I change my mind to get better: Process tracing-based microanalysis of food choice processes reveals differences between anorexia nervosa and bulimia nervosa during inpatient treatment

Claudio Georgii a,*, Katharina Naomi Eichin a, Anna Richard b, Rebekka Schnepper a, Silke Naab b, Ulrich Voderholzer b, c, d, Janet Treasure e, Jens Blechert a

a Department of Psychology and Centre for Cognitive Neuroscience, University of Salzburg, Salzburg, Austria
b Schoen Clinic Roseneck, Prien am Chiemsee, Germany
c Department of Psychiatry and Psychotherapy, University Hospital Freiburg, Freiburg, Germany
d Department of Psychiatry and Psychotherapy, University Hospital Munich, Munich, Germany
e Institute of Psychiatry, King's College, London, England, UK

ABSTRACT

Food choice and its underlying processes is understudied in bulimia nervosa (BN) and anorexia nervosa (AN). Thus, we examined cognitive processes during food choice through mouse tracing in AN (n = 36) and BN (n = 27) undergoing inpatient treatment. Both patient group and matched healthy controls (HC, n = 59) made 153 binary food choices before rating all foods on their liking and calorie density. Choice outcomes and corresponding mouse movements were modelled as a function of inpatient treatment stage in our analyses.

Compared to patients with BN and HC, those with AN showed a clear calorie avoidance on most trials. Yet, mouse paths in AN patients early in treatment, revealed a late direction reversal (‘change of mind’), CoM) on high-calorie choices. AN patients later in treatment, by contrast, showed fewer CoM alongside more choices for – and liking of – high-calorie foods. Patients with BN showed more CoM trials during low-calorie choices and low-calorie choices were more frequent in patients later in treatment. Thus, relative to patients early in treatment, patients who are later in treatment show less of the overall group pattern of consistently choosing low-calorie food (AN) or high-calorie food (BN). Less cognitive regulation (fewer CoM trials) went along with higher liking for high-calorie foods in AN. These cross-sectional differences between AN early and late in treatment might reflect the formation of healthier habits. In addition, clear patient group differences suggest more specific treatment strategies.

1. Introduction

Anorexia nervosa (AN) is among the psychiatric illnesses with the highest mortality rates (Fichter & Quadflieg, 2016). As a result of this high mortality risk, AN treatment often takes the form of inpatient treatment with a focus on supervised eating schedules. Also, in Germany, individuals with severe cases of bulimia nervosa (BN) receive inpatient treatment and undergo guided eating routines to establish a regular diet (American Psychiatric Association, 2006; Golden & Meyer, 2004). Both eating disorders (EDs) share severe weight/shape concerns (Cash & Deagle, 1996), fueling intense investments in restriction and food related self-deprivation. As a result, both EDs also share ambivalence during food choice, as such decisions trigger a conflict between diet goals on the one hand and homeostatic needs (hunger) as well as hedonic desires for palatable foods on the other. Studying indices of decision conflict during food choices in detail might reveal the relative force of these competing eating motives. Thus, the present study measured food choice outcomes alongside the respective choice processes using mouse tracing methodology (Stillerman & Freeman, 2019b). During treatment, such choice determinants might change in one way or another, revealing potential key change processes, but this has not been studied to date. Thus, we included individuals with AN and BN during different inpatient treatment stages and considered this in our analyses.

The study of food choice determinants has fascinated decision
science across various fields (Leng et al., 2017). Decision dilemmas – emerging from the aforementioned ambivalence inherent in food choice in EDs – can be described through dual process theories, which differentiate bottom-up from top-down processes. In the psychological sense, bottom-up processes are assumed to be fast, efficient, intuitive and effortless in their implementation (Strack & Deutsch, 2004). Thus, they are thought to modulate the decisional process through the intrinsic, salient features of the stimulus (Frith, 2001). These forces are potentially further amplified by hunger and food deprivation, at least in healthy populations (Stice, Burger, & Yokum, 2013). This might be amplified in individuals with BN, who submit themselves to intermittent food deprivation, interspersed with bingeing. Individuals with restrictive AN seem to have extinguished such food appeal of high-calorie foods through extended self-starvation, as indicated by findings of altered deprivation, as indicated by findings of altered

During treatment, ED patients are helped with revising (AN) or moderating (BN) strict diet rules. While individuals with AN are guided to accept high-calorie foods, individuals with BN are encouraged to eat whiskely while including high-energy foods in moderation. Such new eating ‘rules’ necessarily need to be learned through slow, deliberate routes (e.g., new goals and accumulation of new experiences), possibly representing a top-down process. Thus, as treatment progresses, the relative weight of top-down vs. bottom-up control might shift, but there is currently no research on this. A strong choice preference for low-caloric foods (relative to a standardized reference food) has been shown in AN (Steinglass, Foerde, Kostro, Shohamy, & Walsh, 2015), and is expected in the present study, too, but processes during choice themselves have not been investigated to date, representing a significant research gap. A recent development in process tracing methodology (Freeman & Ambady, 2010; Schulte-Mecklenbeck et al., 2017) holds promise in that top-down processes (Frankish, 2010), by contrast, are considered deliberate, effortless and voluntary processes (Frith, 2001). Thus, they are thought to modulate the decision process based on previous experiences and an achievable, concrete goal (Park & Smith, 1989). In BN, the desire to decrease food intake and to reduce weight might be considered such a controlled, deliberate process. Being more cognitive and deliberative in nature, such top-down processes are necessarily slower in their neural computation compared to competing bottom-up, stimulus driven choice determinants (Chaiken & Trope, 1999; Hofmann, Friese, & Strack, 2009). This would suggest that bottom-up processes affect the choice process at a later time point compared to bottom-up processes (Sullivan, Hutcherson, Harris, & Rangel, 2015).

