSRQ Motivational Bias Score		0.04	0.03	.06	1.20	.23

Abbreviations: *B*, unstandardized beta; *SE*, standard error; *β*, standardized beta.

bias weighted more heavily toward punishment was associated with a higher EDE-Q Global score (Table 3) at admission. Consistent with findings using the BIS/BAS, SPSRQ bias score at admission weighted more toward punishment was also associated with higher EDE-Q Global score at admission.

Controlling for age, regression analyses indicated that BIS/BAS bias score and SPSRQ bias score were not associated with admit BMI score (Table 4).

3.3 | Relationship between motivational bias and ED severity at discharge

Controlling for age, length of stay, and admit EDE-Q Global score, BIS/BAS bias score at admission did not predict discharge EDE-Q Global score (Table 3). Controlling for age, length of stay, admit EDE-Q Global, and admit bias scores, change in BIS/BAS bias score emerged as a significant predictor of EDE-Q Global score at discharge (Table 3). Consistent with findings using the BIS/BAS, SPSRQ bias scores at admission did not predict EDE-Q Global at discharge. Similar to what was observed using the BIS/BAS, change in SPSRQ bias scores from admission to discharge predicted discharge EDE-Q Global, controlling for age, length of stay, and admit EDE-Q Global score.

In contrast, controlling for age, length of stay, and admit BMI, bias score at admission did not predict discharge BMI, using either BIS/BAS or SPSRQ bias score (Table 4). Additionally, controlling for age, length of stay, admit BMI, and admit bias scores, change in bias score did not predict discharge BMI, using either BIS/BAS or SPSRQ bias score (Table 4).

3.4 | Predictive value of reward sensitivity and punishment sensitivity alone

To understand whether bias scores provide additional value above and beyond considering reward sensitivity and punishment sensitivity alone, we conducted separate analyses using reward sensitivity alone and punishment sensitivity alone as predictors (Tables S2 and S3). Punishment sensitivity, but not reward sensitivity, at admission was associated with admit EDE-Q Global scores, such that higher punishment sensitivity related to higher EDE-Q Global scores. This relationship held using either the BIS/BAS or SPSRQ. However, neither punishment sensitivity nor reward sensitivity at admission were associated with BMI. Neither reward sensitivity alone nor punishment sensitivity alone at admission predicted discharge EDE-Q Global scores or BMI. Change in punishment sensitivity, but not reward sensitivity, during treatment predicted EDE-Q Global scores at discharge using both the BIS/BAS and SPSRQ, but did not predict discharge BMI.

3.5 | Sensitivity analyses

Sensitivity analyses assessed how results might vary when restricting our models to subgroups (i.e., adults only, adolescents only, AN-R only, AN-BP only, underweight participants only) and when controlling for additional variables (i.e., psychotropic medication). Overall, results were robust to medication use, age, and weight status (Tables S6–S9, S12, and S13). However, when restricting analyses to patients with AN-BP only (AN-BP had significantly greater change in bias scores than AN-R, $t(260) = 2.04$, $p = .04$), change in bias score no longer significantly predicted EDE-Q Global at discharge (Tables S10 and S11). Given the small AN-BP sample size, we were only powered to detect medium or large effects, and power analyses suggest a sample size of 81 would have been necessary to detect small effects. Lastly, item-level changes in BIS/BAS and SPSRQ scores between admission and discharge are reported in Tables S4 and S5. On both measures, scores generally changed on punishment sensitivity, but not reward sensitivity, items.

4 | DISCUSSION

Findings suggest motivational bias is significantly shifted toward punishment versus reward sensitivity in AN compared to HC and is related to ED symptoms, but not BMI, in AN. This replicates prior work suggesting punishment sensitivity is an important driver of outcome in AN (Jonker et al., 2022). Greater negative Motivational Bias Scores in AN suggest that the risk of punishment may be weighed more heavily in decision-making versus the potential for reward, while HC may factor the potential for reward more heavily. Change in bias scores during treatment predicted change in ED symptoms, though this effect appears to be primarily driven by decreases in punishment sensitivity rather than by increases in reward sensitivity. Overall, results support motivational bias as relevant construct in AN in addition to reward sensitivity and punishment sensitivity.

In line with hypotheses, Motivational Bias Scores differed significantly between AN and HC and this was observed even at discharge for patients with AN. While the present study was the first to our knowledge to calculate Motivational Bias Scores in individuals with EDs, these findings are consistent with prior work that has shown elevated punishment sensitivity in AN versus HC (Glashouwer et al., 2014; Harrison et al., 2010; Jappe et al., 2011) and some work showing that reward sensitivity also differs between these groups (Jappe et al., 2011). Of note, we observed decreased reward sensitivity in AN compared to HC when using the BIS/BAS but not the SPRSQ, consistent with previous studies (Glashouwer et al., 2014) and suggestions that mixed findings regarding reward sensitivity in AN may be in part due to measurement variance (i.e., due to the specific nature of the items included in the SPSRQ) (Jonker et al., 2022). This was the only finding that differed based on the measurement used, as otherwise results were similar across the BIS/BAS and SPSRQ. Interestingly, the current study found that at baseline, higher punishment sensitivity and lower reward sensitivity were associated with ED symptoms, providing additional evidence to suggest that an imbalance in both motivational bias systems may increase ED severity.

