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Body Appearance Values Modulate Risk Aversion in Eating Restriction

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The understanding of eating disorders is hindered by the lack of integration between existing psychosocial and neurobiological approaches. We address this problem by developing a novel transdiagnostic and computational approach to eating restriction decisions. We first validated a novel paradigm which extends an established monetary risk task to involve body stimuli with psychosocial values. We used advanced behavioral data analysis of a large (total $N = 539$) sample of women from across the eating restraint spectrum, including those with anorexia nervosa (AN; $n = 31$), recovered from AN ($n = 23$), and subclinical women with varying levels of eating restraint ($n = 485$), obtained from an online experiment, public event, and laboratory-based study. We found that social and motivational values regarding body appearance have a significant effect on value-based, decision making in eating restriction. Subsequently, validated descriptive and predictive advanced computational modeling indicated that these behaviors are driven by an aversion to risk rather than loss, with desirable body outcomes being associated with less risk aversion, and undesirable body outcomes linked to greater risk aversion. These findings indicate that cognitive and social factors influence eating decisions by distinct mechanisms.

Public Significance Statement

This study demonstrates how socially derived values about the body's ideal appearance can influence risk taking in women who restrict their eating. We cast new light on eating decisions and why some women may choose to take significant health risks in the pursuit of thinness.

Keywords: risk-taking, decision making, restrictive eating, anorexia nervosa, computational modeling

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Making decisions is a fundamental part of everyday life. Watch a movie, or get a couple of extra hours of sleep? Accept the new job offer or stay at the current post? Invest time in learning a new skill or build on current potential? How do we choose between such complex options with different potential gains and losses? According to the framework of value-based decision making, people are able to ascribe subjective value to different options based on their preferences and hence make decisions (Berkman et al., 2017; Rangel et al., 2008). Specifically, people are able to integrate the various gains (e.g., money, self-fulfillment) and costs (e.g., time, risk, energy) of each option into a subjective value function and thus make choices according to the overall (net) value of each option. Value-based decision making has been extensively examined in behavioral, neural, and computational sciences (e.g., Apps et al., 2015; Arulpragasam et al., 2018; Copeland et al., 2022; Levy & Glimcher, 2012).

In addition to relatively abstract choices such as, for example, economic decisions, value-based decision making provides a means of understanding decisions that may affect the body directly, such as decisions around eating and nutrition. The neurobiological regulation of eating is of fundamental homeostatic importance. In contemporary societies where food availability and variety are high, decisions around eating regulation may involve eating restriction (i.e., avoidance of calorie intake) and restraint (effortful attempts to reduce calorie intake; see Coniglio et al., 2018; Forbush et al., 2013; Stice et al., 2007). Recent years have seen an increase in eating restrictions beyond health purposes (Lowe & Levine, 2005), with well-documented risks for adverse physical and psychological effects (French & Jeffery, 1994; Hawks et al., 2008; Polivy, 1996). In neurobiology, restrictive eating (we use this term to address both eating restriction and restraint as defined above; see also Method section) is understood as an abnormality in the bodily systems that mediate energy homeostasis (metabolism), and the complex appetitive motivation systems regulating hunger and satiation. For instance, neuroimaging studies suggest that restrictive eating is the result of decisions based on skewed interactions between dopamine-based reward-learning systems and serotonin-based control or inhibitory systems (see Kaye et al., 2013). However, it has become clear that a generalized blunting of reward responsivity to food is insufficient to explain eating restriction, and studies on eating should take into account many entangled components of value-based decisions, such as valuation, risk preference and aversion, loss aversion, and the handling of uncertainty.

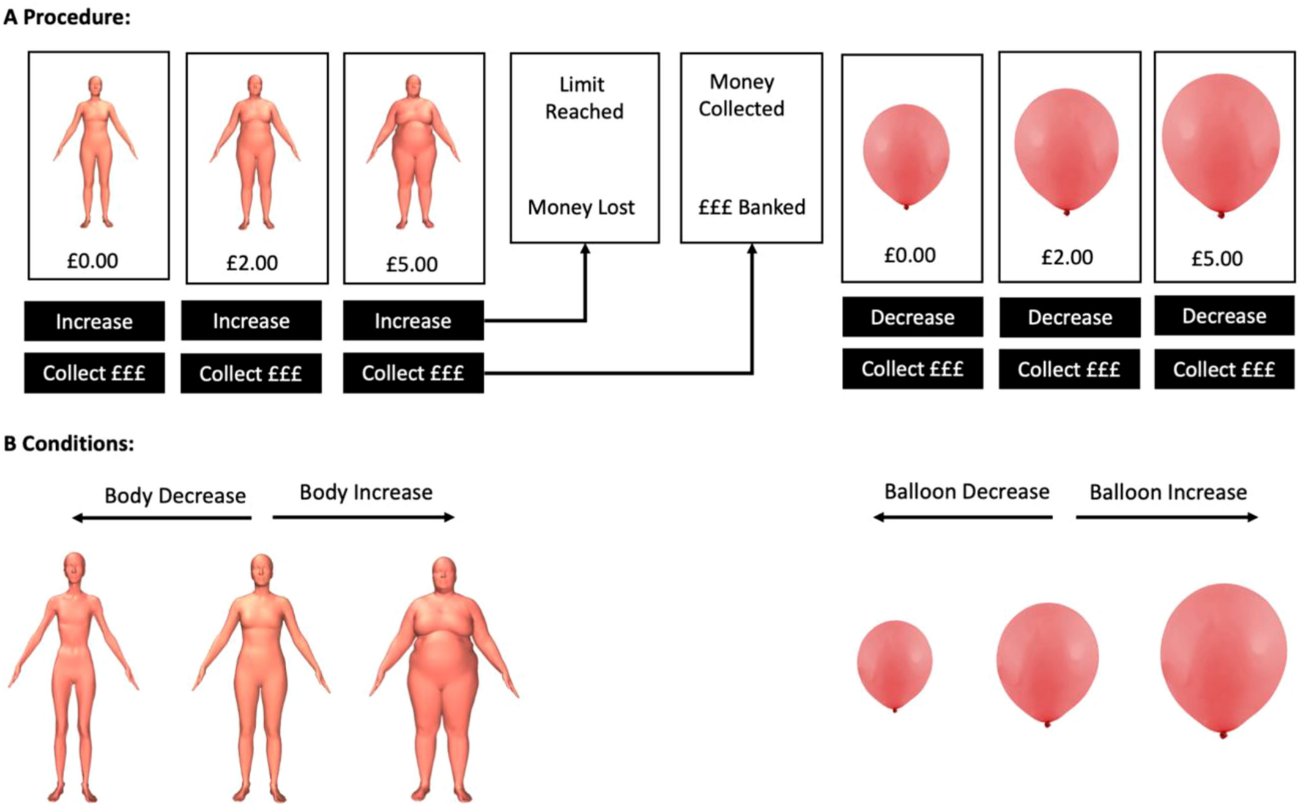
For example, patients with anorexia nervosa (AN), an eating disturbance characterized by an intense fear of gaining weight despite being underweight, a disturbed body image, and a relentless pursuit of thinness (American Psychiatric Association, 2013), have been found to make less risky choices than healthy controls (HCs) on tasks such as the Balloon Analogue Risk Task (BART; Adoue et al., 2015). The BART assesses how people balance potential reward against the possibility of loss under uncertain conditions (i.e., when the particular probability of loss is unknown during the task). Yet studies using various tasks involving *monetary* rewards in AN (King et al., 2016; McClelland et al., 2016; Wu et al., 2016) and in community samples with eating restrictions (Leitch et al., 2013; Yeomans & Brace, 2015), have resulted in mixed findings. Some studies find no differences in sensitivity to loss or punishment between restricting and nonrestricting groups (Chan et al., 2014), while others have found that eating restriction is associated with a *hyper*sensitivity to punishment (Bernardoni et al., 2018), *hypo*sensitivity to loss (Verharen et al., 2019), or a self-reported *heightened* sensitivity to both reward and punishment (Jappe et al., 2011). There can be at least three reasons for such discrepancies that the present study aims to address.