A total of 41 individuals with AN and 31 individuals with BN were included. Each participant completed 153 trials. For each trial, a food stimulus appeared on the screen for 2 seconds, after which the participant had to decide which of two foods to choose as fast as possible. The two possible choices were presented in a random order, and the participant could choose one of the two displayed foods. The trial ended after the participant’s decision was made. After the decision, the participant was presented with the other food item and asked to rate its perceived calorie density and subjective liking. Each participant completed 153 trials (31 for each category, made up of 153 unique food pairs, with 18 foods per condition) and acquired ratings for each food item on liking and calorie density. The latter allowed us to relate these motives or ‘determinants’ (calories – cognitive control; liking – hedonics) to the participants’ choice behavior. Modelling these determinants as predictors of choice outcome within participants across the 153 trials through multi-level modelling permitted us to test hypotheses on four levels: choice outcome, role of determinants (liking, calorie density) for this choice, choice processes and the relationship between liking and calorie density. Regarding

outcomes of choice, we hypothesized a choice preference for low-calorie foods in individuals with AN compared to both healthy controls (HC) and individuals with BN (with the latter two being rather similar in their preference; Walsh, 2011). The main determinant of choice in individuals with AN was hypothesized to be calorie density (negatively correlated with choice) while liking (positively correlated) should be the main choice determinant in individuals with BN and HC. Processes during choice—measured through mouse-tracing—might reveal a differential pattern in each of the three groups: in both patient groups choices—for low-calorie foods in AN and high-calorie foods in BN—should be driven by bottom-up processes, represented by straight mouse paths, due to the salient features of the food stimuli (their calorie density [AN] and their hedonic properties [BN]). Intermittent choices for energy-rich food might also occur in AN but might require top-down processing—exerting cognitive control to be (weight) goal congruent—as represented by the occurrence of CoM. In those with BN, by contrast, rejecting liked, calorie-rich foods (choosing more low-calorie foods)—in accordance with a healthier diet—might require top-down processing, again represented by the occurrence of CoM. Patients with AN who are more advanced/longer in treatment, might have overcome their calorie avoidance and might thus show fewer CoMs, when selecting the more calorie dense food option. By contrast, patients with BN who are more advanced/longer in treatment, might have adapted to the more balanced clinic diet and might thus show fewer CoM trials, when selecting the more low-calorie food option. Last, groups might also differ in how much perceived calorie density of different foods relates to subjective liking of these foods: We expected the highest calorie ‘dependence’ of liking (strongest correlation between liking and calories) in individuals with AN, based on a similar finding in restrained eaters (Georgii, Schulte-Mecklenbeck, Richard, Van Dyck, & Blechert, 2020). This calorie-liking dependence might also differ across treatment but lack of prior research precludes any directed hypotheses here. As a minority of our patients with AN were of the binge-purge subtype, this was explored in supplementary analyses.

2. Methods

2.1. Participants

A total of 41 individuals with AN and 31 individuals with BN

Fig. 1. Schematic illustration of choice paths.
Note. Schematic illustration of a regular choice path (dark gray) and a Change of Mind-choice path (CoM; red). CoM trials directly measure the dynamic interplay of bottom-up processes (greenish)—dominating early during choice—and top-down processes (reddish), reversing the early preference and resulting in a mouse path towards the other option, which is ultimately selected.
underwent the study at the Schoen Clinic Rosenec, Prien am Chiemsee, Germany. In the control-group sixty-six women (predominantly from student population), matched on age and education underwent the study at the University of Salzburg. Exclusion criteria for the healthy controls were no current mental or neurological disorders and lifetime eating disorders, as well as vegetarianism/veganism. All participants signed a written informed consent. Sixteen participants (n = 7/5/4 in the HC/AN/BN group) were excluded from analyses due to non-compliance to the test protocol (failure to move the mouse upward continuously throughout choice, n = 5/3/1), technical issues (2/1/0) or poor data quality (0/1/3, see data analyses section), leaving a final N of 59/36/27 in the HC/AN/BN group. In our group of 36 patients with AN we had throughout choice, post-traumatic stress disorder (22%/11%), borderline personality disorder (9%/9%), and obsessive-compulsive disorder (22%/22%). Current/past mental disorders were assessed with the structured clinical interview for DSM-IV (First & Gibbon, 2004). Current comorbid disorders in AN/BN were depressive disorders (56%/37%), anxiety disorders (11%/67%), post-traumatic stress disorder (22%/11%), borderline personality disorder (9%/9%), and obsessive-compulsive disorder (22%/22%). Table 1 further characterizes the three groups. The study was approved by the ethics committee of the University of Salzburg, Austria and the medical review board of the University of Munich, Germany. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The data can be retrieved from PsychArchives.

