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# Impact of Contextual Learning on Reinforcement Learning Performance in Anorexia Nervosa

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| **Corresponding Author:** | Ilaria Colpizzi<br>University of Florence<br>ITALY |
| **First Author:** | Ilaria Colpizzi |
| **Order of Authors:** | Ilaria Colpizzi |
| | Claudio Sica, PhD |
| | Lisa Guidi |
| | Sara Danti |
| | Silvia Lucchesi |
| | Elisa Giusti |
| | Martina Di Meglio |
| | Donatella Ballardini |
| | Chiara Mazzoni |
| | Caterina Pieraccioli |
| | Romana Schumann |
| | Corrado Caudek, PhD |
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| **Suggested Reviewers:** | Ann F Haynos, PhD<br>Virginia Commonwealth University<br>haynosa@vcu.edu<br>Expert in the field. |
| | Toby Wise, PhD<br>King's College London<br>toby.wise@kcl.ac.uk<br>Expert in the field. |

# Impact of Contextual Learning on Reinforcement Learning Performance in Anorexia Nervosa

# Impacto del Aprendizaje Contextual en el Rendimiento del Aprendizaje por Refuerzo en la Anorexia Nerviosa

Ilaria Colpizzi[1*], Claudio Sica[1], Lisa Guidi[2], Sara Danti[2], Silvia Lucchesi[2], Elisa Giusti[2], Martina Di Meglio[2], Donatella Ballardini[3], Chiara Mazzoni[3], Caterina Pieraccioli[4], Romana Schumann[3], & Corrado Caudek[5]

[1] Heath Sciences Department, University of Florence, Italy

[2] Istituto Specchidacqua, Frida Onlus Montecatini, Italy

[3] Centro Gruber, Bologna, Italy

[4] Neomesia, Villa dei Pini, Firenze, Italy

[5] Department NEUROFARBA, University of Florence, Italy

## Author note

The authors made the following contributions. Ilaria Colpizzi: Conceptualization, Writing - Review & Editing, Data Collection, Statistical analyses; Claudio Sica: Conceptualization, Writing - Review & Editing; Lisa Guidi: Conceptualization, Data Collection, Writing - Review & Editing;

Sara Danti: Conceptualization, Data Collection, Writing - Review & Editing; Silvia Lucchesi: Conceptualization, Data Collection, Writing - Review & Editing; Elisa Giusti: Conceptualization, Data Collection, Writing - Review & Editing; Martina Di Meglio: Conceptualization, Data Collection, Writing - Review & Editing; Donatella Ballardini: Conceptualization, Data Collection, Writing - Review & Editing; Chiara Mazzoni: Conceptualization, Data Collection, Writing - Review & Editing; Caterina Pieraccioli: Conceptualization, Data Collection, Writing - Review & Editing; Romana Schumann: Conceptualization, Data Collection, Writing - Review & Editing; Corrado Caudek: Conceptualization, Writing - Original Draft Preparation, Writing - Review & Editing, Statistical analyses, Supervision.

[*]Correspondence concerning this article should be addressed to Ilaria Colpizzi, via di San Salvi n. 12, Padiglione 26, Firenze, 50139, Italy. E-mail: ilaria.colpizzi@unifi.it

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## Abstract

**Background/Objective:** This study compared individuals with Restrictive Anorexia Nervosa (R-AN; n = 40) to Healthy Controls (HCs; n = 45) and healthy controls at RIsk of eating disorders (RI; n = 38) in a Probabilistic Reversal Learning (PRL) task. The aim was to investigate whether R-AN individuals perform similarly to HCs and RIs in neutral contexts but show significant impairments in food-related contexts. **Method:** Participants completed a PRL task, making choices related to their disorder or unrelated to it. **Results:** R-AN individuals showed lower learning rates for disorder-related decisions, but their performance on neutral decisions was similar to the HC and RI groups. Additionally, only the R-AN patients exhibited reduced learning rates for food-related decisions compared to food-unrelated decisions. **Conclusions:** These findings suggest that contextual cues, like food images, negatively impact Reinforcement Learning (RL) processes in individuals with R-AN. This raises questions about whether the impaired RL performance should be solely attributed to compromised learning mechanisms, especially when RL abilities appear intact in neutral contexts. The study's insights may have implications for developing interventions that target decision-making processes in individuals with R-AN.


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## Introduction

Anorexia Nervosa (AN), specifically its restricting subtype (R-AN), is a pervasive eating disorder characterized by a skewed body image and extreme weight loss (American Psychiatric Association, 2022). The challenge of effectively treating AN is accentuated by its significant lifetime prevalence rates—1.4% in women and 0.2% in men—and a mortality rate ranging between 5-20% (Qian et al., 2022; Linardon et al., 2017). This amplifies the urgency to decode its underlying mechanisms (Chang et al., 2021).

Recent research emphasizes the role of executive functions in AN, particularly cognitive inflexibility and decision-making challenges (Bartholdy et al., 2016). In AN individuals, this rigidity typically manifests as resistance to new information, perpetuating a cycle of maladaptive behaviors.

Building upon this understanding, a largely unexplored area within this domain is examining how such cognitive inflexibility impacts reinforcement learning (RL)— the brain's adaptive mechanism for refining decision-making based on prior experiences (Schaefer & Steinglass, 2021). In AN, the cognitive processes governing food choices diverges significantly from that of average eaters. While initial control strategies may be needed for starting restrictive eating, the subsequent rewards are believed to activate dopaminergic systems, cementing rigid eating habits (O'Hara et al., 2015; Steinglass & Foerde, 2016). Specific brain regions associated with habit formation have been implicated in this skewed food decision-making process (Foerde

et al., 2015, 2020, 2022). This implies that AN individuals inherently assign lower values to food, especially high-calorie options, than do typical eaters (Rouhani, Grossman, & Tusche, 2023).

However, the literature on aberrant RL in AN has been fragmented and inconclusive. Studies have reported a range of findings, from impaired RL in response to negative feedback (Ritschel et al., 2017) to elevated learning rates following punishment (Bernardoni et al., 2018), and even to no noticeable differences at all (Sarrar et al., 2016; Geisler et al., 2017).