In contrast to hypotheses, Motivational Bias Scores at admission did not predict symptom severity at discharge. Prior work has shown

that pre-treatment punishment sensitivity is associated with treatment outcome in adolescent AN (Jonker et al., 2022). It is possible that the relative balance of reward and punishment sensitivity at admission is less important for treatment outcome than the absolute punishment sensitivity score. However, consistent with our hypotheses, change in motivational bias from admission to discharge did predict treatment outcome, although changes in punishment sensitivity alone also predicted treatment outcome. Changes that tipped the balance away from punishment sensitivity were associated with lower EDE-Q Global scores at discharge. This finding builds on prior work indicating that decreases in punishment sensitivity from pre- to post-treatment are associated with greater improvement in ED symptoms even when measures of punishment sensitivity did not change significantly or change only minimally over the course of treatment for AN (Jonker et al., 2022). Indeed, given minimal changes in reward sensitivity from admission to discharge, our findings that changes in motivational bias predicted treatment outcomes appears to primarily be accounted for by punishment sensitivity. While adolescents might be expected to have higher reward sensitivity than adults given neurodevelopmental factors (Galván, 2013), we did not find associations between age and bias score in either HCs or AN.

Changes in bias score predicted ED symptoms at discharge, but bias score and changes in bias score did not predict BMI. The discrepancy between findings with EDE-Q scores and BMI may be explained in part by a relatively restricted BMI range, given that participants were not discharged until they reached a certain BMI (whereas they may have been discharged regardless of EDE-Q score). The inclusion of AN in partial remission in our sample could have affected findings, although sensitivity analyses restricting the sample to those with low weight at admission also did not suggest a relationship between bias scores and BMI.

A closer look at the individual items on the punishment sensitivity subscales that changed significantly among patients from admission to discharge suggest that the change captured by the BIS and SP scales reflects change specifically in the experience of anxiety, fear, and worry. This is consistent with findings showing reductions in anxiety in patients with AN over the course of treatment, though the literature is mixed (Kezelman et al., 2015), and suggests that anxiety reduction may be mechanism underlying improved ED symptomatology despite continued sensitivity to punishment, as items related to salience of potentially aversive outcomes remained stable over time. Thus, further study is needed to elucidate the factors that contribute to reductions in anxiety and punishment sensitivity during treatment of AN.

The current study is strengthened by the size of the clinical sample, use of validated clinical interviews for diagnosis, a longitudinal design, and multiple measures of reward and punishment sensitivity which allowed for construct replication. However, findings should also be taken in the context of limitations. We are limited by the use of self-report measures that conflate distinct processes; reward is increasingly understood to encompass several distinct processes such as "liking" and "wanting" (Berridge et al., 2009) and similarly, recent definitions of reward and punishment sensitivity include both stimulus responsivity (response to rewarding or punishing stimuli) and approach/avoidance behavior (tendency to approach or avoid such stimuli) (see Jonker et al., 2022). Neither the BIS/BAS nor SPSRQ differentiate between these constructs. Future work should employ measures that assess both components, such as the Reward and Punishment Responsivity and Motivation Questionnaire (RPRM-Q) (Jonker et al., 2022). Additionally, due to the study's naturalistic design, we are unable to parse which components of treatment may drive change in bias scores, reward sensitivity, and punishment sensitivity. Further, we note that diagnostic interviews were not conducted with adult HCs, raising the possibility that undetected eating pathology and other psychopathology may have been present, which could have minimized observed group differences. While we took steps to ensure participants were within norms for college students based on EPSI scores, we acknowledge this is an imperfect method for ensuring that controls are free from ED symptoms.

In summary, we found that Motivational Bias Scores differed between AN and HC and this is related to ED symptoms, but not BMI. Additionally, while Motivational Bias Scores at admission did not predict treatment outcomes, change in Motivational Bias Scores over the course of treatment was a significant predictor of outcome. However, these changes are primarily accounted for by changes in punishment sensitivity. Given that changes in both reward and punishment sensitivity and changes in bias scores are predictive of treatment outcome, using bias scores may be a more parsimonious approach to accounting for these variables. Punishment sensitivity in particular may be an important mechanism of change in treatment. Though punishment sensitivity is likely biologically determined and some work has shown that punishment sensitivity may be somewhat resistant to change (Harrison et al., 2016), most current evidence-based treatments do not address reward and punishment sensitivity. It is possible that tailored interventions may assist in modulating punishment sensitivity and the extent to which punishment sensitivity influences behavior (Haynos et al., 2023). Findings also speak to the importance of targeting anxiety reduction in ED treatment as a potential approach to modifying punishment sensitivity. Given its established relationship to ED outcomes, future research should assess predictors of change in punishment sensitivity during ED treatment and the mechanisms by which changes in punishment sensitivity occur during treatment.

AUTHOR CONTRIBUTIONS

Sophie R. Abber: Conceptualization; formal analysis; writing – original draft; writing – review and editing. **Susan M. Murray:** Conceptualization; writing – original draft; writing – review and editing. **Carina S. Brown:** Data curation; writing – review and editing. **Christina E. Wierenga:** Conceptualization; data curation; methodology; supervision; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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