### 2.2. Food choice task and food ratings

Choices were made for one of two foods—displayed at the upper right and left corner of the screen—out of 18 low-energy (e.g., apple, lettuce) and high-calorie (e.g., burger, muffin) food options. Pictures were extracted from the food-pics database (Blechert, Meule, Buech, & Ohla, 2014). Each food was paired with all others leading to 153 unique food pairs. Participants were instructed to choose the food that they would prefer to eat later. Actual later eating was not reinforced in patients with ED due to potential conflict with the inpatient meal schedule. Though, instructions were the same in the patient sample and the healthy controls, it is possible that patients were aware that receiving real food would not be possible due to clinic’s rules. Yet, choice in this task predicted actual intake in a non-patient sample (Georgii et al., 2020) and similar choice tasks have high test-retest reliability (Foerde et al., 2018). To limit variability on hunger, healthy participants were instructed to consume one out of five preset lunches (~550 kcal) 3 h prior to testing, which took place in the early afternoon (start ~ 3–4 pm).

A click on a “Start” button in the lower center of the initially blank screen initiated the trial and image onset was triggered by the upward mouse movement (at 10% of the vertical screen resolution) (Fig. 1). Participants were instructed to continuously move the mouse upwards during choice. After 153 choice trials, all 18 foods were rated by ‘ranking’ food image cards along a 100 mm visual analogue scale separately for “general liking” and “calorie density”. These ratings were subsequently used as predictors (determinants) of food choice (across 153 trials) within participants. Ratings on ‘momentary desire to eat’, and ‘healthiness’ were dropped due to collinearity with liking/calorie density, respectively. In all models the correlation of the fixed effects calorie density and liking was below 0.264, indicating no problems of multicollinearity.

### 2.3. Data analyses

As in our previous paper (Georgii et al., 2020), R (R Core Team, 2017), the R package lme4 (Bates, Maechler, Bolker, & Walker, 2015), and glmmTMB (Brooks et al., 2017) were used to calculate linear mixed-effects models with crossed random effects (see supplement S1 and Table S1). Mouse traces were subjected to a multi-step pre-processing pipeline: trajectories were (1) normalized to the same starting position, (2) mapped to the same side (left response option), (3) time-normalized to 101 time points (Spivey, Grosjean, & Knoblich, 2005) and (4) inspected for artefacts after clustering and for trials displaying CoM characteristics using a custom-build Shiny (Cheng, Allaire, Xie, & McPherson, 2019) app including manual artefact rejection and CoM trial definition (see supplement Fig. S1). A minimum of 65% valid trials (~100) was required. Analysis of the outcome of choice compared total calories chosen between the groups was calculated using an univariate ANOVA. Analyses of the determinants of choice regressed trial level food choice on the respective ratings of liking and calories (i.e., differences in both foods of a given trial on rated liking and rated calorie density) between groups using linear mixed-effects models with crossed random effects. These were then followed by within group analyses comparing patients earlier in treatment with those later in treatment (treatment days; clinic stay in days). Treatment days (log-transformed) were closely associated with weight gain in this AN sample (r = .76,t(34) = 6.93, p < .001; see supplement S2: Fig. S2) and might thus be regarded as proxy for treatment progress. Regarding processes during choice, CoM probability on each of 153 trials was predicted through rating differences on liking and calories, first between groups and then within groups as a function of treatment days. Last, we analyzed the calorie dependence of liking, that is, how much higher energy-density goes along with higher subjective liking, again considering group and treatment days. Calculation of effect sizes in multi-level models is controversial (Nezlek, 2012). We therefore computed standardized beta coefficients, which also allow to compare the size of effects between studies (Lorah, 2018). The results when accounting for ANbp and ANres in each of aforementioned analyses are shown in the respective figures and tables in the supplement.

### 3. Results

#### 3.1. Outcome of choice: calories chosen

As hypothesized, the groups differed significantly on the mean amount of calories chosen (F(2) = 23.9, p < .001, η = 0.29): individuals

### Table 1

| Variable                        | Healthy Controls (N = 59) | Anorexia Nervosa (N = 36) | Bulimia Nervosa (N = 27) | p-values |
|---------------------------------|---------------------------|---------------------------|--------------------------|----------|
| Age (in years)                  | 22.73 (4.09)              | 22.86 (5.11)              | 22.89 (5.85)             | 0.986    |
| Years of Education              | 14.95 (2.43)              | 14.72 (2.88)              | 13.74 (2.22)             | 0.120    |
| Body mass index (BMI)           | 22.87 (2.66)              | 15.35 (1.78)              | 23.23 (4.16)             | <0.001   |
| Anxiety (STAI-T)                | 40.78 (10.17)             | 56.17 (8.24)              | 59.59 (9.76)             | <0.001   |
| Depression (ADS-K)              | 10.03 (6.30)              | 21.53 (8.63)              | 23.11 (11.76)            | <0.001   |
| Impulsivity (BIS-15)            | 32.60 (7.40)              | 27.53 (5.73)              | 37.41 (7.40)             | <0.001   |
| Eating Disorder Symptomatology  | 1.97 (1.32)               | 3.07 (1.32)               | 4.26 (1.31)              | <0.001   |