This inconsistency is compounded by the complex nature of AN's reward processing system, which is often characterized by an overactivation of neural reward circuits, a phenomenon largely attributed to the severe dietary restrictions that accompany the disorder (Keating et al., 2012). Paradoxically, despite this hyperactivation, there is also evidence of a dampened neural and subjective response to typically rewarding stimuli, especially those related to food (Wierenga et al., 2014; Keating et al., 2012).

Supporting this, neuroimaging research has consistently shown that individuals with AN exhibit a tendency to proactively avoid negative outcomes (Matton et al., 2013; Bischoff-Grethe et al., 2013), further illuminating the unusual reward and punishment processing mechanisms at play. Summarily, current neurobiological insights underline significant deviations in how reward and punishment are processed in AN, with a clear predisposition toward an increased sensitivity to negative stimuli and a concurrent decrease in reaction to rewards (Haynos et al., 2020).

Among the complexities of RL research in AN, the concept of "naturalistic RL" presents a promising research trajectory. It stems from an evolving approach that aims to integrate the intricacies of real-life situations into the experimental study of RL (Wise et al., 2023). By doing

so, it acknowledges the limitation of traditional laboratory conditions in capturing the multifaceted nature of human learning and decision-making as it occurs in natural environments.

Traditionally, RL studies have adopted a reductionistic approach, focusing primarily on isolated, non-naturalistic learning and decision-making scenarios. However, this reductionism may not accurately reflect the cognitive processes occurring in natural, everyday environments. In alignment with this perspective, we hypothesize that the inconsistent findings in the existing literature may, in part, be attributed to the overly simplified, non-naturalistic experimental setups commonly employed with individuals diagnosed with AN. These setups might not fully capture the complex dynamics of how individuals interact with their environment. This complexity includes aspects such as the pursuit of long-term goals that go beyond the immediate consequences of choices (Haynos et al., 2020). It also encompasses the inherent biases formed through prior similar experiences, which affect current decision-making (Feher da Silva & Hare, 2020; Palminteri et al., 2015, 2021), the function of episodic memory in these interactions (Dasgupta & Gershman, 2021), and the impact of context-specific factors like the nature of the stimuli (Rosas, Todd, & Bouton, 2013; Haynos, Widge, Anderson, & Redish, 2022). Such omissions can lead to an incomplete picture of RL processes in AN.

This conceptual reorientation provides a way to re-evaluate the inconsistent RL findings in AN (Hildebrandt et al., 2015; Hildebrandt et al., 2018). The disparities in results may not solely be ascribed to the nature of stimuli utilized—be they generic or disorder-specific—but also to the manner in which they are integrated within the experimental design (Schaefer & Steinglass, 2021). For instance, even studies that attempt to incorporate disorder-relevant feedback (Foerde et al., 2021) often revert to generic stimuli during pivotal decision-making phases, inadvertently sidelining the potential contextual influences on RL.

To better investigate naturalistic learning in AN, we devised a unique reward learning paradigm comprising two distinct contextual settings. The first setting required decisions between a disorder-relevant stimulus and a neutral counterpart, while the second presents choices exclusively between neutral stimuli. Building upon prior work that underscored disrupted reward processing in AN (Haynos et al., 2020), we hypothesize a more conservative learning rate among AN individuals when confronted with decisions involving disorder-relevant stimuli, as opposed to healthy controls (HCs). In this context, a conservative learning rate denotes a diminished propensity to alter beliefs or strategies in light of new information. This suggests a potential cognitive rigidity within AN individuals, rendering them less receptive to adapting to evolving scenarios or feedback, even when the food-related content is not intrinsically linked to the task's objective of reward maximization. In contrast, we anticipate no discernible differences in learning rates for decisions unrelated to the disorder. This innovative methodology aims not only to enrich our comprehension of RL mechanisms in AN, but also to unearth novel cognitive avenues for therapeutic interventions (refer to Discussion for further elaboration).

## Methods

The study, which adhered to the Declaration of Helsinki, was approved by the University of Florence's Ethical Committee (Prot. n. 0178082). All eligible participants provided informed consent and willingly agreed to participate in the study.

### Participants

The study involved 40 individuals with Restricting-Type Anorexia Nervosa (R-AN) as per DSM-5 criteria and 45 healthy volunteers. R-AN participants were recruited from three Italian facilities (Specchidacqua Institute, Montecatini, Pistoia; Villa dei Pini Institute, Firenze; Gruber

Center, Outpatient Clinic, Bologna) and underwent a treatment program that included individual psychotherapy, nutritional intervention, and medication when needed. Diagnosis was made by specialized psychiatrists and psychologists using the Structured Clinical Interview for DSM-5 Clinical Version (SCID-5-CV; First, Williams, Karg, & Spitzer, 2015).

An additional 310 young females were recruited through social media and university ads, completing the Eating Attitudes Test-26 (EAT-26). Thirty-eight individuals scoring above 20 on EAT-26 and not currently in treatment were classified as "at-risk" (RI). From the remaining, 45 were randomly selected as healthy controls (HC). Both RI and HC groups, which had normal BMI, were age-, sex-, and education-matched with the R-AN group (see Table 1). Further details are available in the Supplementary Information (SI).

**Procedure**

In the initial session, participants' eligibility was assessed via a clinical interview. Eligible participants underwent anthropometric measurements and completed psychometric scales including the Eating Attitude Test-26 (EAT-26; Garner, 1991), the Body Shape Questionnaire-14 (BSQ-14; Dowson and Henderson, 2001), the Social Interaction Anxiety Scale (SIAS; Mattick and Clarke, 1998), the Depression Anxiety Stress Scale-21 (DASS-21; Lovibond and Lovibond, 1995), the Rosenberg Self-Esteem Scale (RSES; Rosenberg, 1965), and the Multidimensional Perfectionism Scale (MPS; Frost, Marten, Lahart, and Rosenblate, 1990) – see SI.