First, existing paradigms typically examine decision making as driven by the evaluation of abstract monetary rewards, and fail to manipulate parameters that most relate to eating restriction. One possibility is that eating restriction is modulated by the interaction of multiple motivations, which likely also include social parameters such as the Western "thin ideal," which places a positive value on a slim body and a negative value on larger body appearances. Thin ideal internalization (i.e., the extent to which an individual ascribes to this social value; Diedrichs, 2015) has been proposed as a key explanation of eating restriction in psychosocial accounts, with supporting evidence from various correlational, cross-sectional, and experimental studies (Becker et al., 2002; Grabe et al., 2008). Yet to our knowledge, no study on clinical or subclinical eating restriction has explicitly examined the subjective value ascribed to body outcomes in value-based, decision making under risk, and hence the combined effects of risk preference and societal ideals have not been examined in eating restriction.

To address this first aim, we developed the Body and Balloon Analogue Risk Task (B-BART; see Figure 1). Participants make consecutive decisions to "click" a button in order to accumulate money, or stop clicking and "collect" the money already accumulated. In separate conditions, each click causes a virtual body or balloon to increase (get bigger/fatter) or decrease (get smaller/thinner) in size, but carries the risk of reaching a limit ("loss limit"), which ends the trial, at which point the accumulated money not "collected" is lost. We hypothesized that desired and/or undesired body options may be overvalued in relation to more neutral stimuli in individuals with subclinical or clinical eating restriction and hence influence reward-based decisions, over and above any more general tendency to take less risk (Adoue et al., 2015).

Second, existing discrepancies in the literature may relate to the separation of studies on clinical and community samples. To our knowledge, no single study has assessed the relationship between eating restriction and value-based decision making across community and psychiatric samples with subclinical and clinical eating restriction behaviors, respectively. Here, we first tested a large ($n = 485$) sample of women without any psychiatric history, and with a wide range of restrictive eating tendencies. We complemented these studies with a clinical study in which we compared the risk-taking behavior of acute, restrictive subtype AN patients ($N = 31$), and weight-restored AN (AN-WR) patients ($N = 23$). These comparisons in multiple samples allowed us to not only examine multiple levels of eating restriction ranging from subclinical to clinical populations, but also to determine whether appearance-based, risk-taking is a marker of an eating restriction spectrum (i.e., deficits that endure beyond the acute phase and are present during remission, or in at-risk populations) rather than the expression of a categorical disease state like AN (i.e., present only during the acute AN phase as the secondary consequence of malnourishment, comorbidities, or medication). Based on previous studies (Adoue et al., 2015), we predicted that risk-taking would be lower overall in people with higher levels of restrictive eating and in both acute AN and AN-WR groups, and particularly when reward was coupled with an "undesirable" body outcome (i.e., a female body getting gradually larger in size) rather than a neutral stimulus. By contrast, we

Figure 1
The B-BART



Note. (A) The B-BART procedure: participants are presented with either a body (left side) or balloon (right side) stimulus that either increases or (in separate conditions) decreases in size when a button is clicked. Each click involves a decision between clicking to change the size of the stimulus and earn more money, or collecting the money earned so far and ending the trial. (B) The four conditions of the B-BART comprise (a) body increase, (b) body decrease, (c) balloon increase, and (d) balloon decrease. Each trial starts with an average (shown in the center) sized body or balloon. Clicking (as described in A) results in a stepwise change in stimulus size. The extremes of the bodies and balloons are depicted on the left and right sides of each condition's initial stimulus. B-BART = body and balloon analogue risk task. From "Home 3D Body Scans from Noisy Image and Range Data", by A. Weiss, D. Hirschberg, and M. J. Black, 2011 (https://bodyvisualizer.com). Copyright 2011 by MaxPlanck Gesellschaft. Reprinted with permission. See the online article for the color version of this figure.

expected that risk-taking would increase in conditions where the outcome was a "desirable" body (i.e., a gradually thinning body) rather than a neutral stimulus.

Finally, existing studies have failed to differentiate between different components of decision making which produce different responses, such as risk (when the outcome is unknown but the outcome probabilities are known) and uncertainty (when both the outcome and the probability distribution are unknown). Indeed, it has been noted that there is ambiguity regarding these dimensions in the original BART (Lauriola et al., 2014; Lejuez et al., 2002), which seems to involve a transition from initial uncertainty to later risk (De Groot & Thurik, 2018; Groot, 2020). Unfortunately, the point when this transition occurs is typically unknown, meaning that without computational modeling, the processes governing behavior are underspecified. Similarly, without computational modeling—which allows us to examine the mechanisms underlying behavior using mathematical models of experimental data (Wilson & Collins, 2019)—it is not possible to know whether behavior on the task is driven by altered sensitivity to loss (the potential to lose increasing rewards as the task progresses) or to risk (taking an increasing risk as the task progresses), both of which have been previously linked to disordered eating in patients with AN (Adoue et al., 2015; Bernardoni et al., 2018; Verharen et al., 2019). Leveraging computational modeling to disentangle these latent (hidden) explanatory variables was the third aim of the present study. Specifically, we applied and compared between existing, validated computational models of the BART task (Park et al., 2019; Wallsten et al., 2005) to examine which parameters (latent variables) best described the risk-taking behaviors associated with our critical conditions and samples—in particular, risk aversion and loss aversion. Before proceeding to this main aim, we computationally addressed the difficulty of disambiguating between BART trials when the subject is making decisions under risk versus uncertainty (see above; De Groot & Thurik, 2018; Groot, 2020). We present a novel model of the potential transition from uncertainty to risk in our control sample. We developed this model, which adapted an existing model of the BART that focuses on risk (Wallsten et al., 2005), by assuming two phases (uncertainty phase followed by risk phase) and by identifying the point of transition from the uncertainty to the risk phase. We tested the fit of this new model (measuring the discrepancy between observed data and model predictions, while

penalizing for model complexity) compared to an existing "baseline" model (Wallsten et al., 2005). We then validated the recovered parameters by looking into their distributions and by using them in our model to generate simulations of behavior on the BART which were compared to the actual participant BART behavior (see SM3 in the online supplemental materials; see Wilson & Collins, 2019 for descriptions of these different steps). We then assessed whether the transition from uncertainty to risk had any effect on our critical conditions and samples.

Method

Participants

Nonclinical Samples

To establish the feasibility of manipulating body stimuli in the BART task and determine their effects, we conducted a small online pilot study (Study 0: $N = 35$ women recruited via social media), and a larger follow-up at a public science event ($N = 135$), both of which included only increasing body (Study 0 = 23; Study 1 = 67) and decreasing body conditions (Study 0 = 12; Study 1 = 68). Included participants were 18 or over, had a body mass index (BMI) between 18.5 and 30 (based on World Health Organization guidelines for normal weight excluding underweight and obesity), with no reported history of eating disorder, neurological disease, or brain damage. To aid motivation, participants at the public event were told they would receive a small science-themed gift, for example, a brain eraser, for passing a predefined (but unknown to them) "winning" threshold. Participant ethnicity, cultural background, and socioeconomic status were not recorded due to time constraints.

A subsequent 318 women were recruited via a university participant recruitment system (SONA) to a lab-based experiment at UCL (Study 2). The same inclusion/exclusion criteria applied, with the exception of widening our criteria to remove the upper limit and exclude BMI < 16.5, given that BMI varies according to ethnicity (Lin et al., 2011; Zhu et al., 2011) and Western BMI standards did not apply well to the ethnicity of our sample (see below). We excluded from analysis any participants who did not follow instructions and complete all study measures ($n = 3$; final sample $n = 315$). The sample comprised White (48%), Asian (33%), Black (3%), Other ethnicities (11%), and people prefer not to say (6%). Other demographics are summarized in Table S1 in the online supplemental materials. For this experiment participants received a fixed amount of money for taking part (£8), plus a performance-based bonus (£2) if a predefined threshold (unknown to the participant) was reached. Institutional ethics approval was obtained and all participants gave written informed consent.