Note. Different subscripts denote significant differences between the groups. All multiple comparisons (denoted by subscripts) have been Tukey-HSD corrected. STAI-T = State-Trait Anxiety Inventory-Trait (Spielberger, 1983), ADS-K = German version of the Center of Epidemiology Studies Depression Scale (Hautzinger, Baier, Hofmeister, & Keller, 2012), BIS-15 = Barratt Impulsiveness Scale-15 (Meule, Vogele, & Kühler, 2011), EDE-Q8 = Eating Disorder Examination Questionnaire 8 (Kliem et al., 2016).
with AN chose less calorie dense items ($M = 151$ kcal/100 g) compared to individuals with BN (213 kcal/100 g) and HC (210 kcal/100 g).

3.2. Determinants of choice: predicting food choice from liking and calorie density ratings

As hypothesized, more liked foods were chosen more often as indicated by a strong main effect (Fig. 2a and Table 2, $p < .001$, $\beta = 2.27$). This general influence of liking was found in all three groups (AN, BN, HC), however, individuals with AN selected foods slightly less according to their liking ($p < .001$, $\beta = -0.37$) compared to the HC. Besides liking, also the calorie density of a food item was an important choice determinant, however, it differed strongly by group: individuals with AN chose more low-caloric options ($p < .001$, $\beta = 2.03$) compared to HC. Interestingly, individuals with BN chose slightly more high-caloric options compared to HC ($p = .021$, $\beta = 0.13$, see Fig. 2b and Table 2).

3.3. Determinants of choice within AN and BN groups: treatment days

Individuals with AN later in treatment selected more high-caloric ($p < .001$, $\beta = 0.39$) and liked foods ($p < .001$, $\beta = 0.27$, Fig. 2c, and Table 3) compared to patients early in treatment. Within the group with BN, we observed a different pattern: individuals later in treatment chose less calorie dense foods ($p < .001$, $\beta = -0.2$, Fig. 2d, Table 3). Fig. 3 shows food choice in the group with AN on item (food) level, separating patients according to the length of their clinic stay (early, mid, late) for illustration purposes.

3.4. Processes during choice: CoM trials

As hypothesized, CoM trials were more frequent in both patient groups compared to controls (Table 4, in supplement), indicative of an overall more conflicted food choice (no difference between AN and BN, $t (50) < 1.00$). To characterize these trials, we analyzed the probability of CoM trials as a function of calorie density, liking and group. The calorie density × group interaction pointed to a higher probability of CoM trials as a function of calorie density, liking and group. Variables, which have been grand-mean centered are denoted with a subscript $Z$.

### Table 2

| Determinants of choice: Predicting food choice from liking and calorie density ratings by group (in comparison to HC). |
|---|
| **Predictors** | **Choice** |
|   | $\beta$ | SE | CI | p |
| (Intercept) | 0.04 | 0.04 | -0.04–0.12 | .340 |
| Calorie density$_Z$ | 2.03 | 0.07 | 1.89–2.18 | <.001 |
| Calorie density$_Z$ × BN | 2.03 | 0.07 | 1.89–2.18 | <.001 |
| AN | 0.13 | 0.06 | 0.02–0.24 | .021 |
| BN | 0.10 | 0.07 | 0.00–0.20 | .180 |
| Liking$_Z$ × AN | 0.50 | 0.07 | 0.38–0.62 | <.001 |
| Liking$_Z$ × BN | 0.50 | 0.03 | 0.44–0.55 | <.001 |
| Liking$_Z$ × AN × BN | 0.50 | 0.08 | 0.34–0.65 | <.001 |

Note. The standardized estimate ($\beta$), its confidence interval (CI, 95%) and standard error (SE), as well as $p$ values for the mixed model with the cross-level interaction of calorie density, liking and group on choice. Variables, which have been grand-mean centered are denoted with a subscript $Z$.

3.5. Processes during choice within groups with AN and BN: treatment days

In individuals with AN, the interaction between treatment days and calorie density predicted the likelihood of CoM presence ($p = .037$, $\beta = -0.16$, Table 5): for individuals with AN later in treatment—while the absolute frequency of choices for high-calorie food increased—the
Table 3
Determinants of Choice within AN and BN groups as a function of treatment days.