In a subsequent session, participants engaged in a PRL task to maximize 'virtual euro' accumulation (Figure 1, top), involving a 2.5-second choice between two images, guided by trial-and-error feedback. Correct and incorrect choices were signaled by images of a euro coin and a crossed-out euro coin, respectively. Stimuli, randomly selected from sets of food-related and unrelated images from the International Affective Picture System (IAPS) database (Lang,

Bradley, Cuthbert, et al., 1997), varied each trial (see SI for details). The task consisted of two 160-trial blocks: one mixed and one exclusively unrelated. Reward rates, initially at chance, improved over time, enhancing performance (Figure 1, bottom). A contingency switch caused a performance drop, followed by a recovery, stabilizing at a 0.7 success rate due to the 70% reward probability, with three such switches per session.

**Data analysis**

To analyze temporal dynamics in the PRL task's two-choice decision-making, we utilized a hierarchical reinforcement learning drift diffusion model (RLDDM; Pedersen, Frank, & Biele, 2017; Pedersen & Frank, 2020). Employing a Bayesian approach, necessitated by the current feasibility of estimating RLDDM models only through Markov chain Monte Carlo (MCMC) procedures, facilitated estimation over hypothesis testing, addressing the binary nature of decision-making in null hypothesis significance testing (Kruschke & Liddell, 2018). Credible effects were ascertained by examining 95% credible intervals or assessing 97.5% of posterior samples indicating effect direction.

In Probabilistic Reversal Learning (PRL) tasks, performance impairments may arise from learning or decision-making deficits. The Reinforcement Learning Drift Diffusion Model (RLDDM) integrates a delta learning rule for value expectation updates based on reward feedback (Rescorla & Wagner, 1972), and a drift-diffusion model for decision-making (Ratcliff & McKoon, 2008), encompassing six key parameters (see SI for details):

– $\alpha^+$ and $\alpha^-$: Represent learning rates for rewards and punishments, respectively. We predict lower $\alpha^+$ and $\alpha^-$ in AN than in HCs specifically for disorder-related choices, and further reduced $\alpha^+$ within the AN group for disorder-related versus unrelated decisions.

$-$ $v$: Denotes the drift rate or speed of evidence accumulation. No differences are expected between conditions or between groups.

- $a$: Indicates the decision boundary, affecting both decision speed and accuracy. Elevated *a* values are anticipated in mixed-food versus no-food conditions, signifying decreased choice confidence (Lee et al., 2023).

- *t*: Represents non-decision time, accounting for stimulus encoding and motor execution. No condition or group differences are anticipated.

- *z*: Captures the starting point, or initial decision bias. No initial bias is expected between conditions or groups.

To probe learning variations, model parameters were conditioned on choice type—either disorder-related or unrelated—enabling targeted analysis of parameter shifts.

### Transparency and Openness

We report all data exclusion criteria and how the sample size was determined. All measures used in this study are reported. Data, and analysis code are available upon request to the corresponding author. This study was not preregistered.

## Results

### Models selection

We assessed context-dependent learning by comparing various RLDDM models, differing in their conditioning on group (R-AN, HC, RI) and context (disorder-related and unrelated choices). Using the Deviance Information Criterion (DIC) to balance model fit and complexity,

we selected the model with the lowest DIC as the best trade-off. The following RLDDM models were examined. Model M1: Standard RLDDM without conditioning. DIC = 39879.444. Model M2: Separate learning rates for positive and negative reinforcements. DIC = 39124.890 Model M3: Group-based $\alpha^+$ and $\alpha^-$ parameters. DIC = 39194.763. Model M4: Group and context-based $\alpha^+$ and $\alpha^-$ parameters. DIC = 38197.467. Model M5: Group and context-based $\alpha^+$, $\alpha^-$, and decision threshold ($a$) parameters. DIC = 36427.448. Model M6: Group and context-based $\alpha^+$, $\alpha^-$, $a$, and drift rate ($v$) parameters. DIC = 36185.146. Model M7: Group and context-based $\alpha^+$, $\alpha^-$, $a$, $v$, and non-decision time ($t$) parameters. DIC = 34904.053. Model M8: Group and context-based $\alpha^+$, $\alpha^-$, $a$, $v$, $t$, and starting point ($z$) parameters. DIC = 34917.762. Among the evaluated models, Model M7 had the lowest DIC, indicating the best trade-off between goodness of fit and model complexity. In Model M7, the parameters $\alpha^+$, $\alpha^-$, $a$, $v$, and $t$ (excluding $z$) were conditioned on both the group and the context.

**Modelling results**

Model M7 was estimated with 15,000 iterations, including a 5,000 iterations burn-in. Convergence was assessed using the Gelman-Rubin statistic, with $\hat{R}$ values for all parameters in Model M7 below 1.1, indicating good convergence. Collinearity and posterior predictive checks were also conducted for model validity (see SI). To examine the impact of disorder-related versus unrelated information on RL learning, we compared Model M7's RLDDM parameter posterior estimates between the two conditions (see Table 2).

Within-group comparisons (Figure 2, panel B) revealed context-dependent learning in the R-AN group, showing a reduced learning rate from rewards for disorder-related choices compared to unrelated choices (Cohen's $d$ = -1.206, $p$ = 0.0098). No credible difference was observed in learning rate between related and unrelated choices in HC ($p$ = 0.5544) or RI ($p$ =

0.2247) groups. Similarly, no credible difference was found in the learning rate from punishments across all groups (R-AN: $p = 0.2349$, HC: $p = 0.6993$, RI: $p = 0.5101$). Individuals with R-AN exhibited a higher decision threshold for disorder-related choices compared to unrelated choices (Cohen's $d = 0.802$, $p = 0.0013$), a result also found in HCs (Cohen's $d = 0.474$, $p = 0.0256$) – Figure 3, panel B.