AN Patients

Thirty-one Italian women with acute AN were recruited from an eating disorder clinic at the San Paolo University Hospital in Milan, Italy. AN patients were aged 18 years or over, with a BMI < 18.5 and met *Diagnostic and Statistical Manual of Mental Disorders (DSM-5*; American Psychiatric Association, 2013) criteria for restrictive subtype AN, as diagnosed by an experienced psychiatrist, using standard clinical interview procedures. Exclusion criteria for the AN group were any documented history of brain injury, substance abuse or dependency, or concurrent psychotic disorder. AN-WR patients ($N = 23$) were diagnosed by their clinician as no longer meeting *DSM-5* criteria for AN, with a BMI of >16.5, and no binge eating, purging, or restrictive eating patterns for at least 6 months. The presence/absence of menses (amenorrhea) was not used to diagnose weight-restoration/recovery, since this is no longer recommended as part of *DSM-5* diagnostic criteria for AN. We chose this combination of behavioral and clinical criteria rather than characterizing AN or AN-WR based purely on weight (BMI), because weight-based criteria fail to capture the clinical complexity of AN/AN recovery. While weight status remains an important consideration in determining a diagnosis of AN, definitions of recovery vary substantially (Khalsa et al., 2017), and there is a lack of evidence-based consensus regarding the definition of low body weight (Harrop et al., 2021), or expected weight needed to achieve restoration (Lebow et al., 2018). BMI does not account for differences in body composition based on race, muscularity, or age, nor the complex biopsychosocial determinants of AN (Ralph et al., 2022), or symptom severity (Machado et al., 2017). With this in mind, in all cases where a patient's BMI was between 16.5 and 18.5, we verified the functional restoration status of the patient with their clinician. Characteristics of the AN and AN-WR groups, including data on current psychiatric comorbidities and medication, are summarized in Table S1 in the online supplemental materials.

B-BART

We developed the B-BART (Figure 1) by adapting a well-established behavioral measure of risk-taking, that is, the BART (Lejuez et al., 2002; see also Salvato et al., 2019, 2020 for a similar adaptation of the BART). In the B-BART, monetary reward is coupled with desirable or undesirable (body) outcomes (i.e., changes to either a female body avatar or a balloon). During the task, participants click a button to win money. Each click increases the amount of money won by £0.05, and simultaneously causes the avatar body (or balloon) to increase in size (or in separate conditions, decrease in size). Importantly, each body/balloon has a random maximum limit (herein referred to as the "loss limit") that is unknown to the participant. The probability that a body or balloon would reach its "loss limit" was determined following the method described by Lejuez et al. (2002), using an array of N numbers. When the loss limit is reached any money not collected into a permanent bank is lost. Thus, on each trial participants must choose between collecting the money they have won so far, or risk losing their winnings and increasing/decreasing the body/balloon size further to earn more money.

Stimuli

Stimulus bodies (avatars) were created using a Body Shape Visualizer (Weiss et al., 2011), which generates a three-dimensional (3D) rendered model of a female body using specified body measurements (e.g., height and weight), based on a statistical model of human shape created from thousands of laser scans of actual human bodies. In order to generate bodies within a visually realistic range, we fixed the height of the model (164 cm) and generated three bodies corresponding to World Health Organization BMI values in the normal weight (64 kg, BMI = 23.7), underweight (34 kg, BMI = 12.6), and obese (125 kg, BMI = 46.4) categories. Using these three 3D models, a computerized morphing procedure implementing a mesh warping algorithm (Abrosoft FantaMorp) was then used to morph the average body model into the maximally decreased (underweight) and maximally increased (obese) body size (see Figure 1, Panel B), generating 116 equally stepped, morphed frames

for each of the two directions (decreasing and increasing). We used 116 steps to optimize the time taken to complete the task. We followed a similar method to generate balloon stimuli: beginning with threes image of a (red) balloon of approximately the same overall image size as the average, underweight, and obese bodies, we morphed the average balloon into the maximally inflated (increased) and deflated (decreased) balloon, generating 116 images in each direction. This resulted in each pump of the balloon increased or decreased the image by approximately one pixel in all directions.

Probability of Reaching the Maximum Limit

The probability that a body or balloon would reach its "loss limit" was determined following the method described by Lejuez et al. (2002), using an array of *N* numbers. The number 1 was designated as the limit being reached. On each click, a number was randomly selected without replacement from the array. The body/balloon reached its limit if the number 1 was selected. The array contained the integers 1–116 (reflecting the 116 image frames in each condition). Thus, the probability that the limit would be reached on the first pump is 1/116. If the limit was not reached after the first click, the probability that it would be reached was 1/115 on the second click, 1/114 on the third click, and so on until the 116th click, at which point the probability of reaching the limit was 1/1 (i.e., 100%). According to this algorithm, the optimal number of clicks is 58, after which point the possible increase in earnings is reduced relative to the increased likelihood of reaching the maximum limit and losing any money accrued in the temporary bank.

Task Procedure

In all studies, participants completed 20 trials of the relevant body/balloon conditions. We chose 20 trials per condition to limit boredom/fatigue, and fit within prescribed time limits. Each trial began with the average (normal weight) body or balloon, and depending on the condition, clicking caused the stimulus to increase or decrease in size as described above (see also Figure 1). The body conditions and questionnaires took about 20 min to complete in Studies 0 and 1, and all four conditions and questionnaires took 90 min in Study 2. Participants were given standardized, computerized instructions at the start of the task. The number of trials (balloons or bodies) remaining and the total amount of money in the temporary and permanent bank were displayed on-screen, but the maximum number of pumps possible or probability of reaching the maximum limit was unknown. The decision to display the temporary bank balance was made following piloting, and allowed us to examine learning rates based on feedback in our statistical modeling.

Task Measure

A number of measures can be derived directly from the BART/B-BART task, based on the clicking behavior of the participant (see Schmitz et al., 2016 for a review and discussion). In the present study we took the following measures: (a) to assess explicit *risk-taking*, we calculated the number of clicks made by the participant on "winning" trials, that is, where earnings were collected prior to the limit being reached, and (b) as an implicit measure of decision-making uncertainty, we calculated the logarithm of the time taken between the last pump and the collection of temporary earnings (multiplied by 1,000 to make the results more readable). We labeled this variable *hesitancy* (in collecting earnings), which we collected in Studies 1 and 2 but not the pilot (Study 0) due to limitations of the software used. This measure is based on the "Save-Decision" reaction time described by Schmitz et al. (2016), and is preferable to mean reaction time across all trials, which is influenced by individual differences in mental speed, and includes the first clicks of the trial which are typically performed faster and are less informative about the final reflective decision process (Schmitz et al., 2016).

Questionnaires and Scales

Eating Disorders Examination Questionnaire

The Eating Disorders Examination Questionnaire (EDE-Q) is a widely used self-report measure of eating disorder symptoms, used in research with both clinical and nonclinical samples (Fairburn & Beglin, 1994). The EDE-Q provides measures of dietary Restraint, Eating Concern, Shape Concern, and Weight Concern—plus a global scale, average score. Although eating restriction (i.e., avoidance of calorie intake) and restraint (effortful attempts to reduce calorie intake) are considered distinct concepts (see Coniglio et al., 2018; Forbush et al., 2013; Stice et al., 2007), we use the term eating restriction throughout our paper to mean a combination of both concepts, as measured by the restraint subscale of the Eating Disorder Examination Questionnaire (Fairburn & Beglin, 1994). Higher scores reflect greater eating-related pathology. Cronbach's α for the present study samples ranged from .85 to .95 (see SM1 in the online supplemental materials).

Control Measure

Several, well-established psychometric measures were collected as control variables in our analyses (see Design and Statistical Analysis section). We used the Body Image Disturbance Questionnaire (BIDQ; Cash et al., 2004) to assess body image impairment, the Barratt Impulsiveness Scale Version 11 (BIS-11; Patton et al., 1995) to assess impulsiveness, the Depression Anxiety Stress Scales-21-Item Version (DASS-21; Lovibond & Lovibond, 1995) to measure depression, anxiety, and stress and the Obsessive–Compulsive Inventory (short version, OCI-R; Foa et al., 2002) to assess a variety of obsessions and compulsions.