| Choice | AN | | | | BN | | | | | | HC | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Predictors | β | SE | CI | p | β | SE | CI | p | β | SE | CI | p |
| | (Intercept) | −0.05 | 0.05 | −0.15−0.05 | .319 | 0.18 | 0.05 | 0.08−0.28 | .001 | 0.05 | 0.05 | −0.05−0.15 | .367 |
| | Likingₜ | 2.09 | 0.08 | 1.94−2.24 | <.001 | 1.99 | 0.07 | 1.85−2.13 | <.001 | 2.38 | 0.05 | 2.27−2.49 | <.001 |
| | Calorie density₂ | −1.44 | 0.06 | −1.56−−1.32 | <.001 | 0.58 | 0.05 | 0.48−0.68 | <.001 | 0.52 | 0.03 | 0.45−0.58 | <.001 |
| | Treatment daysₜ | −0.02 | 0.04 | −0.11−0.06 | .619 | 0.11 | 0.05 | 0.01−0.21 | .039 | 0 | 0 | 0.05 | 0.12 |
| | Likingₜ × Calorie density₂ | 0.22 | 0.09 | 0.05−0.40 | .013 | 0.06 | 0.07 | −0.08−0.19 | .410 | −0.02 | 0.05 | −0.12−0.08 | .732 |
| | Likingₜ × Treatment daysₜ | 0.27 | 0.07 | 0.13−0.41 | <.001 | 0.03 | 0.08 | −0.12−0.19 | .684 | 0.79 | 0.07 | 0.66−0.92 | <.001 |
| | Calorie density₂ × Treatment daysₜ | 0.39 | 0.06 | 0.26−0.52 | <.001 | −0.20 | 0.05 | −0.31−0.10 | <.001 | 0.38 | 0.06 | 0.27−0.50 | <.001 |
| | Likingₜ × Calorie density₂ × Treatment daysₜ | 0.08 | 0.10 | −0.12−0.28 | .454 | −0.06 | 0.08 | −0.22−0.09 | 0.439 | 0.99 | 0.07 | 0.85−1.13 | <.001 |
| | * Treatment daysₜ | 0.60 | 0.09 | 0.44−0.77 | <.001 | 0.17 | 0.08 | −0.34−0.00 | .044 | 0.20 | 0.08 | −0.26−0.04 | .013 |
| | * AN | −0.20 | 0.08 | −0.36−0.04 | <.001 | 0.03 | 0.08 | −0.19−0.13 | .691 | 0.03 | 0.08 | −0.19−0.13 | .691 |
| | Observations | 4603 | 3564 | 7923 | | | | | | | | | |

Note. The standardized estimate (β), its confidence interval (CI, 95%) and standard error (SE), as well as p values for the mixed model with the cross-level interaction of calorie density, liking and treatment days on choice within each experimental group. Variables, which have been grand-mean centered are denoted with a subscript Z or log for log-transformed.

Fig. 3. Choice frequency for each food item in anorectic patients early in treatment compared to patients tested later in treatment.

Note. Images on the x axis are the stimuli displayed during the experiment. Each line represents anorectic patients grouped according to their clinic stay at time of testing (treatment days).

Table 4
Processes during Choice: CoM trials by group (in comparison to HC).

| CoM | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Predictors | β | SE | CI | p | | | | | | | | |
| | (Intercept) | −3.44 | 0.18 | −3.79−−3.10 | <.001 | | | | | | | | |
| | Calorie density₂ | −0.09 | 0.05 | −0.19−0.01 | .089 | | | | | | | | |
| | Likingₜ | −0.27 | 0.05 | −0.37−0.17 | <.001 | | | | | | | | |
| | AN | 0.88 | 0.28 | 0.33−1.44 | <.001 | | | | | | | | |
| | BN | 0.68 | 0.31 | 0.08−1.28 | .027 | | | | | | | | |
| | Calorie density₂ × AN | 0.60 | 0.09 | 0.43−0.77 | <.001 | | | | | | | | |
| | Calorie density₂ × BN | −0.17 | 0.08 | −0.34−0.00 | .044 | | | | | | | | |
| | Likingₜ × AN | −0.20 | 0.08 | −0.36−0.04 | <.001 | | | | | | | | |
| | Likingₜ × BN | −0.03 | 0.08 | −0.19−0.13 | .691 | | | | | | | | |
| | Observations | 16410 | | | | | | | | | | | |

Note. The standardized estimate (β), its confidence interval (CI, 95%) and standard error (SE), as well as p values for the mixed model with the cross-level interaction of calorie density, liking and group on “Change of Mind”. Variables, which have been grand-mean centered are denoted with a subscript Z.

3.6. Calorie ‘dependent’ liking: relationship with calorie density and treatment days by group

Individuals with AN did not only give generally lower liking ratings for all foods compared to controls (p = .048, β = −0.63; Table 6) but did so particularly for high-calorie foods (p < .001, β = −1.69), as expected. Like the CoM trial results, this effect (the strong disliking of high-calorie foods) was strongest for patients early in treatment and was significantly weaker for patients later in treatment (p = .002, β = 0.5, Fig. 5; Table 7). No interactions with treatment days were found in individuals with BN relative to controls (all ps > .34).

4. Discussion

The current study is the first to embark on a detailed, process-based study of food choice in individuals with AN and BN while also considering treatment stage of patients. Advanced multilevel-modelling statistics examined calorie density and liking as continuous predictors of choice as a function of treatment days. Mouse-tracking unraveled the ‘microstructure’ of choice processes and thus provided a unique window into early, bottom-up, and later, top-down determinants of choice.