Between-group comparisons provide additional evidence of context-dependent learning. For disorder-related choices, R-AN individuals showed a decreased learning rate from rewards compared to HC ($p = 0.0009$, Cohen's $d = 1.498$) and RI ($p = 0.0085$, Cohen's $d = 1.209$) – Figure 2, panel A. Conversely, no credible difference in reward learning rate was observed between R-AN and HC ($p = 0.4325$), or R-AN and RI ($p = 0.3232$), for disorder-unrelated choices. Furthermore, individuals with R-AN exhibited a decreased learning rate from punishment in disorder-related choices compared to HCs ($p = 0.0274$, Cohen's $d = 1.144$), but not in disorder-unrelated ones (Figure 4, panel A). However, this effect only emerged in comparisons between R-AN individuals and HCs, not in the within-group comparisons of food-related and unrelated choices among the R-AN participants (Figure 4, panel B).

R-AN individuals exhibited a higher decision threshold for disorder-related choices compared to HC (Cohen's $d = -0.622$, $p = 0.0068$) and RI (Cohen's $d = -0.454$, $p = 0.0118$), with no credible group differences for disorder-unrelated choices (Figure 3, panel A). Lastly, no credible differences were noted in both within-group and between-group comparisons for the drift rate (v) and non-decision time parameters (t).

**Preferential choices**

To examine a potential bias against food choices in R-AN individuals during the PRL task, we analyzed food choice frequency in blocks pairing a food image with a neutral image. The AN-R group showed no bias against the food image, with a food choice proportion of 0.49, 95% CI [0.46, 0.51]. No credible differences in food choices were found between the R-AN and HC groups (contrast R-AN - HC = -0.007, 95% CI [-0.037, 0.024]), or between the R-AN and RI groups (contrast R-AN - RI = 0.013, 95% CI [-0.019, 0.046]).

**Comorbidity**

To assess the possible impact of comorbidity and medication status on our findings, we compared R-AN participants with diagnosed comorbidities (45% of the sample) to those without, using Model M7. No credible parameter differences were found between the two groups. Specifically, when considering the disorder-related context, the parameter differences were as follows: $\Delta\alpha^{-}$ = 2.614, 95% CI [-3.173, 8.364]; $\Delta\alpha^{+}$ = -0.635, 95% CI [-4.301, 2.449]; $\Delta a$ = -0.034, 95% CI [-0.188, 0.124]; $\Delta v$ = 0.230, 95% CI [-1.203, 1.586]; $\Delta t$ = 0.002, 95% CI [-0.050, 0.055]. Similarly, for the disorder-unrelated context, the parameter differences were: $\Delta\alpha^{-}$ = -0.768, 95% CI [-6.570, 4.401]; $\Delta\alpha^{+}$ = -1.739, 95% CI [-6.184, 1.654]; $\Delta a$ = -0.126, 95% CI [-0.281, 0.025]; $\Delta v$ = 0.744, 95% CI [-0.453, 1.886]; $\Delta t$ = -0.003, 95% CI [-0.057, 0.052]. The correlation between comorbidity and medication was 0.78.

**Discussion**

In both individuals with R-AN and HCs, we observed elevated decision thresholds for food-related choices compared to choices unrelated to the disorder (as indicated by parameter *a*). This aligns with prior research, which has shown that the presence of food-related stimuli

typically amplifies both attentional bias and cognitive control (Stockburger et al., 2009; Sänger, 2019).

More importantly, our study reveals a context-dependent learning asymmetry in individuals with R-AN, specifically in the positive learning rate ($\alpha^+$). This asymmetry is evident when comparing their performance in the PRL task for disorder-related choices versus disorder-unrelated choices. Notably, this difference is not observed in the two control groups.

The presence of context-dependent learning asymmetry is also supported by between-group comparisons. Individuals with R-AN exhibited lower learning rates ($\alpha^+, \alpha^-$) compared to the HC and RI group. However, these differences were observed only for disorder-related choices. In contrast, no credible differences in learning rates were found among the three groups for choices unrelated to the disorder.

Support for context-dependent learning in R-AN is also provided by the DDM parameters of the RLDDM model. Specifically, we observed that the R-AN group exhibited a higher decision threshold (parameter "a" in the RLDDM model) compared to the HC and RI groups, but this difference was only evident in the context of disorder-related choices. These results suggest that individuals with R-AN tended to display a more cautious and conservative decision-making behavior in relation to choices related to the disorder (see also Caudek, Sica, Cerea, Colpizzi, & Stendardi, 2021). We did not find any credible contextual effects or group differences for the parameters $\nu$ and $t$.

The analysis of preferential choices supports the conclusion that the learning performance asymmetry observed in individuals with R-AN is not due to a preferential selection of the disorder-unrelated image during the learning task. Additionally, our analysis examining the

relationship between the model's parameters and the presence of comorbidities indicates that the learning performance asymmetry in individuals with R-AN cannot be attributed to comorbid conditions.

## General discussion

In this study, we explored "naturalistic reinforcement learning" examining the impact of food-related biases on reward learning and decision-making in individuals with R-AN, healthy controls, and those at risk for eating disorders. Our novel probabilistic reversal learning paradigm included two contexts: food-related and unrelated. We observed lower learning rates in the food-related context for R-AN individuals, while learning rates among healthy controls were consistent across both contexts.

Previous research has indicated that individuals with AN exhibit altered responses to reward and punishment, as evidenced by both self-report and implicit measures. For instance, they find predictable behaviors like calorie counting rewarding, and show heightened aversive responses to cues related to palatable foods (Haynos et al., 2020). Our study extends this, illustrating that context not only impacts subjective experience valuation but also the RL process itself (Heald et al., 2023).

Eating behavior engages both goal-directed (model-based) and habit-based (model-free) learning systems. Previous studies link maladaptive eating to increased habit-learning reliance (Foerde et al., 2021, 2015; Koban et al., 2023). In our task aimed at selecting the highest reward probability category, we used high-calorie food images to investigate if pre-existing food biases trigger habit-like behavior, possibly conflicting with goal-directed decision-making. Our results showed consistent learning rates across food-related and neutral contexts for healthy controls and

individuals at risk for eating disorders, while R-AN individuals exhibited a slower learning rate specifically in the food-related context, suggesting their habit-like high-calorie food avoidance influenced goal-directed decision-making (see also Rouhani, Grossman, & Tusche, 2023).