Design and Statistical Analysis

We examined how risk-taking varies when reward is coupled with desired or undesired body outcomes. Our pilot and public event studies (Studies 0 and 1) employed a between-subject design, with body-related stimuli only due to practical and time-limitations, whereas our laboratory subclinical study (Study 2) and our clinical study used a fully factorial, within-subject design to examine the effect of stimulus type (balloon vs. body) and direction (increasing vs. decreasing) on risk taking. In subclinical samples, we examined how the extent of restrictive eating (see Questionnaires and Scales section) may affect risk taking, as well as how key psychometric variables in eating restriction research, such as body image disturbances and concerns (BIDQ; Cash et al., 2004), and related psychological dimensions of impulsiveness (Barratt Impulsiveness Scale; BIS-11; Patton et al., 1995), obsessions and compulsions (Obsessive–Compulsive Inventory Short Version; OCI-R; Foa et al., 2002), and affective factors such as depression, anxiety, and stress (DASS-21; Lovibond &

Lovibond, 1995) influenced the effects found in our main analyses (see SM1 in the online supplemental materials).

All statistical analyses were performed using R (R Core Team, 2013) with figures generated using ggplot 2 (Wickham, 2016). Following preliminary analyses on our initial studies (0 and 1; see SM1 in the online supplemental materials), to evaluate the relative difference in risk taking between conditions as EDE-Q Restraint increases, we performed step-wise multilevel modeling analysis on the combined data from Studies 0, 1, and 2, culminating in the effect of the interaction between stimulus type (*Body/Balloon*), direction (*Increasing/Decreasing*), and EDE-Q Restraint score. As random effects, we used the intercepts (not slopes) of the subject (Participant ID), condition order, and experimenter. As fixed effects, participant age and BMI were used as covariates, and stimulus, direction, and EDE-Q restraint were used as independent variables of interest. This same analysis was run twice using the two key behavioral measures of the BART (i.e., explicit risk taking and hesitancy) as dependent variables (see SM1 in the online supplemental materials for full statistical models and results).

Similarly, in our clinical samples, we examine the effect of group on risk taking, controlling for the influence of affective traits (depression, anxiety, and stress). Four out of the 31 AN patients completed only two out of the four B-BART conditions due to an administrative error. To examine risk-taking in acute AN and AN-WR patients compared to HCs, we first performed a series of preliminary analyses (reported in SM2 in the online supplemental materials) to create and validate an HC group from our large, nonclinical, HC sample (collected in Study 2). Briefly, this involved creating two subgroups of HCs characterized by high or low disordered eating (HC-L and HC-H, respectively). Our main analysis on the above two key BART measures followed the same overall strategy to that used to analyze the nonclinical data, that is, using step-wise multilevel modeling that culminated with the three-way interaction between the stimulus type (*Body/Balloon*), direction (*Increasing/Decreasing*), and group, with some minor variation in the variables included (as specified and explained below). As random effects, we used the intercepts (not slopes) of the subject (participant ID) and condition order as fixed effects (not experimenter as in the nonclinical analyses, since this study had only one experimenter). Age was used as a covariate but not BMI, since BMI was used to create the HC control groups and is a diagnostic feature of AN, making it inappropriate to include as a covariate. Stimulus, direction, and group were used as the independent variables of interest. The full statistical models and results from these analyses are presented in the SM2 in the online supplemental materials. Note that this analytic approach does not necessitate adjustments to the significance threshold (alpha level) as typically applied to account for possible inflation of Type 1 error from multiple testing (Gelman et al., 2012; Rubin, 2021).

Computational Modeling

We used computational modeling to understand the latent processes driving risk-taking behavior, and to disentangle the contribution of general cognitive versus social-motivational (thin-ideal) factors in the risk-taking of restrictive eaters. We aimed to first ascertain if our samples tended to shift between uncertainty and risk at different rates depending on their level of restrictive eating (i.e., EDE-Q restraint score or clinical diagnosis) or experimental condition (body vs. balloon; increasing vs. decreasing), and whether this could explain the observed differences in risk-taking behavior. To do this, we developed an exploration–exploitation model to study uncertainty and risk taking in sequential decision making. The model assumes that in earlier trials of the BART decision making is driven by higher *uncertainty* and exploration to reduce uncertainty (exploration stage), while in the later trials uncertainty has reduced and *risk-taking* drives behavior (exploitation stage). Participants are assumed to hold a belief in the probability that they will reach the maximum limit (loss limit) during each of these two stages, and that a transition from exploration to exploitation occurs at a specific moment (threshold). Thus, the model has three parameters: (a) *prior probability of loss belief* (loss belief during exploration), (b) *posterior probability of loss belief* (loss belief during exploitation), and (c) *threshold* (the trial at which the transition from exploration to exploitation takes place. Full details of this model are reported in SM3 in the online supplemental materials.

To achieve our second computational aim we used the Exponential-Weight Model (EW model; Park et al., 2019) to model risk parameters (*risk aversion* vs. *loss aversion*) during the BART. The EW model was developed to overcome the limitations of the earlier four-parameter model (Wallsten et al., 2005), which has been criticized for failing to reproduce accurate parameters in parameter recovery, and being difficult to interpret within a general reinforcement learning (RL) framework (see van Ravenzwaaij et al., 2011; Wagenmakers et al., 2007 for details). The EW model describes how sequential decisions are made during the BART, assuming that participants have a belief about the probability that the balloon (or body) will reach the maximum (loss limit), and that this belief is updated during the task through learning and evaluation that involves five parameters (this model is described fully in Park et al., 2019 and summarized further in SM4 in the online supplemental materials). Two of the model's parameters are of direct relevance to the current aims (for brevity the remaining three parameters and results relating to these parameters are described in SM4 in the online supplemental materials only). Risk aversion (ρ) indicates an individual's sensitivity to the value of reward change, such that individuals with higher risk avoidance take less risk to get the same amount of reward. Loss aversion (λ) indicates an individual's sensitivity to negative outcomes, such that potential loss is perceived as more severe at higher λ.

For both sets of modeling, we tested the fit and compared the models in the nonclinical data using maximum likelihood estimation, BIC, and AIC. We selected the winning model by comparing these models with baseline models that assume no change in uncertainty, nor any influence of loss avoidance (respectively), in the behavior of the nonclinical sample (see SM3 and SM4 in the online supplemental materials). After assessing the fit of these models and performing model comparison, we used the parameters of the winning model in subsequent analyses (see Analysis section) to identify whether overall risk-taking, and body-related risk taking (i.e., differences in behavior observed when reward is coupled with an increasing/decreasing body vs. balloon) in individuals with different levels of restrictive eating (i.e., in relation to EDE-Q restraint score in our nonclinical sample, and clinical diagnosis in our clinical samples) is best accounted for by risk aversion or loss aversion.

Model Validation

To validate the exploration–exploitation model of uncertainty and risk, we analyzed in our nonclinical samples whether two independent

behavioral measures not used to construct the model (i.e., hesitancy calculated as described above, and behavioral variability calculated as SD/Average clicks), showed an expected difference between exploration and exploitation phases, with greater hesitancy and behavioral variability expected during exploration compared to exploitation. We compared between phases (exploration vs. exploitation) the hesitancy and behavioral variability (see SM1 in the online supplemental materials). Secondary validation was performed via supervised learning clustering analysis as specified in SM2 in the online supplemental materials.

Analysis

We conducted two sets of analyses on the modeling data, with the aim of first examining if decisions are made under uncertainty versus risk, and then whether risk- or loss aversion might provide a better explanation of the risky decision-making behaviors observed across the different levels of nonclinical and clinical restrictive eating. To analyze data from the nonclinical sample, we used separate MLMs with the winning models' parameters and hesitancy as dependent variables, and EDE-Q restraint, age, and BMI as independent variables. In supplementary analyses, we ran these models again, controlling also for key body image disturbances and concerns, impulsiveness, obsessions and compulsions, and affective factors (depression, anxiety, and stress; see SM1 in the online supplemental materials).

For our clinical data, we examined how the model parameters were affected in AN and AN-WR patients, following the same plan of analysis used for our behavioral data, that is, by examining for each dependent variable the overall effect of group (HC-L, HC-H, AN, AN-WR) and the three-way interaction between Group (HC-L, AN, AN-WR), Stimulus Type (Body, Balloon), and Direction (Increase, Decrease), with planned comparisons carried out if the main effect or three-way interaction was significant.

Transparency and Openness

The research was not preregistered. Data and code used in the manuscript are available via GitHub: https://github.com/katlaboratory/RiskTaking.