4.1. Food choice in AN: outcome, determinants, and processes, as well as treatment days

Food liking was the main positive choice determinant overall, meaning that choice followed liking ratings to a high degree. Also perceived calorie density was a significant predictor of choice but it differed clearly by group: it was a strong negative choice determinant in the group with AN (= calorie avoidance), while the groups with BN and HC showed positive relationships (high-calorie foods increased the likelihood of choice). This is consistent with previous research findings of a preference for low-calorie foods in AN in similar tasks (Foerde et al., 2018; Lloyd & Steinglass, 2018). Choice behavior in such tasks is predictive of actual consumption in a test meal (Foerde, Steinglass, Shohamy, & Walsh, 2015; Georgii et al., 2020), indicating validity of the choice task. In addition, our study broke new grounds in considering treatment days, supposedly indicating treatment progress. Days in treatment modulated this calorie avoidance: individuals with AN in advanced treatment stages chose relatively more high-caloric foods compared to patients in early treatment. This is in line with questionnaire data showing increasing fat preference in AN across treatment compared to patients tested later in treatment. This is in line with questionnaires, which showed a negative correlation of BMI increase in the present sample.

Beyond choice outcome and its determinants, we also investigated choice processes, that is, the mechanisms of how choices were enacted by participants on the background of dual process models. CoM
trials—trials with an early mouse path toward one choice option, followed by a later reversal toward the other option—were more frequent in individuals with AN and BN than in healthy individuals, indicating that both clinical groups enacted food choices with more top-down cognitive control and thus more conflictive and non-intuitively. Importantly, in individuals with AN, such CoM trajectories led up to choices in favor of more high-caloric food options. This implies that an early, stimulus-driven, intuitive mouse-path towards the more low-caloric option was reversed in favor of a more high-caloric food option most likely through the engagement of top-down, controlled processes based on an individual’s salient goals.

Strikingly, the rate of CoM trials, especially the ones with choices for high-caloric foods was lower in individuals with AN tested at a later point in treatment, which was paralleled by a higher liking of high-caloric foods in these patients. Thus, patients with AN early in treatment needed top-down control to override their pathological calorie avoidance. In contrast, individuals with AN later in treatment, might have ‘learned to like’ high-calorie foods, which might have opened a more intuitive, stimulus-driven route to goal-congruent choices (assuming that treated patients with AN adopted a goal of weight gain), based on the salient feature of the food item, its perceived liking. This finding mirrors previous findings in restrained eaters, who were able to pursue their low-calorie goal in an ‘effortless’ manner, as represented by smooth decision mouse paths and an increased liking for low calorie foods.

Fig. 4. Likelihood of change of mind trials.
Note. A) Influence of calorie density on the CoM likelihood by group, illustrating high change of mind probability in AN when choosing high calorie foods. B) Interaction of liking and experimental group predicting the likelihood of change of mind. C) Interaction between calorie density and treatment days in AN (left side) illustrating more CoM likelihood early (-1SD) compared to late (+1SD) in treatment. On the right side, raw ratios of CoM for high-caloric food options chosen (1SD above calorie difference mean) separated for AN patients early and late in treatment (median split) are shown for illustrative purposes. HC = Healthy Controls, AN = Anorexia Nervosa, BN = Bulimia Nervosa and CoM = change of mind.

| Predictors                  | AN          |            |            | p       | BN          |            |            | p       | HC          |            |            | p       |
|-----------------------------|-------------|------------|------------|---------|-------------|------------|------------|---------|-------------|------------|------------|---------|
| (Intercept)                 | -2.39       | 0.18       | -2.75–2.04 | <.001   | -2.74       | 0.25       | -3.23–2.26 | <.001   | -3.62       | 0.21       | -4.03–3.21 | <.001   |
| Liking<sub>Z</sub>          | -0.42       | 0.06       | -0.54–0.29 | <.001   | -0.29       | 0.06       | -0.42–0.17 | <.001   | -0.24       | 0.05       | -0.35–0.13 | <.001   |
| Calorie density<sub>Z</sub>| 0.52        | 0.07       | 0.38–0.65  | <.001   | -0.26       | 0.07       | -0.40–0.12 | <.001   | -0.08       | 0.06       | -0.19–0.03 | .150    |
| TreatmentDays<sub>logZ</sub>| -0.39       | 0.17       | -0.72–0.06 | .022    | 0.03        | 0.29       | -0.53–0.59 | .912    | 0.03        | 0.05       | -0.08–0.13 | .617    |
| Liking<sub>Z</sub> * Calorie density<sub>Z</sub> | 0.10        | 0.07       | -0.03–0.23 | .149    | -0.06       | 0.06       | -0.18–0.06 | .347    | 0.05        | 0.09       | -0.08–0.26 | .275    |
| Liking<sub>Z</sub> * TreatmentDays<sub>logZ</sub> | -0.10       | 0.06       | -0.23–0.03 | .119    | 0.09        | 0.09       | -0.08–0.26 | .275    | 0.05        | 0.09       | -0.13–0.23 | .577    |
| Calorie density<sub>Z</sub> * TreatmentDays<sub>logZ</sub> | -0.16       | 0.08       | -0.31–0.01 | .037    | 0.05        | 0.09       | -0.13–0.23 | .577    | 0.05        | 0.09       | -0.20–0.14 | .719    |
| Liking<sub>Z</sub> * Calorie density<sub>Z</sub> * TreatmentDays<sub>logZ</sub> | -0.13       | 0.08       | -0.28–0.02 | .097    | -0.03       | 0.09       | -0.20–0.14 | .719    |             |            |            |         |
| Observations                | 4727        | 3547       |            |         | 7965        |            |            |         |
Note. The standardized estimate (β), its confidence interval (CI, 95%) and standard error (SE), as well as p values for the mixed model with the predictors palatability, calorie density, liking and treatment days on “change of mind” for each experimental group. Variables, which have been grand-mean centered are denoted with a subscript Z or log for log-transformed.
the ventromedial prefrontal cortex, supporting goal-directed behavior without the need for top-down self-control, typically located in the more dorsal lateral prefrontal cortex (Hare, Malmaud, & Rangel, 2011). As CoM trials, indicating top-down control, were accompanied by corresponding liking differences it seems likely that changes in the food’s value represent such an effortless route to behavioral change. Although speculative, particularly in this cross-sectional approach to treatment progress, one could draw therapeutic conclusions: a less cognitive approach to food experience would not emphasize nutritional, health related facts but seek a sensory and taste based approach to diet change in AN. Current practice in inpatient treatment of focusing on food enjoyment (increased liking), social cooking sessions and an overall pleasurable exploration of different taste qualities would thus be supported by our findings and could potentially be intensified further.