In PRL tasks, performance may be affected by two factors: learning impairment, where participants struggle to accurately update stimulus value, and decision impairment, where incorrect stimulus is chosen despite intact learning. Our findings show individuals with R-AN face difficulty in both domains, but only with food-related stimuli, supporting the notion of context-dependent RL deficits in R-AN and challenging the generalized RL impairment hypothesis in this group (Bernardoni et al., 2021).

Our findings show that individuals with R-AN exhibit a conservative learning rate in disorder-related contexts when engaging with rewards, a caution not seen with punishments. This aligns with a neurobiological model suggesting AN symptoms are maintained by diminished reward responses and amplified aversive responses, possibly due to an overreliance on cognitive control circuits (Wierenga et al., 2014). Supporting this, Bernardoni et al. (2018) noted that, in a PRL task with disorder-unrelated stimuli, AN individuals adjusted beliefs more rapidly to negative feedback compared to healthy controls. We speculate that the lack of contextual effect on negative learning rates may result from a trade-off between cautious learning from disorder-related cues and accelerated learning following punitive feedback.

The idea that contextual factors may affect RL anomalies in R-AN individuals has treatment implications. Cognitive Remediation Therapy (CRT) is employed to tackle cognitive inflexibility in AN, using cognitive exercises and behavioral interventions to improve central coherence, reduce inflexibility, and enhance thinking style comprehension (Tchanturia et al., 2010). CRT typically avoids symptom-related themes, using neutral stimuli in exercises to foster

a therapeutic alliance and minimize drop-out rates, especially in AN cases. However, recent studies indicate CRT may not consistently ameliorate central coherence, cognitive flexibility, or eating disorder symptoms (Hagan et al., 2020; Tchanturia et al., 2017). Trapp et al. (2022) suggest modifying CRT, questioning the use of neutral stimuli and referencing Beck's cognitive theory of depression (Beck & Alford, 2009). This proposition aligns with the hypothesis of our study. If future research corroborates maladaptive reinforcement learning's context-sensitivity, a reevaluation of current intervention approaches may be warranted.

Our study has several limitations and suggests directions for future research. Firstly, the use of symbolic rewards and punishments, depicted as euro coin images, prompts further investigation with tangible incentives. Secondly, the exclusion of hospitalized R-AN patients calls for research on how illness severity impacts food-related biases in reinforcement learning. Thirdly, while no discernible choice biases between food-related and neutral stimuli were observed, exploring alternative metrics like fixation duration might be insightful. Fourthly, omitting women under 18, a critical age group for AN onset, underscores the need for including this demographic in future studies to better understand context-dependent learning in R-AN. Lastly, the results' generalizability may be limited to individuals from different cultural and ethnic backgrounds. Despite these limitations, our study introduces a novel PRL paradigm for contextual learning in R-AN, isolates learning asymmetry from comorbid conditions, and compares with an HC group, shedding light on the role of context in naturalistic RL for R-AN.

## Conclusions

Our findings reveal that contextual cues interfere with reward learning in individuals with R-AN, thereby highlighting potential cognitive targets for treatment.

**Supplementary Information**

Additional statistical analyses, detailed information about measurement scales, and further information regarding sample properties, along with an in-depth explanation of the RLDDM model, can be accessed at the Open Science Framework:

https://anonymous.4open.science/r/naturalistic_rl/sup_mat.pdf

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Table 1: Summary of Sample's Demographic and Clinical Characteristics.

| | R-AN (n = 40) Mean (SD) | HC (n = 45) Mean (SD) | RI (n = 38) Mean (SD) | AN - HC PE (95% CI) | AN - RI PE (95% CI) | AN - HC Cohen's *d* | AN - RI Cohen's *d* |
|---|---|---|---|---|---|---|---|
| Age (years) | 21.11 (4.33) | 19.49 (2.32) | 21.31 (4.82) | -0.00 (-0.22, 0.18) | 0.01 (-0.21, 0.25) | 0.09 | -0.18 |
| Education (years) | 14.53 (1.11) | 14.11 (0.98) | 13.89 (0.78) | 0.08 (-0.14, 0.33) | 0.13 (-0.11, 0.41) | -0.08 | -0.13 |
| BMI ($kg/m^2$) | 17.79 (2.85) | 21.78 (3.53) | 21.64 (4.11) | -2.74 (-3.67, -1.79) | -3.22 (-4.32, -2.07) | 2.67 | 3.15 |
| EAT-26 Total score | 35.89 (19.46) | 5.09 (5.10) | 25.86 (12.44) | 1.76 (1.32, 2.20) | 0.18 (-0.25, 0.62) | -1.84 | -0.18 |
| EAT-26 Dieting | 19.11 (11.24) | 3.27 (3.96) | 16.06 (8.00) | 53.96 (32.78, 80.9) | 4.38 (-2.46, 12.10) | -4.54 | -0.36 |
| EAT-26 Bulimia | 7.17 (3.95) | 0.76 (1.48) | 5.78 (3.86) | 1.36 (0.99, 1.72) | 0.11 (-0.17, 0.41) | -2.33 | -0.18 |
| EAT-26 Oral control | 9.61 (6.23) | 1.07 (1.67) | 4.03 (4.05) | 1.53 (1.12, 1.96) | 0.81 (0.42, 1.20) | -1.95 | -1.03 |
| BSQ-14 Total score | 139.78 (35.26) | 97.47 (32.37) | 147.94 (37.13) | 17.50 (11.30, 23.91) | -3.40 (-10.10, 3.15) | -1.21 | 0.24 |
| RSES Total score | 22.69 (5.29) | 28.33 (5.76) | 22.53 (5.76) | -5.601 (-8.12, -3.15) | 0.192 (-2.31, 2.90) | -1.22 | 0.23 |
| DASS-21 Stress | 12.86 (4.67) | 9.13 (3.55) | 12.17 (3.74) | 3.73 (1.89, 5.38) | 0.69 (-1.12, 2.59) | -0.94 | -0.18 |
| DASS-21 Depression | 10.61 (5.49) | 6.82 (4.33) | 11.22 (4.99) | 3.78 (1.76, 6.14) | -0.62 (-2.91, 1.77) | -0.77 | 0.12 |
| DASS-21 Anxiety | 8.25 (4.51) | 5.76 (4.26) | 7.56 (4.47) | 2.48 (0.50, 4.33) | 0.70 (-1.39, 2.64) | -0.56 | -0.16 |
| SIAS Total score | 37.31 (15.45) | 27.69 (13.01) | 39.03 (14.87) | 9.63 (3.12, 15.84) | -1.68 (-8.28, 5.07) | -0.66 | 0.12 |