Results

Risk Taking in Subclinical Eating Restriction

Women With Subclinical Eating Restrictions Take Less Risk and Show Greater Hesitancy When Monetary Reward Is Coupled With an Undesired Body Outcome

We found that higher levels of self-reported eating restriction were predictive of significantly less risk taking (fewer clicks) overall (see Table 1). This overall relationship between eating restraint and risk taking is illustrated in Figure 2a, which shows a negative slope for each of the four conditions. A significant three-way interaction indicated that this effect varied depending on Stimulus Type and Direction (Figure 2a), and was driven by behavior in the body increase condition. Specifically, women with greater self-reported eating restriction clicked significantly fewer times when monetary reward was coupled with an increasing body compared to an increasing balloon. There was no significant difference between the decreasing body and decreasing balloon conditions. This interaction remained significant when accounting for general body image disturbances, impulsiveness, compulsiveness, and affective traits (see SM1 in the online supplemental materials).

Performing these same analyses with hesitancy (i.e., time taken to collect earnings after the final click; see Method section) as the dependent variable revealed similar results (see Table 1). The overall effect of restrictive eating on hesitancy was not significant, however, there was a significant three-way interaction between Stimulus Type, Direction, and EDE-Q restraint (Figure 2b), and this remained significant when controlling for secondary body image, cognitive and affective factors (see SM1 in the online supplemental materials). In the same way as for explicit risk-taking, women with higher levels of restrictive eating showed significantly greater hesitancy when an increasing body was compared with an increasing balloon, but no significant difference when a decreasing body was compared with a decreasing balloon.

Finally, given the lower BMI cutoff (i.e., <16.5) applied to the participants in Study 2, we ran these same analyses again excluding participants with BMI < 18.5 ($N = 36$). This exploratory sensitivity analyses did not change the above pattern of effects found for risk taking (number of clicks) or hesitancy, with minor changes to p values and slopes (see SM1 in the online supplemental materials).

Risk Taking Across Subclinical and Clinical Eating Restriction

Acute AN and AN-WR Patients' Risk Taking and Hesitancy Is Modulated by Body Outcome

Our MLM including all four groups (AN, AN-WR, HC-H, HC-L) showed that overall risk taking differed significantly between groups, with AN and AN-WR patients taking significantly less risk (i.e., making fewer clicks) compared to the HC-L group (see Table 1; Figure 2c). The expected three-way interaction between stimulus Type, Direction, and Group was significant (Table 1), and this interaction was unaffected when affective variables (DASS scores) were included in the analyses (see SM2 in the online supplemental materials). Examining this interaction using our key comparisons, we found that AN-WR patients took significantly *less* risk than HC-L when looking at the difference between the *increasing* body and *increasing* balloon conditions (the AN group showed the same tendency but it was nonsignificant, see Table 1), while both AN groups took significantly *more* risk than the HC-L group when looking at the difference between the *decreasing* body and *decreasing* balloon conditions.

Performing these same analyses with hesitancy as the dependent variable confirmed the results from our analysis of explicit risk-taking. Overall hesitancy was significantly different between groups, with both AN and AN-WR patients showing significantly greater hesitancy compared to the HC-L group (see Figure 2d; Table 1). Hesitancy also showed the expected three-way interaction between Stimulus Type, Direction, and Group, and this interaction was unaffected when affective variables (DASS scores) were included in the analyses (see SM2 in the online supplemental materials). Examining this interaction with our standard pairwise comparisons, we confirmed that patients with acute AN (but not the AN-WR patients) exhibited significantly *more* hesitancy than the HC-L group when considering the difference between the *increasing* body and *increasing* balloon conditions. However, there was no significant difference between the two AN

Table 1
Results of Main Behavioral Analyses in Nonclinical (Upper Half) and Clinical (Lower Half) Samples

	Nonclinical explicit risk-taking				On-clinical hesitance			
Effect	β (*SD*)	*p*	χ^2 (*df*)	f^2	β (*SD*)	*p*	χ^2 (*df*)	f^2
EDE-Q restraint	−0.81 (0.38)	**.034**	4.48 (1)	0.008	−2.95 (7.55)	.696	0.15 (1)	0.026
Stimulus × Direction × EDE-Q Restraint	−0.76 (0.26)	**<.001**	18.79 (3)	0.008	8.67 (6.49)	**.014**	10.57 (3)	0.035
	Nonclinical risk-taking increase body versus balloon				Nonclinical hesitance increase body versus balloon			
Effect	β (*SD*)	*p*	χ^2 (*df*)	f^2	β (*SD*)	*p*	χ^2 (*df*)	f^2
Stimulus × EDE-Q Restraint	−0.64 (0.18)	**<.001**	12.12 (1)	0.014	13.45 (4.56)	**.003**	8.67 (1)	0.023
	Nonclinical risk-taking decrease body versus balloon				Nonclinical hesitance decrease body versus balloon			
Effect	β (*SD*)	*p*	χ^2 (*df*)	f^2	β (*SD*)	*p*	χ^2 (*df*)	f^2
Stimulus × EDE-Q Restraint	0.01 (0.18)	.957	0 (1)	−0.007	4.66 (4.6)	.311	1.03 (1)	0.037
	Clinical explicit risk-taking				Clinical hesitance			
Effect	β (*SD*)	*p*	χ^2 (*df*)	f^2	β (*SD*)	*p*	χ^2 (*df*)	f^2
All groups		**.005**	12.7 (3)	0.055		**<.001**	21.25 (3)	0.102
AN versus HC-L	−7.44 (2.6)	**.005**	7.72 (1)	0.062	316.6 (68.51)	**<.001**	18.65 (1)	0.150
AN-WR versus HC-L	−8.63 (3.25)	**.01**	6.66 (1)	0.067	271.77 (71.3)	**<.001**	13.02 (1)	0.111
HC-H versus HC-L	−2.01 (1.97)	.308	1.04 (1)	0.021	48.51 (78.34)	.536	0.38 (1)	0.014
Stimulus × Direction × Group		**.001**	27.36 (9)	0.059		**<.001**	41.84 (9)	0.106
	Clinical risk-taking increase body versus balloon (AN vs. HC-L)				Clinical hesitance increase body versus balloon (AN vs. HC-L)			
Effect	β (*SD*)	*p*	χ^2 (*df*)	f^2	β (*SD*)	*p*	χ^2 (*df*)	f^2
Stimulus × Group	−1.93 (1.01)	.058	3.61 (1)	0.085	124.95 (27.66)	**<.001**	20.27 (1)	0.202
	Clinical risk-taking decrease body versus balloon (AN vs. HC-L)				Clinical hesitance decrease body versus balloon (AN vs. HC-L)			
Effect	β (*SD*)	*p*	χ^2 (*df*)	f^2	β (*SD*)	*p*	χ^2 (*df*)	f^2
Stimulus × Group	4.11 (1.03)	**<.001**	15.49 (1)	0.049	12.87 (26.64)	.63	0.23 (1)	0.142
	Clinical risk-taking increase body versus balloon (AN-WR vs. HC-L)				Clinical hesitance increase body versus balloon (AN-WR vs. HC-L)			
Effect	β (*SD*)	*p*	χ^2 (*df*)	f^2	β (*SD*)	*p*	χ^2 (*df*)	f^2
Stimulus × Group	−2.37 (1.1)	**.031**	4.66 (1)	0.069	35.73 (27.59)	.195	1.68 (1)	0.121
	Clinical risk-taking decrease body versus balloon (AN-WR vs. HC-L)				Clinical hesitance decrease body versus balloon (AN-WR vs. HC-L)			
Effect	β (*SD*)	*p*	χ^2 (*df*)	f^2	β (*SD*)	*p*	χ^2 (*df*)	f^2
Stimulus × Group	2.65 (1.11)	**.017**	5.68 (1)	0.060	19.66 (28.01)	.483	0.49 (1)	0.121

Note. Significant effects ($p < .05$) are indicated in bold. Stimulus × Group comparisons indicate the difference between body and balloon in the clinical AN or AN-WR group that is over and above the difference between body and balloon in the HC-L control group. EDE-Q = Eating Disorders Examination Questionnaire; AN = anorexia nervosa; AN-WR = weight-restored AN; HC-H = healthy controls characterized by high disordered eating; HC-L = healthy controls characterized by low disordered eating.

groups and the HC-L group when considering the difference between the *decreasing* body and *decreasing* balloon conditions.