4.2. BN food choice and treatment days

One strength of the present paper is the comparison of individuals with AN not only with controls but also with a population that shares many of the eating concerns with AN, namely BN. BN is also often linked with more impulsivity and less effective top-down control (Wu et al., 2012). The differences between individuals with BN and controls were more subtle overall, and these patients tended to favor calories, however—similar to AN—they also showed more trials with intervention of top-down choice control (i.e., CoMs). This opposes findings of more impulsive choices in BN but is more in line with research characterizing food choice as conflictive and ambivalent in these individuals (Friederich et al., 2006). Interestingly, just as in AN, treatment days (i.e., treatment progress) were reflected in the decision-making task: patients later in treatment made less high-calorie choices, thus, overall improved the quality of their diet.

4.3. Limitations and conclusions

Although our groups of individuals with AN and BN were larger than those of several comparable studies, we did not preregister sample size or a dedicated sampling stopping rule. Yet, sampling was stopped well before data analysis. Future studies should aim to increase power further or a dedicated sampling stopping rule. Yet, sampling was stopped well before data analysis. Future studies should aim to increase power further and preregister all hypotheses. Furthermore, with mouse tracking being a relatively recent methodology, there is no firm consensus yet on all design factors (e.g., clicking vs. hoovering over the selected food). Some of them may affect the shape of the mouse trajectories and thus the frequency of change of mind trials (for a detailed overview, see Kieslich, Schoemann, Grage, Hepp, & Scherbaum, 2019). Therefore, future studies should investigate whether the findings replicate across different experimental designs. In addition, the correspondence of treatment days with choice behavior is based on cross-sectional data (each participant was measured only once, patients at different treatment stages were measured only once, patients at different treatment stages were

![Graph showing interaction between treatment days and calorie density on liking in anorectic patients.](image)

**Fig. 5.** Interaction between treatment days and calorie density on liking in anorectic patients.

foods (Georgii et al., 2020). However, the difference in the frequency of CoM trials in favor of high-calorie foods between patients with AN who were tested early versus late in treatment was significant, but small in magnitude, and thus should be interpreted with caution. Yet, our findings dovetail with behavioral and neurophysiological findings that place more emphasis on goal-directed behavior that is enacted without the need for top-down self-control (Fujita, 2011). Based on findings from neuroscientific studies, there is evidence for a value system centering on the ventromedial prefrontal cortex, supporting goal-directed behavior without the need for top-down self-control, typically located in the more dorsal lateral prefrontal cortex (Hare, Malmaud, & Rangel, 2011). As CoM trials, indicating top-down control, were accompanied by corresponding liking differences it seems likely that changes in the food’s value represent such an effortless route to behavioral change. Although speculative, particularly in this cross-sectional approach to treatment progress, one could draw therapeutic conclusions: a less cognitive approach to food experience would not emphasize nutritional, health related facts but seek a sensory and taste based approach to diet change in AN. Current practice in inpatient treatment of focusing on food enjoyment (increased liking), social cooking sessions and an overall pleasurable exploration of different taste qualities would thus be supported by our findings and could potentially be intensified further.

A related stream of research that ‘bypasses’ cognitive control is the habit literature (Verplanken, 2018). Habits are acquired stimulus response couplings that are overlearned to the degree of obviating cognitive control. Habit formation provides one possible frame to the present findings, as more intuitive, smooth and straight-lined choice pathways (i.e., the opposite trajectory to CoMs) were relatively more frequent in individuals with AN later in treatment – possibly due to the repeated practice of choosing high-energy foods in their daily eating schedules.