| | R-AN (n = 40) Mean (SD) | HC (n = 45) Mean (SD) | RI (n = 38) Mean (SD) | AN - HC PE (95% CI) | AN - RI PE (95% CI) | AN - HC Cohen's *d* | AN - RI Cohen's *d* |
|---|---|---|---|---|---|---|---|
| MPS Cmd | 45.47 (8.21) | 40.02 (7.24) | 49.25 (8.17) | 5.46 (2.05, 9.02) | -3.73 (-7.47, -0.15) | -0.69 | 0.48 |
| MPS Ps | 25.33 (5.74) | 22.00 (4.86) | 25.67 (6.33) | 3.33 (0.89, 5.86) | -0.32 (-3.07, 2.19) | -0.60 | 0.06 |
| MPS Pepc | 20.78 (6.64) | 21.02 (5.84) | 25.22 (7.92) | -0.63 (-3.49, 2.42) | -3.88 (-7.09, -0.90) | 0.09 | 0.57 |
| MPS Or | 23.94 (5.11) | 23.07 (5.16) | 22.17 (5.55) | 0.84 (-1.49, 3.17) | 1.77 (-0.66, 4.26) | -0.17 | -0.34 |

*Note. PE: Posterior Estimate; EAT-26: Eating Attitude Test-26 (Garner, 1991); BSQ-14: Body Shape Questionnaire-14 (Dowson and Henderson, 2001); SIAS: Social Interaction Anxiety Scale (Mattick and Clarke, 1998); DASS-21: Depression Anxiety Stress Scale-21 (Lovibond and Lovibond, 1995); RSES: Rosenberg Self-Esteem Scale (Rosenberg, 1965); MPS: Multidimensional Perfectionism Scale (Frost et al., 1990).*

Table 2: Posterior Parameter Estimates of DDMRL Model M7 by Group (R-AN, HC, RI) and Context of PRL Choice (disorder-related vs. disorder-unrelated information). The learning rates ($\alpha$) are shown on a logit scale. The probability ($p$) describes the Bayesian test that the posterior estimate of the parameter in the disorder-related context is greater than the posterior estimate of the parameter in the disorder-unrelated context. Standard deviations are provided in parentheses.

| Group | Par. | Neutral choice | Food choice | $p$ | Cohen's $d$ |
|---|---|---|---|---|---|
| R-AN | a | 1.273 (0.039) | 1.442 (0.040) | 0.0013 | 0.802 |
| R-AN | v | 1.403 (0.320) | 1.776 (0.342) | 0.7907 | 0.190 |
| R-AN | t | 0.188 (0.011) | 0.174 (0.011) | 0.8311 | -0.253 |
| R-AN | $\alpha^-$ | 1.815 (1.081) | 0.738 (1.096) | 0.2349 | -0.432 |
| R-AN | $\alpha^+$ | 1.006 (0.899) | -1.786 (0.756) | 0.0098 | -1.206 |
| HC | a | 1.222 (0.033) | 1.314 (0.034) | 0.0256 | 0.474 |
| HC | v | 2.157 (0.265) | 1.790 (0.263) | 0.1606 | -0.358 |
| HC | t | 0.183 (0.009) | 0.172 (0.009) | 0.8228 | -0.280 |
| HC | $\alpha^-$ | 2.780 (0.874) | 3.442 (0.980) | 0.6993 | 0.298 |
| HC | $\alpha^+$ | 1.198 (0.680) | 1.326 (0.700) | 0.5544 | 0.071 |
| RI | a | 1.245 (0.041) | 1.316 (0.039) | 0.1026 | 0.403 |
| RI | v | 2.197 (0.322) | 1.849 (0.307) | 0.2133 | -0.381 |
| RI | t | 0.188 (0.011) | 0.186 (0.011) | 0.5462 | 0.166 |
| RI | $\alpha^-$ | 2.857 (1.067) | 2.904 (1.062) | 0.5101 | 0.015 |

| Group | Par. | Neutral choice | Food choice | $p$ | Cohen's $d$ |
|---|---|---|---|---|---|
| RI | $\alpha^+$ | 1.573 (0.847) | 0.739 (0.752) | 0.2247 | -0.438 |