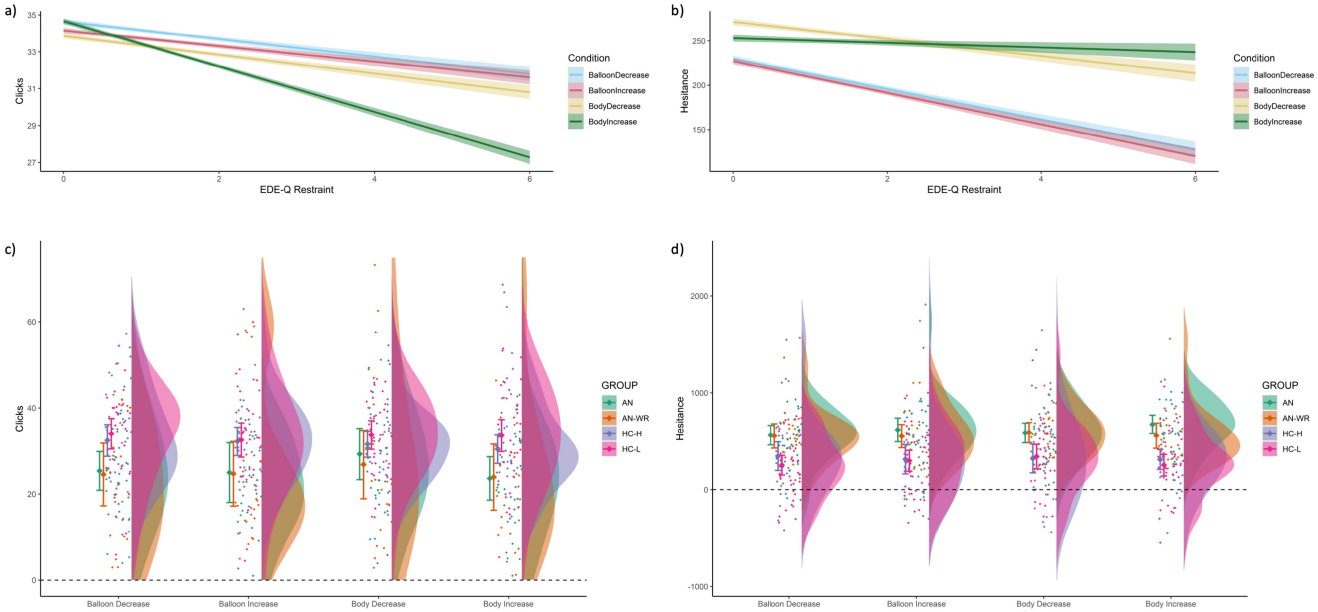
Computational Modeling

Women With Greater Subclinical and Clinical Eating Restriction Believe That Loss Is More Probable

Our first set of modeling supported the existence of two phases in the B-BART, characterized by initially high and subsequently lower levels of uncertainty (see SM3 in the online supplemental materials for full model fit results). We validated this model by showing that, as theoretically expected (Gopnik et al., 2017; Hills et al., 2015), the degree of hesitancy and click variability (two behavioral measures that were not used to create the model) was significantly greater during the exploration compared to the exploitation phase (see SM1 in the online supplemental materials). We then applied this model to our key subclinical and clinical comparisons finding that the higher the subclinical levels of self-reported eating restriction the more women behave as though loss is more probable overall (i.e., irrespective of condition), with this effect being significant during exploitation but not exploration (see Table S2 in the online supplemental

Figure 2

Overall Clicks per Condition (Panel a) and Hesitance (Panel b) in the Subclinical Sample Study. Overall Clicks per Condition (Panel c) and Hesitance (Panel d) in the Clinical Sample Study



Note. Illustrating slopes from multilevel models takes only fixed effects into account by necessity, so the exact direction of the slopes should be interpreted with caution. Subclinical plots include combined data from subclinical participants in Studies 0, 1, and 2. Clinical study HC-L and HC-H samples are derived from Study 2 nonclinical participants (as described in the main text). EDE-Q = Eating Disorders Examination Questionnaire; AN = anorexia nervosa; AN-WR = weight-restored AN; HC-H = healthy controls characterized by high disordered eating; HC-L = healthy controls characterized by low disordered eating. See the online article for the color version of this figure.

materials). The three-way interaction between Stimulus, Direction, and EDE-Q restraint was not significant for exploration or exploitation and so we did not conduct further planned comparisons. Running these same analyses controlling for general body image disturbances, impulsiveness, compulsiveness, and affective traits produced similar effects, although the significant finding during the exploitation phase became nonsignificant (but with the same slope direction and a similar slope size) due to a smaller N and subsequent loss of statistical power (see SM1 in the online supplemental materials). Running these analyses with hesitancy as the dependent variable did not yield any significant effects (Table S2 in the online supplemental materials).

In our clinical study, there was an overall effect of group on the probability of loss belief, both for exploration and exploitation (Table S2 in the online supplemental materials), with both acute AN and AN-WR patients behaving as if the probability of reaching the loss limit was significantly greater overall (i.e., irrespective of condition; see Table S2 in the online supplemental materials) than the HC-L group. This effect was present for both exploration (at trend level in acute AN) and exploitation. However, the three-way interaction between Group, Direction, and Stimulus was not significant for either exploration or exploitation (Table S2 in the online supplemental materials). Running these same analyses with hesitancy as the dependent variable replicated and confirmed the same pattern of findings (Table S2 in the online supplemental materials).

In sum, our first set of computational modeling supports the idea that the B-BART involves two phases, which are characterized by initially high and subsequently lower degrees of uncertainty (but ongoing risk), as suggested by recent methodological discussions of the BART (De Groot & Thurik, 2018; Groot, 2020). Importantly, loss beliefs, particularly in the second, exploitation "pure risk" phase, were generally higher in our subclinical sample with high levels of eating restriction, and in our two clinical samples (AN and AN-WR) relative to the HC-L group. While these loss beliefs may relate to the main risk effects of our behavioral analyses, they did not explain the behavioral differences in body-related risk-taking.

Risk Aversion Best Describes the Risk-Taking Behavior of Women With Greater Subclinical and Clinical Eating Restrictions

In our second set of computational modeling, we examined which key latent parameters, namely risk aversion versus loss aversion, may best describe the general and body-related, risk-taking behaviors of our different samples. Model comparisons revealed that the most recently developed and validated model of the original BART task (Park et al., 2019) best captured our data and revealed that higher levels of subclinical, self-reported eating restriction were predictive of small but significantly less risk aversion (ρ) overall (i.e., irrespective of condition). The three-way interaction between Stimulus, Direction, and EDE-Q restraint was not significant for risk aversion. There were no significant effects for loss aversion (λ; Table 2).

Similarly in our clinical group comparisons, risk aversion was significantly less overall (i.e., irrespective of condition) in AN-WR women compared to the HC-L group, and a similar, nonsignificant tendency in the same direction was found in acute AN women

Table 2
Results of Risk Versus Loss Aversion Computational Modeling Analyses in Nonclinical (Upper Half) and Clinical (Lower Half) Samples