### Table 6

| Liking |            |            |            |        |
|--------|------------|------------|------------|--------|
|        | O          | SE         | CI         | p      |
| Intercept | 1.94     | 0.12     | 1.53–2.46 | <.001 |
| Calorie density | 1.08 | 0.07 | 0.94–1.24 | .290 |
| AN | 0.82 | 0.10 | 0.68–1.00 | .048 |
| BN | 0.84 | 0.11 | 0.68–1.03 | .097 |
| Calorie density x AN | 0.60 | 0.06 | 0.53–0.67 | <.001 |
| Calorie density x BN | 1.02 | 0.07 | 0.89–1.17 | .778 |
| Observations | 2074 |

Note. The odds ratio (O), its confidence interval (CI, 95%) and standard error (SE), as well as p values and standardized β-coefficients for the mixed model with the cross-level interaction of calorie density and group on liking. Variables, which have been grand-mean centered are denoted with a subscript Z.

### Table 7

| Liking |            |            |            |        |
|--------|------------|------------|------------|--------|
|        | E          | SE         | CI         | p      |
| AN | 0.52 | 0.14 | 0.25–0.78 | <.001 |
| Calorie density | -0.59 | 0.10 | -0.78–0.4 | <.001 |
| Treatment days | 0.15 | 0.08 | -0.02–0.32 | .085 |
| Calorie density x Treatment days | 0.16 | 0.05 | 0.06–0.26 | .002 |
| Observations | 615 |

Note. The Estimate (E), its confidence interval (CI, 95%) and standard error (SE), as well as p values and standardized beta-coefficients for the mixed model with the predictors calorie density and treatment days on liking for each experimental group. Variables, which have been group-mean centered are denoted with a subscript Z or log for log-transformed.
Appetite 168 (2022) 105745

showed that patients later in treatment adopted a more health-oriented emphasis on a) the normalization of eating behavior and the establishment of (bottom-up) choice habits, as well as b) a pleasure-based, liking-centered approach to energy-dense foods alongside c) disorder-specific treatment approach to AN and BN.

Data availability statement

The data that support the findings of this study are retrievable from https://doi.org/10.23668/psycharchives.4419.

Acknowledgements and conflicts of interest

This work was supported by the Austrian Science Fund (JG; FWF): [I02130–B27], the European Research Council (JG; ERC-StG-2014 639445 NewEat) and the Doctoral College “Imaging the Mind” (FWF; W1233–B). The authors have no conflict to declare.

Author contributions

J.B. developed the study concept. C.G. and J.B. contributed to the study design. Testing and data collection were supervised by A.R., R.S. and C.G. C.G. performed the data analysis and interpretation. J.B. and C. G. drafted the manuscript. K.E., S.N., U.V. and J.T. provided critical comparisons to the study. G. drafted the manuscript. K.E., S.N., U.V. and J.T. provided critical comparisons to the study. G. drafted the manuscript. K.E., S.N., U.V. and J.T. provided critical comparisons to the study. G. drafted the manuscript.
Spivey, M. J., Grosjean, M., & Knoblich, G. (2005). Continuous attraction toward phonological competitors. *Proceedings of the National Academy of Sciences*, 102(29), 10392–10398.

Steinglass, J., Forde, K., Kostro, K., Shohamy, D., & Walsh, B. T. (2015). Restrictive food intake as a choice—a paradigm for study. *International Journal of Eating Disorders*, 48(1), 59–66. https://doi.org/10.1002/eat.22245

Stillerman, B. S., & Freeman, J. B. (2019a). In Mouse-tracking to understand real-time dynamics of social cognition (2nd ed.). New York: Routledge.

Stillerman, B. S., & Freeman, J. B. (2019b). Mouse-tracking to understand real-time dynamics of social cognition. In *A handbook of process tracing methods* (p. 146).

Stice, E., Burger, K., & Yokum, S. (2013). Caloric deprivation increases responsivity of attention and reward brain regions to intake, anticipated intake, and images of palatable foods. *NeuroImage*, 67, 322–330. https://doi.org/10.1016/j.neuroimage.2012.11.028

Stillman, P. E., Shen, X., & Ferguson, M. J. (2018). How mouse-tracking can advance social cognitive theory. *Trends in Cognitive Sciences*, 22(6), 531–543. https://doi.org/10.1016/j.tics.2018.03.012

Strack, F., & Deutsch, R. (2004). Reflective and impulsive determinants of social behavior. *Personality and Social Psychology Review*, 8, 220–247.

Sullivan, N., Hutcherson, C., Harris, A., & Rangel, A. (2015). Dietary self-control is related to the speed with which attributes of healthfulness and tastiness are processed. *Psychological Science*, 26(2), 122–134.

Verplanken, B. (2018). The psychology of habit: Theory, mechanisms, change, and contexts. Cham: Springer.

Walsh, B. T. (2011). The importance of eating behavior in eating disorders. *Physiology & Behavior*, 104(4), 525–529. https://doi.org/10.1016/j.physbeh.2011.05.007

Walsh, B. T. (2013). The enigmatic persistence of anorexia nervosa. *American Journal of Psychiatry*, 170(5), 477–484.

Wu, M., Giel, K. E., Skunde, M., Schag, K., Rudofsky, G., de Zwaan, M., … Friederich, H.-C. (2013). Inhibitory control and decision making under risk in bulimia nervosa and binge-eating disorder. *International Journal of Eating Disorders*, 46, 721–728. Retrieved from http://onlinelibrary.wiley.com/store/10.1002/eat.22143.pdf?v=1&t=ig0v02w9&s=1236ca04967099ab42a583577cc065731971f11.