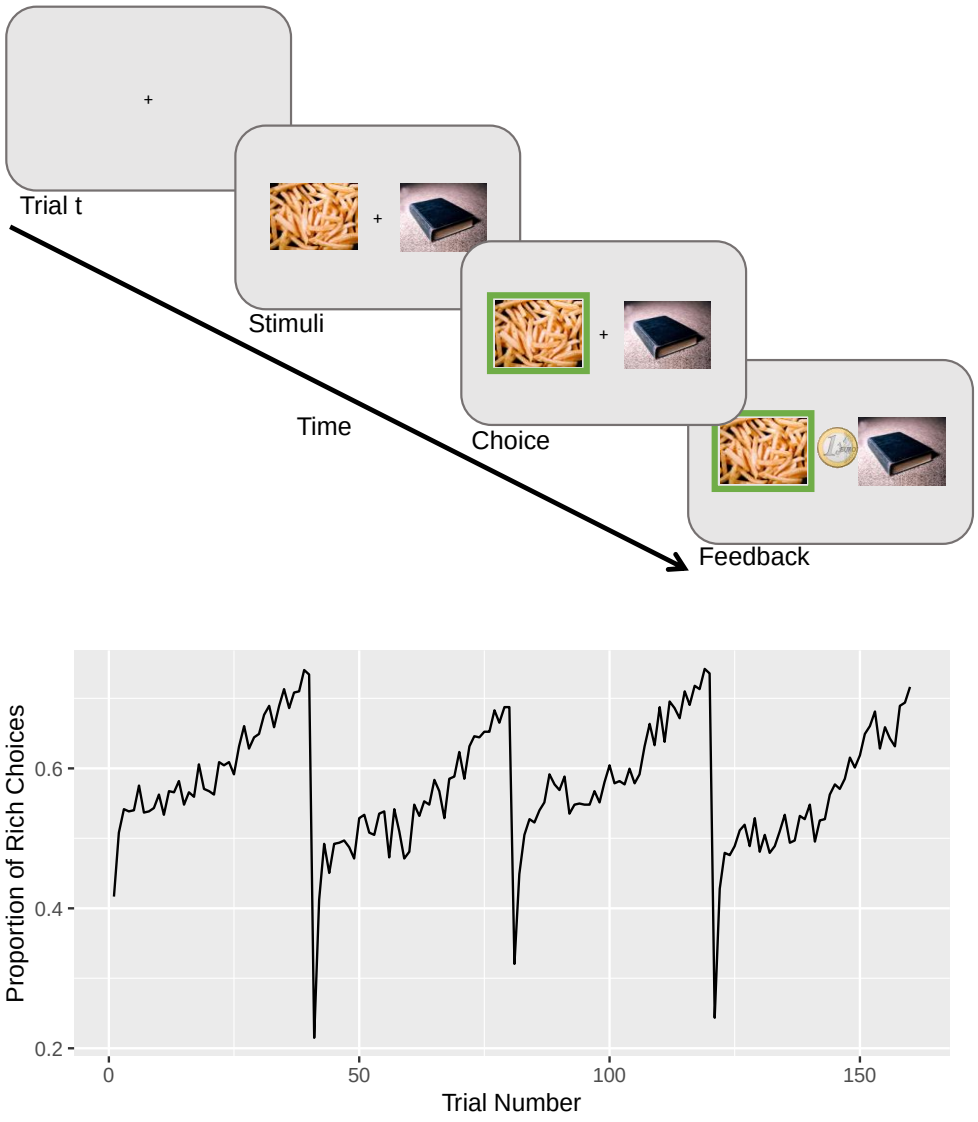


Figure 1: **Top.** The figure illustrates a single trial of the PRL task. **Bottom.** The trial-by-trial proportion of choosing the image with the highest probability of reward in the first epoch is shown for all participants.

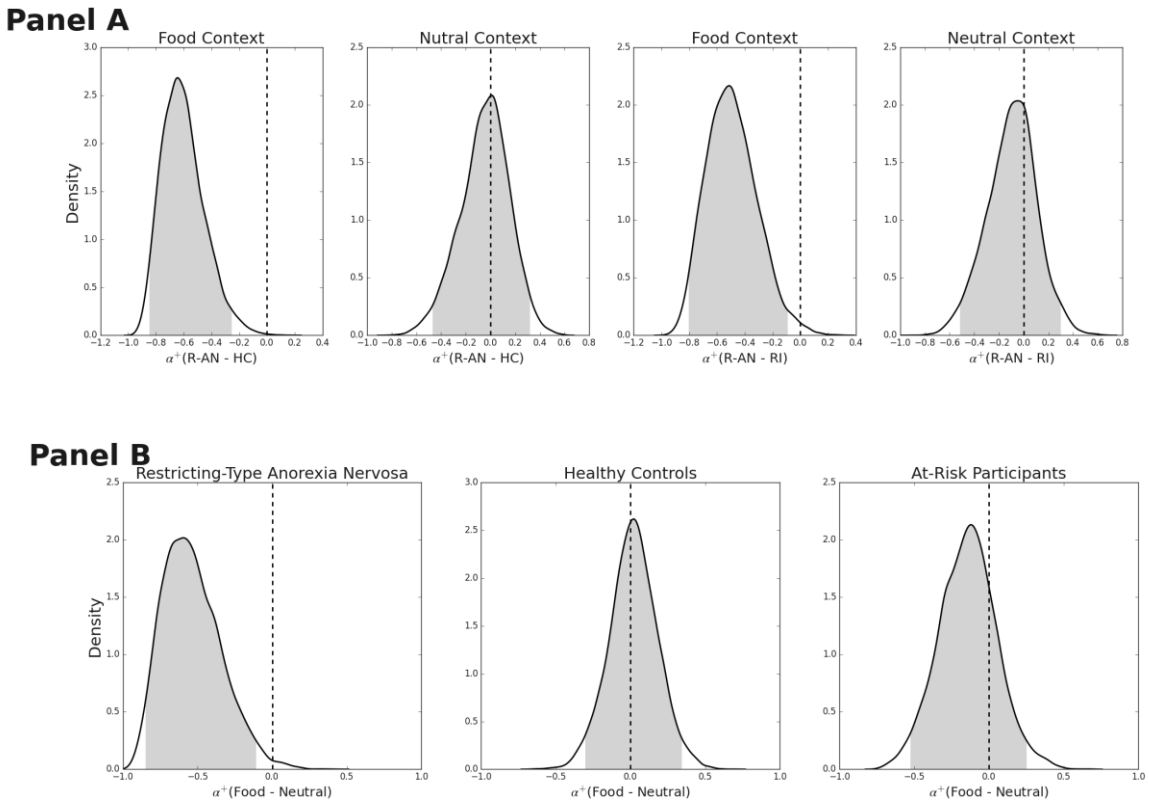


Figure 2: **Panel A.** Plots of the posterior distribution of the group effects (AN - HC; AN - RI) for parameter $\alpha^+$ of the DDMRL, for disorder-related choices (Food context) and disorder-unrelated (Neutral context) choices. **Panel B.** Plots of the posterior distribution of the within-group effects ($\alpha^+_{food} - \alpha^+_{neutral}$) across the three groups of participants.