	Exponential weighting model (risk-aversion and loss-aversion parameters ρ and λ)					
	Risk aversion (ρ)			Loss aversion (λ)		
Effect	β (*SD*)	*p*	f^2	β (*SD*)	*p*	f^2
EDE-Q restraint	−0.02 (0.01)	**<.001**	0.067	0.01 (0.03)	.675	0.001
Stimulus × Direction × EDE-Q Restraint	0 (0)	.25	0.068	0.01 (0.01)	.689	0.001
	Risk-aversion increase body versus balloon			Loss-aversion increase body versus balloon		
Effect	β (*SD*)	*p*	f^2	β (*SD*)	*p*	f^2
Stimulus × EDE-Q Restraint	0 (0)	.545	0.069	0 (0.01)	.503	0.001
	Risk-aversion decrease body versus balloon			Loss-aversion decrease body versus balloon		
Effect	β (*SD*)	*p*	f^2	β (*SD*)	*p*	f^2
Stimulus × EDE-Q Restraint	0 (0)	.152	0.065	0 (0.01)	.562	0.001
	Exponential weighting model (risk-aversion and loss-aversion parameters ρ and λ)					
	Risk aversion (ρ)			Loss aversion (λ)		
Effect	β (*SD*)	*p*	f^2	β (*SD*)	*p*	f^2
All groups	−0.01 (0.05)	.16	0.067	0 (0.17)	.42	0.023
AN versus HC-L	−0.09 (0.05)	.073	0.125	0 (0.17)	.993	0.000
AN-WR versus HC-L	−0.11 (0.05)	**.041**	0.072	0.31 (0.18)	.09	0.048
HC-H versus HC-L	−0.05 (0.03)	.089	0.120	0.01 (0.13)	.919	0.001
Stimulus × Direction × Group	0.03 (0.02)	**.006**	0.068	0.04 (0.06)	.123	0.024
	Risk-aversion increase body versus balloon (AN vs. HC-L)			Loss-aversion increase body versus balloon (AN vs. HC-L)		
Effect	β (*SD*)	*p*	f^2	β (*SD*)	*p*	f^2
Stimulus × Group	0.01 (0.01)	.417	0.108	−0.01 (0.04)	.751	0.004
	Risk-aversion decrease body versus balloon (AN vs. HC-L)			Loss-aversion decrease body versus balloon (AN vs. HC-L)		
Effect	β (*SD*)	*p*	f^2	β (*SD*)	*p*	f^2
Stimulus × Group	−0.02 (0.01)	.064	0.128	−0.05 (0.04)	.208	0.001
	Risk-aversion increase body versus balloon (AN-WR vs. HC-L)			Loss-aversion increase body versus balloon (AN-WR vs. HC-L)		
Effect	β (*SD*)	*p*	f^2	β (*SD*)	*p*	f^2
Stimulus × Group	0.03 (0.01)	**.015**	0.065	0.07 (0.04)	.141	0.048
	Risk-aversion decrease body versus balloon (AN-WR vs. HC-L)			Loss-aversion decrease body versus balloon (AN-WR vs. HC-L)		
Effect	β (*SD*)	*p*	f^2	β (*SD*)	*p*	f^2
Stimulus × Group	−0.02 (0.01)	**.044**	0.085	−0.08 (0.04)	.043	0.051
	Risk-aversion increase body versus balloon (HC-H vs. HC-L)			Loss-aversion increase body versus balloon (HC-H vs. HC-L)		
Effect	β (*SD*)	*p*	f^2	β (*SD*)	*p*	f^2
Stimulus × Group	0.02 (0.01)	**.032**	0.122	0.04 (0.04)	.268	0.000
	Risk-aversion decrease body versus balloon (HC-H vs. HC-L)			Loss-aversion decrease body versus balloon (HC-H vs. HC-L)		
Effect	β (*SD*)	*p*	f^2	β (*SD*)	*p*	f^2
Stimulus × Group	−0.02 (0.01)	**.022**	0.126	−0.03 (0.03)	.373	0.002

Note. Significant effects ($p < .05$) are indicated in bold. Stimulus × Group comparisons indicate the difference between body and balloon in AN, AN-WR, or HC-L group that is over and above the difference between body and balloon in the HC-L control group. EDE-Q = Eating Disorders Examination Questionnaire; AN = anorexia nervosa; AN-WR = weight-restored AN; HC-H = healthy controls characterized by high disordered eating; HC-L = healthy controls characterized by low disordered eating.

compared to the HC-L group (Table 2). In addition, the three-way interaction between Stimulus, Direction, and Group was significant for risk aversion. Examining this interaction with our standard contrasts, we found that AN-WR (but not acute AN) patients showed significantly *more* risk aversion than the HC-L group when considering the difference between the *increasing* body and *increasing* balloon conditions, and also significantly *less* risk aversion than the HC-L group (a nonsignificant tendency in the acute AN) when considering the difference between the *decreasing* body and *decreasing* balloon conditions (Table 2). Similar patterns of results were observed for the selected HC-H versus HC-L groups, as reported in SM2 in the online supplemental materials. There was no significant effect of group (AN, AN-WR, HC-L, HC-H) on loss aversion overall, nor a significant three-way interaction between Stimulus, Direction, and Group.

Discussion

We used a new, body and balloon analog risk-taking task (B-BART) and computational modeling to disentangle the social and cognitive mechanisms underlying restrictive eating behaviors. We examined risk taking and eating restriction across clinical and nonclinical samples, taking into consideration the influence of the social value of thin body ideals. Our findings indicate that body appearance values influence reward-based decisions in women with subclinical and clinical levels of eating restriction. We confirmed existing behavioral findings of less risk taking (i.e., fewer clicks) overall in patients with AN (Adoue et al., 2015), and established the presence of this trait in AN-WR patients, and in a nonclinical "at risk" sample of women with higher levels of restrictive eating. This overall relationship between eating restraint and risk taking could be driven by behavior in specific body or balloon conditions, and our subsequent analysis of the three-way interaction clarified this point. Using our new task, we found that subclinical women with greater self-reported eating restriction took less risk when monetary reward was coupled with an increasing body compared to an increasing balloon. We also found that both clinical and subclinical eating restriction is associated with greater behavioral *uncertainty* (hesitancy) when the decision is coupled with an undesirable (bigger) body outcome compared to a neutral balloon. Moreover, in both our clinical samples we discovered that, in spite of the above general and larger-body-related tendencies to take *less* risk, patients take *more* risk when the same monetary reward is coupled with a desired, thinner body compared to a neutral (balloon) stimulus. Importantly, a combination of greater behavioral risk taking for increasing bodies and lower risk taking for decreasing bodies may be especially problematic for perpetuating disordered eating behavior.

Our findings cast new light on recent research which suggests that restrictive eating is the result of aberrant decision and learning processes, caused by dysfunctional punishment and reward brain circuitry (Kaye et al., 2013). By regarding eating restriction as a dimension varying along a continuum of severity from nonclinical to clinical samples, we were able to show that low risk-taking and high behavioral uncertainty were characteristic not only of the acute AN state, but were also an enduring trait that is present in "at risk" healthy individuals with subclinical levels of eating restriction and AN-WR patients.

By extending an existing, generic risk-taking paradigm to couple monetary reward with both neutral and body-related stimuli, we were able to provide behavioral evidence that body appearance may have a role in value-based decisions. Existing studies that have used experimental decision-making tasks (Adoue et al., 2015; Bernardoni et al., 2018) or self-report measures (Jappe et al., 2011) in AN suggest that these patients have an altered sensitivity to reward, loss, or punishment, but fail to consider why AN patients, as well as healthy individuals restricting their diets, are paradoxically willing to take significant health risks in their pursuit of thinness. Based on our findings, one likely explanation is that eating restriction decisions are influenced by social and motivational values regarding body appearance, such as the thin ideal (Diedrichs, 2015; Thompson & Stice, 2001), or the reverse, the aversive value nonthin bodies may have for some individuals. Our findings may explain why individuals who have been found to have heightened sensitivity to loss or punishment (Jappe et al., 2011) and intolerant of uncertainty (Frank et al., 2012) in self-report measures, nevertheless engage in behaviors such as extreme eating restriction or excessive exercise, that are known to have severe health risks (French & Jeffery, 1994; Hawks et al., 2008; Polivy, 1996). Indeed, previous questionnaire studies have shown that individuals make daily decisions about what, when, and how much to eat by taking into account not only bodily signals (e.g., hunger, stomach fullness) and food parameters (availability, desirability; Lowe & Levine, 2005), but also the potential effects of eating on their body weight and size and more generally their body appearance (Keery et al., 2004; Mills et al., 2002). However, to our knowledge, no experimental, decision-making study has provided mechanistic insight regarding such motivations by examining how women value different body appearances when making value-based decisions under uncertainty.

It might be argued that our findings are explained by low-level perceptual or attentional biases in our population, that is, certain individuals may have changed their behavior because they process body stimuli with less attention or accuracy than balloon stimuli. Although there are conflicting results regarding the role of perceptual, as opposed to attitudinal and emotional, abnormalities in body image research (Cash & Deagle, 1997; Hagman et al., 2015), at least some studies claim that subclinical and clinical populations with disordered eating have perceptual deficits, and not just different attitudes and emotional responses to body stimuli (Esposito et al., 2018). We think this interpretation is unlikely in the present study, as our results were not only stimulus-specific but also direction specific. It is not clear how such low-level perceptual deficits could explain our specific and directional risk-taking findings.

Differences in stimulus complexity or salience between and within body and balloon conditions might also affect perceptual or attentional biases. We used morphing software to create objectively equivalent, stepwise changes between the endpoint body and balloon images used in the task. However, the difference between each step may not be equally detectable subjectively across body and balloon conditions. The nature of the human body also means that increasing and decreasing body conditions might be unbalanced, since bodies do not simply get bigger/smaller in a uniform manner when people gain or lose weight. Our avatars were created using a realistic body visualizer, which uses a statistical model of natural changes in human shape created from thousands of laser scans of actual human bodies. Our extremely thin and fat body images, therefore, reflect the realistic but disproportionate way that bodies change. Thus, although each step of our increasing and decreasing body conditions is objectively balanced, and participants were able to detect changes in both body and balloon conditions over multiple trials, future work is needed to check if change is equally detectable within and across conditions.

Existing studies using the BART in patients with AN have failed to disentangle different components of the task, such as the role of risk versus uncertainty, and avoidance of risk versus loss (e.g., Adoue et al., 2015; see also De Groot & Thurik, 2018; Groot, 2020 for discussion). To address these limitations, we used computational modeling to first establish whether our nonclinical and clinical samples were making decisions under risk or uncertainty, and whether this would provide an explanation for observed differences in behavior. Our first set of modeling supports the idea that the BART involves two phases, characterized by initially high levels of uncertainty and later risk. However, neither of these two phases, nor the point when people transition from uncertainty to risk, were able to explain the behavioral differences between our samples in body-related risk-taking. That is, nonclinical individuals with increased eating restriction showed an increased belief in the probability of experiencing a loss during the lower uncertainty, higher risk (exploitation) phase. Acute AN, as well as AN-WR, patients show a similar increase in loss beliefs and greater hesitancy during both uncertainty and risk phases. These findings suggest that the risk taking observed generally in women with higher levels of restrictive eating is underscored by a belief that loss or punishment is more likely to occur, and this increased loss belief is a trait that spans acute AN and recovering AN-WR patients, as well as subclinical eating restriction tendencies. However, there were no statistically significant differences in the threshold between the two phases, nor any interactions with body-specific variables in either phase of the exploration–exploitation model. Thus, there was no evidence suggesting that eating restriction, or associated values ascribed to body ideals, were associated with a faster or slower transition between uncertainty and risk during the B-BART.

Our modeling of risk-parameters, however, indicated that decision making in individuals with greater levels of restrictive eating is linked to differences in *risk aversion* but not *loss aversion*. In particular, both acute AN and AN-WR patients are *less* risk averse overall (when not specifically considering the body), and are *less* risk averse (i.e., willing to take more risk) when monetary rewards are coupled with a desired, *decreasing* body size. Additionally, AN-WR patients are *more* risk averse when monetary rewards are coupled with an undesirable, *increasing* body size. Overall, this pattern of results indicates that risk aversion rather than loss aversion plays a key role in the decisions of individuals with increased levels of restrictive eating. Our findings are also consistent with the paradoxical behavior of individuals with AN, whereby patients take considerable risk to obtain their desired body size, despite a more general low risk-taking propensity observed in their everyday behavior and recent experimental work (Adoue et al., 2015). Further research is needed to determine whether this behavioral propensity to take less risk is related to the self-reported sensitivity to punishment (Jappe et al., 2011) and intolerant of uncertainty (Frank et al., 2012) that has been found in individuals who engage in extreme eating restriction or excessive exercise.

Our study tested only women, and did not collect complete data on ethnicity, cultural background, or socioeconomic status. Eating restrictions, body image concerns and AN are more common in women than in men, and body appearance values in men involve more than just weight variables (Smith et al., 2011; Talbot et al., 2019), and hence they are more complex to experimentally manipulate and directly compare to those of women. Body ideas may also differ in Western, Educated, Industrialized, Rich Demographic (e.g., WEIRD) versus non-WEIRD populations, and further work is needed to determine if our findings apply to people from different ethnic, cultural, and socioeconomic backgrounds. We also noted that our AN group had a longer illness duration than the AN-WR patients, although we examined and found no relationship between severity of eating disorder symptoms and degree of risk-taking. Our study also included women with a BMI as low as 16.5 in the AN-WR group. Although applying a higher cutoff of 18.5 did not change our results, we chose to keep these women in our analyses based on our inclusive, transdiagnostic sampling and analysis approach, and recent developments in the diagnosis of eating disorders and recovery that decenters the importance of weight. However, our BMI cutoff of 16.5 is not intended to be used as a general criterion for clinical purposes. The diagnosis of AN requires consideration of the complex interplay of physical, behavioral, and psychological/cognitive factors (Bardone-Cone et al., 2018), and our classification of women with a BMI between 16.5 and 18.5 was based on a consideration of these various factors by an experienced clinician. Similarly, our nonclinical samples were not screened for the absence of psychiatric conditions via a formal interview, but indicated their eligibility via self-report, which is typical in experimental studies. Subsequent studies might also screen healthy participants using a formal psychiatric interview to ascertain their psychiatric history. Moreover, although we tested many samples across the spectrum of eating restriction, our study remains cross-sectional and hence with limited explanatory potential regarding developmental variables.

To further specify the interpretation of our findings, future studies could also use explicit measures of the degree to which each participant values body appearance ideals, instead of only measuring body image concerns and preoccupations with one's own body image, as we did in this study. Although we did not directly measure body appearance values using questionnaires or other explicit measures that are commonly used in body image and eating disorder research, our approach utilizes a well-established value-based decision-making framework (Berkman et al., 2017) that is more common in other fields of cognitive and experimental psychology. It is axiomatic to such tasks that performance involves an evaluation of subjective values, based on the information available, which is not necessarily conscious. Our task included the assessment of body appearance values via the varying thin/fat appearance of the body stimuli. Future studies could extend our work by including questionnaires that capture explicit body appearance values in a different way to that of value-based decision-making paradigms, and may promote greater cross-disciplinary insights. By the same token, although we did not assess eating in a controlled setting (e.g., assessing how much food is eaten when offered in a specific context), we did measure everyday eating behavior via the EDE-Q, which is a validated measure of eating restriction. Future research might, therefore, include a controlled assessment of eating behavior.

Additionally, while we did not find an effect of body image concerns or preoccupations on our findings, future studies could use more detailed measures for this multifaceted dimension. Also, it went beyond the scope of the current study to combine the two modeling approaches that we applied separately to our B-BART results, and we did not examine whether the observed level of risk taking is "rational" or "optimal" (see discussions by Benjamin & Robbins, 2007; Keller et al., 2019), nor whether using food stimuli, or manipulating hunger level might influence decision making. However, our study paves the way for future research to consider these issues in

unison rather than in isolation. Finally, although we tested multiple samples and we controlled for a number of confounding variables such as mood and compulsivity symptoms, it remains possible that risk aversion as observed in the present study relates to some other pathogenic dimension in eating restriction.

In conclusion, our study combined neurobiological and psychosocial perspectives on eating restriction into a common decision making and computational framework that allowed us to test the interrelations between key determinants of eating restriction across subclinical and clinical samples. We found that values related to body appearance influence how individuals with eating restrictions take value-based decisions. Computational modeling suggested that differences in risk-taking behavior are driven by differences in *risk* aversion rather than *loss* aversion. These findings cast new light on current debates concerning the psychosocial and neurobiological factors that motivate eating behavior, by combining several advanced methodologies, including transdiagnostic sampling, experimental manipulation and inference of implicit values, and computational modeling. These approaches are less common in traditional body image and eating disorder research, but more common in broader fields of experimental psychology. Our study thereby paves the way for future interdisciplinary work that considers how insights from the body image literature (e.g., the internalization of thin ideal and related values about one's own body image) may be applied to the wider study and theoretical conceptualization of decision making and motivation. A greater interdisciplinary approach to the topic of body image and eating restriction can advance both the specific fields in question and develop a wider understanding in the broader field of psychology and cognitive neuroscience.

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