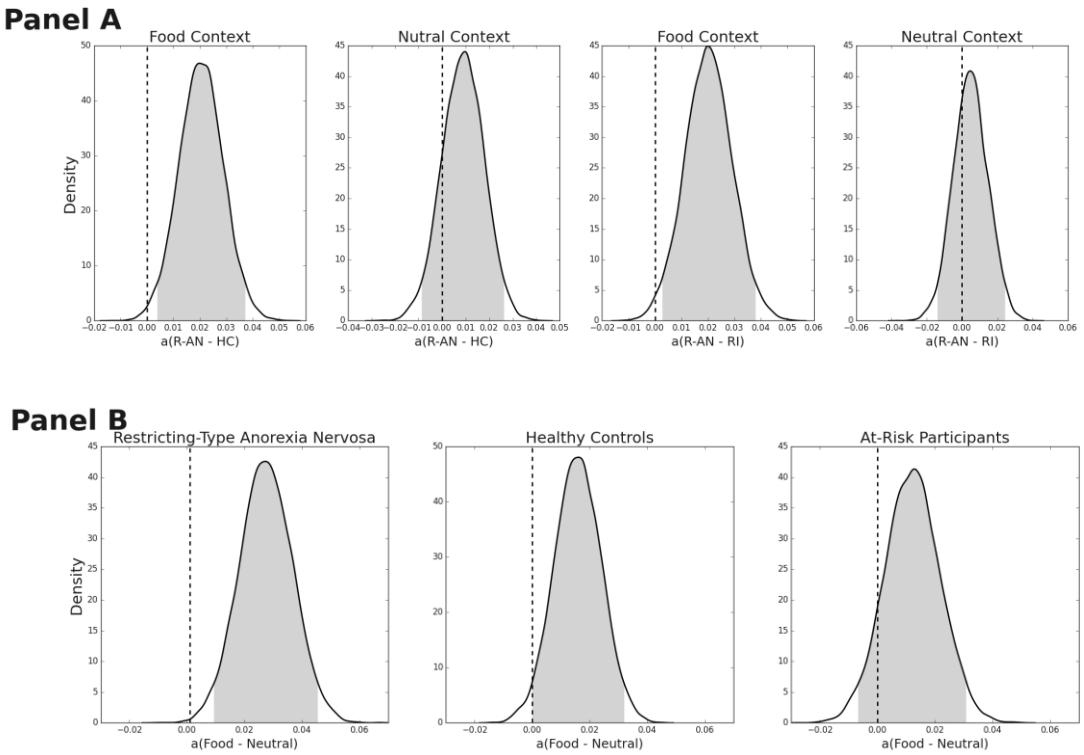


Figure 3: **Panel A.** Plots of the posterior distribution of the group effects (AN - HC; AN - RI) for parameter $a$ of the DDMRL, for disorder-related choices (Food context) and disorder-unrelated (Neutral context) choices. **Panel B.** Plots of the posterior distribution of the within-group effects ($a_{food} - a_{neutral}$) across the three groups of participants.

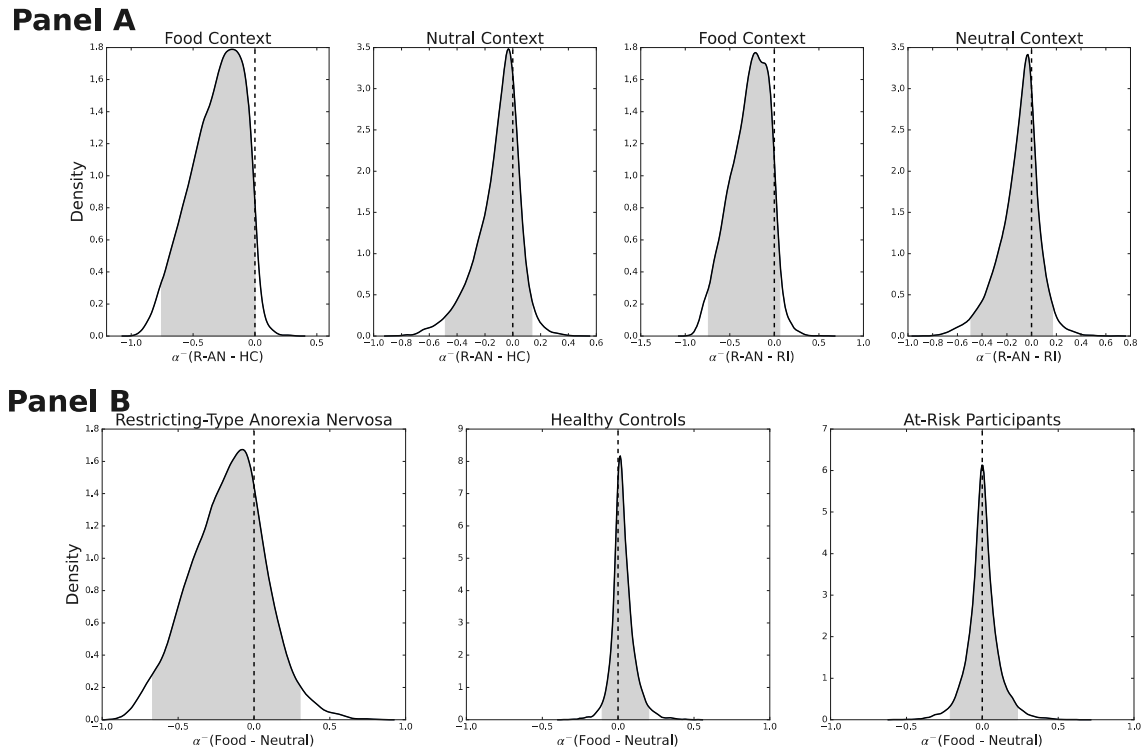


Figure 4: **Panel A.** Plots of the posterior distribution of the group effects (AN - HC; AN - RI) for parameter $\alpha^-$ of the DDMRL, for disorder-related choices (Food context) and disorder-unrelated (Neutral context) choices. **Panel B.** Plots of the posterior distribution of the within-group effects ($\alpha^-_{food} - \alpha^-_{neutral}$) across the three groups of participants.

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